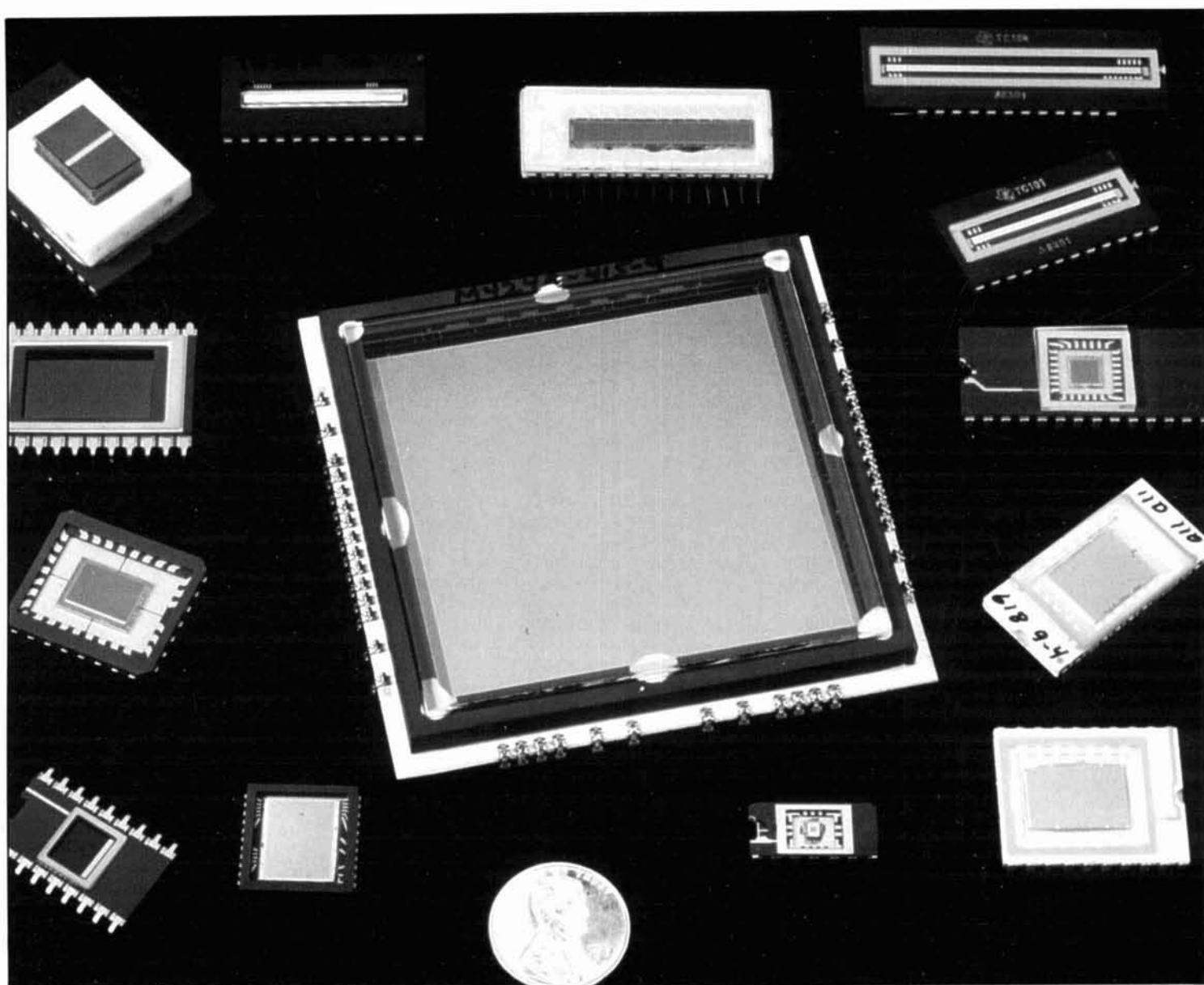


COMMUNICATIONS QUARTERLY

THE JOURNAL OF
COMMUNICATIONS
TECHNOLOGY

Spring 1992

\$9.95



- HF Radio Data Communication
- Diagnosing RFI Problems in Vehicles
- Parasitic Elements for Pattern Shaping in Vertical Antennas
- A User's View of Charge Coupled Device Imaging

- Low-pass Filter Performance
- Be a CAD (User)
- Radio Receivers of the Past
- Technical Conversations
- Quarterly Devices
- The Solar Spectrum

6 Reasons why build your system



IC-725 HF Transceiver

PS-55 Power Supply

IC-2KL Linear Amplifier

IC-475 UHF Transceiver
IC-275 VHF Transceiver

The IC-725 system above is just one example of how you can build your system.

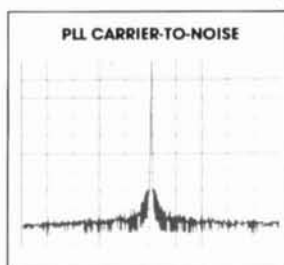
"Don't just buy a radio. Build a system." Experienced ham operators have been giving this advice for a long time. As you build your station, you don't want "stand alone" rigs that cannot integrate with the rest of your equipment. You can avoid serious disappointments in the future by comparing compatibility, performance, reliability and service *before* you purchase each component of your system.

1 A HIGHER LEVEL OF PERFORMANCE

If you have ever made a weak signal QSO, had it fade out, then dialed the same frequency on an ICOM transceiver and found a strong, clear signal... you're already aware of ICOM's superior performance.

We have devoted three decades of research and design to ensure that our transceivers consistently meet or exceed your critical expectations. Our engineers have achieved a balance of dynamic range, selectivity and sensitivity thought unobtainable a few years ago. Their development of

the ICOM DDS System, with an extremely low carrier-to-noise ratio, has resulted in loud and clear transmissions and the ultimate in HF receiver performance.



2 DESIGNED FOR COMPATIBILITY

It has been said many times, "Once you learn to operate one ICOM radio, every other ICOM is a snap to pick up." This is especially helpful as you upgrade or when you operate two or more transceivers simultaneously.

Even more important is the interchangeable, system design of ICOM equipment. This allows the integrated operation of your HF, VHF, UHF, antenna tuner, power amplifier, microphone and even your PC.

3 RELIABILITY YOU CAN COUNT ON

Ever wonder why you rarely see an ICOM radio at a swap meet? A remarkable majority of ICOM transceivers made in the last fifteen years are still making contacts in ham shacks around the world.

ICOM's outstanding reputation for reliability is a result of our integrity of construction. We use only the highest quality components and do not skimp on important details (i.e. heavy duty front panels and one-piece heat sinks).

When you compare a transceiver's value over several year's time, it is well worth buying the best.

4 CUSTOMER SERVICE THAT WILL KEEP YOU ON THE AIR


ICOM serves you regionally with four factory service centers. We provide a Customer Service Hotline for technical support and answers to your many

Why you should start your HF system with Icom.



IC-970 UHF/VHF Transceiver IC-2KL Linear Amplifier IC-765 HF Transceiver

This IC-765 system is another classic combination of ICOM components.



questions. ICOM averages 7 to 10 days turn-around on radio servicing. And we still carry complete lines of parts for radios built years ago. Can other manufacturers compare to ICOM's service?

6 THE MORE YOU LEARN THE MORE YOU WILL WANT AN ICOM

Ask experienced amateurs what they look for in a transceiver. Learn which features and performance characteristics are essential to quality operation and which are not. Notice which brands are winning all of the contests and DX competitions around the world. The more you learn, the more distinct advantages you will see in ICOM's quality, performance, compatibility and reliability.



At ICOM, our heritage is built on amateur radio. We are dedicated to its growth and progress. Our company is comprised of over 90% licensed amateurs and we collectively strive to make ICOM equipment the benchmark to which all others are compared. Simply, the best.

FOR MORE INFORMATION:
See your ICOM Dealer or call the ICOM Brochure Hotline 1-800-999-9877.

ICOM America, Inc., 2380-116th Ave. N.E.
Bellevue, Washington 98004
Customer Service Hotline (206) 454-7619

All stated specifications are subject to change without notice or obligation. All ICOM radios significantly exceed FCC regulations limiting spurious emissions. 6R292



Simply the Best®

5 THE LEADING EDGE OF TECHNOLOGY

ICOM continues to be on the leading edge of technology and innovation. We pioneered digital control technology and made history by eliminating the need for manual adjustment in the transmitter final amplifier stage. ICOM produced the FIRST all-transistorized HF amateur transceiver. We were also the FIRST to use fiber optics to create a truly modular multi-band amateur mobile radio.

KENWOOD

Mobile Companion!

TM-241A
TM-441A/TM-541A

Compact FM Mobile
transceivers



Here are your new mobile companions – at your service whenever you're on the road! Their compact size makes installation a snap, and the remote control options allow you to customize your installation for that "professional" look!

- Wide band receiver coverage. The TM-241A receives from 118–173.995 MHz. Transmit range is 144–148 MHz. (Modifiable for MARS and CAP operation, permits required.)
- TM-441A covers 438–449.995 MHz, and the TM-531A covers 1240–1299.995 MHz.
- CTCSS encode built-in, selectable from the front panel.
- Selectable frequency steps for quick and easy QSY.
- TM-241A provides 50 W. TM-441A 35 W, and TM-541A 10 W. Three power positions, 5, 10, and full. The TM-541A has two power positions, 1 and 10 watts.
- 20 full-function memory channels store frequency, repeater offset, sub-tone frequencies, and repeater reverse information. **Repeater offset on 2m is automatically selected.** There are **four channels** for "odd split" operation.
- Tone Alert System with Elapsed Time indicator.
- Auto-power off function, and time-out timer.



RC-20 Remote Control Unit

As supplied, one RC-20 will control one transceiver. **Most often-used front panel functions** are controllable from the RC-20. The RC-20 and IF-20 combine to allow control of up to four radios.

- **Selective calling and pager option.** The DTU-2 option enables the Dual Tone Squelch System (DTSS), allowing selective calling and paging using standard DTMF tones.
- **Digital recording system option.** Used in conjunction with the tone alert system, the DRU-1 allows message storage of up to 32 seconds.
- **Multiple scanning functions.** Band and memory scan, with selectable scan stops and memory channel lock-out.
- **Large LCD display with four-step dimmer control.**
- **Automatic Lock Tuning (ALT)** for the TM-541A. Compensates for drift.

- **Supplied accessories.** Mounting bracket, DC cable, fuses, MC-44DM multi-function DTMF mic.

Optional accessories

- DRU-1 Digital Recording Unit
- DTU-2 DTSS unit • IF-20 Interface unit, used with the RC-20, allows more than two transceivers to be remotely controlled
- MA-700 2m/70cm dual band antenna with duplexer (mount not supplied)
- MB-201 Extra mounting bracket
- MC-44 Multi-function hand microphone
- MC-55 (8-pin) Mobile mic. with time-out timer
- MC-60A, MC-80, MC-85 Base station mics.
- PG-2N Extra DC cable
- PG-3B DC line noise filter
- PG-4G Extra control cable
- PG-4H Interface connecting cable
- PG-4J Extension cable kit
- PS-50/PS-430 DC power supplies
- RC-10 Handset remote controller
- RC-20 Remote control head
- SP-41 Compact mobile speaker
- SP-50B Mobile speaker
- TSU-6 Programmable CTCSS decoder

KENWOOD U.S.A. CORPORATION
COMMUNICATIONS & TEST EQUIPMENT GROUP
P.O. BOX 22745, 2201 E. Dominguez Street
Long Beach, CA 90801-5745
KENWOOD ELECTRONICS CANADA INC.
P.O. BOX 1075, 959 Gana Court
Mississauga, Ontario, Canada L4T 4C2

KENWOOD

...pacesetter in Amateur Radio

COMMUNICATIONS QUARTERLY

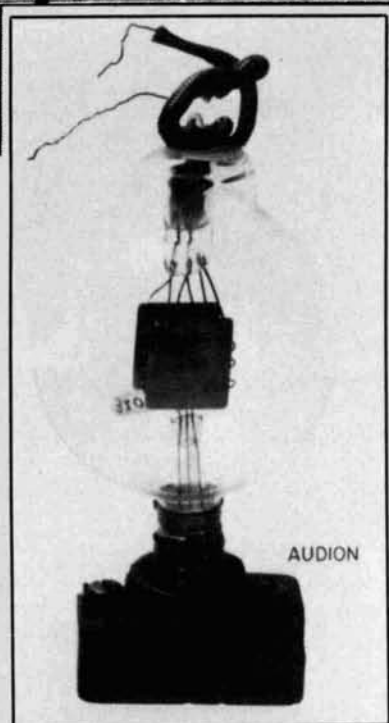
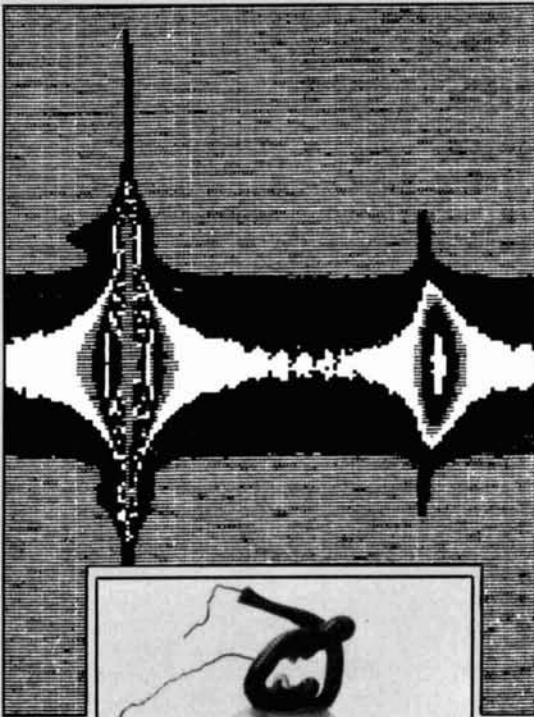
THE JOURNAL OF
COMMUNICATIONS
TECHNOLOGY

CONTENTS

Volume 2, Number 2

Spring 1992

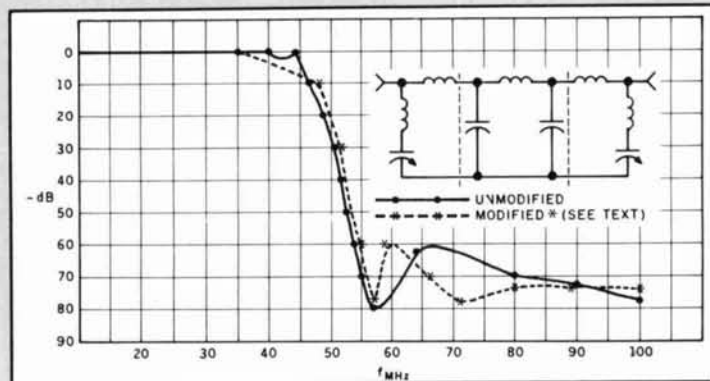
Mork, page 49



Carr, page 93

- 11 HF Radio Data Communication**
Bill Henry, K9GWT and Ray Petit, W7GHM
- 25 Diagnosing RFI Problems in Vehicles**
Irv Karwick
- 28 Parasitic Elements For Pattern Shaping In Vertical Antennas**
R.P. Haviland, W4MB
- 35 Be A CAD (USER)**
F. Dale Williams, K3PUR
- 49 A User's View Of Charge Coupled Device Imaging**
Brian Mork, KA9SNF
- 72 The Solar Spectrum**
Peter O. Taylor
- 75 Low-Pass Filter Performance**
Marv Gonsior, W6FR
- 85 Quarterly Devices**
Rick Littlefield, K1BQT
- 92 Technical Conversations**
Reader's comments on articles previously run in Communications Quarterly
- 93 Radio Receivers Of The Past**
Joseph J. Carr, K4IPV

Cover photo: An assortment of CCDs and CIDs ranging from a single element CID through linear to the large (2-1/4" x 2-1/4") active area Tektronix 2048 x 2048 CCD device. Photo courtesy of The Denton Research Group and Photometrics, Ltd.



Gonsior, page 75

EDITORIAL

An Editor Caps His Pen.

Like any other business, *Communications Quarterly* has a staff of dedicated workers. But unlike many offices, CommQuart's staff is scattered across several states and we pull our journal together with the aid of the phone, FAX, and U.S Mail. We have a production department, business offices, and sales staff in New York; a technical draftsman in New Hampshire; editorial review board members in Massachusetts, New Jersey, Florida, New Mexico, and California; columnists in New Hampshire and Georgia; freelance writers from all over the country; and editors in New Hampshire, Connecticut, and California. Some of us have met at the Dayton Hamvention® or at "corporate headquarters." But many of us have never had the opportunity for an "eyeball" QSO. All we know of each other is what we've learned from phone conversations or letters received in the mail.

Although the trappings of the electronic age make it easy for all the members of our staff to work as a unit to produce CommQuart four times a year, it's impossible to get together for holiday celebrations or to recognize certain achievements, events, and milestones in the lives of individual staff members. So in lieu of a more private party, I'm asking you, our readers, to join me in acknowledging the contribution that one of our number has made not only to *Communications Quarterly*, but to the amateur radio community as a whole.

Early in March, I received a call from Alf Wilson, W6NIF, CommQuart's senior technical editor, saying that he felt the time had come to put down his red pen and retire. It was a sad day for me because Alf has been a person I've relied on from the time I joined the amateur radio publishing industry in 1987. I knew I was going to miss his witty editorial insights, technical expertise, and attention to detail. Although we've never met, Alf has been by my side from the first offering his views on manuscripts, catching technical errors, admonishing me for working too hard, agonizing and commiserating over tough assignments. He's been a good friend and sounding board.

A ham since the early 1930s, Alf's career as an amateur radio journalist began with some behind-the-scenes work for Jim Fisk, W1DTY, during his tenure at *73 Magazine*. When Jim left *73* to start *Ham Radio Magazine* with Skip Tenney, W1NLB, he brought Alf along for the ride. Alf wore many hats during the 24-year span of *Ham Radio* and when it ceased publication in June 1990, joined *Communications Quarterly* as senior technical editor. His technical expertise and ham radio savvy has been an asset to all of us with whom Alf has worked over the years.

As I wrote these words, I kept going back over the bits and pieces of Alf's work that I have tucked into the nooks and crannies of my office. I read through his articles and editorials in *Ham Radio*, his comments on manuscripts he's edited for CommQuart, the letters he's written to me. What emerged was a picture of Alf as a man who understands all the nuances of amateur radio: the technical side; the thrill of working the different bands and modes; the political game; the tricks of the trade for upgrading, hiding antennas, and troubleshooting problems; in short—a very knowledgeable ham. Over the years, Alf has shared this knowledge with all of us and for this we owe him our thanks.

So, here's to you Alf! To a long and happy retirement. To time spent with the grandkids, to walking in the California sunshine (something that I, living through cold, rainy New Hampshire winters, frequently dream about), to working some rare DX station with a wild antenna that you've created to get around the restrictions so many "apartment hams" wrestle with. Let's open the champagne, cut the cake, and let me present you with your gold-plated red editing pen. It has been a joy and a privilege to work with you. And, Alf, if you ever get restless and have the need to ink up a manuscript, just give me a call.

Terry Northup, KA1STC
Editor

EDITORIAL STAFF

Editor

Terry Northup, KA1STC
Consulting Technical Editor
Robert Wilson, WA1TKH
Senior Technical Editor
Alfred Wilson, W6NIF
Technical Editor
Peter Bertini, K1ZJH
Editorial Assistant
Linda Romanello

EDITORIAL REVIEW BOARD

Forrest Gehrke, K2BT
Michael Gruchalla, P.E.
Hunter Harris, W1SI
Bob Lewis, W2EBS
Walter Maxwell, W2DU
William Orr, W6SAI

BUSINESS STAFF

Publisher
Richard Ross, K2MGA
Advertising Manager
Arnie Sposato
Sales Assistant
Tracy Parbst
Controller
Frank Fuzia
Circulation Manager
Catherine Ross
Data Processing
Melissa Kehrwieler
Carol Minervini
Customer Service
Denise Pyne

PRODUCTION STAFF

Art Director
Elizabeth Ryan
Asst. Art Director
Barbara Terzo
Artist
Susan Reale
Production Manager
Dorothy Kehrwieler
Phototypographers
Pat Le Blanc
Florence V. Martin

A publication of
CQ Communications, Inc.
76 North Broadway
Hicksville, NY 11801-USA

Editorial Offices: P.O. Box 465, Barrington, NH 03825. Telephone/Fax: 603-664-2515.

Business Offices: 76 North Broadway, Hicksville, NY 11801. Telephone: (516) 681-2922. FAX: (516) 681-2926.

Communications Quarterly is published four times a year (quarterly) by CQ Communications, Inc. Subscription prices: Domestic—one year \$29.95, two years \$56.95. Foreign—one year \$39.95, two years \$76.95. Foreign Air Mail—one year \$60.95, two years \$118.95. Contents copyrighted CQ Communications, Inc. 1992. Communications Quarterly does not assume responsibility for unsolicited manuscripts. Allow six weeks for change of address.

Second-class postage paid at Hicksville, NY and additional mailing offices.

Postmaster: Please send change of address to Communications Quarterly, CQ Communications, Inc., 76 North Broadway, Hicksville, NY 11801. ISSN 1053-9344

...The Perfect Solution

If you're living in an area with antenna restrictions, if you're tired of hassling with huge multi element yagis or if you're just looking for a compact, rugged, easy-to-use portable antenna that really *works*, the 150 watt IsoLoop 10-30 (MHz) HF Antenna is the Perfect Solution to your antenna problems.

The IsoLoop 10-30 has been redesigned to provide greater durability, lower SWR and extended frequency coverage. Because the loop is isolated from the feedline, your radiated power goes into the antenna, not into the shack. Efficiency is maximized because the new design has no mechanical joints and no assembly is required. **No ground plane or antenna tuner needed!**

The IsoLoop comes fully assembled complete with LC-2 Loop Controller (including signal strength LEDs) and 50 feet of control cable in a UPS shippable package.

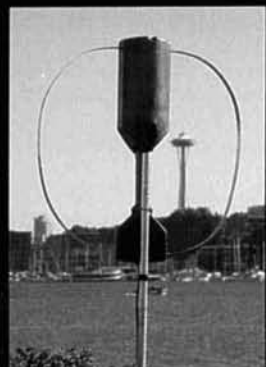
This HF antenna goes where few others have gone before!

See the IsoLoop 10-30 today at your favorite AEA dealer.

For a complete specification sheet on this or any other AEA product, call the toll-free AEA Lit Line at 1-800-432-8873.



LC-2
Loop Controller.

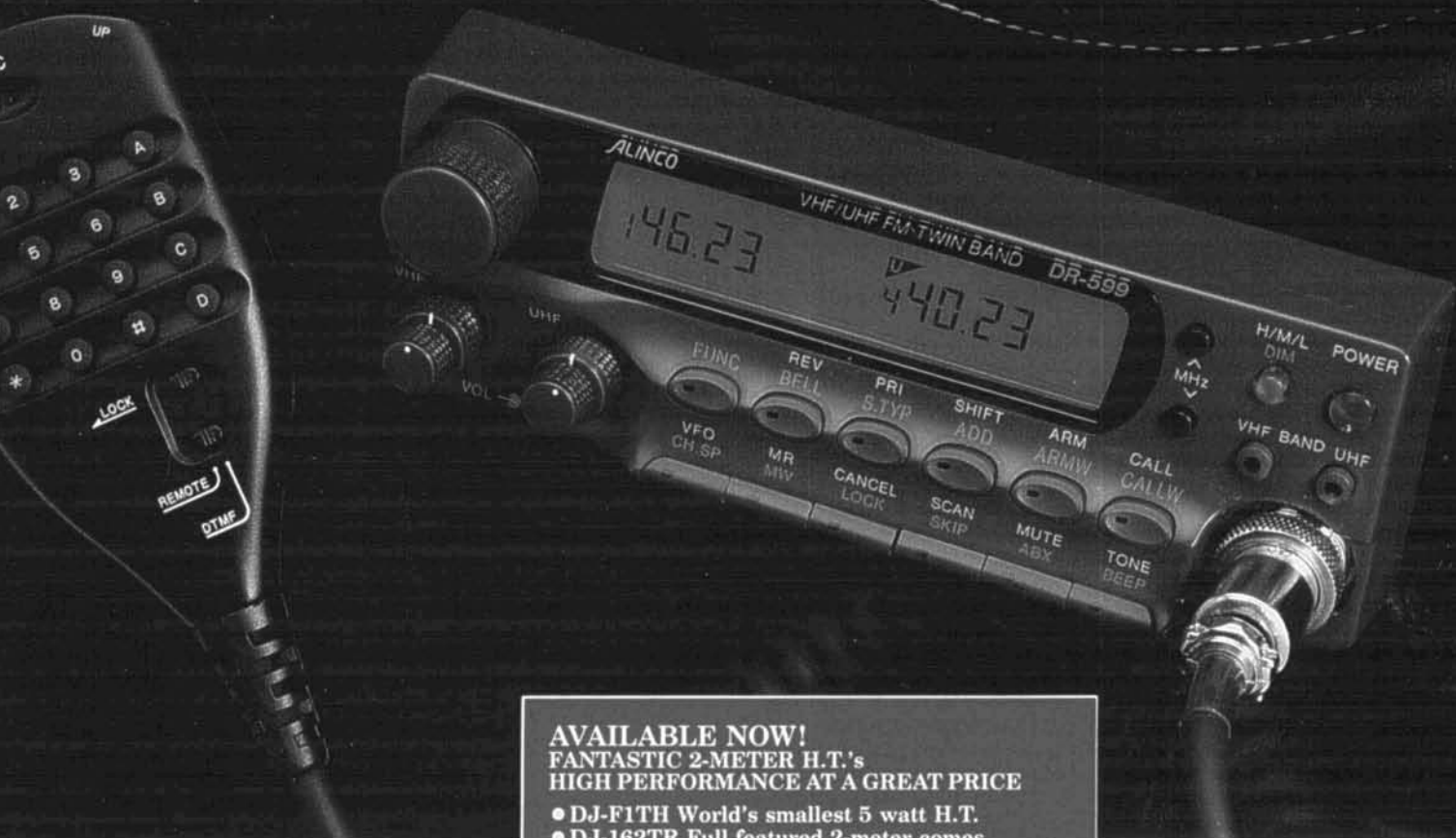


Advanced Electronic Applications, Inc.

P.O. Box C2160/2006 196th St. S.W. Lynnwood, WA 98036-0918
Technical Support: (206) 775-7373 Office (206) 774-5554
FBS (206) 234-5678 CompuServe user ID 76702,1013

All specifications subject to change without notice or obligation.
© AEA, Inc. 1991. All Rights Reserved.

**Fastback styling
and detachable
convenience.**



**AVAILABLE NOW!
FANTASTIC 2-METER H.T.'s
HIGH PERFORMANCE AT A GREAT PRICE**

- DJ-F1TH World's smallest 5 watt H.T.
- DJ-162TR Full featured 2-meter comes standard with EDC-34 rapid charger

New Model DR-599T

Here's the radio that goes where no radio has gone before. This is truly the most advanced twin-bander available today.

Hi-tech features and ergonomic design put the DR-599T in a league of its own. From the Remote control microphone to the contoured fingertip buttons, the DR-599T looks and feels like a smooth operator.

Space limitations are not a problem for the DR-599T. The detachable control head allows the transceiver body to be hidden from view while the sleek control head can be neatly mounted on a dash or visor. (Optional separation kit required).

This DR-599T has full duplex cross band operation and cross band repeater functions with real-world

power and excellent sensitivity. Airband receive is also possible with a simple modification.

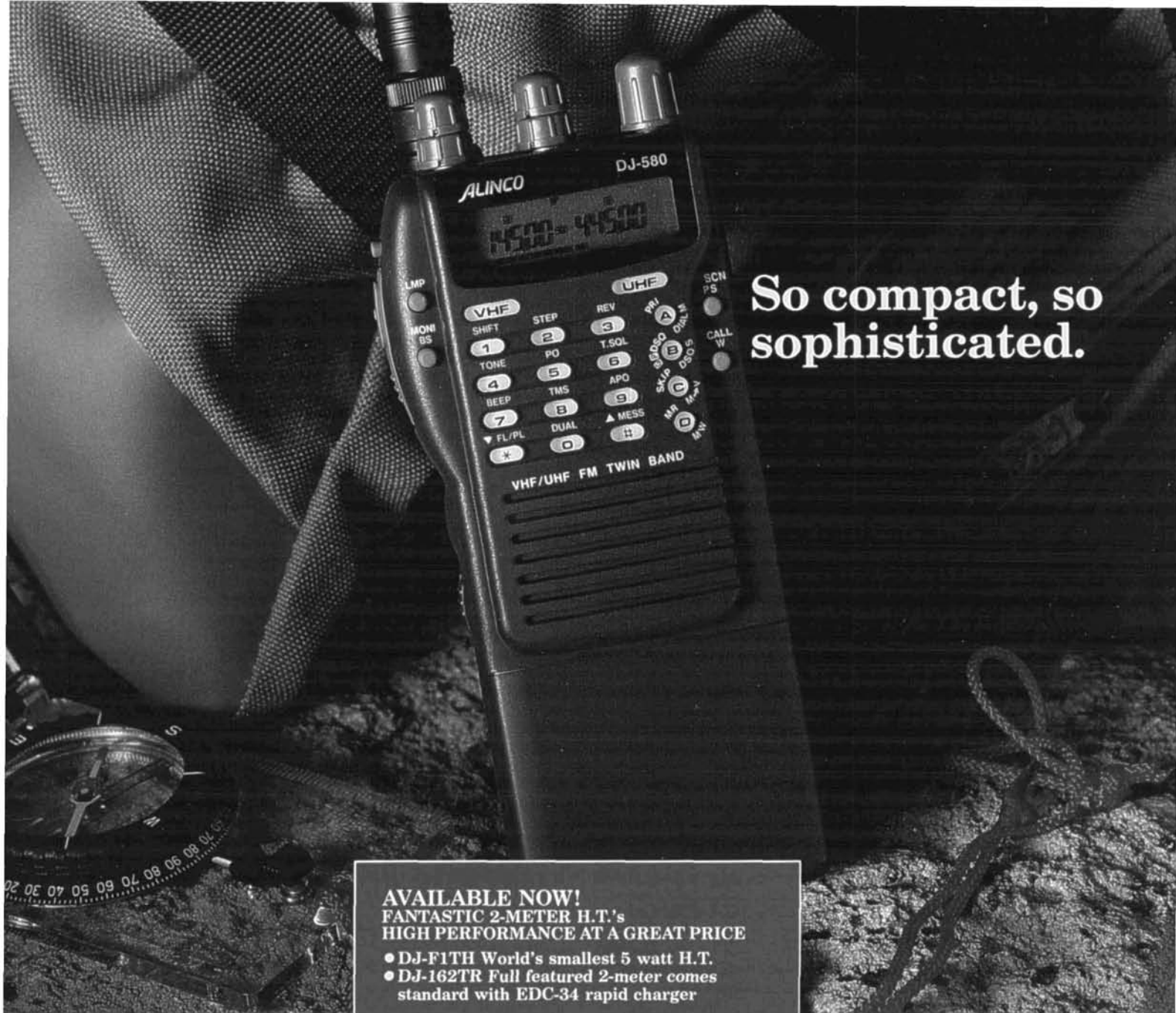
The standard features include 3 power output selections, ARM, ABX, Bell, Reverse, Mute, and Auto Dialer functions. Also, with the optional EJ-8U DTMF Decoder board installed, the DR-599T can be remotely operated from another transceiver.

**Check out the affordable technology of the 90's.
Check out ALINCO.**

 **ALINCO**
ELECTRONICS INC.

ALINCO ELECTRONICS INC.
438 Amapola Avenue, Unit 130, Torrance, CA 90501
Tel. (310) 618-8616 Fax (310) 618-8758

Two Year Limited Warranty.
Specifications and features are subject to change without notice or obligation.



So compact, so sophisticated.

AVAILABLE NOW!
FANTASTIC 2-METER H.T.'s
HIGH PERFORMANCE AT A GREAT PRICE

- DJ-F1TH World's smallest 5 watt H.T.
- DJ-162TR Full featured 2-meter comes standard with EDC-34 rapid charger

New Model DJ-580T

RATED # 1 IN JAPAN, NOW AVAILABLE IN THE U.S.

A super-compact handheld, the tiny DJ-580T is a powerful, feature-packed twin bander. This super-compact HT is the smallest you'll find, and literally fits in the palm of your hand.

Ergonomic design, combined with excellent sensitivity and unbelievable great sound, sets a new standard for miniature HT's.

New MCF function allows you to set the 40 memory channels regardless of which channels you want for VHF or UHF. Any combination is possible.

Alinco's DJ-580T has Full-Duplex Cross Band Operation and Cross Band Repeater Functions with real world power and excellent sensitivity. Airband

receive with simple modification.

If the battery is depleted to less than 5 volts, Alinco's Patented Super Low Battery Consumption Function is automatically activated. You can continue to operate the radio all the way down to 3.5 volts. This feature is effective with dry cell batteries only.

This unit has built in DSQ for paging, CTCSS encode and decode standard, various scanning functions, 3 power level selections for each band, bell function, and an illuminated keypad.

Check out the affordable technology of the 90's. Check out ALINCO.



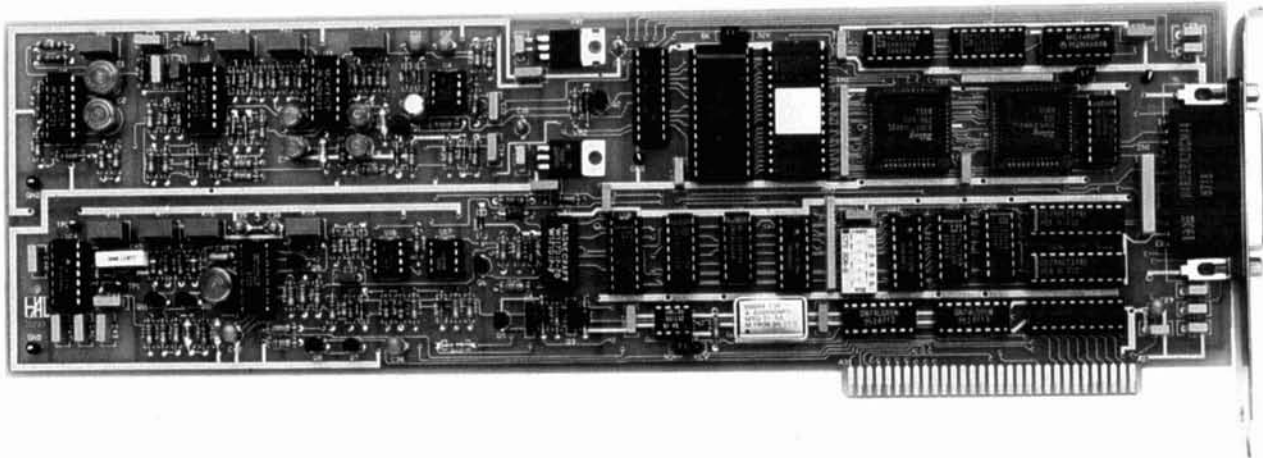
ALINCO ELECTRONICS INC.
 438 Amapola Avenue, Unit 130, Torrance, CA 90501
 Tel. (310) 618-8616 Fax (310) 618-8758

Two Year Limited Warranty.
 Specifications and features are subject to change without notice or obligation.

For Serious HF Work

Get the card that makes copying weak and fading signals possible!

The HAL PCI-3000 PC-AMTOR System



The PCI-3000 PC-AMTOR system gives you excellent HF performance on AMTOR, RTTY, and CW at a reasonable price. The PCI-3000 card plugs into a full size PC card slot. Filter circuits are optimized for 170 Hz shift - the RTTY and AMTOR standard. CW is optimized for an 800 Hz receive tone. Outstanding features of the PCI-3000 PC-AMTOR system are:

- Installs in your PC
- AMTOR, RTTY and CW modes
- High performance at a low price
- Split Screen operation
- Continuous receive storage
- Message transmission from disk
- APLink compatible
- HELP pages
- Search Mode
- Xmit & Rcv buffer storage
- Complete with software
- Optional SPT-2 & FIL-1

Don't wait any longer to experience what a true HF data interface can do for your station. Put your PC on the HF bands with high performance at a low price. Order the PCI-3000 PC-AMTOR system from HAL today!



SPT-2 Spectra-Tune

The SPT-2 makes tuning AMTOR, RTTY, and CW signals a breeze. It connects to the PCI-3000 via the supplied cable. The radio connections for the PCI-3000 are then made to the phono connectors on the SPT-2 rear panel. The tuning indicator is a 30-segment LED bar graph representing a 600 Hz range of the audio spectrum. The RTTY and AMTOR tuning range is centered at 2210 Hz. In CW mode the range is centered at 800 Hz. Simply tune the receiver until the signal is centered on the proper calibration marks.

FIL-1 AMTOR/RTTY Filter

If your transceiver doesn't have good RTTY filters, install the FIL-1 in your Spectra-Tune. The FIL-1 is a 500 Hz wide filter centered at 2210 Hz to optimize AMTOR and RTTY copy. The FIL-1 greatly reduces the noise input to the PCI-3000. This can mean the difference in barely detecting a signal and solid copy.



HAL Communications Corp.
P.O. Box 365
Urbana, IL 61801
Phone (217) 367-7373
FAX (217) 367-1701

PCI-3000 PC AMTOR with software \$395.
SPT-2 Spectra Tune with cable \$169.
FIL-1 Filter (installs in SPT-2) \$69.
Complete System Price \$595.

VISA and Mastercard Welcome

LETTERS

For those on a leaner budget

Mr. Bergeron's fine article, "Micro-Computer Based Instrumentation Systems" (Winter 1992), certainly shed a lot of light on this very interesting subject.

Unfortunately though, much of the software and hardware described was in the "big bucks" category, something which need not be the case for those of us on a leaner budget.

The key to low-priced data logging and control of serial instruments is a certain inexpensive MS-DOS spreadsheet, Quattro Pro SE[®], which costs about \$50.

This program can read and write text files directly, including the predefined device files available in DOS—notably the two serial ports, COM1 and COM2.

It is only necessary to write a program (macros) to send and receive and process the data, using the excellent analysis and graphics capabilities of this spreadsheet. A few simple demo routines will make this clear.

The first macro sends the "ATZ" reset to a modem on COM1 and then reads the response; cell D1 will show CR-LF OK CR-LF, with CR-LF shown as graphic symbols. The modem echo should be off. The second macro just reads a few characters from COM2, the mouse port, when the mouse is moved. No mouse driver is needed; the characters (in D12) are meaningless. The third macro just sends a string to the printer.

These simple demos have been tested with Quattro SE and will probably work with any version of Quattro Pro. They do not work with Lotus 1-2-3[®], which at \$300 a pop, is a poor value for lean budgets anyway.

Coupled with the many inexpensive serial micro-controllers and instruments available, this spreadsheet can make short work of data display, logging and storage, and is just what the experimenter needs for rapid development.

John T. Lenihan
Altamonte Springs, Florida

```
{OPEN "COM1",M}  
{WRITELN "ATZ"}  
{READ 6,D1}  
{?}  
{BLANK D1}  
{CLOSE}
```

```
{OPEN "COM2",R}  
{READ 2,D12}  
{?}  
{BLANK D12}  
{CLOSE}
```

```
{OPEN "LPT1",W}  
{WRITELN "THIS IS A TEST"}  
{CLOSE}
```

Electronics Workbench[®]

The electronics lab in a computer™

Powerful software to build and simulate analog and digital circuits.

Building and testing circuits is fast and easy with *Electronics Workbench*. Just click-and-drag with a mouse to add parts, run wires, and adjust instruments. The traces on the simulated instruments are the same as you'd get on real equipment.

Electronics Workbench really is an electronics lab in a computer. It's ideal for learning about electronics, experimenting, and prototyping circuits.

"Electronics Workbench is pretty amazing." - Jerry Pournelle, Ph.D., *InfoWorld*

DOS Professional Version - \$299
Macintosh Version - \$199

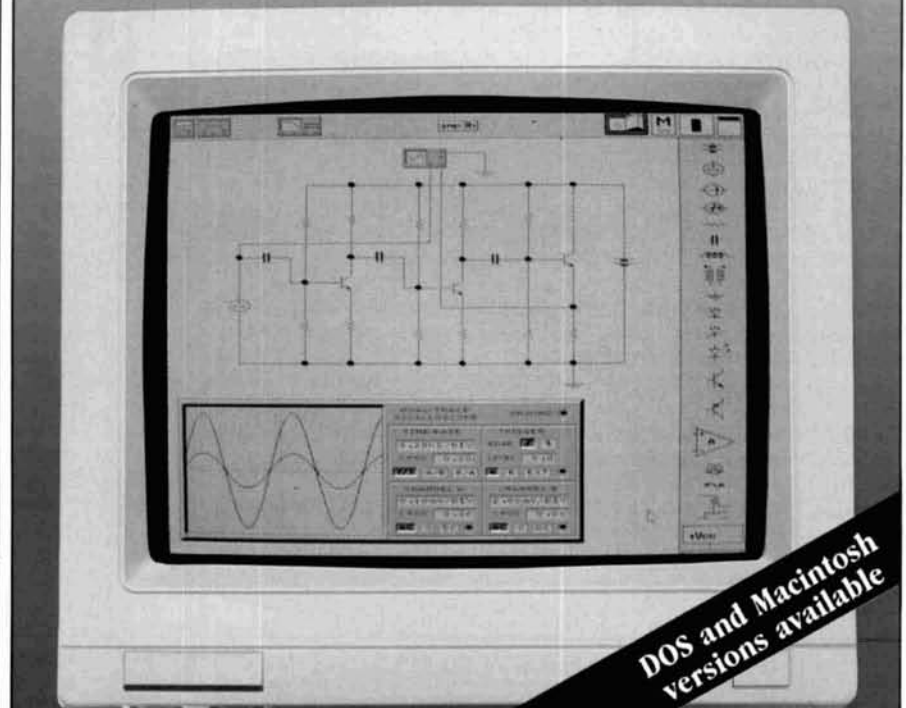
Electronics Workbench includes:

- **Analog Module** with passive and active components including transistors, diodes, and op-amps; a function generator, an oscilloscope, a multimeter, and a Bode plotter.
- **Digital Module** with gates, flip-flops, adders, a word generator, a logic analyzer, and a unique logic converter and simplifier.

(416) 361-0333

Interactive Image Technologies Ltd.
908 Niagara Falls Boulevard
North Tonawanda, NY
14120-2060
Fax (416) 368-5799

Prices are in US dollars. Offer valid in the USA and Canada only. Macintosh Version is monochrome only. All trademarks are the property of their respective owners.



DOS and Macintosh versions available

NO PROBLEMO

You want a bargraph & a full range counter – Optoelectronics can deliver!

\$199.

Don't Wait,
This Offer Can't Last!
No discounts. No trade-ins.

Now for a limited time only, \$160. off the list price. for our Full Range Model 2810 with bargraph – plus:

- Full range -10Hz to 3GHz.
- LCD display (daylight visibility).
- True state-of-the-art technology with the high speed ASIC.
- NiCads & Charger included.
- Ultra-high sensitivity.
- 4 fast gate times.
- Extruded metal case.
- Compatible with MFJ207.

Suggested options

TA100S:

Telescoping Whip Antenna.....\$ 12.

CC30

Vinyl Carry Case.....\$ 15.

BL28:

EL Backlight for use in roomlight and low light.....\$ 45.

TCXO 30:

Precision ± 0.2 ppm 20 to 40°C temp. compensated time base\$100.

Universal
Handi-Counter™
Model 3000, \$375. and
Bench Model 8030, \$579.
Both offer frequency,
period, ratio and time
interval.



**Made in
the USA**

OPTOELECTRONICS

Call for free catalog - Factory Direct Order Line:

1-800-327-5912

FL (305)771-2050 • FAX (305)771-2052

5821 NE 14th Ave. • Ft. Lauderdale, FL 33334
5% Ship/Handling (Max. \$10) U.S. & Canada.
15% outside continental U.S.A.
Visa and Master Card accepted.

HF RADIO DATA COMMUNICATION

CW to CLOVER*

Amateur radio operators have been engaged in data communications since the first days of spark gap transmitters. In fact, the first and ONLY means of early radio communications required ON/OFF keying of the radio transmitter using a digital code. That code was, of course, the Morse code. With the invention of amplifiers and voice modulators, some amateurs "strayed" into nondigital modes (AM, SSB, etc.). However, amateur radio has seen a resurgence of interest in digital modulation, and there are now many of us using RTTY, AMTOR, packet, and CW. In this article, we'll discuss these popular digital modes, along with a new one called "CLOVER."

Digital modes

Morse code

Morse code is the original data communications code used by amateur radio operators. Often abbreviated as CW (continuous wave), Morse code is transmitted by ON/OFF keying of the transmitter carrier. Combinations of dots and dashes (short and long key-down times) make up the character codes. Morse code is unique among digital codes in that the length of time required to send each character varies with the character sent. For instance, E is one dot, while zero is five dashes. An E is sent in 1/10th the time required to send zero. Morse is a

very efficient code for sending English language text because the most frequently used characters are assigned the shortest code combinations (E, I, S, T, A, N). Morse code is relatively easy to learn, and requires only a key and a skilled operator. It is designed for manual operation.

However, the varying time length of each Morse character and the ON/OFF carrier keying used to send Morse code, make automatic reception of Morse code by computers a very difficult task. Automatic computer Morse code decoders have been designed, and Morse receive algorithms improve with each generation. However, automatic Morse decoding still is not equal to the decoding skills of a good CW operator.

It must also be noted that the abbreviation CW in reference to Morse code transmission has helped perpetuate a myth that survives to this day: "Morse code is the most bandwidth-efficient mode of communications," and "CW has no bandwidth at all." As can be seen in **Figure 1**, this is by no means the case! **Figure 1** shows the frequency spectra generated by a 60-WPM CW transmitter using the ARRL-approved rise and fall times (5 ms). Morse code is obviously not a "zero-bandwidth" emission!

RTTY

RTTY (radio teletype), the successor to Morse code, was originally developed to automate wire-line message communications. Very complicated teletype machines allowed automation of message handling. Some of us still use these "mechanical computers." As a result of military requirements during World War II, teletype ma-

*This article is an update of the paper, "Digital Communications for HF Radio—AMTOR & CLOVER," Bill Henry, K9GWT, and Ray Petit, W7GHM, presented to the Amateur Radio Digital Communications Seminar, St. Louis, Missouri, October 26, 1991.

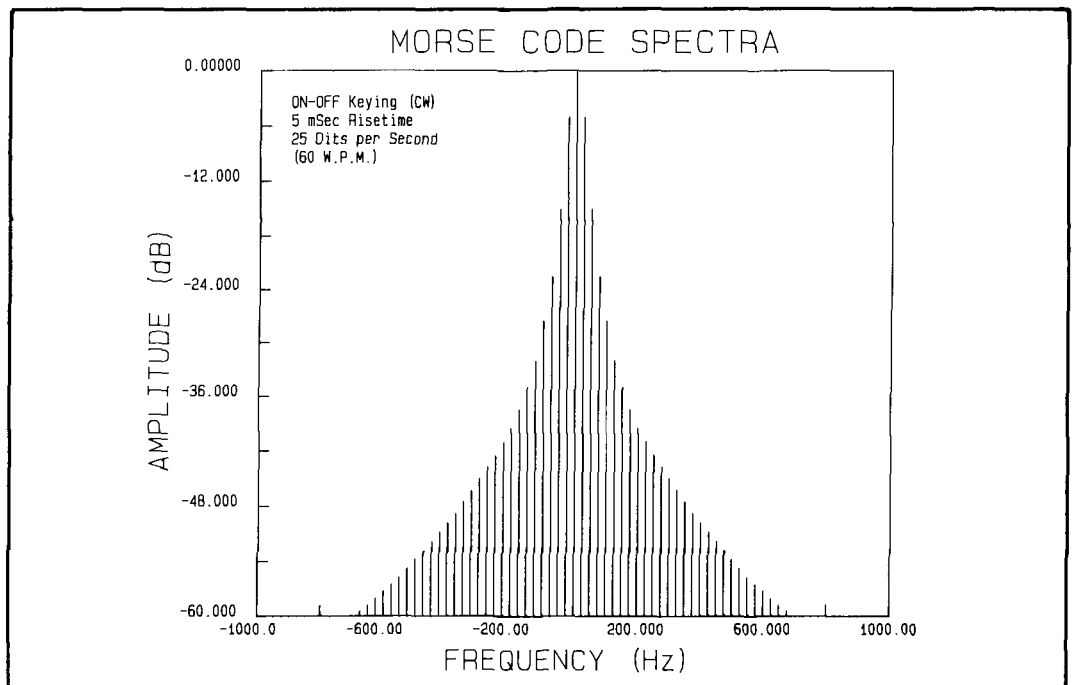


Figure 1. Morse code spectra.

chines were connected to radio transmitters and RTTY came into being. Amateur RTTY today still follows the general techniques first used in the 1940s (but with notable improvements in terminals and modems).^{2,3}

Most amateur RTTY operators use the original five-bit "Baudot" (or "Murray") code. The five bit code length limits Baudot to a maximum of 32 unique characters—not enough to represent 26 letters, 10 numbers, and punctuation. This problem is solved by use of LTRS and FIGS case-shift characters; each code combination is used twice. However, Baudot can't be used to send lower-case letters or an extensive set of control characters.

In 1980, United States amateurs were allowed to use the seven-bit computer ASCII code as well.* This code is used in all mo-

dern computers and allows unique encoding of 128 different letter, number, punctuation, and control characters. Many of us experimented with ASCII, and soon learned that it's not very robust when used on HF. Noise and QRM "hits" often convert a valid character into a control code that wreaks havoc with our printers (large/small type, form-feeds, etc). Most RTTY amateurs continue to use the Baudot code.

Baudot and ASCII are both "asynchronous" codes. They have START and STOP pulses that allow receive synchronization on each character. Other data modes use codes that are "synchronous." They have no START or STOP pulses.

Amateur RTTY can be used at many "speeds," but 45 baud (60 WPM) and 75 baud (100 WPM) are by far the most popular.** When ASCII is used on HF, it's almost always sent at 110 baud (100 WPM). These speeds correspond to a data "throughput rate" of 6 to 10 characters-per-second (cps). RTTY modes offer no means to correct transmission errors.

HF RTTY is transmitted using Frequency Shift Keying (FSK) of the transmitter radio frequency. This can be done by either shifting a transmitter oscillator directly, or by driving an LSB transmitter with audio tones. Most of the modern transceivers that include an "FSK" mode really use an internal audio oscillator to drive LSB transmitter circuits. The standard RTTY "SHIFT" is 170 Hz—the difference between the MARK

*There is more than a little confusion as to whether ASCII is a seven-bit or eight-bit code. When sending ASCII on HF at 110 baud, most terminals send seven data bits and one "parity" bit. There are eight bits between the Start and Stop pulses. One-hundred and ten baud ASCII usually has one start bit, eight "data field bits," and two stop bits, for a total length of 11 bit units. However, this is by no means "standard." Some systems send only seven data bits and no pulse where the parity bit is normally located. If an eight-bit generator sets bit 8 to MARK, the serial asynchronous code will be compatible with receiving UARTs set for either seven-bit or eight-bit codes (bit 8 set to "always MARK").

**For FSK RTTY, AMTOR, and packet radio, the baud rate is equal to 1 divided by the time width of one data pulse. For example, 60-WPM RTTY has a data pulse width of 22 ms. Its baud rate is $1/0.022 = 45.45$ baud, usually abbreviated as 45 baud. However, CLOVER has the capability of sending more than one data state per data pulse, by using multiple phase and amplitude levels. Therefore, CLOVER has one baud rate—31.25 baud per tone pulse (125 baud composite)—but several throughput rates—18.75 bits-per-second (bps) to 750 bps.

and SPACE frequencies. Most HF RTTY demodulators use audio tones at 2125 (MARK) and 2295 Hz (SPACE). RTTY demodulators come in many different shapes and price ranges. High performance demodulators can be very complicated—and expensive.^{4,5}

RTTY has proven to be a convenient and popular mode for most of us. In addition to its wide use for rag chewing and chasing DX, RTTY made a new service possible—“mailbox” store-and-forward message handling (MSOs). However because neither Baudot nor ASCII RTTY include error correction, other modes like AMTOR, packet, and CLOVER are more suited for mailbox use.

AMTOR

AMTOR is an amateur adaptation by G3PLX of a commercial RTTY mode first devised in the late 1950s for ship-to-shore use. The commercial version is often called TOR (Teleprinting Over Radio) or SITOR (Simplex Teleprinting Over Radio). The CCIR and FCC call it Direct Printing Radiotelegraph. AMTOR specifications are defined in CCIR 476-4 and CCIR 625. AMTOR adds one mode not described by the CCIR—the “Monitor” or “Listen” mode.⁶⁻¹³

Like RTTY, HF AMTOR uses simple FSK transmitter modulation with 170-Hz shift. Commercial SITOR also uses 170-Hz shift FSK modulation, but with reverse data polarity. AMTOR signals are always sent at a data rate of 100 baud.

AMTOR digital code has seven bits. The AMTOR code is arranged so all characters contain four MARK and three SPACE data pulses (called “B” and “Y” pulses in “AMTOR-speak”). The receiving code converter examines each character for this 4/3 ratio and assumes that the character is in error if the ratio test fails. This is the error detection algorithm of AMTOR.

AMTOR has two primary operating modes: ARQ (Automatic Repeat reQuest) and FEC (Forward Error Correction). In ARQ mode, the sending station sends a burst (or “chirp”) of three characters and turns its transmitter OFF. The receiving station examines each character for the 4/3 bit ratio. If all three characters have the correct ratio, the receiving station sends a short control signal that means “send next chirp.” If any of the three characters fail the 4/3 ratio test, the receiving station sends a different control code that means “repeat last chirp.”

Note that in ARQ mode, both transmit-

ters chirp ON and OFF, but data is sent in one direction only. The station sending data is called the ISS (Information Sending Station) and the station receiving text the IRS (Information Receiving Station). Data always flows from the ISS to the IRS. However, a special OVER command reverses the roles of the two stations so data may be passed in either direction. ARQ mode only works in a two-station network. Three or more stations may not use ARQ mode with full error correction. Additional stations may, however, Monitor, but without error correction.

ARQ stations are time synchronized so the transmitting time of one corresponds to the receiving time of the other. AMTOR is also a “synchronous” rather than “asynchronous” mode. AMTOR characters do not include START and STOP pulses. Accurate timing is important in AMTOR and, for this reason, AMTOR controllers must be considerably more sophisticated than RTTY decoder devices. To assure correct timing, the station making the original call is named the MASTER station. It sets the timing for both stations for the duration of the ARQ “link.” The station originally called is the SLAVE station.

AMTOR ARQ mode uses station identifier SELCAL characters (SElective CALI). An ARQ mode link is initiated by the MASTER station that sends the SELCAL of the desired station. When a receiving station recognizes its SELCAL code, it responds with a chirp and the link is established. Note that only the designated station will respond, and many stations may listen on the same frequency. A CCIR-476 link requires only the SELCAL of the destination station; a CCIR-625 link exchanges the SELCAL of both stations. The CCIR-625 SELCAL code is also longer—seven characters rather than four for CCIR-476. Both CCIR-476 and CCIR-625 formats are legal for U.S. amateur use, but most of us continue to use CCIR-476 SELCAL codes. A special control END character is used to terminate an AMTOR ARQ transmission.

AMTOR FEC transmissions are one-way and may be received and printed by any AMTOR-equipped station monitoring the frequency. A SELCAL isn’t used in FEC mode. Amateurs use FEC mode primarily for calling CQ, but sometimes also for round-table rag-chewing.

FEC mode is much like RTTY in that one station sends his complete message and then turns his transmitter OFF to receive the other station(s). FEC mode does not use three-character chirps or repeat/continue

control signals from the receiving station. FEC mode provides limited error correction by sending every character twice. The repeat of each character is spaced in time so a character lost by a noise or interference burst may be received correctly at a later time. The receiving AMTOR controller examines the first received character for the 4/3 ratio and prints it when the ratio passes. If the first transmission of a character fails the test, the second transmission of that character is examined and printed if it is correct. If both transmissions of a character fail, a blank space (or underline) is printed to indicate an uncorrectable transmission error.

FEC mode isn't as "robust" as ARQ mode, and some errors can't be corrected. However, FEC mode does allow transmission to more than one other station with some means of error correction.

Selective FEC (SEL FEC) is a third mode used in commercial SITOR. This mode requires a SELCAL code, much like ARQ mode, and will only be received by stations whose SEL-FEC SELCAL matches that sent by the transmitting station. SEL-FEC is commonly used by commercial land stations to restrict transmissions to "company ships." The ARQ SELCAL and SEL-FEC SELCAL are usually different sets of characters. To date, most amateurs haven't used SEL-FEC mode.

AMTOR and SITOR enjoy widespread use all over the world, and the benefits of error detection and correction are greatly appreciated. The APLink program developed by W5SMM is widely used to link HF AMTOR to VHF packet message networks. As will be discussed later, AMTOR is considerably more reliable for HF data transmission than packet radio.

However, AMTOR is not without its limitations. AMTOR uses an error detection code, but the code is not infallible. In fact, a burst error can frequently change the states of not only one but two data bits—resulting in the printing of incorrect characters. This happens infrequently, but it does happen.

Also, the AMTOR throughput speed is

very slow by modern data standards. If there are no errors to be corrected in ARQ mode, the maximum rate at which data can be transmitted is 6.67 characters per second (cps). This is about 66 WPM, or the equivalent of 50-baud RTTY. When errors are detected and must be corrected by retransmission, this rate slows down. AMTOR, therefore, is not a rapid way to send a lot of data.

Finally, due to the unique 4/3 ratio encoding of the seven-bit characters, the AMTOR code supports a maximum of only 36 unique code combinations, including control signals. AMTOR uses the same algorithm as Baudot, and each bit combination is used twice: once in LTRS case and again in FIGS case. AMTOR, therefore, suffers the same problems as Baudot for transmission of lower-case letters and computer codes. This isn't normally a serious limitation for ship-to-shore commercial use, or in most amateur applications. However, it is a big handicap if computer data is to be sent.*

AMTOR, like RTTY and CW, is a fairly narrow-bandwidth emission. The measured spectrum of an AMTOR modulator (ARQ-1000 and ST-8000) is shown in **Figure 2**.** This spectrum is also representative of that produced by a RTTY station (45 baud is slightly narrower). Due to sidebands and demodulator filter bandwidths, AMTOR stations can be operated with a minimum of 1 kHz spacing between signals if all stations use 500-Hz wide receiver filters.

PACTOR

PACTOR is a new development from DL6MAA, DF4KV, DL1ZAM, and DL3FCJ. At this time, only a few PACTOR units have found their way into the United States, and some features of the new mode are still under development. PACTOR is a modification of AMTOR that provides moderate speed improvements over AMTOR. PACTOR uses an ASCII character set rather than Baudot, and error detection is by means of a CRC (Cyclic Redundancy Check) much like that used for AX.25 packet radio. PACTOR also includes an optional data compression mode that can further increase the data speed. However, the compression algorithm (Huffman encoding) is language specific; it works great on text in some languages, but won't increase speed on nontext data transmissions. Finally, PACTOR includes a speed-change algorithm in which the bit rate of the data may be increased from 100 baud to 200 baud when few errors are detected

*W5SMM and G3PLX are now experimenting with an extended AMTOR code that supports upper and lower case letters.

The spectra shown in **Figure 2 is a plot of measured data taken from the audio output of a HAL ST-8000 and ARQ-1000 operating in ARQ mode (170-Hz shift, tones = 2125/2295 Hz). The data has been numerically shifted to show 0 Hz as the center frequency and 0 dB as the maximum peak amplitude. The measurement device was a Hewlett-Packard Model HP-3561A Dynamic Signal Analyzer. The spectra of a 60-WPM (45 baud) FSK RTTY signal will be similar, but the MARK and SPACE spectra will be slightly narrower.

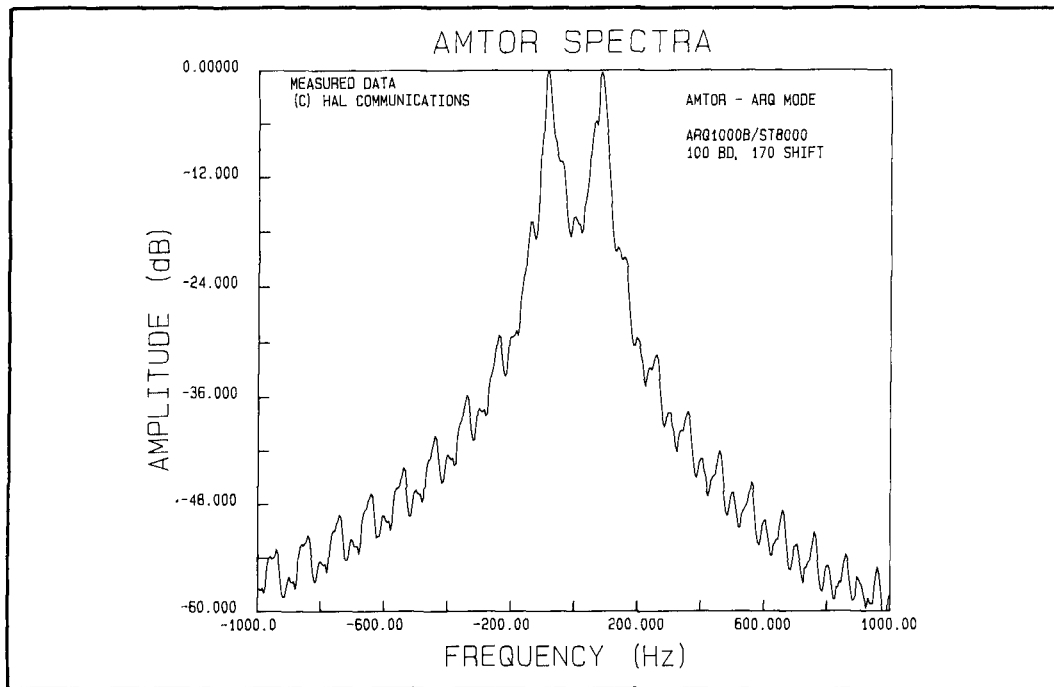


Figure 2. Amtor spectra.

(good conditions). PACTOR is still experimental and promises moderate gains in data throughput on HF radio—two times if 200 baud can be used, and also up to two times when Huffman data compression can be used. PACTOR, like AMTOR and RTTY, uses 170-Hz shift FSK modulation.^{14,15}

As with AMTOR ARQ mode, PACTOR is an error detection and repeat mode, rather than a true error correction mode (without requiring repeats). At this time, PACTOR is an interesting new mode that holds good promise for modest improvements in HF data transmission over that presently offered by AMTOR.

Packet radio

Packet radio has truly caused a revolution in amateur radio digital mode operations, thanks to pioneering work by TAPR (Tucson Amateur Packet Radio group). Packet radio uses a modification of the ANSI X.25 protocol—AX.25.¹⁶⁻²⁰

Like AMTOR, packet data is sent in bursts called “data packets.” Unlike AMTOR, data is encoded in eight-bit “bytes,” and the ASCII code may be sent and received directly (as well as eight-bit binary data). The start of a packet includes callsign identifiers and allows specification of repeater paths. The data packet ends with a CRC check sum number (Cyclic Redundancy Check). The receiving station computes a CRC number from the packet data it has received, compares that to the CRC sent, and requests a

repeat if the two do not match. This is much the same as AMTOR ARQ mode and, in fact, packet radio is another form of the generic ARQ class of data transmission modes. Also like AMTOR, packet includes station identifiers, and links only with designated stations. However, these identifiers can be complete callsigns.

Unlike AMTOR, packets contain many bytes or characters—32, 64, and 80 are common numbers in use—and may have up to 255 bytes per packet. Packet radio burst transmissions aren’t evenly spaced in time; packet transmissions are randomly spaced. At present, packet radio uses CSMA (Carrier Sense, Multiple Access): the controller listens and does not transmit if other stations are already sending. CSMA allows many packet radio stations to share the same frequency—each responding only to the station with which it is linked. This feature was a large boon to early development of VHF packet radio, but has proven to be a major limitation now that thousands of hams are using the mode. If a lot of stations (10 or more) attempt to use the same frequency, all traffic slows and eventually bogs down completely. On HF, it takes only three or four stations to gridlock the channel.

Packet radio has become almost the exclusive data mode used on VHF. Typical 2-meter VHF FM packet stations use 1200-baud, 1000-Hz shift AFSK modems based on the Bell 202 modem standard (1200/2200 Hz). A growing number of VHF

and UHF packet operations are now switching to 2400-baud PSK modulation. A few UHF packet network relay stations operate at very high data rates.

Packet radio has also been attempted on high frequencies, using 300-baud, 200-Hz shift FSK modulation. HF packet radio hasn't been a big success, and most of the problems may be traced to the modulation format and to the AX.25 protocol itself.

The modulation format used for HF packet is based on the Bell 103 300-baud telephone line modem. While this format is well suited for stable low-noise wire lines (and VHF radio), it has serious problems for HF use. First, use of simple FSK at a 300-baud data rate flies in the face of years of evidence that ionospheric multipath distortion severely affects any modulation in which the base modulation rate exceeds 100 to 150 baud. Multipath time "smearing" often exceeds 3 to 5 milliseconds. Since the width of a 300-baud data pulse is only 3.3 ms, time smearing irretrievably masks data bits. Second, use of the 300 baud rate with a very narrow FSK shift (200 Hz) creates a spectrum that is not easily detected. In fact, traditional in-band diversity from separate filters for MARK and SPACE, like those used for RTTY and AMTOR, is not possible. In retrospect, it can be stated that the choice of narrow shift FSK and a 300-baud data rate for HF packet was a poor engineering decision.

The AX.25 protocol is excellent for wire-

line and VHF radio use. However, the very features that make the protocol so useful on VHF, conspire to create big problems for HF use of AX.25. First, packets are loaded with a lot of "overhead"—non data characters (callsigns and repeater fields, for example). Second, packet radio is an error detection mode, not a direct error correction mode. The CRC is computed for the entire packet (including overhead). If the received CRC doesn't match that transmitted, the entire packet must be repeated.

Packet lengths can be set as short as 32 characters, but this is very inefficient. Often there are more overhead than data characters in a short packet. We would much rather send longer packets (64, 80, or greater) and improve the efficiency. Sending longer packets increases the time the transmitter is on the air and, more importantly, the time over which the CRC is computed, and the time during which completely accurate data must be received.

HF ionosphere disturbances are often of a "burst" nature—short, high intensity, and widely spaced. One "burst" within a packet requires the repeat of the complete packet. As the packet length is increased to improve efficiency, the probability of damage by a burst greatly increases to the state that no data can be passed. We, therefore, have the contradiction that short packets should be used to combat burst interference and noise, but that long packets give better efficiency. The ultimate result in both con-

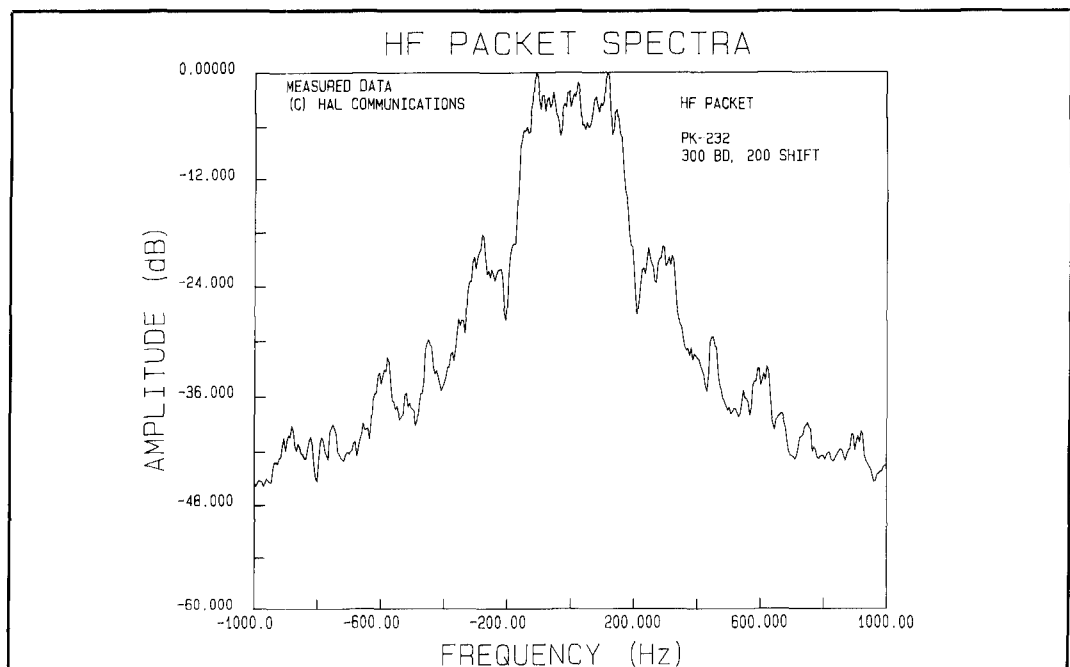


Figure 3. HF packet spectra.

ditions (long or short packets) adds up to very slow transmission of data. HF packet throughput can be as high as 15 to 20 characters-per-second at 300 baud under ideal conditions. However, what is actually observed are throughputs on the order of two to four characters-per-second—less than AMTOR, which operates at 1/3 the baud rate and in a narrower bandwidth!

Further, the “CSMA” concept doesn’t work well on HF. It is easily tricked by noise bursts and splatter from other HF packet signals. Also, CSMA doesn’t prevent simultaneous transmissions by multiple stations (collisions) due to propagation skip zones—the “hidden transmitter effect” (that is, your station can’t hear the interfering station but your destination station can).

HF packet radio at 300 baud, 200 Hz shift is very spectrum inefficient. **Figure 3*** shows the measured spectrum of an HF packet modulator (PK-232). The “gentlemen’s agreement” is that all HF packet stations must be spaced by at least 2 kHz to avoid mutual interference. This interference is caused by the wide bandwidth of the modulation sidebands themselves and the poor selectivity requirements forced on the receive modem by the FSK modulation format (300 baud/200 Hz shift). Two AMTOR stations can operate without interference in the spectrum required for one HF packet station. As we shall see, CLOVER allows four stations to operate in the same bandwidth as an HF packet signal.

In summary, we must comment that while packet radio is a wonderful VHF and UHF mode, it has very basic limitations for HF use. Practically all aspects of today’s HF packet signal are wrong for the conditions radio operators face daily on HF radio circuits.

CLOVER

CLOVER is a new data mode invented by Ray Petit, W7GHM. Ray’s work was inspired, first, by his earlier development and experience with very narrow bandwidth coherent CW and then by his observation of the many HF packet radio problems we’ve discussed. Rather than modifying existing modes, the CLOVER design started with a careful analysis of the unique problems of sending data via HF radio. CLOVER is tailored to overcome HF radio’s unique problems.²¹⁻²⁵

There are two variations of CLOVER: CLOVER-I is a 100-Hz bandwidth mode;²² CLOVER-II is a 500-Hz bandwidth mode. The CLOVER-I waveform is a steady se-

quence of smoothly shaped pulses at a single carrier frequency. Data is sent in the difference in the phase between successive pulses. The base data rate of CLOVER-I is 25 bits per \log_2 PSK level per second. Ray uses shaping of the time pulse to reduce all CLOVER sidebands to less than -60 dB beyond the 100 Hz bandwidth. CLOVER-I requires relatively simple analog circuits in the modem, but it makes extreme requirements on the radio equipment. In CLOVER-I, the radio frequency stability and tuning accuracy must be maintained within ± 0.10 Hz! Because this is not achievable by most commercial transmitters or receivers presently available, part of the CLOVER-I design includes the transceiver itself.

CLOVER-II is a much expanded version of CLOVER-I.²⁴ This mode makes heavy use of digital signal processing (DSP) techniques. CLOVER-II bandwidth is expanded to 500 Hz to better match the “narrow” filters commonly available for modern commercial transceivers. The CLOVER-II “carrier” is a steady sequence of four tone pulses at ascending audio frequencies. Each pulse has a duration of 32 milliseconds; successive pulses reach their peaks at instants 8 ms apart. The four tone pulses are also spaced 125 Hz apart in frequency, and carefully shaped in amplitude so that their spectra don’t overlap. Data is carried in the difference between phase and/or amplitude of successive pulses at the same frequency. These changes are made only at the instants midway between the peaks of two successive pulses when their amplitudes are zero. As a consequence, the usual wide bandwidth associated with phase modulation is avoided. The composite signal is 500 Hz wide. The crosstalk between two CLOVER signals spaced 500 Hz apart is less than 50 dB. As with CLOVER-I, varying levels of PSK and ASK modulation are used on each tone pulse so data throughputs as high as 750 bits-per-second are achieved from a base modulation rate of 31.25 bits-per- \log_2 (level)-per-second.

CLOVER-II has a total of eight different modulation formats that may be selected. In order of increasing throughput, these are: dual diversity BPSK (Binary PSK), dual diversity FSK, BPSK, QPSK (4-level PSK), 8PSK (8-level PSK), 16PSK (16-level

*The spectra shown in **Figure 3** is a plot of measured data taken from the audio output of an AEA PK-232 operating in HF packet mode with 300 baud data and a shift of 200 Hz (tones = 2110/2310 Hz). The data has been numerically shifted to show 0 Hz as the center frequency and 0 dB as the maximum peak amplitude. The measurement device was a Hewlett-Packard Model HP-3561A Dynamic Signal Analyzer.

CLOVER-II THROUGHPUT									
		Binary Data Through-put (Bits-per-second)							
Modulation		4 x BPSK	2 x "FSK"	BPSK	QPSK	8PSK	16PSK	8PSK/2ASK	16PSK/4ASK
Base Rate		31.25	31.25	125.00	250.00	375.00	500.00	500.00	750.00
MODE		"BDIV"	"FDIV"	"2P"	"4P"	"8P"	"16P"	"8P2A"	"16P4A"
R-S		|	|	|	|	|	|	|	|
CODE	EFF	|	|	|	|	|	|	|	|
"60"	60%	18.75	18.75	75.00	150.00	225.00	300.00	300.00	450.00
"75"	75%	23.44	23.44	93.75	187.50	281.25	375.00	375.00	562.50
"90"	90%	28.13	28.13	112.50	225.00	337.50	450.00	450.00	675.00
"100"	100%	31.25	31.25	125.00	250.00	375.00	500.00	500.00	750.00

COMPARISON HF DATA MODES						
[- HF Data Throughput -]						
RATE	COMMON NAME	Usable Data Bits	MAXIMUM CPS/bps	TYPICAL CPS/bps	ERROR CORRECT	HF SUITABILITY
45 BD	"60 WPM" RTTY	5 bits	6/30	*	None	GOOD, Few Errors
75 BD	"100 WPM" RTTY	5 bits	10/50	*	None	GOOD, Some Errors
110 BD	"100 WPM" ASCII	7 bits	10/70	*	None	FAIR, Many Errors
300 BD	"300 BAUD" ASCII	7 bits	30/210	*	None	VERY BAD, All Errors
100 BD	"AMTOR/SITOR"	5 bits	6.67/50	6/30	Yes	VERY GOOD, No Errors
300 BD	"HF PACKET"	8 bits	20/160	2/16 - 4/32	Yes	POOR, Many Repeats
1200 BD	"VHF PACKET"	8 bits	80/640	0/0	Yes	VERY BAD, No Data

* = No error correction, reception of good or bad data is at constant rate
 CPS = Characters-Per-Second Data Throughput
 bps = Bits-Per-Second Data Throughput

Table 1. Typical data throughput rates of the various combinations of CLOVER modes and codes.

PSK), 8PSK/ASK (8PSK plus 2-level ASK), and 16PSK/4ASK (16PSK plus 4-level ASK). As might be expected, the data throughput increases with the complexity of the modulation, and much better ionosphere conditions are required for the complex modes. Typical data throughput rates

of the various combinations of CLOVER modes and codes are shown in **Table 1**.

CLOVER-II also includes self-adapting software that can adjust for frequency drift and tuning inaccuracies. CLOVER-II requires frequency resolution of ± 10 Hz and will track variations up to ± 25 Hz, achiev-

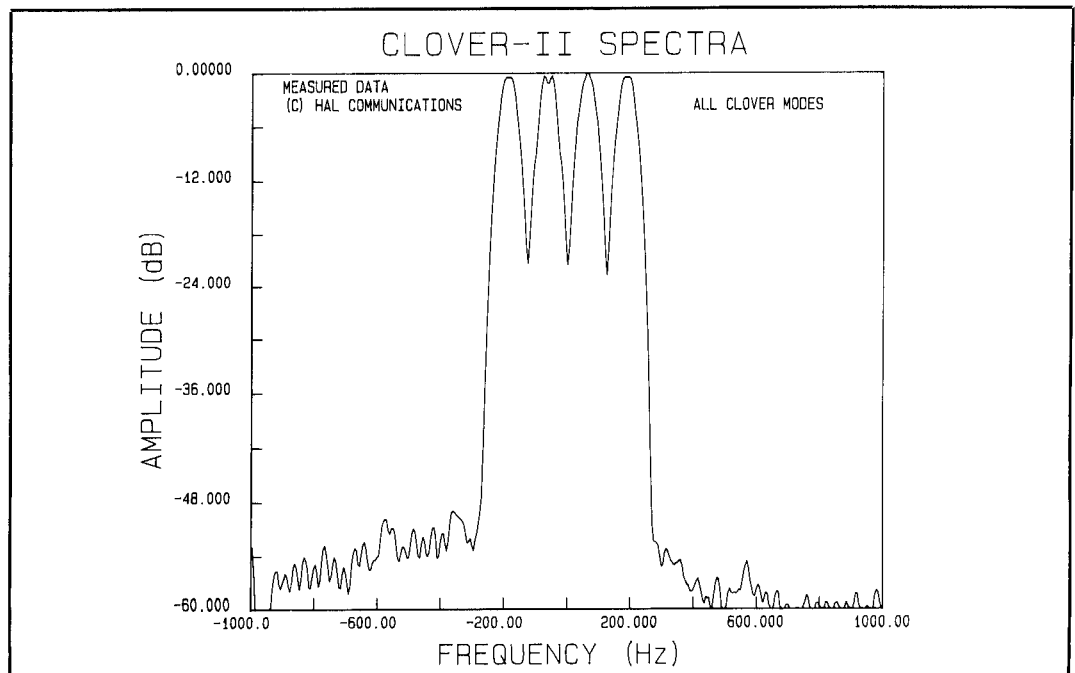


Figure 4. CLOVER-II spectra.

able in most modern HF transceivers. The CLOVER-II frequency spectra is shown in **Figure 4**.*

CLOVER ARQ mode is also automatically adaptive. Ionospheric conditions are measured and the data mode of the sending station is adjusted to produce the highest throughput possible at the current conditions. As previously noted, CLOVER has eight modulation modes, four Reed-Solomon encoder modes and four data block lengths—a total of 128 different and unique combinations. These combinations provide great freedom for adaptive adjustment in small increments. The CLOVER demodulation system dynamically and continuously measures key received signal-to-noise ratio (S/N), frequency dispersion, and time dispersion. Thus, the adaptive protocol can determine with a great deal of accuracy which parameter should be changed to optimize data transmission.

Another unique feature of CLOVER-II is Reed-Solomon error correction encoding. This differs notably from that used for AMTOR ARQ and packet radio. AMTOR uses parity coding (4/3 bit ratio) and packet a check-sum (CRC) so the receiving station can detect errors and request repeats. CLOVER's Reed-Solomon encoding allows the receiving station to fix errors without requiring repeat transmissions. This greatly increases the efficiency of CLOVER compared to AMTOR or packet. Of course, there are limits to the capability of in-code error correction and CLOVER will also revert to requesting repeats (ARQ-style) when its error correction system is overloaded.

One of the variable parameters in CLOVER-II modulation is the length of the block of data sent. This is analogous to packet length. However, in this case, block length and the number of Reed-Solomon correctable errors are proportional—longer blocks can correct more errors without requiring repeat transmissions. As noted in the packet radio discussion, longer block transmissions lead to higher efficiencies—higher data throughput. Thus CLOVER, unlike packet, includes an algorithm that is compatible with sending long blocks of data at high efficiency. Of course, if interference, QRN, or ionosphere distortion is high, the error correction ability of the Reed-Solomon encoding can become “overloaded” and repeats are necessary. Also, if bursts occur frequently, a long block may contain several and also overload the error corrector. Four different Reed-Solomon block lengths are available (17, 51, 85, and 255 8-bit bytes) so the different conditions of burst

interference/distortion can be tolerated. Efficiency is, of course, inversely related to block length, and the shorter block lengths will result in lower data throughput (as in packet).

The number of errors which the Reed-Solomon coder can correct is adjustable. For each block length, there are three settings corresponding to a maximum of 20, 12, and 5 percent of the bytes in the block that can be in error without loss of the block. Of course, higher error-correcting capacity requires higher coding overhead. The percentage of the bytes in a block that are DATA bytes (“coder efficiency”) for the choices named are 60, 75, and 90 percent, respectively. When conditions are exceptionally good and error correction isn't required, the Reed-Solomon error correction algorithm can be completely bypassed—increasing the efficiency to 100 percent (all bits sent are data bits).

For those who may be wondering how this complex modulation fits Part 97 of the FCC Rules and Regulations, let us assure you that all CLOVER modes are indeed in conformance with existing rules. CLOVER passes only one data stream and is therefore not a “multiplex” modulation format. The CLOVER modulation output is audio tones that are used to drive the input to an SSB transmitter. This is CCIR mode “J2,” which is allowed. The CLOVER base data rate is 31.25 bits-per-second—well within the 300-baud maximum HF limitation. The CCIR emission designator for CLOVER-II is “500HJ2DEN.”

CLOVER places no restrictions on the alphabet used for sending the data. CLOVER accepts any sequence of bytes for transmission and presents the bytes unmodified at the receiver. This avoids the code-specific problems noted for RTTY and AMTOR.

Like AMTOR, CLOVER-II has two primary modes of operation: ARQ and FEC. Also like AMTOR, CLOVER ARQ mode uses rigorous timing of the data transmissions by the two stations. We call CLOVER ARQ transmissions “twitters.” ARQ mode is a two-station link requiring SELCAL (full call sign) exchange when linking. CLOVER FEC mode is a “broadcast” format receivable by many stations.

*The spectra shown in **Figure 4** is a plot of measured data taken from the audio output of a HAL “CLOVER-II” Modem, a developmental model. The ensemble output was centered at 1000 Hz with individual tone center frequencies of 812.5, 937.5, 1062.5, and 1187.5 Hz. The data has been numerically shifted to show 0 Hz as the center frequency and 0 dB as the maximum peak amplitude. The measurement device was a Hewlett-Packard Model HP-3561A Dynamic Signal Analyzer.

As we write this, the CLOVER mode is still under development and working prototypes are now being tested. To date, on-the-air results have confirmed the theoretical work. On typical HF links, CLOVER passes error-free data at rates 10 times faster than either AMTOR or HF packet. Average HF data throughput on the order of 200 to 300 bps is realistic. When conditions are good, the throughput can be as high as 500 to 600 bps.

Mode comparison

We have discussed a total of six unique modes that may be used for transmission of HF data (CW, RTTY, AMTOR, PACTOR, PACKET, and CLOVER). In the sections that follow, we'll compare the performance of these modes.

Data throughput

Table 1 shows typical data rates and character throughput that can be expected from the various HF data modes.

Typical amateur CW speeds are 20 WPM or slower—a throughput of about 2 characters-per-second. Some operators can send and receive code at speeds of 60 WPM and higher, but this is the exception. Also, CW generally requires manual decoding and there is no “automatic” error correction.

RTTY is typically run at 45 baud (60 WPM), but some MSOs operate at 75 baud (100 WPM). At best, RTTY throughput is 10 characters-per-second. None of the RTTY modes offer error correction.

AMTOR, at best, has a throughput of 6.67 characters-per-second, and slows as errors and repeats increase. AMTOR does include error detection, and most receive errors can be corrected and fixed by repeat transmissions. AMTOR ARQ throughput of 5 cps is probably the “typical” condition.

PACTOR offers some improvements over AMTOR: up to 13 cps with 200-baud data rate, and even twice that when data compression is fully active. However, as noted earlier, sending data at 200 baud using simple FSK on HF is risky business and the data compression algorithm will generally not produce a full 2 times speed increase. PACTOR remains to be tested, but the “typical” throughput may be on the order of 10 cps.

As we've noted, HF packet has many problems. As it is now used, the long-time average data throughput of 20-meter HF packet stations is on the order of 4 characters-per-second—often, even less.

Like PACTOR, CLOVER is an experimental mode. Early tests have produced error corrected data throughput at 50 cps in typical conditions, and higher levels in good conditions. To date, CLOVER promises at least a 10 times increase in data throughput over AMTOR or HF Packet.

Error processing

Neither CW nor RTTY has any provision for automatic error detection and/or correction. The human mind is a great “interpreter,” and often we can “fill in the blanks.” This is fine for chit-chat, but is totally useless for transmitting nontextual data.

AMTOR ARQ mode offers error detection and correction by means of repeat transmissions. However the seven-bit “parity” detection scheme isn't infallible, and AMTOR can print incorrect characters. AMTOR FEC mode also offers limited error correction by sending each character twice. However, if both characters are flawed, errors won't be corrected. FEC suffers the same problem with printed undetectable errors as ARQ mode.

PACTOR, like packet, uses a CRC block error detection system. Like AMTOR, errors can only be detected and then corrected by repeat transmissions. The CRC algorithm is quite robust and the chances of passing an incorrect block are very small.

HF Packet also uses a block CRC calculation to detect received errors which then must be fixed by repeat transmissions. As noted for PACTOR, the CRC algorithm is very robust. HF packet is, however, very susceptible to transmission errors. This generally results in a time-consuming process of sending repeats.

CLOVER is the only mode that includes error correction in its data encoding. The receiving station can correct a limited number of errors without requiring repeat transmissions. If the correctable error limit of the CLOVER mode is exceeded, repeat transmissions are used in ARQ mode. The Reed-Solomon algorithm is also very robust and the chances for undetected errors is very small.

Bandwidth and bandwidth efficiency

Signal bandwidth and its uses are very misunderstood parameters of a radio data signal. Often, the bandwidth of a mode is specified as that range of frequencies between the -3 dB or -6 dB points on a spectral plot of the signal. A more realistic measurement of bandwidth is to determine how closely in frequency two signals can be

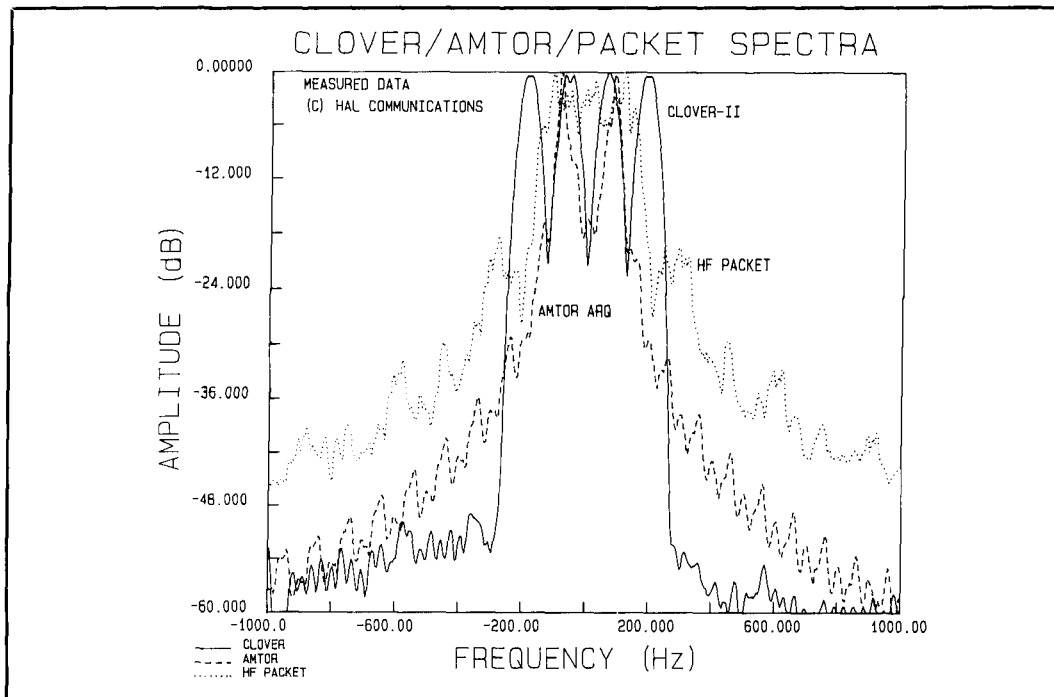


Figure 5. CLOVER/AMTOR/packet spectra.

placed without mutual interference. Because the signal strengths of two adjacent HF signals often vary by 30 to 50 dB, and all data modes (except CLOVER) have wide sidebands, minimum channel spacing is a much higher number than might be indicated by the -3 or -6 dB spectrum bandwidth.

Figure 1 shows the bandwidth of a CW transmitter sending code at 60 WPM. The -50 dB bandwidth of this signal is approximately 800 Hz (± 400 Hz). You can't have two 60-WPM CW stations closer than 800 Hz to each other without potential mutual interference. This bandwidth scales with speed—a minimum spacing of 267 Hz

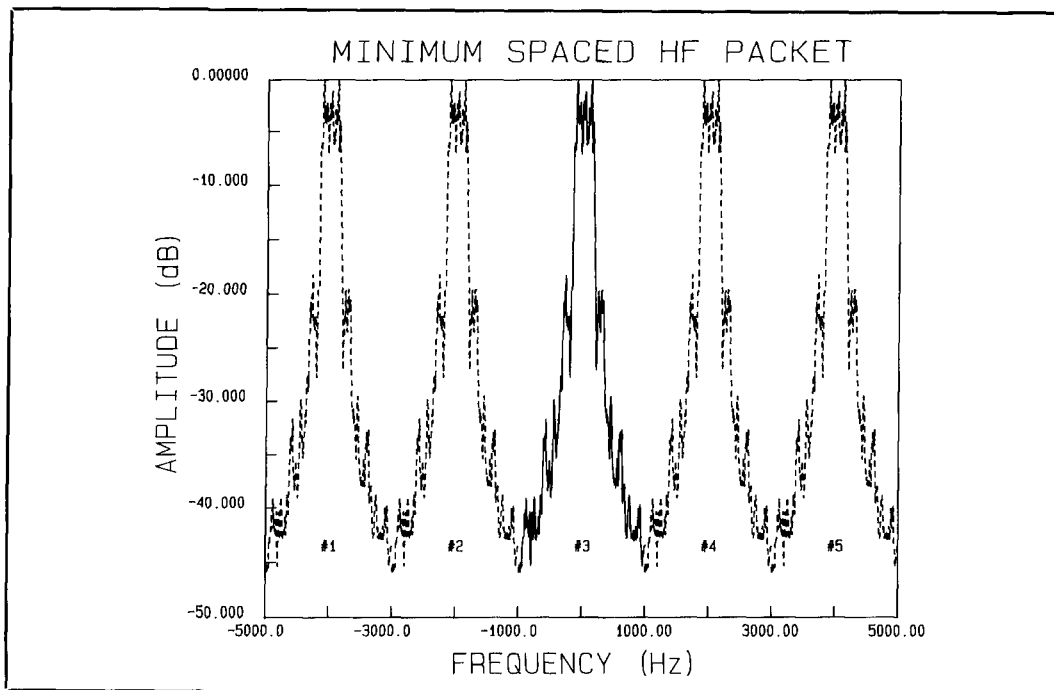


Figure 6. Minimum spaced HF packet.

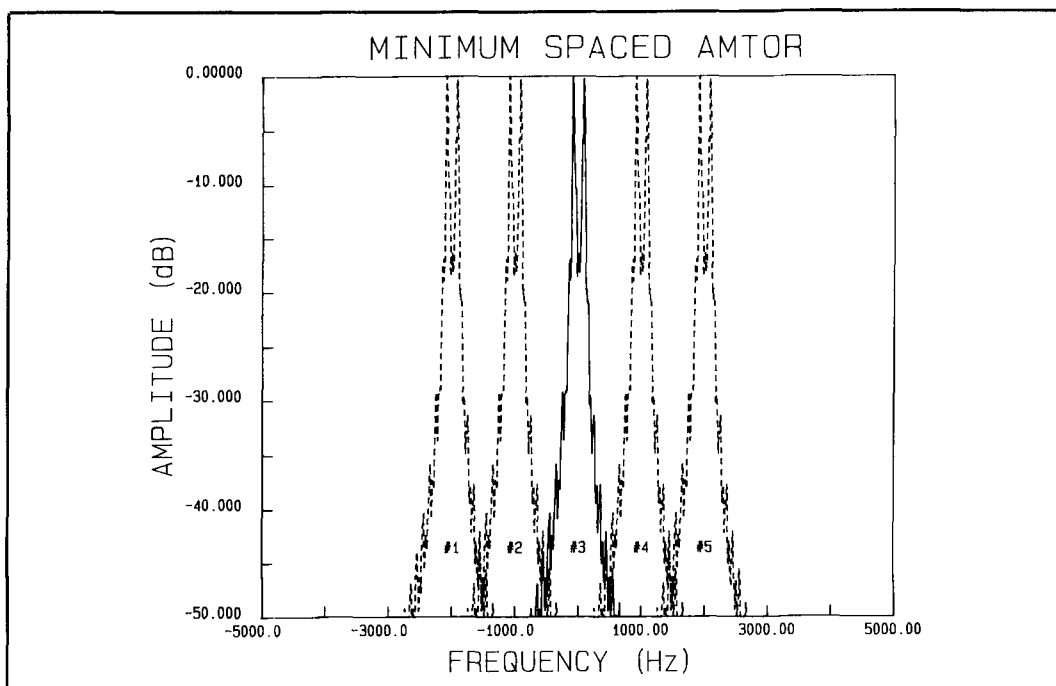


Figure 7. Minimum spaced AMTOR.

for 20-WPM signals. Here, the receiver selectivity becomes the controlling point. If all stations have a 500-Hz receiver filter, the minimum signal spacing is at least 500 Hz, regardless of CW speed. Note also that the "500 Hz" receiver filter bandwidth specification is almost always the -6 dB bandwidth, not the -50 dB bandwidth. Automatic CW reception is, therefore, probably limited to a minimum CW signal spacing of 1 kHz or more. The human brain is adaptive and interpretative, and we can indeed "copy through the QRM." A good CW operator can often decipher CW signals spaced as closely as 100 Hz, but only if the two signal strengths are similar.

Figure 2 shows the measured spectrum of an AMTOR signal. While this is a 170-Hz shift, 100-baud FSK signal, the curve can be taken as representative of all RTTY and AMTOR modes (45-baud RTTY will be slightly narrower, but not by much). Note that the -50 dB bandwidth of this curve is approximately 1200 Hz. Practical observation has shown that, if all stations use 500-Hz receiver filters, AMTOR stations can be spaced as closely as 1 kHz apart with little or no mutual interference. However, if either station in an ARQ link uses his 2.4-kHz SSB filter, the spacing must be increased to 1.5 or even 2.0 kHz. The same arguments apply to RTTY signals.

Figure 3 shows the measured spectrum of an HF packet signal (300 baud, 200 Hz shift). Its -50 dB bandwidth is greater than 2 kHz! A minimum spacing of 2 kHz is, in fact, the practical limit based upon on-the-air experiences. Some HF packet stations use a 500-Hz receiver filter. This may help reduce interference in some cases, but the interference sidebands of an adjacent HF packet signal will still fall within the receiver filter's passband. Also, narrowing the receiver bandwidth to 500 Hz may introduce data distortion that compounds the already poor performance of packet radio on HF.

Figure 4 shows the measured bandwidth of a CLOVER-II signal. CLOVER-II signals are designed to eliminate sidebands. The -3, -6, and -50 dB bandwidths of CLOVER are the same—500 Hz. The CLOVER-II demodulator uses receiving filters that have passbands identical to the CLOVER-II spectrum. Therefore, CLOVER receivers are very resistant to interference from nearby signals—CW, RTTY, AMTOR, packet, even another CLOVER signal. CLOVER signals may be placed exactly "edge-to-edge" at 500 Hz spacing with no mutual interference; a "guard-band" is not required. Laboratory tests have shown that the co-channel interference rejection of CLOVER receivers is greater than 50 dB.

Figure 5* shows a combined plot of the spectrum of AMTOR, HF packet, and

* The data plotted in Figures 5, 6, 7, and 8 are the same data shown in Figures 2, 3, and 4.

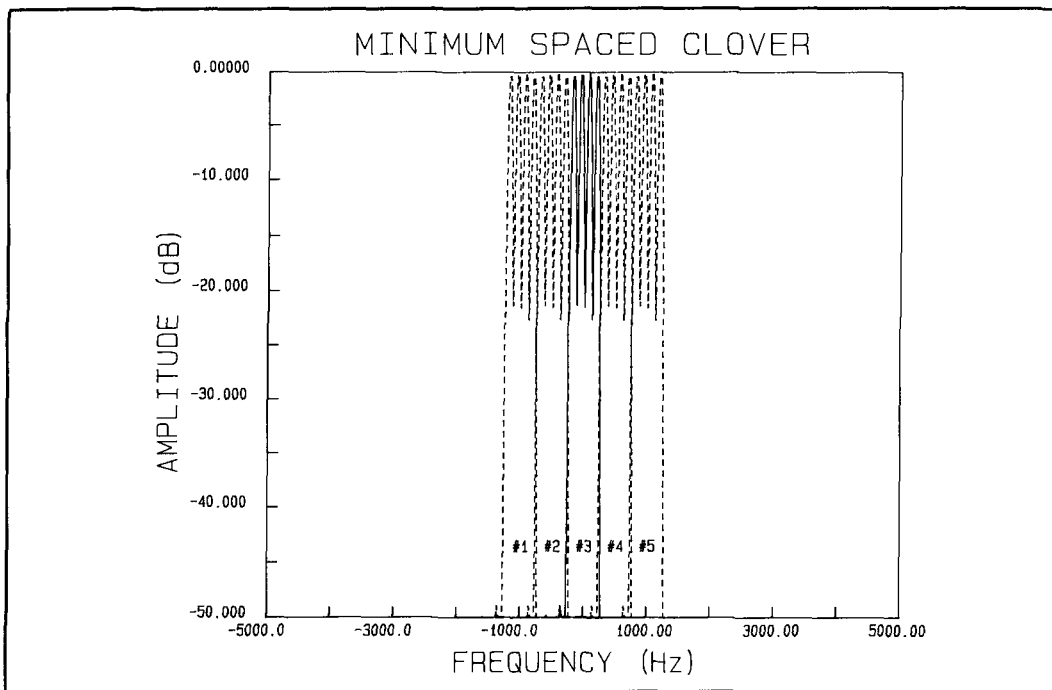


Figure 8. Minimum spaced CLOVER.

CLOVER signals. The wide sideband nature of AMTOR and HF packet is readily apparent, as is the very compact and concentrated spectrum of CLOVER.

Figures 6, 7, and 8 show how much bandwidth is required to support five minimally spaced HF Packet, AMTOR, and CLOVER signals, respectively (see the footnote for Figure 5). Five HF packet signals require 10 kHz of an HF band, five AMTOR signals require 5 kHz, and five CLOVER signals require 2.5 kHz of the band. Put another way, four CLOVER signals will fit in the same bandwidth required for one HF packet signal, and the data throughput is ten times higher on each CLOVER signal.

Summary

There are presently four different modulation and protocol formats used to send amateur data via HF radio: CW, RTTY, AMTOR, and packet. Two new modes have been developed that promise increases in the data speed: PACTOR and CLOVER. The six modes differ considerably in performance, each with its own advantages. CW requires minimum additional equipment to send and receive (key and good operator); RTTY equipment is relatively simple and easy to use. AMTOR offers error correction at modest data rates and is very robust for HF use. HF packet can send ASCII data at good speed when conditions are perfect, but quickly falls apart in typical HF conditions.

PACTOR promises modest speed improvement and ASCII coding over AMTOR. CLOVER promises much higher data speeds, error correction, and efficient use of our radio spectrum. No one mode completely satisfies all aspects of the others.

Amateur radio experimentation with data modulation techniques is in the midst of a new explosion. This renewed interest comes as a result of the rapid growth of amateur data message systems by VHF packet radio and the emerging new DSP technology. The need and desire to send data more accurately and faster via HF radio would not exist without the growth of the packet radio traffic network. New modulation techniques like CLOVER would not be possible without DSP technology. Although we have concentrated only on the modulation and modem aspects of modern radio data transmission, it must also be recognized that the next "level"—inter-station communications protocol—is also undergoing rapid advancements that wouldn't have been possible without low-cost and readily available high-performance personal computers. It can truly be said that amateur radio is not "standing still." Amateur radio continues to lead the technology.

REFERENCES

1. Figure 1 (Morse Code Spectra) is based on measured data shown in the 1989 *ARRL Handbook*, Page 9-9, Figure 12, American Radio Relay League, Newington, Connecticut.
2. G. W. Henry, K9GWT, "ASCII, Baudot, and the Radio Amateur," *QST*, September 1980, American Radio Relay League, Newington, Connecticut, pages 11-16.

3. Bill Henry, K9GWT, "Understanding Modern RTTY Codes and Modes," *CQ*, CQ Publishing, Hicksville, New York, November 1984, pages 20-25 and December 1984, pages 28-32.
4. Bill Henry, K9GWT, "High Tones, Low Tones, Modem Tones . . .," *CQ*, CQ Publishing, Hicksville, New York, November 1982, pages 42-48.
5. Bill Henry, K9GWT, "RTTY Demodulators", *CQ*, CQ Publishing, Hicksville NY, November 1983, pages 20-24.
6. Peter Martinez, G3PLX, "AMTOR, an Improved Error-Free RTTY System," *QST*, American Radio Relay League, Newington, Connecticut, June 1981, pages 25-27.
7. Paul Newland, AD7I, "An Introduction to AMTOR," *QST*, American Radio Relay League, Newington, Connecticut, July 1983, pages 11-13.
8. Paul Newland, AD7I, "A User's Guide to AMTOR," *QST*, American Radio Relay League, Newington, Connecticut, October 1985, pages 31-34.
9. Paul Newland, AD7I, "Algorithms and Methods for SITOR/AMTOR Systems," *QEX*, American Radio Relay League, Newington, Connecticut, July 1988, pages 9-12.
10. Bill Henry, K9GWT, "New AMTOR Mode," *CQ*, CQ Publishing, Hicksville, New York, November 1989, pages 36-40.
11. Victor Poor, W5SMM, and Paul Newland, AD7I, *APlink AMTOR User's Guide*, 1989. Available from the authors.
12. CCIR Recommendation 476-4 (1986), "Direct-Printing Telegraph Equipment in the Maritime Mobile Service," *Recommendations and Reports of the CCIR*, 1986, Volume VIII-2, Maritime Mobile Service, International Telecommunication Union, Geneva, Switzerland, pages 60-69.
13. CCIR Recommendation 625 (1986), "Direct-Printing Telegraph Equipment Employing Automatic Identification in the Maritime Mobile Service," *Recommendations and Reports of the CCIR*, 1986, Volume VIII-2, Maritime Mobile Service, International Telecommunication Union, Geneva, Switzerland, pages 5-59.
14. Hans-Peter Helfert, DL6MAA, and Ulrich Strate, DF4KV, "PAC-R—Radioteletype with Memory ARQ and Data Compression," *QEX*, American Radio Relay League, Newington, Connecticut, October 1991, pages 3-6.
15. Martin Clas, DL1ZAM, and Peter Mack, DL3FCJ "PTC—The PACTOR Controller," *QEX*, American Radio Relay League, Newington, Connecticut, October 1991, pages 7-11.
16. *The ARRL Handbook*, Chapter 19, current edition, American Radio Relay League, Newington, Connecticut.
17. *ARRL Computer Networking Conference Proceedings*, Volumes 1 through 10, American Radio Relay League, Newington, Connecticut.
18. Buck Rogers, K4ABT, "Packet User's Notebook," monthly column, *CQ*, CQ Publishing, Hicksville, New York.
19. Stan Horzempa, W1LOU, "Packet Perspective," monthly column, *QST*, American Radio Relay League, Newington, Connecticut.
20. Bob Hansen, N2GDE, editor, "Packet Status Register," monthly newsletter of the Tucson Amateur Radio Corporation (TAPR), Tucson, Arizona.
21. Ray Petit, W7GHM, "The 'COVERLEAF' Performance-Oriented HF Data Communication System," *QEX*, American Radio Relay League, Newington, Connecticut, July 1990, pages 9-12. Also reprinted in *ARRL/CRRL Amateur Radio 9th Computer Networking Conference Proceedings*, 1990, American Radio Relay League, Newington, Connecticut, pages 191-194.
22. Ray Petit, W7GHM, "Frequency-Stable Narrowband Transceiver for 10100.5 kHz," *ARRL/CRRL Amateur Radio 9th Computer Networking*

- Conference Proceedings*, 1990, American Radio Relay League, Newington, Connecticut, pages 195-202.
23. Ray Petit, W7GHM, "CLOVER is Here," *RTTY Journal*, Fountain Valley, California, January 1991, pages 16-18, February 1991, pages 12-13, March 1991, pages 16-17, April 1991, page 10.
 24. Ray Petit, W7GHM, "CLOVER-II: A Technical Overview," *ARRL Amateur Radio 10th Computer Networking Conference Proceedings*, 1991, American Radio Relay League, Newington, Connecticut, pages 125-129.
 25. Ray Petit, W7GHM, and Bill Henry, K9GWT, "CLOVER Update," *RTTY Journal*, Fountain Valley, California, January 1992.

More on CLOVER

The first CLOVER product available to amateurs will be a plug-in card for "IBM-compatible" PCs, manufactured by HAL Communications Corp. It will be called "PC-CLOVER," the "PCI-4000." PC-CLOVER was demonstrated first at the 1992 Dayton Hamvention® and targeted for delivery soon thereafter. Patents have been applied for CLOVER, CLOVER-I, and CLOVER-II technology by Ray Petit and HAL Communications. CLOVER, CLOVER-I, and CLOVER-II are registered trademarks. HAL plans to license CLOVER technology as freely and inexpensively as possible to all amateurs and amateur manufacturers.

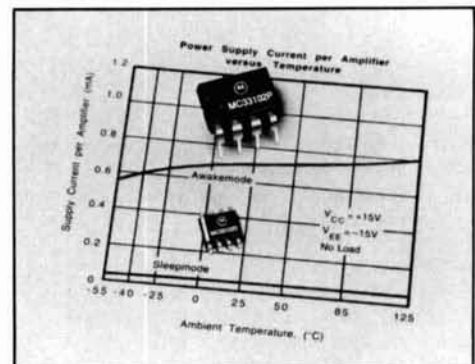
PC-CLOVER will include a simple, single-operator application PC program to get you started. However, HAL would like to encourage all "network" software authors to write drivers to allow their programs to take advantage of the increased performance of CLOVER. The PCI-4000 hardware interface is specifically designed to work in network and "windowed" PC environments. An interface protocol definition document is being prepared for all who are interested.

PRODUCT INFORMATION

Sleep-Mode® Dual Op Amp

Motorola has introduced a dual Sleep-Mode® operational amplifier IC with two separate modes of operation, resulting in very low standby power operation. In the "sleepmode" state, the MC33102 op amp operates at very low current drain (typically 45 μ A per amplifier). Each amplifier automatically changes to the "awakemode" state when an input signal is applied to the amplifier, causing it to sink or source sufficient load current. The dual Sleep-Mode amplifier uses industry standard pin-outs and each amplifier has independent Sleep-Mode capability; no extra pins or external components are required.

The MC33102 is presently available for



commercial applications in both an 8-pin plastic DIP, and an 8-pin plastic SO-8 surface mount package. Samples are available. For a data sheet on the Sleep-Mode op amp contact: Motorola Literature Distribution, P.O. Box 20912, Phoenix, Arizona 85036. Ask for data sheet MC33102/D.

Irv Karwick
Senior Experimental Engineer
GM Truck and Bus Group
General Motors Corporation
GM Proving Ground
Milford, Michigan 48380-3726

DIAGNOSING RFI PROBLEMS IN VEHICLES

*How to find out what's interfering with
your mobile radio*

The modern automobile contains many new electronic features providing safety, comfort, and entertainment enhancements over older models. Systems like anti-lock brakes, supplemental inflatable restraints (airbags), engine/transmission controls, CD players, and body computers, all electronically controlled, occupy a great deal of real estate in a new vehicle. Unfortunately, a by-product of electronic controllers or control modules is radio frequency interference (RFI).

Automakers routinely test their vehicles to evaluate the RFI components and systems may generate. Guidelines for acceptable levels of RFI are established based on radio receiver sensitivity. In other words, an acceptable level of RFI is one that is lower than the receiver's ability to process a signal.

During the new vehicle development cycle, RFI is considered at the component level. Techniques employed in circuit board design are usually successful in eliminating interference. But, as the complexity of the electronics and power levels increase, RFI can sometimes be difficult to control. It is in these cases, where interference to entertainment and two-way radio operation can occur.

Troubleshooting an RFI problem requires knowledge of the vehicle electrical system and mobile radio operation. Normally, the new car dealer is familiar with the vehicle electrical system, but not with the mobile radio. On the other hand, the mobile radio installer (which may be you) knows his radio system, but is unfamiliar with the complexities of the new vehicle.

The problem of RFI can be particularly acute in the case of vehicle fleets like trucks. The reliance on mobile communications, especially in remote rural areas, is usually essential. However, interference can be eliminated with correct mobile radio installation, knowledge of troubleshooting techniques, information on the vehicle electrical system, and, possibly, cooperation from the vehicle manufacturer.

The answers to how and why vehicle electrical systems cause interference are typically found in the microprocessor-based systems controlling the electrical functions. Microprocessors in the vehicle environment operate with clock or crystal speeds in the range of 1 to 22 MHz. Because of the laws of nature, a "field" is created when switching electrical currents or voltages at these rates. The characteristics of the field include a fundamental frequency and its associated

harmonics (harmonic is a component frequency that is an integral number of the fundamental) and a field strength or amplitude. Commonly known as radiated emissions (because the interference is emitted by a particular module or its associated wiring then radiated through the air), microprocessor clock emissions are narrowband in nature and may radiate in mobile radio bands. The amplitude or strength of the emissions are such that a receiver can't discern them from the actual or desired signal because the interference has the same characteristics as an actual signal; that is, a narrow frequency band and sufficient energy.

The frequency content of microprocessor interference is the harmonic frequencies of the fundamental. For example, suppose your vehicle's engine computer has a radiated emissions problem. Its internal clock rate is probably about 2 MHz. At this rate, the 24th harmonic of that clock rate falls in a land mobile band. If your receiver happens to be tuned to 48 MHz, you may have a problem using your radio because it is processing a noise signal as well as the desired one. As the multiple of the fundamental increases, the energy content or signal strength drops off. In the cellular phone band, 870 to 890 MHz, interference problems are nearly nonexistent. At this high band of frequency, the energy content has completely diminished. In the AM-FM entertainment band, interference from narrowband-type emissions can result in reduced reception range.

Diagnosing the problem

When diagnosing an interference problem, the first thing to do is make sure the radio has been installed correctly. "Clean" power and ground are essential to radio performance. A general rule of thumb is to power all devices directly from the vehicle battery and also return all ground leads to the battery. Each of these lines should be fused for maximum equipment protection. Mobile radio installation guidelines are available from General Motors. To obtain a copy, see the address provided at the end of this article.

Relocating the radio antenna may also help eliminate interference. This is particularly easy with mag-mount antennas. A little bit of time spent experimenting with different locations can be worth the effort.

If interference continues to plague you at this point, you must locate its source within your vehicle. Basically, you want to de-energize each electronic module in the vehicle,

thereby shutting down its microprocessor. Doing this prevents the module from radiating energy in your frequency of interest. Through a process of elimination, you can track down the offending device.

Step 1. Locate your vehicle fuse panel. Your dealer can point out its location, or you can find it yourself. Some common locations include the instrument panel, glove box, or engine compartment.

Step 2. With the key in the "run" position, but without the engine running, remove or "pull" one fuse in the panel.

Step 3. Turn your mobile radio "on," and determine if the interference has stopped. If not, repeat the process with each fuse in the fuse panel until you locate the one that eliminates the interference.

(Note: If your interference is engine-r.p.m. related, and comes from a source such as alternator noise, this technique won't help. The problem is probably related to the radio installation.)

Each fuse normally feeds power to several branch circuits. By identifying the fuse "feeding" your interference source, you have narrowed down the possibilities. As this point, a trip to your dealer is required. The advisable approach is to explain the problem to the service department, telling them what you have found as far as the fuse powering the source of the interference. The dealer probably won't be able to address your problem immediately; he'll need to contact the manufacturer for technical assistance. It is possible that the manufacturer may already be aware that a particular module has radiated emissions in a particular frequency band. Depending on the manufacturer's service policy, a modified replacement part may be provided to you. This policy varies between manufacturers. The replacement part will be tailored to avoid emissions in your frequency band of interest.

Automaker electromagnetic compatibility testing

Automakers routinely test their vehicles for electromagnetic compatibility. Testing ensures harmony between electrical systems within the vehicle and immunity from interference from off-vehicle sources.

When evaluating the electromagnetic compatibility of a vehicle and its systems, two criteria are used to categorize interference. One criterion characterizes an electrical system as to whether it is predominantly susceptible to electromagnetic interference (EMI) or principally an emitter of EMI.

The second criterion is concerned with the media by which the energy is carried to or from a device. It may be radiated through the air or conducted through the vehicle wiring system.

Combining these two criteria creates the following four areas of electromagnetic compatibility.

Radiated immunity

Radiated immunity testing evaluates the immunity of the vehicle to sources emitting electromagnetic radiation on or around the vehicle.

A mobile radio antenna is one obvious source of emitted radiation. The field created by the antenna when transmitting may interact with the vehicle electrical systems. One commonly seen interaction is the disruption of instrument clusters. When this occurs, the user may notice the various displays become erratic, then return to normal when the transmission is over. Other possible sources of "interference radiation" include overhead high power lines, air traffic control radar, and antenna towers. Interaction from these are normally rare, but can occur if their transmission pattern is in close proximity to roadways.

Radiated emissions

Radiated emissions testing identifies the type and strength of electromagnetic emissions from a vehicle during normal operation. There are two types of emissions. First, narrowband emissions, as discussed earlier, identify carrier-type emissions. The second type, known as broadband emissions, identifies emissions from sources such as electric motors and ignition systems. Broadband emissions can be a source of AM radio interference.

Conducted immunity

Conducted immunity testing evaluates how immune the vehicle electrical system is

to electrical signals that propagate through the vehicle wiring harnesses. Specifically, the electrical signals of interest are those produced by motors and solenoids. When cycled, motors and solenoids in the vehicle electrical system produce an "inductive kick." The inductive kick is a high energy waveform that, if not adequately controlled, is capable of interfering with normal operation of electronic modules.

Conducted emissions

Conducted emissions testing is used to identify the characteristics of the electromagnetic energy conducted through the wiring system. The emission characteristics of interest are the frequency content and amplitude of "inductive kicks" mentioned previously. The goal in designing vehicle motors and solenoids is to suppress the emissions at the component, before it can be conducted onto vehicle wiring harnesses.

The troubleshooting/diagnosis process discussed here is basically the procedure employed by the General Motors Truck & Bus Group in assisting its customers in resolving two-way radio interference problems. It involves the cooperation of the Truck & Bus service and engineering groups, as well as component suppliers working through the Chevrolet and GMC Truck dealer network. The process was designed to provide assistance to large fleets and individuals whose problems might otherwise go unresolved. The Truck and Bus Group is responsible for the engineering of all of General Motors light and medium duty trucks—including compact and full-size pickups and vans.

For a copy of General Motors' "Mobile Radio Installation Guidelines" write:
Electromagnetic Compatibility Department
EMC Building 40
General Motors Proving Ground
Milford, Michigan 48380-3726.

PRODUCT INFORMATION

Technical Brief Available

QUALCOMM Incorporated offers a technical brief describing the application of frequency synthesis and forward error correction technology for the International Maritime Satellite Organization (INMARSAT) digital communication services. The 12-page brief, "Successful Integration of QUALCOMM VSLI Products into INMARSAT," provides an introduction to the fundamentals of INMARSAT digital serv-

ices and covers such topics as system performance and configurability, low power dissipation, full-duplex operation, and cost effectiveness.

To obtain a copy of the INMARSAT technical brief, write to: QUALCOMM Incorporated at 10555 Sorrento Valley Road, San Diego, California 92121-1617. Phone: (619)597-5005. FAX: (619)452-9096. Ask for Technical Brief TB0256-1.

R.P. Haviland, W4MB
1035 Green Acres Circle, North
Daytona Beach, Florida 32119

PARASITIC ELEMENTS FOR PATTERN SHAPING IN VERTICAL ANTENNAS

*Enhanced pattern control using
parasitic elements*

Amateurs haven't been very concerned about pattern shaping except as a way to increase the gain of the main lobe. Minor lobes and nulls are allowed to "take care of themselves." But there are times when a particular pattern is advantageous. One example is a net control station located on the edge of the net coverage area—a situation common on 20 and 40 meters. A 2-meter operator in the suburbs may want to concentrate radiation towards the downtown area. Here in Florida bidirectional coverage is useful, because of the seacoast concentration of cities.

Parasitic elements are commonly used in antennas to increase the gain in one direction, as in the Yagi. In contrast, the usual practice when an antenna installation requires a particular pattern shape is to add driven elements, changing spacing and phasing to give the desired pattern. Exten-

sive catalogs of the shapes possible with driven elements are available. One source is the *NAB Engineering Handbook*.¹ But data on patterns with parasitics other than that available for Yagis are rare. Even *The ARRL Antenna Handbook*² has pattern data for only a few conditions, and only for the elements plane.

I'd like to share pattern and gain results from several arrangements using one to four parasitic elements, both director and reflector tuning. These are calculated results, obtained with MININEC 3.12. All are for a frequency of 150 MHz, using a radiator 1 meter long, with a radius of 0.006 meters (1/2-inch diameter).

Directors are 0.9 wavelengths long; reflectors are 1.1 wavelengths. The director size is close to that for maximum gain, and the reflector for maximum bandwidth. Change in parasitic element length will have relatively little effect on intensity of the

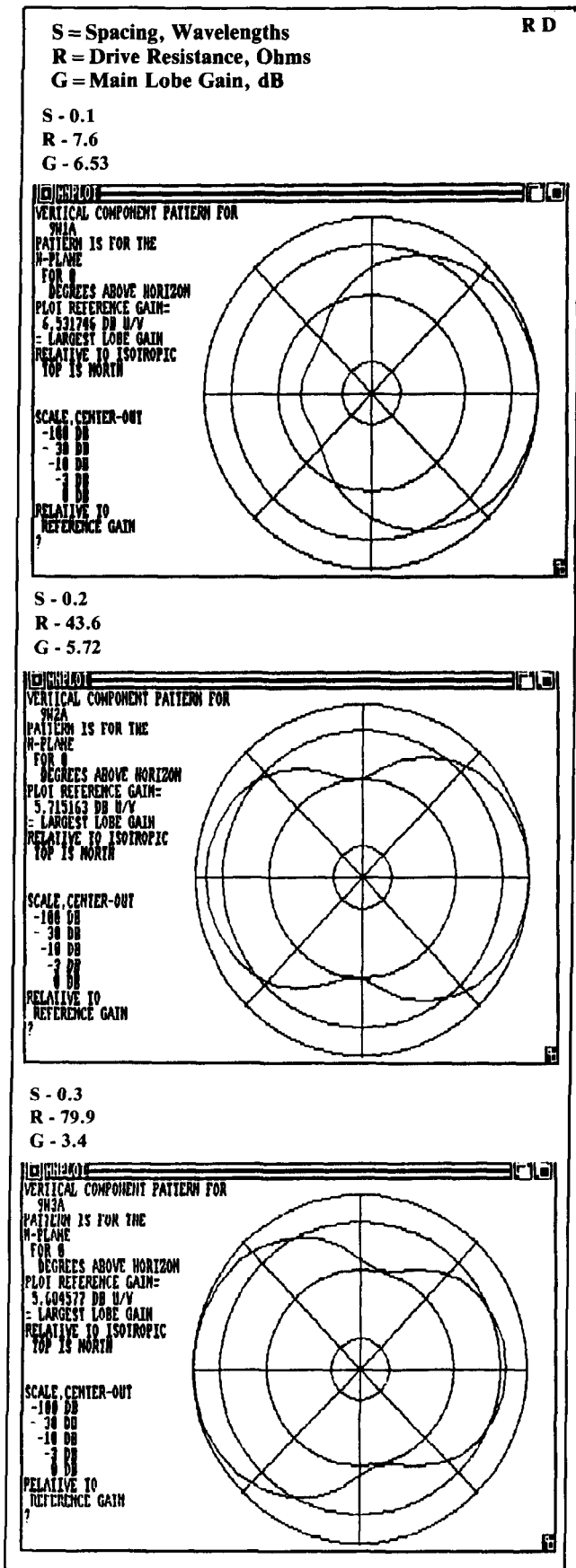


Figure 1. Pattern and performance data for a single director spaced 0.1, 0.2, and 0.3 wavelengths.

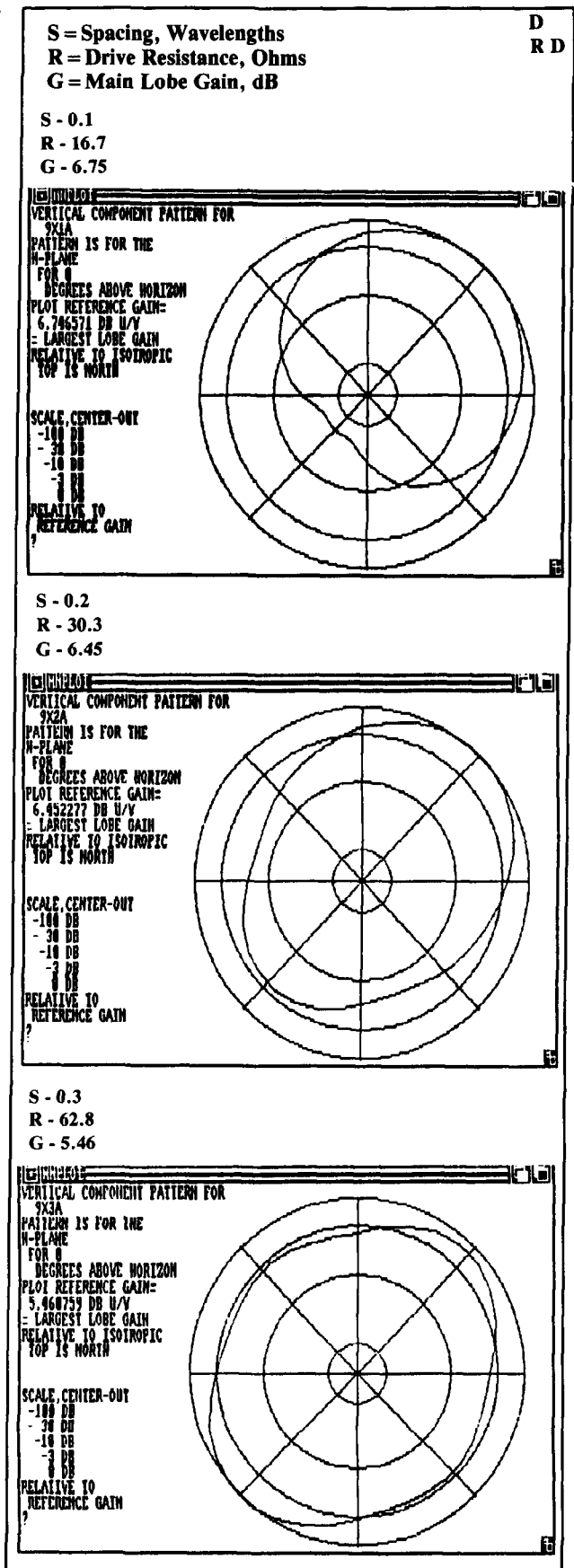


Figure 2. Patterns and data for two directors, one at north and one at east (90 and 0 degrees).

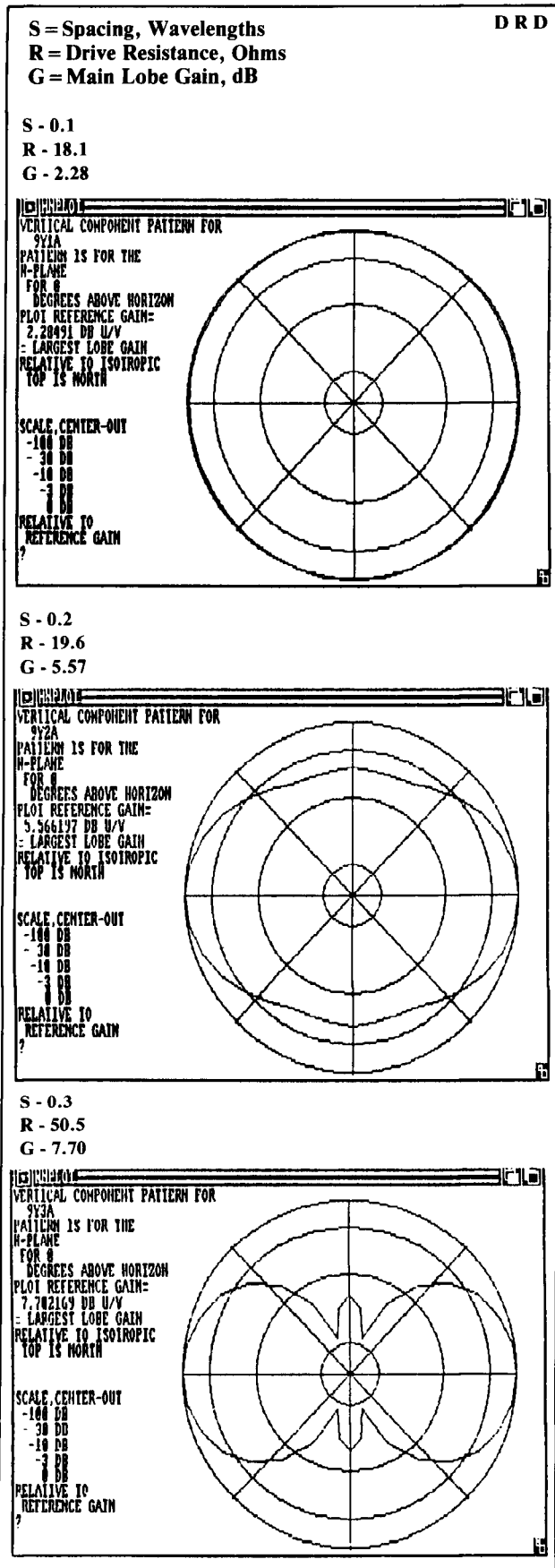


Figure 3. Results with two directors on opposite sides of the radiator.

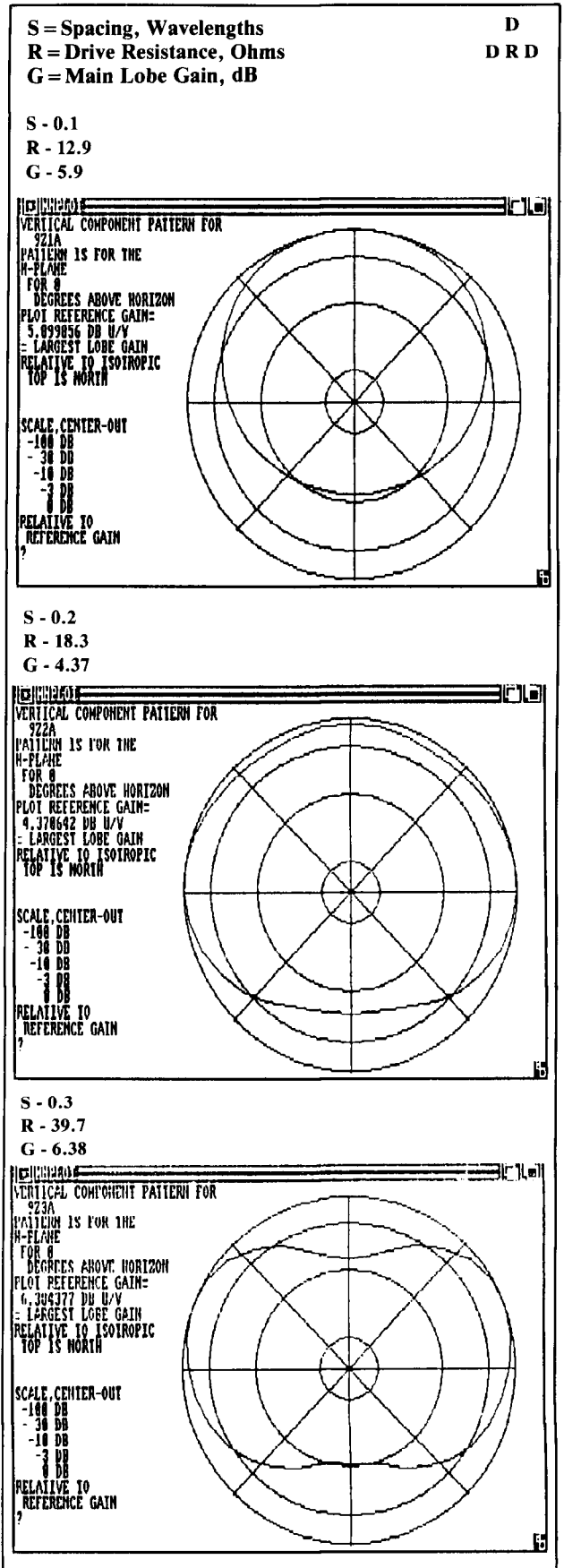


Figure 4. Results for three directors at right angles, at west, north, and east.

largest lobe, but more effect on the gain in the opposite direction; that is, on the back lobe.

You'll find rules for scaling to other frequencies later.

Single director

Figure 1 shows the pattern and performance data for a single director spaced 0.1, 0.2, and 0.3 wavelengths. As in Yagis generally, gain is maximum and front-to-back ratio is best with close spacing. Note that the parasitic acts as a reflector at 0.3 spacing. At about 0.22 wavelength, the pattern is bi-directional, with a front/side ratio of about 10 dB.

Two directors

Refer to Figure 2 for patterns and data for two directors, one at north and one at east (90 and 0 degrees). Gain and F/B increase slightly, but the main effect is rotation of the pattern to the line of symmetry. This can be useful on a small lot, or with four parasitics switched in pairs.

As with the single director, the wide-spaced parasitics act as reflectors. The front/side ratio is lower, but the main lobe gain is slightly higher.

Figure 3 gives the results with two directors on opposite sides of the radiator. At close spacing the ensemble acts very much as a single vertical element, but with low drive resistance. At greater spacing the pattern develops a lobe toward each director. Front-to-side ratio can be high, with the gain exceeding that of a single director. At spacing just below 0.3 wavelength, the pattern is essentially a classic doughnut.

Results with two directors on the same side of the antenna fall into the Yagi class. Forward gain goes up by about 2 dB maximum, but there's little effect on the back lobe.

Three directors

Figure 4 shows results for three directors at right angles, at west, north, and east. At close spacing, the three directors tend to act as an ensemble, pulling the pattern to the line of symmetry. At greater spacing, the pattern remains symmetrical about the north-south line, with the east-west directors having the greatest influence. All show gain with respect to the radiator alone.

I investigated the patterns for four directors spaced 90 degrees. For the range of spacings used here, patterns were circular to a fraction of a dB. Drive resistance was very

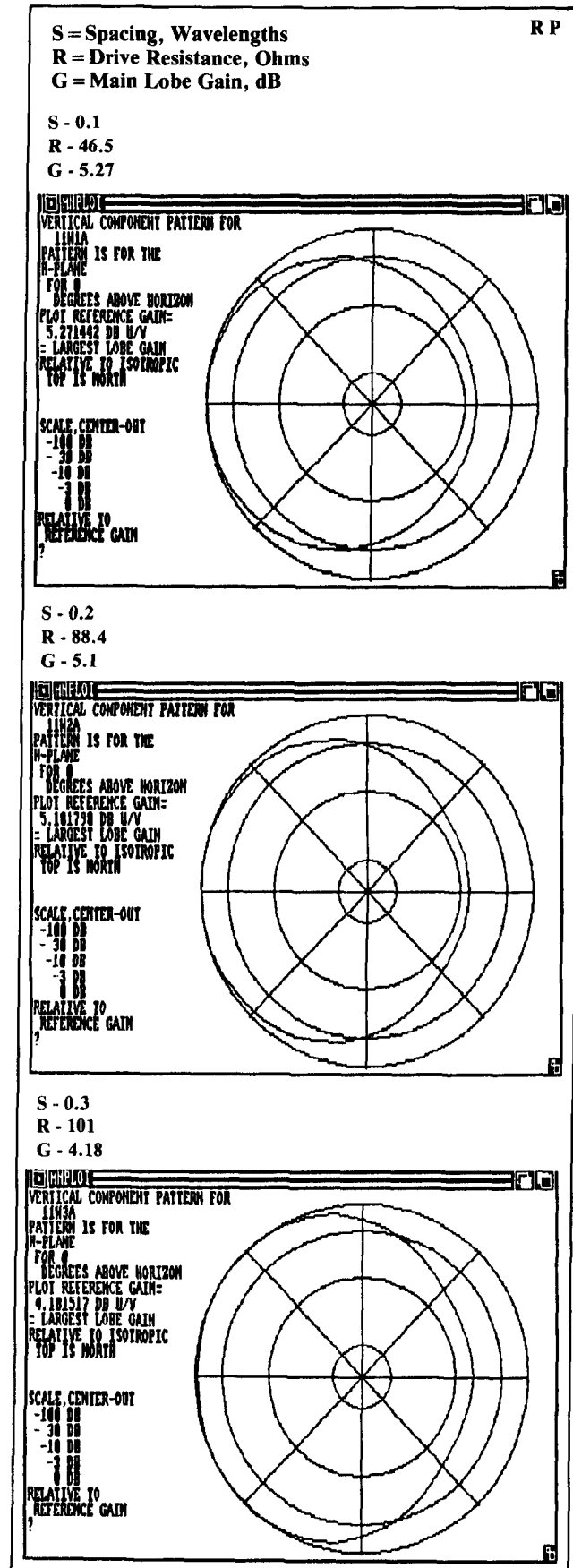


Figure 5. Pattern and performance data for a single reflector.

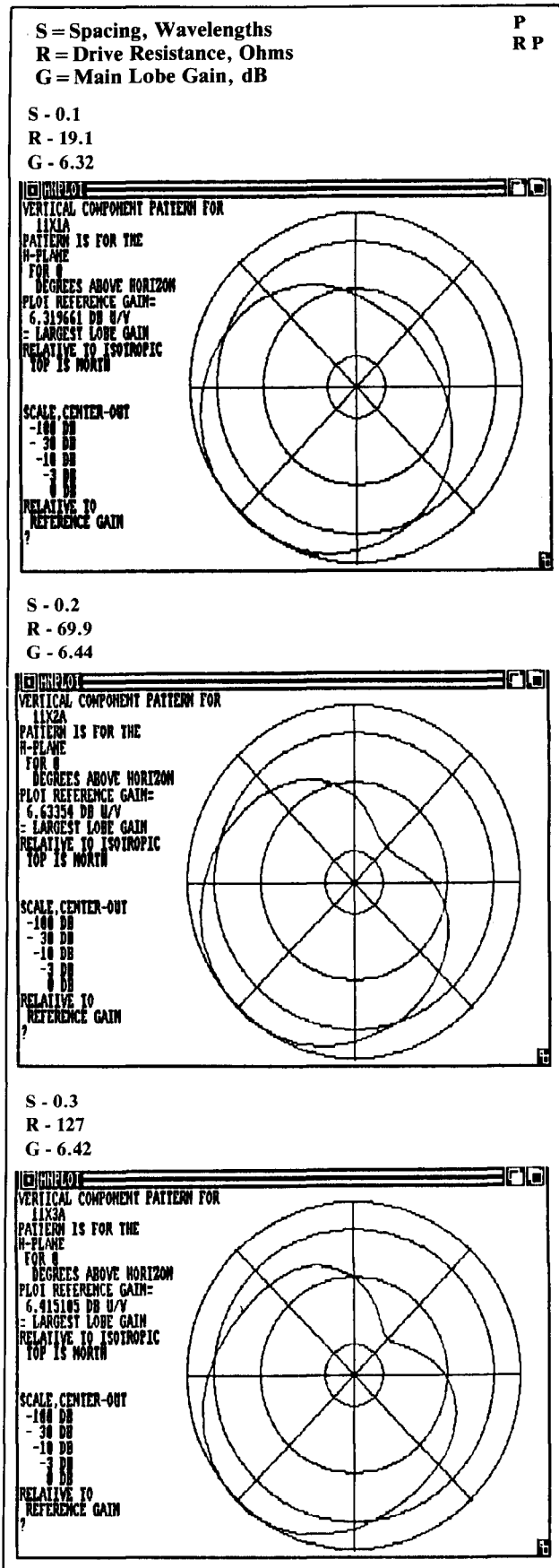


Figure 6. Results for two reflectors at right angles.

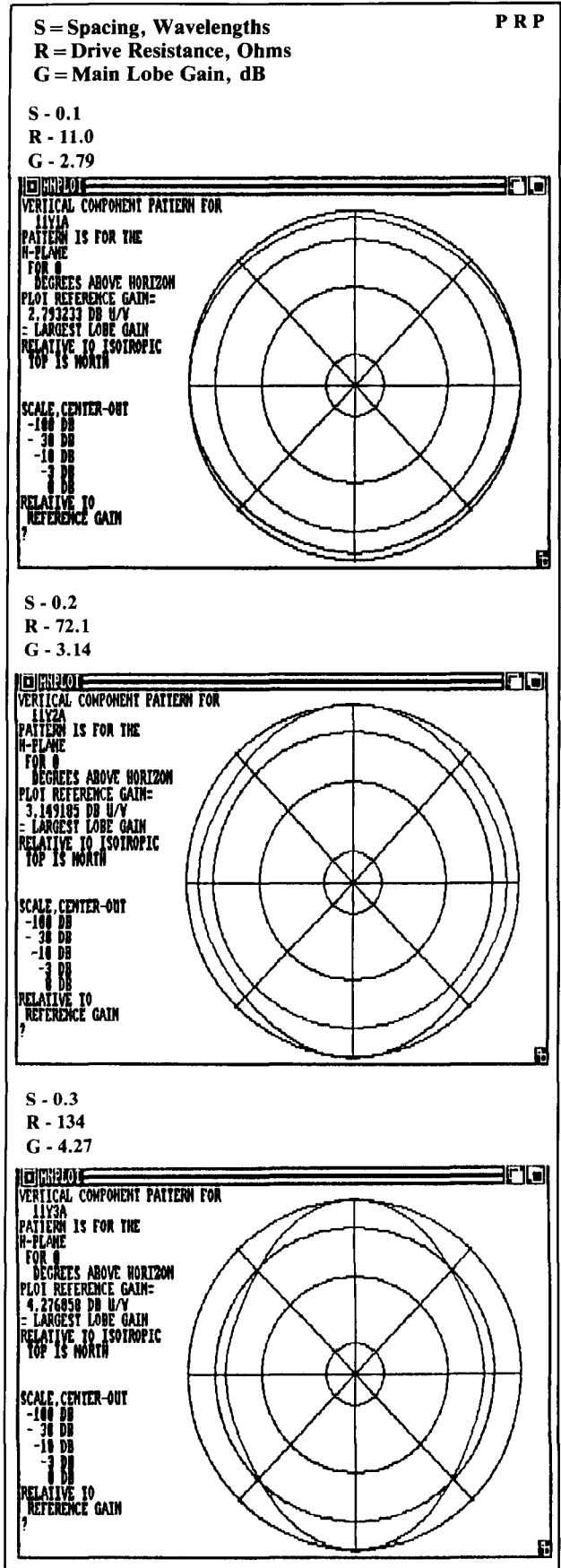


Figure 7. Pattern and data for the in-line configuration.

low. I didn't investigate the effect of parasitic tuning.

Single reflector

Figure 5 corresponds to Figure 1, but for a reflector. Main radiation is now away from the parasitic at all spacings. Close-spaced F/B isn't as good as it is for a director, but the F/B is better at wide spacings. Drive resistance tends to increase, and remains relatively high at close spacings.

Two reflectors

Figure 6 shows results for two reflectors at right angles. Gain is quite good at all spacings, and the F/B ratio is reasonably high. Drive resistance does decrease at close spacing.

Figure 7 gives patterns and data for the in-line configuration. At close spacing, the tendency to act as a single radiator appears. There is some directivity at higher spacings, but this is markedly less than it is for directors.

Placing two reflectors on the same side of the element yields very little change from the single-reflector case.

Three reflectors

Results for three reflectors at right angles appear in Figure 8. Gain is reasonably high and F/B is fair to good. The maximum gain is always away from the middle reflector. Further changes in the rear-lobe intensity would be possible by changing reflector length.

Other arrangements

I have investigated a few of the many other element arrangements possible. The details are different, but the general trend doesn't depart from that evident in the patterns shown.

Scaling to other frequencies

If the exact pattern and drive resistance is to be duplicated at some other frequency, all dimensions must be scaled exactly. For example, to scale to 15 MHz, element length and diameter must be multiplied by 10. This means the radiator length would be 10 meters, with a diameter of 5 inches.

If the scaled diameter isn't convenient, the scaled length will need to be adjusted. The procedure is described in Lawson's *Yagi Antenna Design*,³ which also gives the procedure for tapered elements.

All of the combinations shown have an

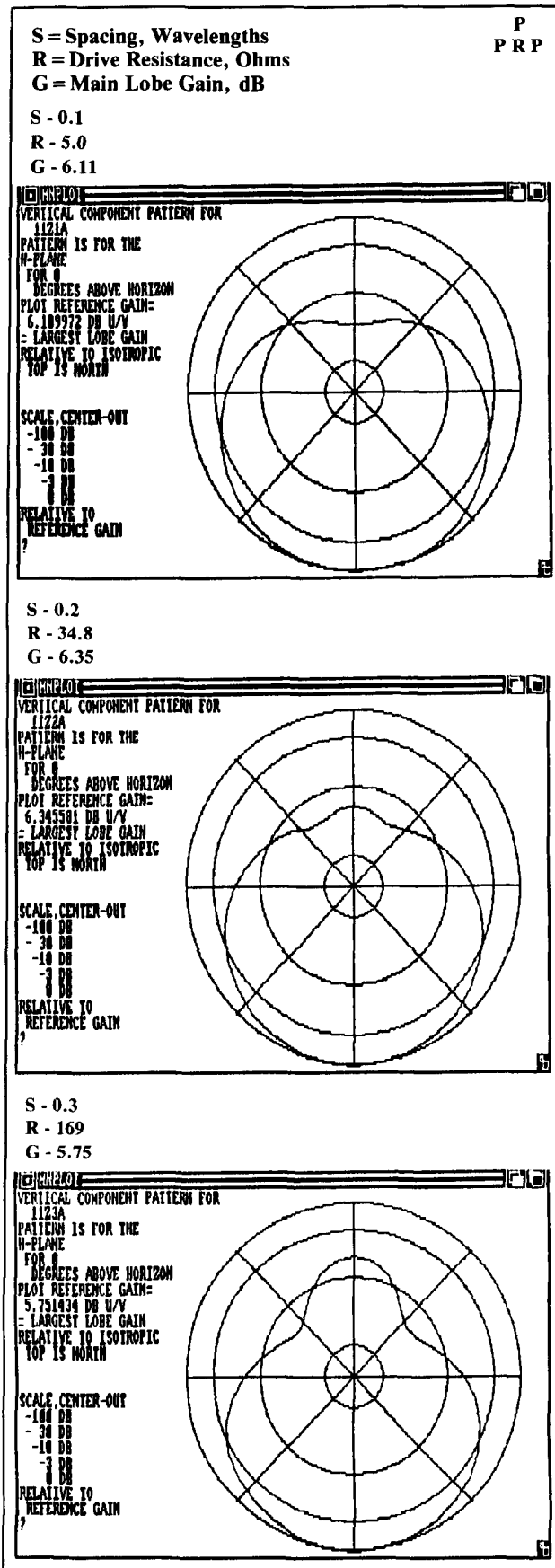


Figure 8. Results for three reflectors at right angles.

appreciable reactive drive component. I haven't reported this, partly because it varies with installation details, and partly because the calculations were made with relatively few "MININEC pulses." Calculation error for reactance is much higher than for the quantities shown.

Conclusions

It appears that some of the multiple parasitic systems can be very useful. The multi-director ones seem best for gain, the multiple reflector for rear lobe control. The multiple-reflector type also provides a way to increase the gain of Yagis, as has been re-

ported many times. However, if F/B or front/side requirements aren't stringent, a radiator plus a single parasitic element can offer reasonable performance and good simplicity.

As the number of stations on the air continues to increase, there will be more and more need to hold down unnecessary radiation. Good pattern control is one of the keys to meeting this requirement. ■

REFERENCES

1. A. Prose Walker, W4BM, Editor, *NAB Engineering Handbook*, McGraw-Hill, New York, 1960
2. *The ARRL Antenna Handbook*, American Radio Relay League, Newington, Connecticut, 1988.
3. James P. Lawson, W2PV, *Yagi Antenna Design*, American Radio Relay League, Newington, Connecticut, 1986.

PRODUCT INFORMATION

Low Profile Quartz Crystals

Raltron Electronics Corp has a new line of low-profile quartz crystals. The Model HC-49-Short-SMD crystals are only 3 mm high. The AT-strip-cut surface mount crystals are targeted for use in high-density laptop computers and peripheral applications, including memory drives and local and wide-area networks.



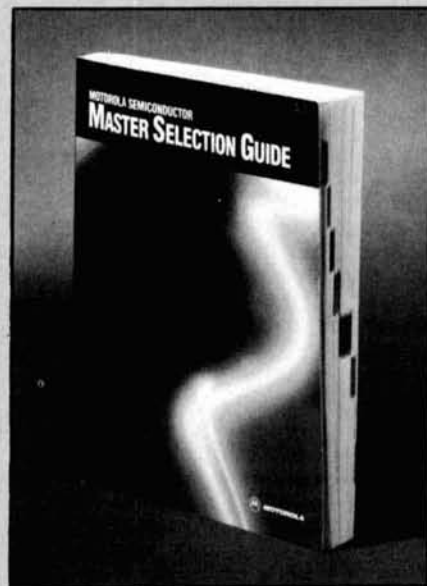
The crystal's base material is nickel plated, the bottom insulator is polyphenilen sulphide, 40 percent glass filled (PPS-G40). Connecting leads are nickel plated and solder pre-tinned with 60/40 tin/lead formula to a precision thickness of 1.5 to 2.2 microns.

For more information on the Model HC-49-Short-SMD, contact Raltron Electronics Corp., 2315 NW 107th Avenue, Miami, Florida 33182.

New Master Selection Guide for Semiconductors

A newly designed Master Selection Guide for semiconductors is now available from Motorola. The expanded guide provides

three-way assistance in locating information regarding specific circuits or system designs. You'll find an index with a complete listing of Motorola semiconductor products, a subject cross-reference with complete defini-



tions of product acronyms and abbreviations, and a standard table of contents.

There's a complete list of available components and applications for each product line. In addition, a separate section is included for Motorola's military ICs and discrete products.

To obtain a copy of the Master Selection Guide, call Motorola Literature Distribution at (800)441-2447, or write: Motorola Inc., Literature Distribution Center, P.O. Box 20924, Phoenix, Arizona, 85063. Ask for SG73/D.

BE A CAD (USER)

A look at some economical computer assisted engineering/design programs

Everybody appreciates an easier way to solve problems, especially ham radio operators. I haven't seen any statistics, but I imagine there aren't too many amateurs who don't have at least one computer—the majority of which are probably IBM-PCs/compatibles. For those amateurs who either own or have access to such a computer, and also like to do their own design and fabrication of homebrew circuits, I've put together some data describing what I consider the most economical and worthwhile computer assisted engineering programs.

From schematic drawing to microwave design, there's a program available, most for \$150 or less, to help you over the rough spots. But before you reach for your checkbook, there are two basic tenets you should

remember. First, you'll never find a program that has every feature you desire. Second, artificial intelligence hasn't been integrated into engineering CAD software, so you still need the knowledge/experience to outline the initial circuit design and to know what to modify when the program results don't meet your specifications. Addresses for all the software suppliers of the programs described are listed at the end of the article.

UTILITIES +

Utility programs are like grab-bags; sometimes you have to take a lot of unwanted material just to get one gem. I find it more efficient to build up a library of single utilities from magazine articles and

- | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none">- Calculation of Noise Figure for Cascaded Networks- Calculation of Inductance, Resistance, and Q of a Straight Wire Above a Groundplane- Pi Network Computation- Calculation of Wye-Delta Resistive or Reactive Transformations- L-Network Calculations- Conversions for VSWR, Reflection Coefficient, Return Loss and Mismatch Loss- Conversion Between Reflection Coefficient and Complex Impedance- Calculation of Hyperbolic Trig Functions- Butterworth Lowpass Filter- Chebyshev Lowpass Filter- Calculation of Minimum VSWR Across a Frequency Band With Series or Parallel Load- Calculation of Physical or Electrical Transmission Line Length- Calculation of Input Impedance for Shorted or | <ul style="list-style-type: none">Open Transmission Line Stubs- Resonant Circuit Component Calculations- Calculation of Capacitance Between Parallel Plates or Strips- Calculation of T and L Pad Resistances- Transmission Line Length Calculation to Match Two Different Impedances- Calculation of Cutoff Frequency, Attenuation, and Resonant Frequency of Waveguides- Conversion of Series/Parallel Impedances- Eighth and Quarter Wave Transmission Line Lengths to Match a Complex Impedance- Linear Fit for Two X/Y Points- Reduction of VSWR Via Attenuation Pad- Conversion of AWG Wire Sizes to Mils- Calculation of Transmission Line Input Impedance Versus Load- Calculation of Air Wound Coils |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Table 1. UTILITIES + programs.

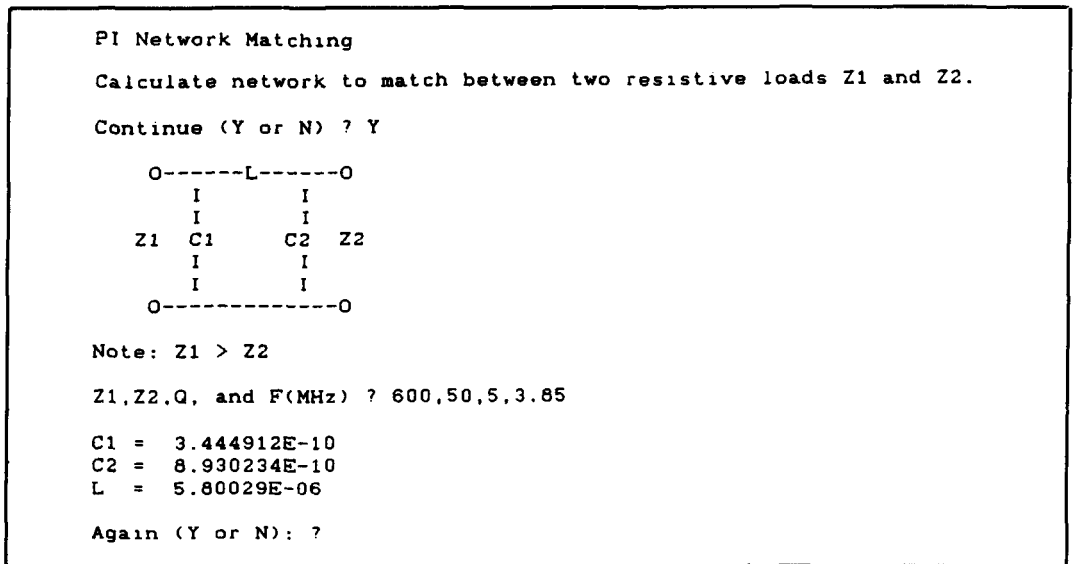


Figure 1. UTILITIES+ program display.

engineering software houses. But for \$95, UTILITIES+ gives you 25 design utilities for Apple and IBM-PCs/compatibles. These programs are written in BASIC and space is provided for adding additional user programs. Selection of the programs outlined in Table 1 is made from an introduc-

tory menu. Figure 1 shows the program display and user response for the calculations for a Pi network to match a 600-ohm impedance to 50 ohms. However, the main advantage of UTILITIES+ is that it contains transmission line/stub and other programs necessary to use the MSTRIP+ microwave microstrip/stripline design program offered by the same people (more about MSTRIP+ later).

NOVA

NOVA, a \$99.95 circuit analysis program (\$15 for a version without the math co-processor from *RF Design* magazine), can be used to analyze circuits such as amplifiers, filters, etc. The program will calculate voltage, phase delay, and complex input impedance. Either S-parameters or voltage may be used. Time domain analysis via Fourier square wave response can be performed on circuits with graphical output available. The program runs on IBM-PCs/compatibles, doesn't require color adaptors, and uses the DOS GRAPHIC utility for printing.

I mainly use this program to perform a quick check on filters and matching networks designed with other sources. In five or ten minutes I can enter the circuit parameters, set the frequencies I desire to be "swept" by the program, and alter values back and forth until I have the response required. It's also a good "what if" simulator where a given circuit may be modified in various ways to determine the effect on other circuit parameters. A library is available for storing component parameters that can then be recalled for entry into the circuit to be

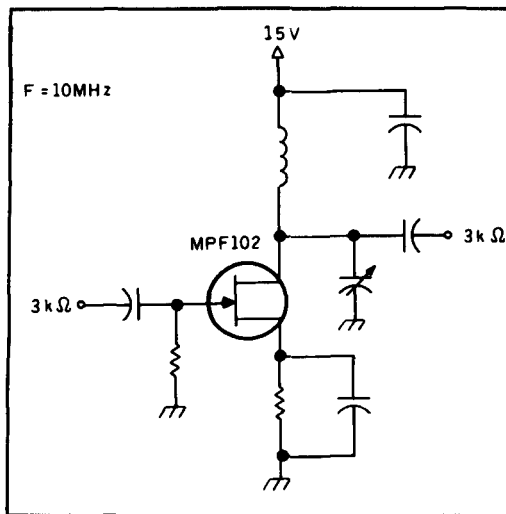


Figure 2. Amplifier circuit for NOVA analysis.

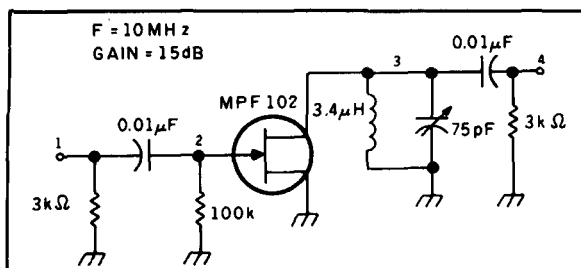


Figure 3. Amplifier redrawn for computer entry.

Comp.	Type	Value	Node	Node	Node	Node
1	Generator	3000.00	0	1		
2	Capacitor	0.01000 E -6	1	2		
3	Resistor	100000	2	0		
4	Capacitor	70.0000 E-12	3	0		
5	Capacitor	70.0000 E-12	1	0		
6	Inductor	3.00000 E -6	1	0		
7	Inductor	3.00000 E -6	3	0		
8	FET	MPF-102	0	2	3	
9	Capacitor	0.01000 E -6	3	4		
10	Resistor	3000.00	4	0		
11						
12						

To erase any component, value, or node number: press "Space-bar"
 Analysis-A, Save-S, Get-G, Freq.-F, S-Para-/, Term Node-V, = (4)
 Time Domain-W, Graph-J, Param-Q, Scale-Z, New Cir-N, Lib-I, Exit-Ctrl C

Figure 4. NOVA display for Figure 3 entries.

analyzed. Circuits containing up to 80 components can be investigated. Although the model is useful with decreased accuracy from 500 to 1000 MHz, I find other programs more useful above 500 MHz.

Figure 2 shows the circuit of an amplifier stage to be analyzed by NOVA. Because the model is an AC or RF simulation, components that do not affect the response need not be included. As a general rule, this includes all DC resistors or biasing components that are bypassed. The gain of the transistor, input resistance, and output capacitance are part of the library data for the device being used. Figure 3 is the amplifier redrawn with node numbers assigned for computer reference. Node numbers and

components don't have to be entered in order, but there can be no numbers missing between 0 (ground) and the highest chosen node. Some value must be entered for each component. Therefore, computer aided engineering can only be considered an aid to designing and not a source of design. Pencil and paper, as well as knowledge and experience, are still necessary precursors to CAD.

After entering the circuit to be analyzed, the computer screen appears as shown in Figure 4. In order to bound the area of computer analysis, the operator enters the lowest, highest, and step value of frequencies he wishes the computer to sweep. Output level values can be in voltage or S-parameters, as shown in Figure 5. The computer

Frequency	S21	Return Loss	Phase	Delay	Z (in)	
	in dB	in dB	deg.	usec	R	+ - J
1.000 MHz	-68.267	0.001	-2.724		0.124	+j 19.04
2.000 MHz	-55.699	0.002	-5.260	0.0070	0.272	+j 39.26
3.000 MHz	-47.742	0.003	-7.806	0.0071	0.470	+j 62.11
4.000 MHz	-41.383	0.004	-10.522	0.0075	0.761	+j 89.67
5.000 MHz	-35.589	0.007	-13.562	0.0084	1.235	+j 125.4
6.000 MHz	-29.763	0.012	-17.199	0.0101	2.107	+j 176.2
7.000 MHz	-23.334	0.023	-22.035	0.0134	4.002	+j 257.3
8.000 MHz	-15.420	0.054	-29.764	0.0215	9.455	+j 414.7
9.000 MHz	-3.884	0.206	-47.671	0.0497	38.62	+j 871.3
10.00 MHz	15.902	2.475	-154.211	0.2959	15.53 E3	+j 9251
11.00 MHz	2.460	0.242	31.808	0.4833	46.56	-j 1017
12.00 MHz	-9.156	0.066	5.712	0.0725	11.73	-j 523.0
13.00 MHz	-15.777	0.030	-3.515	0.0256	5.334	-j 359.8
14.00 MHz	-20.306	0.018	-8.726	0.0145	3.075	-j 277.9
15.00 MHz	-23.711	0.012	-12.363	0.0101	2.017	-j 228.4
16.00 MHz	-26.421	0.008	-15.214	0.0079	1.435	-j 195.0
17.00 MHz	-28.660	0.006	-17.607	0.0066	1.080	-j 170.9
18.00 MHz	-30.563	0.005	-19.705	0.0058	0.846	-j 152.6
19.00 MHz	-32.212	0.004	-21.598	0.0053	0.684	-j 138.2
20.00 MHz	-33.663	0.003	-23.339	0.0048	0.566	-j 126.6

Print- PrtSc. Erase bottom line- B. Erase top lines- E. Continue- Space Bar

Figure 5. Swept frequency response for 10-MHz amplifier.

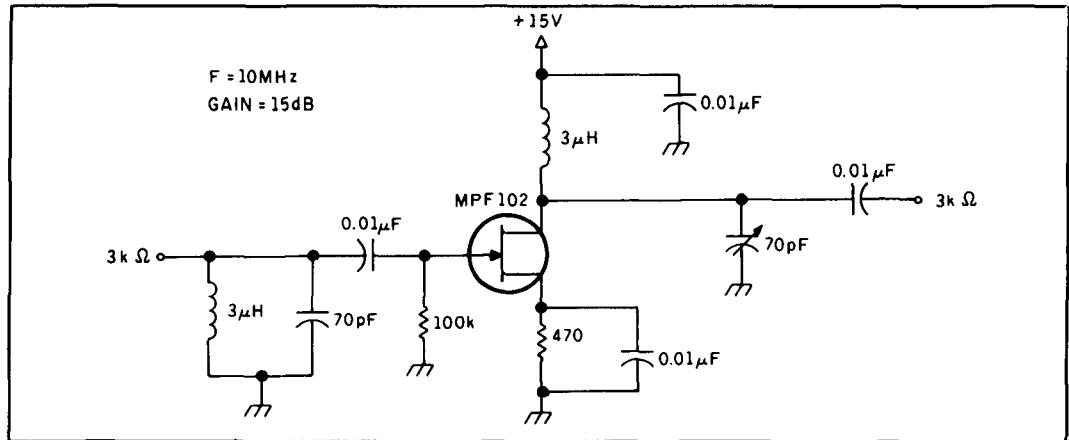


Figure 6. Completed amplifier configuration.

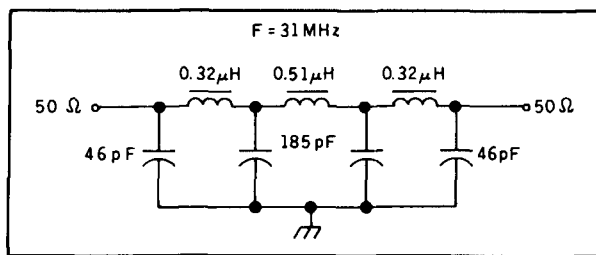


Figure 7. Lowpass filter configuration.

model simulates a generator level of one volt, the internal generator resistance being set by the user. I changed the output tank values five times to provide the highest gain at 10 MHz and added the input network to optimize the 3-k ohm input and further increase the gain. Figure 6 is the computer assisted design. Note that although we now

have an amplifier with RF component values, we still must optimize the bias values by DC analysis and testing. There are programs available that will do DC analysis but, in general, I don't find them worthwhile. Design parameters in the RF world aren't terribly precise, and bias component values are easily determined with published S-parameters at given voltage levels. Such DC analysis programs are most useful for op amps, servo, and other DC networks.

We can use the lowpass filter of Figure 7, designed under the UTILITIES+ section, to check the plotting and time domain analysis capabilities of NOVA. Figure 8 shows the printout of the swept frequency response, while Figure 9 traces the response in graphical form. To perform a time domain analysis, you may choose a square wave of any number of harmonics up to 1001. The

Frequency	S21 in dB	Return Loss in dB	Phase deg.	Delay usec	Z (in)	R	J
20.00 MHz	-0.118	27.504	-176.127		49.98		-j 4.218
21.00 MHz	-0.135	24.406	173.606	0.0285	48.86		-j 5.853
22.00 MHz	-0.160	21.502	163.005	0.0294	46.88		-j 7.556
23.00 MHz	-0.199	18.767	152.011	0.0305	43.87		-j 8.974
24.00 MHz	-0.261	16.190	140.559	0.0318	39.84		-j 9.654
25.00 MHz	-0.360	13.768	128.580	0.0333	35.05		-j 9.165
26.00 MHz	-0.514	11.508	116.018	0.0349	29.93		-j 7.250
27.00 MHz	-0.751	9.426	102.848	0.0366	24.95		-j 3.893
28.00 MHz	-1.104	7.548	89.107	0.0382	20.46		+j 0.730
29.00 MHz	-1.607	5.901	74.921	0.0394	16.66		+j 6.366
30.00 MHz	-2.287	4.506	60.522	0.0400	13.58		+j 12.79
31.00 MHz	-3.160	3.371	46.221	0.0397	11.16		+j 19.87
32.00 MHz	-4.216	2.486	32.347	0.0385	9.323		+j 27.55
33.00 MHz	-5.432	1.821	19.177	0.0366	7.954		+j 35.87
34.00 MHz	-6.771	1.335	6.885	0.0341	6.970		+j 44.98
35.00 MHz	-8.195	0.987	-4.457	0.0315	6.306		+j 55.07
36.00 MHz	-9.671	0.741	-14.859	0.0289	5.919		+j 66.46
37.00 MHz	-11.172	0.568	-24.383	0.0265	5.791		+j 79.58
38.00 MHz	-12.678	0.446	-33.109	0.0242	5.932		+j 95.06
39.00 MHz	-14.178	0.358	-41.126	0.0223	6.393		+j 113.8
40.00 MHz	-15.661	0.295	-48.518	0.0205	7.286		+j 137.4

Print- PrtSc. Erase bottom line- B. Erase top lines- E. Continue- Space Bar

Figure 8. Swept frequency response for 31-MHz LP filter.

program defaults to 3rd and 21st harmonics. **Figure 10** shows the input and output square waves. Any portion of the graph can be expanded, as in **Figure 11** where the rising edge is isolated to check for ringing.

TAME

Top Algorithms for Microwave Engineering (TAME) performs linear circuit analysis and optimization of one or two-port networks. It will also synthesize broadband matching networks between complex sources and loads. Although the program will run on IBM-PC/XT/ATs/compatibles, it requires a minimum of 384K RAM and a CGA compatible display if graphics output is desired. At \$75, TAME is a good value for UHF and microwave design with S-parameters. I have only two complaints. Since I don't use the program every day, I sometimes (make that many times) forget the correct data entry format, or try to perform some impossible operation. At best, the program provides an error message asking you to check the entries; at worst, it hangs between asking if you want a printout of the input data and loading the processing file—making a system reset necessary. My other gripe is the necessity of going back to system and reselecting the program from hard disk (or floppy) to begin processing after entering data and saving the file. This operation requires quite a bit of time when you need to return to the EDIT mode to change a component parameter, resave the file, and then go through the routine to bring up the program again.

To demonstrate some of the capabilities of TAME, I'll use the amplifier circuit of **Figure 12**. The circuit requirements are shown on the schematic while the circuit nodes for computer input are displayed in **Figure 13**. Once again it's apparent that some knowledge is required to provide estimated values, as well as component placement. When entered into the computer, each component value may remain constant or be allowed to be changed by the program. Input inductance L1 is used to limit the frequency range with the trimmer cap, which also helps to match the input impedance to the transistor. Output tuned circuit L2 and the trimmer cap perform the same functions. The program may change the values of these components during optimization, but can't change locations within the circuit. Therefore, if some of the component values appear to be out of range, or the desired input parameters can't be met, some circuit redesign will be necessary.

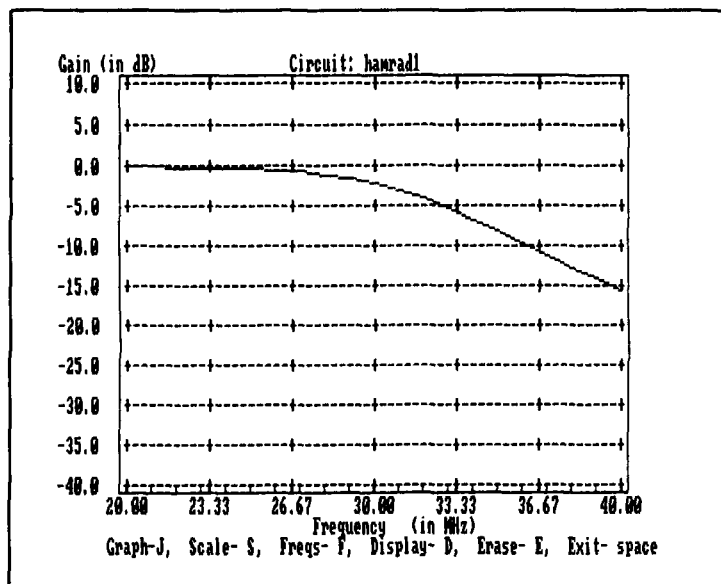


Figure 9. LP filter response curve.

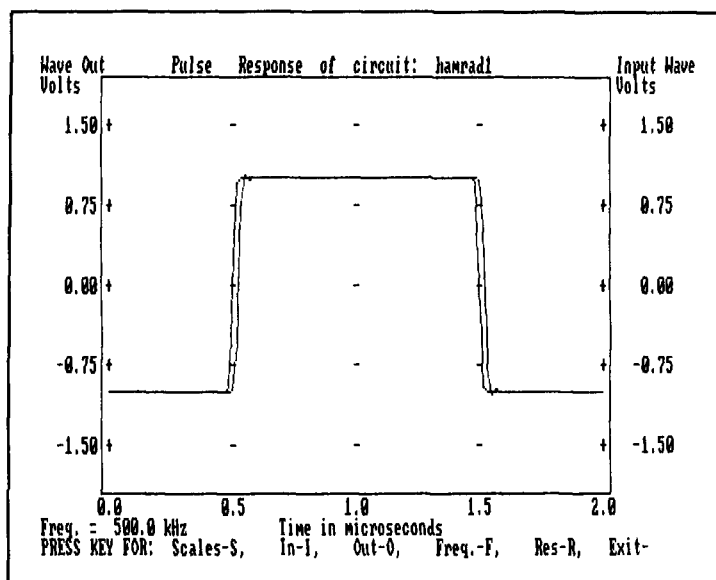


Figure 10. Time domain analysis of input/output pulse.

Using the EDIT function, the circuit parameters are entered in the format shown in **Figure 14**. Inductor L1 is in the form of a microstrip transmission line chosen to be 90 degrees or less in length (inductive) and to pass frequencies 500 MHz and above with the aid of the trimmer cap. Inductor L2 is resonant with the output trimmer capacitor to provide the best match for 50 ohms at 1 GHz and is used in the shorted stub configuration. It must be less than 90 degrees (one quarter wavelength) to act like an inductance. Because the program will determine the best values, we can enter a dummy value or best guess estimate. The first value entered after the nodes is the impedance of the transmission line. The transistor input and

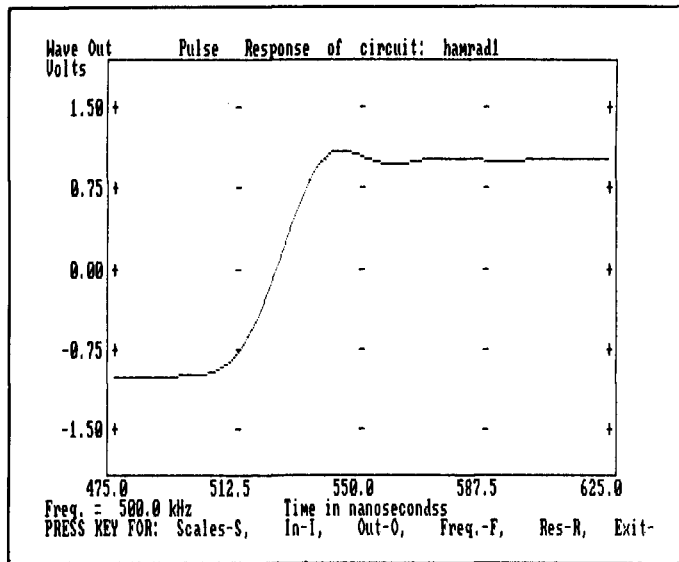


Figure 11. Expanded rising edge response.

output DC blocking capacitors may be used as part of the matching network or perform only a blocking function. In this case, they are performing the latter role, allowing all matching to be provided by the other reactive components.

In the data description, our circuit must be described as a two-port network between applicable nodes with a given input/output impedance. If there are specifications, such as S-parameters, for an active device, their input/output nodes must be listed with a reference to the table where the device specifications can be found. Because our network is a two-port device and we wish to analyze and optimize the circuit, the last data line of the first section must have the indicated format. The next to the last line of the data section tells the program that we wish to have the S21 parameter (gain)

graphed in blue. All sections must be completed with an END line.

In the Frequencies and Weights section, the user enters the desired parameters he wishes the circuit to achieve. For each frequency, he enters the desired S-parameter value and weight to be assigned to that parameter. In Figure 14, the Frequencies section shows that for S21, for example, a gain of 0, 5, 12, and 15 dB at frequencies of 100, 500, 750, and 1000 MHz, respectively, is desired. The values are input as S-parameters where Forward Gain (dB) = $20\text{Log}S_{21}$. A weight of 1 is assigned to all the desired values (a weight of 0 means that there is no contribution of that value to the error function during processing).

The Tables section contains all data specifications, such as impedances, S-parameters, gain parameters, etc. that are referenced in the main data listing. In Figure 14, the entries are S-parameters in magnitude and phase across 50 ohms at a collector/emitter voltage of 10 volts and collector current of 20 mA, as given on the NEC data sheet. The 750-MHz entry is extrapolated because the data sheet entries are given only for 100, 500, and 1000 MHz. After six iterations, the processing program provides the information shown in Figure 15. In order to obtain the computer values for the circuit components, a new file is generated providing the values in Figure 16. Using the program-generated parameters for the transmission line and shorted stub, we must access a different program to calculate the physical dimensions of the microstrip.

MSTRIP +

This program lets the user examine the design of single microstrip transmission

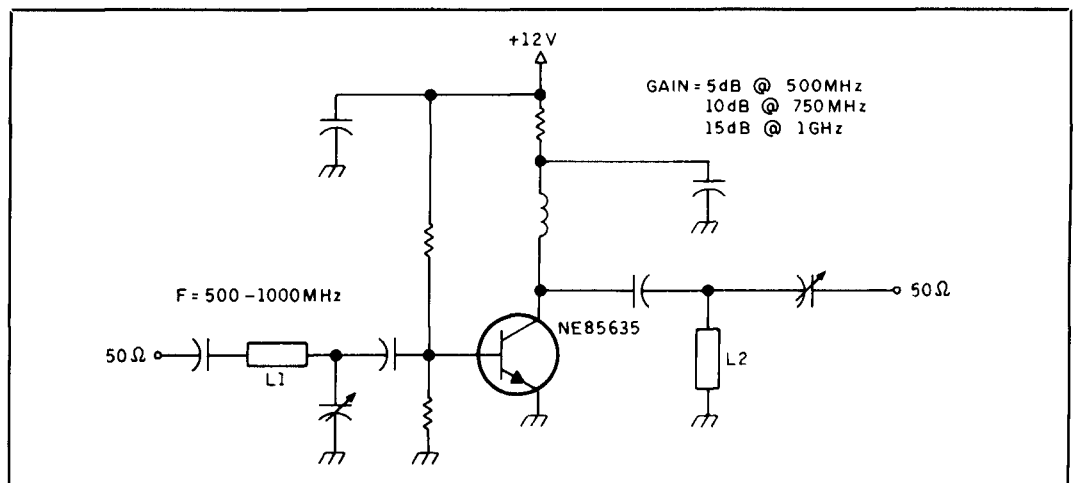


Figure 12. Amplifier circuit for TAME optimization.

lines, coupled microstrip transmission lines, and stripline. It runs on IBM PCs/compatibles and is available for \$195. After selecting the category of interest, the user has the further option of choosing to synthesize, analyze, or obtain tabular data. The TAME program provided us with the design parameters for two microstrip transmission lines in the 500 to 1000-MHz amplifier. Using MSTRIP+, we can determine line width for circuit board layout.

To calculate the foil area required, we need to know certain parameters. These are listed in Table 2. The physical attributes are shown in Figure 17. After we choose "synthesis" from the menu, Figure 18 shows the entries and computed values for the microstrip widths for L1 and L2, respectively. The circuit board material used is G10 epoxy.

To determine the microstrip transmission line lengths, we can return to the UTILITIES+ program and run the Line Length utility, as shown in Figure 19 for L1 and L2, respectively. The completed design is shown in Figure 20. As an aside, the area of

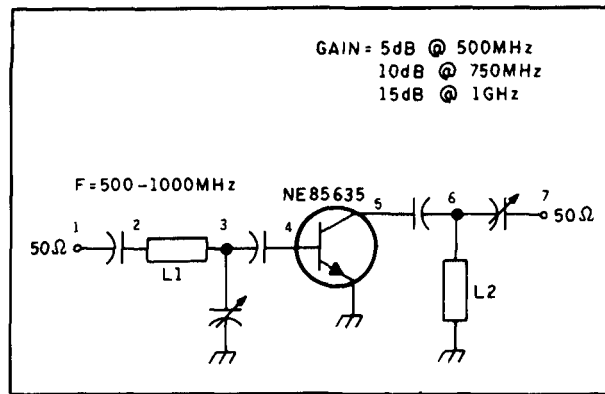


Figure 13. Amplifier configuration for computer entry.

L1 is very long and thin. It can be placed on the circuit board by running short lengths back and forth, separated by at least four times the width, or we could rerun TAME to attempt to find a different configuration that would provide the same frequency response.

The Tabular Data section of the MSTRIP+ program provides the user with the means to compare different variables to

```

TAME: Top Algorithms for Microwave Engineering
(C) Copyright 1988 Stephen E. Sussman-Fort
All Rights Reserved

Summary of Input Data from disk file: HAMRAD

CAP# 1 2 1.000E-011
TRL# 2 0 3 0 5.000E+001 9.000E+001 <<deg. 5.000E+008 0.000E+000
CAP# 3 0 8.000E-012
CAP 3 4 1.000E-009
TWO 4 0 5 0 TABLE1
PORT1 1 0 5.000E+001
PORT2 7 0 5.000E+001
CAP 5 6 1.000E-009
SST# 6 0 5.000E+001 7.500E+001 <<deg. 1.000E+009 0.000E+000
CAP# 6 7 8.000E-012
PERFORMING TWOPORT OPTIMIZATION MAGNITUDE
GRAPHICS ON SM21 Blue

Weights: 1/.87 0 0 1/.87
Frequencies:
1.000E+008
Weights: 1/0 0 1/1.78 1/0
Frequencies:
5.000E+008
Weights: 1/0 0 1/3.98 1/0
Frequencies:
7.500E+008
Weights: 1/0 0 1/5.62 1/0
Frequencies:
1.000E+009

Table Number 1 Table Type S
50.00
6.50E-001 -78.00 0.00 9.00 34.20 141.00 7.90E-001 -27.00
6.40E-001 -162.00 0.00 43.00 10.38 93.00 2.60E-001 -49.00
6.30E-001 20.00 1.00E-002 48.00 7.35 80.00 2.30E-001 -53.00
6.20E-001 179.00 2.00E-002 52.00 5.32 75.00 2.10E-001 -56.00

```

Figure 14. TAME parameter entry screen.

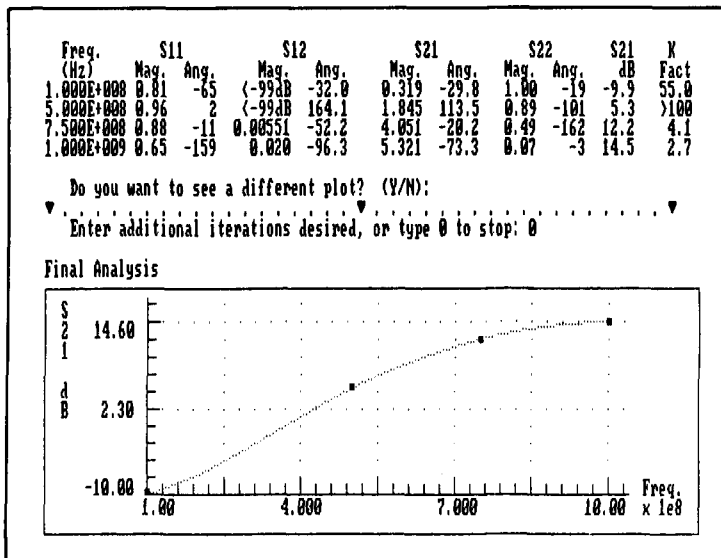


Figure 15. TAME output for 500 to 1000-MHz amplifier.

determine their effect on the other transmission line parameters. Using the parameters for G10 epoxy board, **Figure 21** illustrates the effects of varying the microstrip width to substrate thickness ratio W/H .

When the Analysis option is selected, the user can investigate the line width effects on impedance. In **Figure 22**, variations of the computed L2 Line width are shown with their corresponding impedances.

MICRO

Instead of a general microstrip design program, MICRO is a collection of microstrip transmission line design and analysis routines for particular types of microwave

circuits. For \$195, you receive the design programs for various types of filters, hybrids, couplers, and impedance transformers, as shown in the display of the main screen in **Figure 23**. MICRO will prepare and display a table of design values following processing. A plotting or printing utility is included in the updated version. Other more exotic data manipulation and graphing programs are also available from BV Engineering. Because the data file created by the program is in ASCII, it can also be used for other programs.

As an example of one of the programs available, **Figure 24** shows the design of an impedance-matching transformer to convert the 3.25 ohm-3.5j series output impedance of a 900-MHz amplifier to 50 ohms. Due to the problems in obtaining precise trace formation during the etching process, I used a compensation factor, based on experience, in the computations. Without such information, a value of "1" is entered. The output screen lists the impedance, width, and length for each section forming the configuration outlined in **Figure 25**.

A Comprehensive Filter Design Program

For many years, *RF Design* magazine has published software printouts to accompany their articles, but disks were usually available only from the authors. However, within the last couple of years, the magazine has begun making disks available for a minimum fee of \$15. The list of available programs for MS-DOS systems, and a

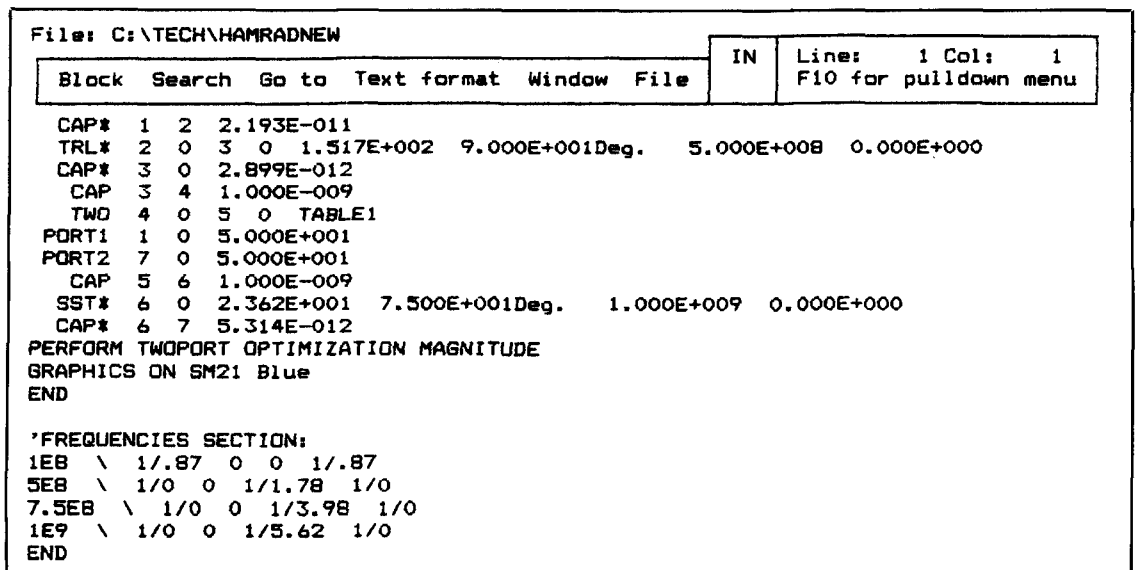


Figure 16. TAME component values for amplifier.

H2 - Distance between top of circuit board and enclosure cover.
 H - Thickness of circuit board dielectric.
 W - Width of microstrip line.
 T - Metalization (foil) thickness
 ER - Circuit board dielectric constant
 Z0 - Impedance of microstrip.
 F - Frequency of microstrip.

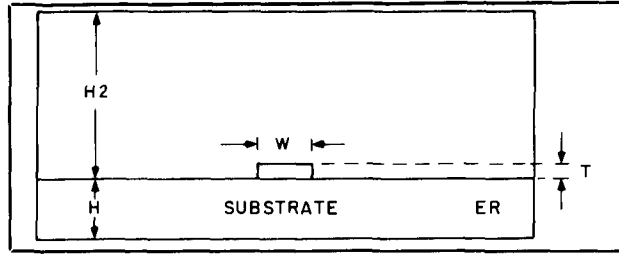


Table 2. Microstrip transmission line parameters

Figure 17. Physical parameters for microstrip calculations.

```

Z0 = 151.7000 ohms
T = .0028 in.
H = .0540 in.
Er = 5.98
H2/H = 12.0
F = 500 MHz

Iterating
Z0 = 134.1600799560547
Z0 = 166.0759887695312
Z0 = 150.9125061035156
Z0 = 151.9016876220703
Z0 = 151.6512298583984
Z0 = 151.7115631103516
Z0 = 151.6972503662109
Z0 = 151.6999664306641

Output Data
W = .0015 in.
Er' = 3.3866

Input Data
Z0 = 23.6000 ohms
T = .0028 in.
H = .0540 in.
Er = 5.98
H2/H = 12.0
F = 1000 MHz

Iterating
Z0 = 23.58208274841309
Z0 = 23.60115814208984
Z0 = 23.59992408752441

Output Data
W = .2502 in.
Er' = 4.7905

- Press any Key -

```

Figure 18. Computed transmission line widths.

```

Line Length
Electrical and physical length of a transmission line.
Continue (Y or N) ? y
Units: MHz,inches
Input Elec or Physical length (E or P): ? E
Enter F,TH,Er ? 500,90,5.982
Length = 2.409 in.
Again (Y or N): ?

Line Length
Electrical and physical length of a transmission line.
Continue (Y or N) ? y
Units: MHz,inches
Input Elec or Physical length (E or P): ? E
Enter F,TH,Er ? 1000,75,5.982
Length = 1.004 in.
Again (Y or N): ?

```

Figure 19. Computed transmission line lengths.

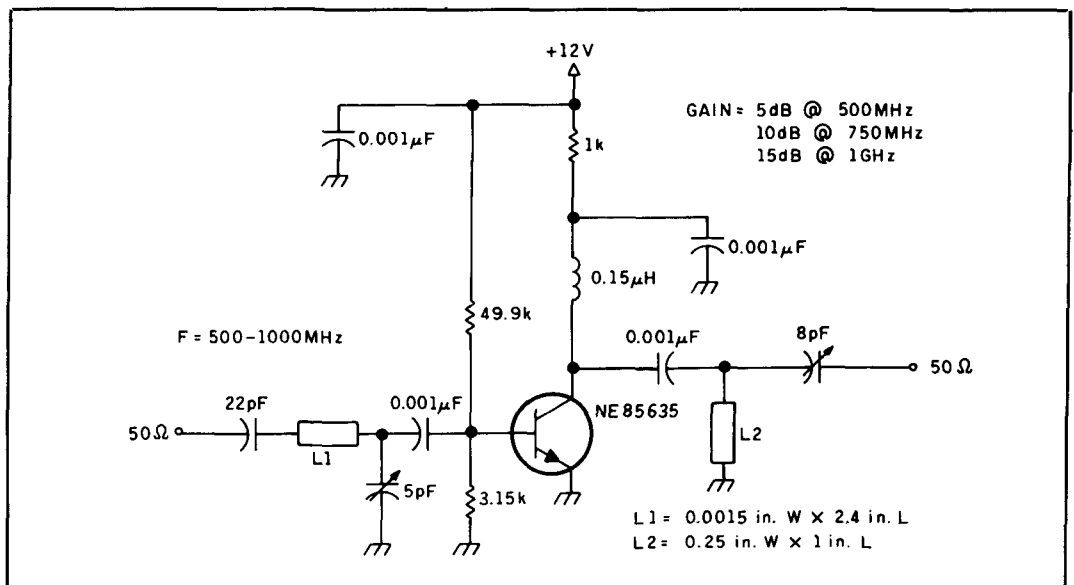


Figure 20. Completed UHF amplifier configuration.

few for Macintosh, includes practical engineering design subjects and is one of the best values offered in CAE/CAD software. I highly recommend you write to the magazine for a list of the available programs, which are indexed by monthly issues. The Nodal Analysis Program, which performs AC nodal analysis with 50 nodes and 10 component models; the Microstrip CAD Program, which computes microstrip transmission line parameters for printed circuit boards; and A Comprehensive Filter Design Program are examples of the programs I have used and found well worthwhile.

A Comprehensive Filter Design Program will compute, display, plot, and print more parameters of user-chosen lowpass, high-

pass, bandpass, and bandstop configurations using elliptic, Butterworth, or Chebyshev rolloff modes than you'll ever want to know. The main program is made up of modules, most of which can be used independently or called from the main program. RF1 calculates the order necessary to implement the desired filter from the given parameters. RF2 provides magnitude and phase plots, while RF3 will compute the filter transfer function and display the poles and zeros locations. RF4 implements a partial fraction expansion and inverse Laplace transform to display the time domain impulse and step response. RF5 performs passive and active network analysis for circuits up to 25 nodes and RF6 determines the

MStrip+ Z0 vs. W/H Analysis on 05-23-1989 at 11:15:47

Input Data

T = .0028 in.
H = .0540 in.
Er = 5.98
H2/H = 12.0
F = 1000 MHz

W/H	Z0	Er'
1.00	59.8660	4.1052
2.00	41.6539	4.3789
3.00	32.2381	4.5691
4.00	26.3221	4.7141
5.00	22.2756	4.8305
6.00	19.3341	4.9269
7.00	17.0962	5.0087
8.00	15.3334	5.0792
9.00	13.9066	5.1408
10.00	12.7262	5.1953

Figure 21. Results of varying trace width to board thickness ratio.

number of turns of wire in air coils that will provide the inductance required in the filter coils.

Using the main program module, RF Design, I specified a bandpass filter with 3 dB frequencies of 10.694 and 10.706 MHz, of third order with 600-ohm input and output impedances. Figure 26 shows the filter topology, as displayed on the screen. A swept frequency response or plot of the various parameters is also available in this module, or the parameters can be saved to a file which can then be called up from any of the individual modules. The magnitude plot of the 10.7-MHz filter is shown in Figure 27 using RF2, accessed from the alternate menu.

Drawing programs

For the technical experimenter and builder there are two main requirements a CAD program must meet. The program must be capable of making schematic diagrams, and printed circuit board layout must be to reasonable scale. Although there are a lot of drawing programs on the market, there aren't many which are both economical and offer the various features necessary to provide a satisfactory rating in the above categories.

There are two major problems that make many less expensive drawing programs less than desirable for electronics/engineering use. It is, many times, very difficult, and sometimes impossible, to align the horizontal ends of two lines in different parts of a schematic diagram. For instance, if we wanted to draw a two-stage amplifier, the transistor diagram would be called from the library and various components added to the circuit in appropriate places. When the input coupling capacitor is added horizontally to the base, the lines should connect or overlap. Most of the time there's no problem. But when components are removed and/or reinserted in another location, or a section of the drawing is modified, these lines don't always line up but rather overlap at a slight offset to each other. It doesn't help to use the zoom feature because the lines may appear good at one magnification but offset at another. This is a common problem with all CAD programs used on PCs, which, after all, are not engineering workstations.

The more annoying feature of these programs is the inability of the output file to scale to the input dimensions. For example, if you scaled a printed circuit board layout drawing for 4 × 5 inches, that is the output

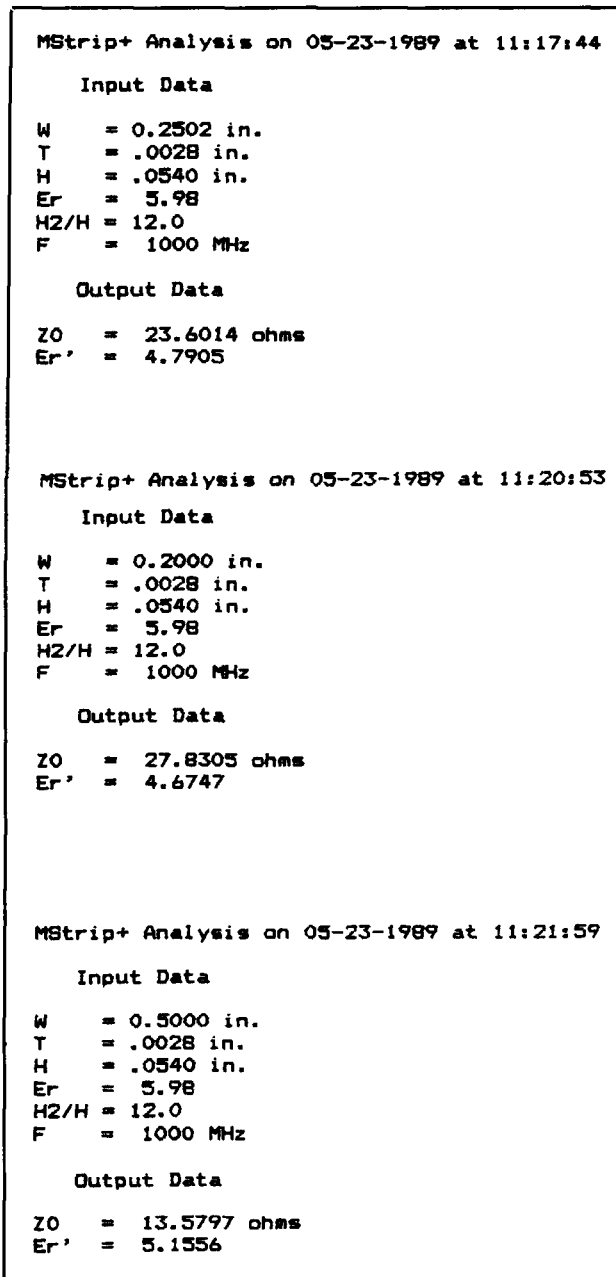


Figure 22. Impedance versus L2 width.

size you would expect to obtain. Scaling can be done by changing the horizontal-to-vertical CRT aspect ratio in the setup program, but is not carried through to the output, which is sometimes featured in a separate program.

AutoSketch

AutoSketch is produced by the same people responsible for AutoCad—probably the most widely used industry CAD program. AutoSketch portends to be object rather than pixel oriented. That is, instead of storing a circle with an X in the center as a number of dots in a circle with additional

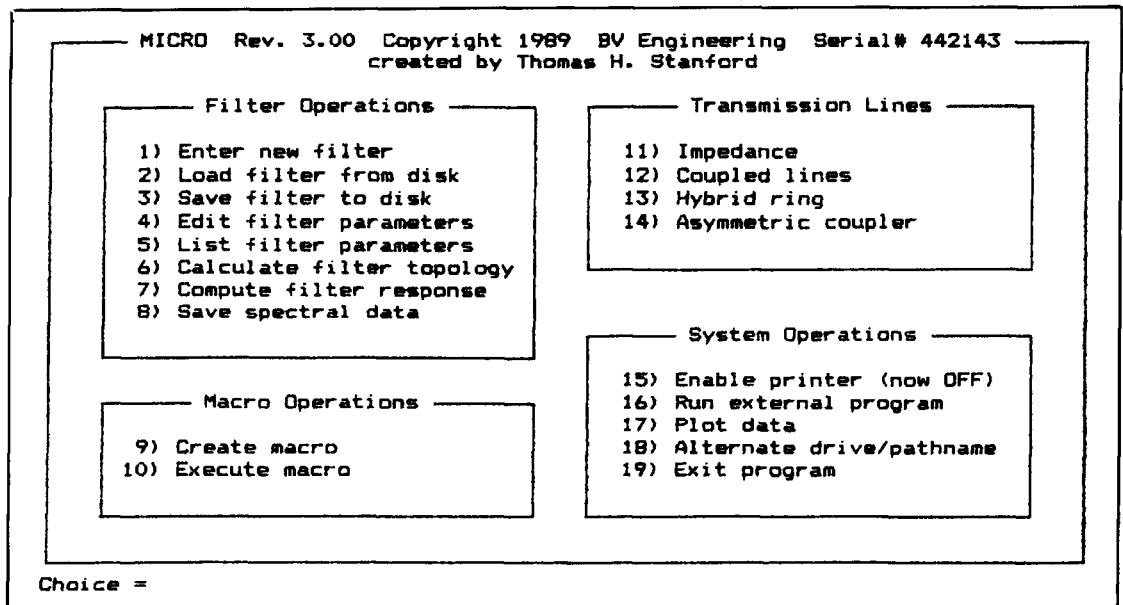


Figure 23. MICRO main menu screen.

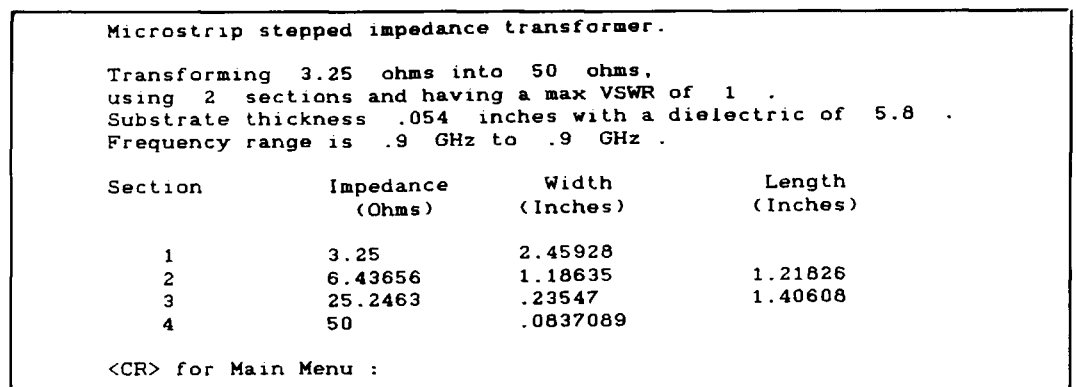


Figure 24. MICRO impedance matching display.

dots in the form of an X in the circle, it records the object as a circle with a center point, radius, and lines with particular end points and mathematical dimensions. Be that as it may, AutoSketch has the same problems with connecting lines as other drawing programs, although not as pronounced. The program will run on PC-

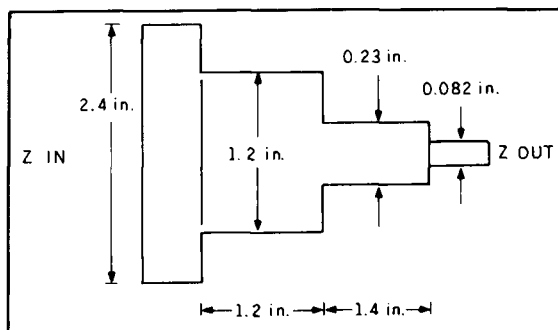


Figure 25. 3.25 to 50-ohm transformer.

DOS/MS-DOS machines with 512K RAM and two disk drives or a hard drive. Any of the common color graphics are acceptable (also Hercules) and various pointing devices are compatible. In addition to standard graphics printers, AutoSketch also supports Hewlett Packard, Houston Instruments, and ADI plotters.

Pull-down menus allow fast parameter selection and input of library components. The screen background is white as opposed to some programs in which the is screen black. Crosshatching is provided in many different patterns, as is a fill option, which is handy when drawing mechanical items or to separate copper from substrate on printed circuit boards. The only disadvantage to these options is that you must outline the area to be filled instead of simply clicking the mouse within the outline of the area. Multiple layers, which can be displayed together or individually, are also available.

Version 2.0 was \$149.95 (the original version was \$79.95) and Version 3.0 has been released recently for \$249. You may be able to get a free symbols library with the initial purchase (normally \$49.95). Although somewhat involved, AutoSketch will provide scaled output on the basis of user input parameters. A complete drawing to scale, or only a portion of the screen, may be output by placing a "window" around the desired material. The plotter menu also allows the selection of pen colors and plot speed for each—a very useful option for various pen widths and paper types. Although symbol libraries are available, I prefer to make up my own component libraries. My experience with prepackaged libraries has been that they are only partially useful because either

the items are of a dimension that I don't wish to use, or aren't in the form to which I am accustomed. AutoSketch provides a list of entered components in the library when the pull-down menu is accessed, or, if you can remember the file name, you can enter it directly. The retrieved component symbol then appears on the screen either in a predetermined location or where it can be moved to the desired entry point.

System memory is important in CAD work. As the amount of memory remaining decreases, the program will have difficulty finding locations for the changes/additions as they are made. Some programs will continue to let you work without informing you that unless what you delete is equal to or greater than what is added, it will not be

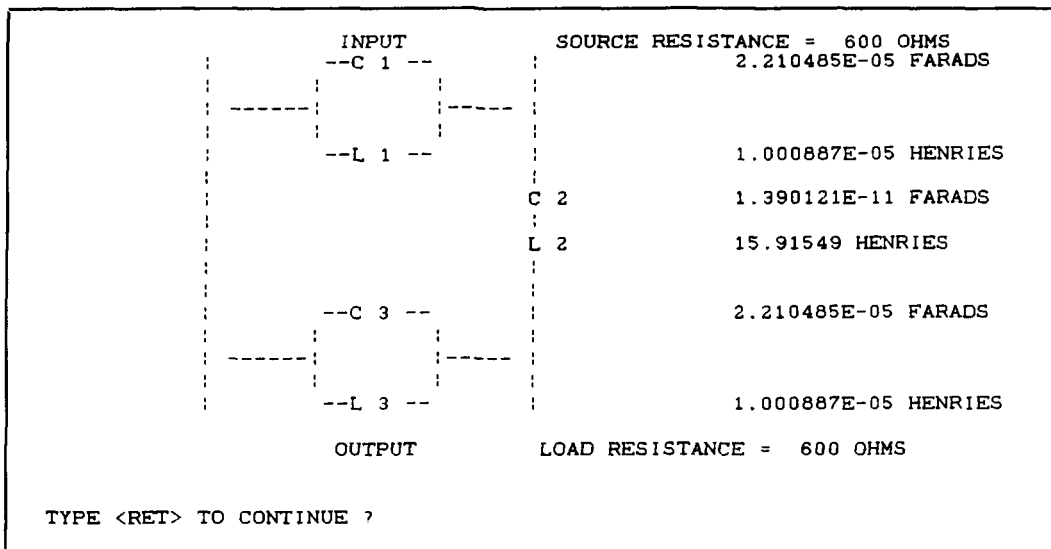


Figure 26. 10.7-MHz filter topology.

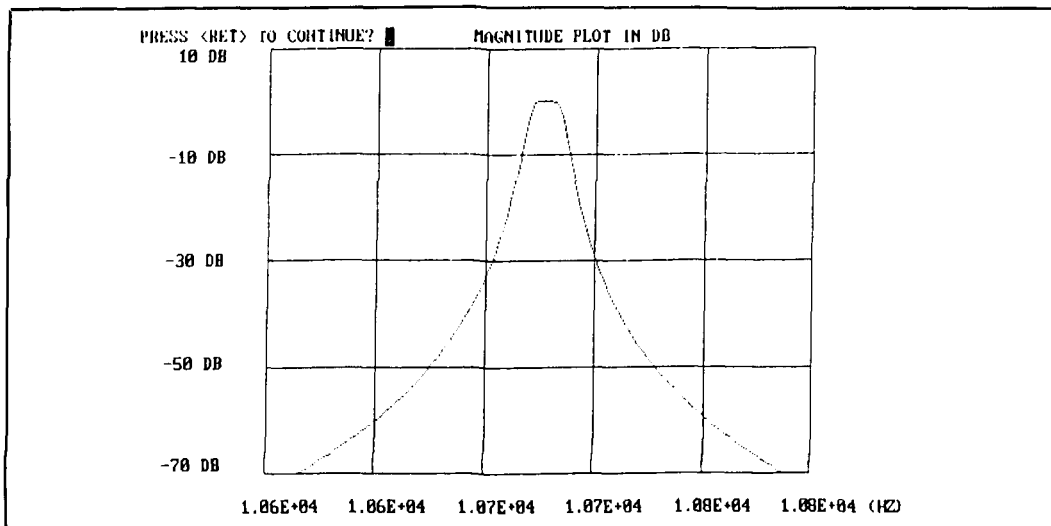


Figure 27. Bandpass filter magnitude plot.

Program Purchasing Information

Program	Price	Supplier	Telephone Number
UTILITIES + MSTRIP +	\$95 \$195	Microwave Software P.O. Box 764 San Juan Capistrano, California 92693	(714) 831-5687
NOVA	\$99.95	RF Engineering RD#1, Box 587 Norwich, New York 13815	(607) 334-8911
TAME	\$75	SPEFCO Software 18 Bennet Lane Stony Brook, New York 11790	(516) 689-6582
MICRO	\$195	BV Engineering Professional Software 2023 Chicago Avenue, Suite B13 Riverside, California 92507	(714) 781-0252
SMITHSOFT +	\$259	Somersoft 2939 Burnside Road Sebastopol, California 95472	(707) 829-0164
AUTOSKETCH	\$249	Autodesk, Inc. 2320 Marinship Way Sausalito, California 94965	(415) 331-0356
A COMPREHENSIVE FILTER DESIGN PROGRAM		RF Design Software Service P.O. Box 3702 Littleton, Colorado 80161	(303) 770-4709 Request list of programs available

stored. In addition, strange things will begin to happen—like the inability to delete adjacent objects or move components for alignment. Even if the screen isn't full, the RAM might be! AutoSketch maintains a running tally of the memory used and displays the figure on the menu bar at the top of the screen. As the maximum system level gets closer, operations become progressively slower.

Smithsoft +

If you are one of the many people dedicated to the use of the Smith charts for your engineering calculations, Smithsoft + (upgraded) deserves a look. This program is mouse oriented and the circuit being analyzed is displayed with pull-down menus available for parameter selection. The upgraded version is now \$259.

Summary

Computer assisted design programs have

lessened the manual toil of parameter calculation and simplified the overall design and educational process. However, they are no substitute for basic knowledge and won't overcome the garbage in/garbage out syndrome. When searching for a good applications program, it's worth the effort to investigate as many sources as possible, instead of purchasing the first candidate. Many times, as various possibilities are reviewed, your requirements may change or become more realistic as you determine just what options are available. Hopefully the information I've given here will help in some small way to make your selection easier or, at least, has initiated the process.

Acknowledgements

IBM-PC is a registered trademark of International Business Machines, Inc. Smith is a trademark owned by Analog Instrument Co. UTILITIES+ and MSTRIP+ are trademarks of Microwave Software. AutoSketch is a trademark of Autodesk, Inc.

CORRECTION

A clarification

Figure 2 of W6FR's article, "Titan 425 Reliability Enhancements" (Winter 1992), shows a measurement of 1/16-inch on the

bottom of the "sail detail" portion of the figure. This measurement refers to the length of the lip seen in the cross section of the sail shown in the box at the left-hand side of the drawing. Ed.

A USER'S VIEW OF CHARGE COUPLED DEVICE IMAGING

An introduction to CCD technology

Charge coupled devices (CCDs) are becoming an essential part of laboratory opto-electronics, consumer recording devices, and high-tech instruments. When I read about amateur radio operators setting QSO distance records with Helium-Cadmium (HeCd)¹ and Helium-Neon (HeNe)² lasers, I knew it was time to give these devices wider coverage in amateur radio literature. Because I'm presenting what may be new technology to many of you, I've included numerous references throughout this discussion.

Introduction

CCDs are one subset of a broader class of devices called Charge Transfer Devices (CTDs). This class of devices is characterized by metal oxide semiconductor construction and high impedance manipulation of electrons.

Electrons are collected and contained within "pockets" or "wells" built as part of the integrated circuit. If you're comfortable with physics terminology, consider these pockets as potential energy wells, separated by energy barriers higher than the ambient kinetic energy of the electrons. If you're an electronics person, these wells are sufficiently described as thousands (or millions) of very low leakage electrolytic capacitors built onto an integrated circuit. There are also facilities built on the integrated circuit chip to move the packets between adjacent wells.

Table 1 shows seven areas where these de-

Analog Shift Register
Video Delay
Scan Rate Converter
Digit Storage
Digital Device Emulation
Filter and Transform Device
Photon-Induced Charge Collector

Table 1. Seven areas where electron wells have seen service.

vices have already seen service. Take the first one, an analog shift register, as an example. Digitize a voltage into a discrete number of electrons and store the electrons in a well. Shift the packet onto the chip and wait for the next packet. Thousands of samples could be stored this way, and the packets of charge could be accessed serially or all in parallel.

The sixth area has particular relevance considering the recent article on image processing by Bergeron.³ All of the weighted or moving average algorithms described in that article can be done *on the chip* by physically manipulating micron (millionths of a meter) sized packets of electrons. Even better, various filtering and transform functions can be performed before data ever leaves the chip!

Packets of electrons are moved around on a CTD using a technique similar to "chasing rats under a blanket." As you step from one area of the blanket to another, the

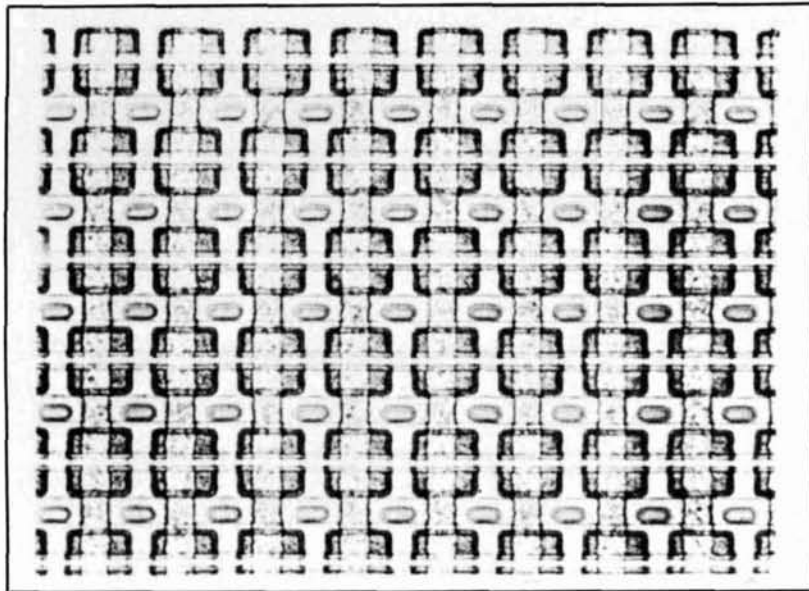


Photo A. Photograph of an actual CTD chip. The array of collection wells and the conductor matrix is clearly visible. The construction material is largely transparent, hence the translucent appearance. Source of photograph unknown.

lumps move out from under your feet. If you had enough feet, you could squeeze the rats right out from under the blanket. This is amazingly similar to how stepping voltages shifts charge packets on the chip. I'll give you more details on this later.

Most of the functions listed in **Table 1** retain thousands of sampled voltages by generating charge packets proportional to an input voltage. How else can you generate electrons?

First, a bit of background information is necessary. One of the basic concepts in semiconductor technology (really no more than double-entry bookkeeping) is that of holes (h^+) and electrons (e^-).⁴ A hole is no more than an absence of an electron where one would normally be in a cold, power-off hunk of silicone. Once heat (something above absolute zero) and power (voltage) is applied, we can shuffle the distribution of electrons on an integrated circuit wafer. In the case of *n-doped* semiconductor conduction, heat has provided energy to release electrons from contaminant parent atoms (such as arsenic) distributed in the silicone. For *p-doped* wafers, electrons have enough energy to shuffle over and be trapped near a contaminant parent atom (such as gallium), leaving a hole to wander around.

Once thermal equilibrium is reached, things

could get boring. However, if a light photon penetrates into the silicone wafer, it may rip an electron from loose association with an atom, generating an extra e^-/h^+ pair. By quickly trapping the extra electrons, we can indirectly record photon hits. A *p-doped* charge collecting layer (collecting electrons, the minority carrier in a *p-doped* semiconductor) is typically used for CCDs.

CCDs are designed to whisk the electrons quickly into a nearby well, while the hole is directed down a nearby conductor. It, too, in concept, is trapped opposite the well. The chip as a whole must maintain charge neutrality, which explains the earlier reference to dielectric capacitors. In practice, the shuffle of holes is usually ignored. It's no more of a simplification than that which an amateur radio operator makes when he says the RF is carried on the center conductor of a coax.*

Optical CTDs make up the last family of devices listed in **Table 1**. These optical CTDs are manufactured in two varieties—CCDs and CIDs (charge injection devices). CIDs are conceptually the same as CCDs, except in their flexibility of measuring the quantity of accumulated electrons on the chip. Back in 1987, General Electric was the sole manufacturer of CID technology, with patents barring others from the technology. Since then, the technology was sold to CIDTEC** and licensed to Jarrel-Ash for use in their DC Arc spectrometers. Other consumers look to a maturing CCD market. For these reasons, CCDs will probably be

*The point here is that there is always RF on the outer conductor. Unfortunately, colloquial antenna vocabulary uses "RF on the shield" to describe the condition of *unbalanced* current on the shield.

**CIDTEC, CID Technologies, 101 Commerce Blvd., Liverpool, New York 13088. (315)451-9410.

the detector of choice for readers of this article. The remainder of my discussion will deal primarily with the CCD, pointing out CID differences only in important areas.

If you're interested in a more technical presentation of both devices, but not in all the mathematical details, see the introductory articles in the list of references.^{5,6,7,8}

For the purposes of this article, I've chosen to view CCDs as a family of detectors. Always keep in mind that we want to detect and measure something, collect the measurements, and interpret those measurements. From this perspective, I'll first talk about construction and character of the devices, and some unique operating procedures. Then I'll cover special data handling opportunities and present a comparison of four competitive detector technologies. Lastly, I'll present two specific uses of the detector and give you some ideas of where to look for more information if you're interested.

Construction and characteristics

Packaging

Photo A shows a microscopic view of an actual detector. A mechanical cross-section of a typical CCD appears in **Figure 1**. The CCD used to collect data for this article is shown in **Photo B**.

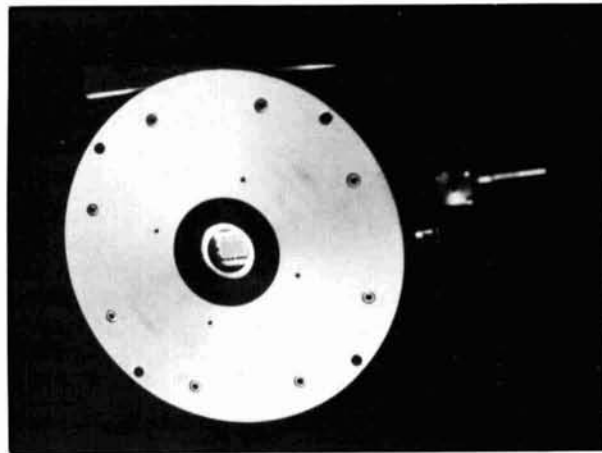


Photo B. A 384 × 576 Thompson TH7882 array mounted so as to look out the bottom of a cryogenic dewar. A mechanical diagram of the dewar is shown in *Figure 8*.

The backbone is a doped silicone wafer. For consistency, I'll stay with the *p-doped* substrate most common with CCDs. It's upon this that all other features are built. For the technical depth of this article, you need to recognize only the insulating layer over the collecting region and the conductors laid down on top to impose a potential on the substrate. In this sense, it's much like a FET with insulated gates.

The finished wafer is anywhere from less than 1 to more than 3 square inches. Row and column conductors are separated by

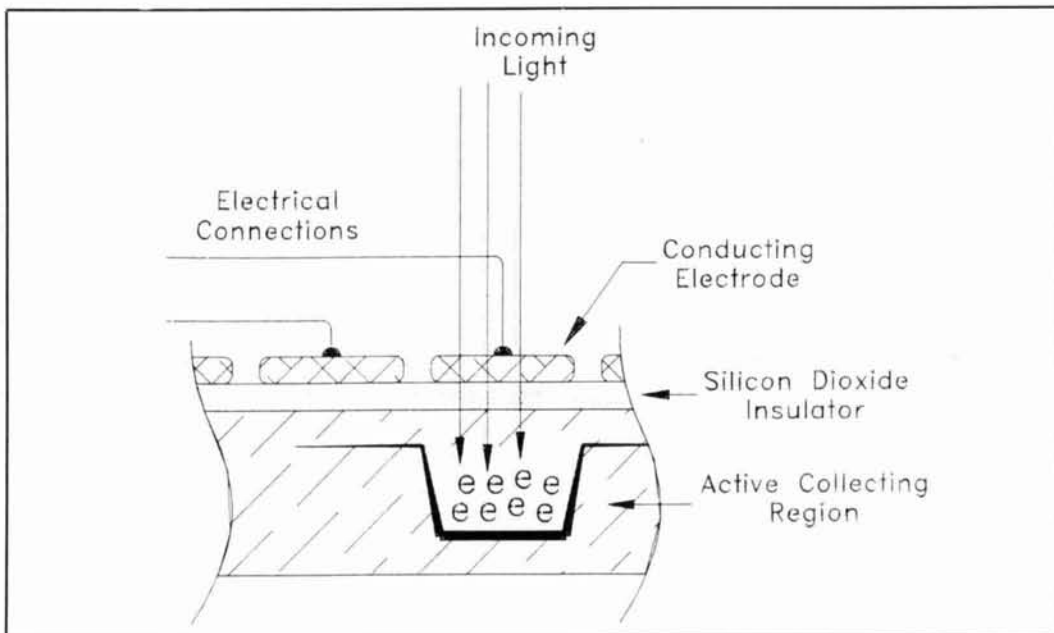


Figure 1. Mechanical CCD cross-section. Important features are the *p-doped* silicon base, the silicon dioxide insulating layer, and the conducting polysilicon gates. The insulating layer and the gates may actually be entwined more than shown here, depending on the clocking scheme used. There is, of course, no physical line boundary for the electrons—it only represents the voltage-induced favored location, or "potential well."

tens of micrometers. This wafer is glued to a ceramic package and jumpers are run out to external contacts just like EPROM packages.* In fact, I've read of EPROMs used as image detectors by programming so each bit is hanging on the edge of 0/1. Light subsequently pushes the bit over the edge. The glass cover cemented over a CCD circuit is, of course, of optical quality, and sometimes a special blend of glass, so as to not absorb at the far reaches of the spectral region the CCD would otherwise be sensitive to.

Nearly all CCDs are illuminated from the top (top exposed to the glass window suspended above the chip). Several manufacturers, however, have mounted the array upside down and etched the silicon substrate chemically down to a few tens of microns. This has potential for extending the sensitivity and spectral response (optical bandwidth) of the device. As a tradeoff, the thinned array is less mechanically durable.

By virtue of the ceramic packaging and solid crystal design, CCDs are able to withstand large pressure and temperature changes. I have used them in the micro-torr range (1 torr = 1/760 sea level atmospheric pressure) and at temperatures less than -137°C (-215°F). These are not arbitrary heroics. Such durability and environmental flexibility is critical to many applications ranging from military airborne weapon systems⁹ to telescopes focused all night at a distant star to see if it has a planet in tow.¹⁰

Spectral bandwidth

Just as radio signals are encoded in different regions of the RF spectrum, the information available from different optical regions of the spectrum varies. A perfect detector would be able to see all wavelengths with 100 percent efficiency.

The spectral width of CCDs is limited by fundamental behavior of the material out of which the device is made. I'll make a few simple calculations that will predict the wavelengths of light the CCD will be sensitive to, and compare this information to actual data. You'll see that CCDs have excellent spectral response, covering visible wavelengths of interest to astronomers, la-

ser users, photographers, military contractors, and so on.

Pure silicon exhibits a bandgap of 1.1 eV.¹¹ Common hybrid semiconductors have bandgaps ranging from tenths of a volt up to 5.3. When crystallized into a solid, all the lower electron energy levels of individual semiconductor atoms coalesce into a continuum of energy levels. The upper levels also combine and, due to similar neighbor effects, smear into a continuum of available, but empty energy levels for electrons. The region between the upper and lower level is the bandgap.¹² It is this bandgap across which the photon must move an electron to generate an e⁻/h⁺ pair.

In order for a photon of light to transfer energy to an electron, promoting it across the bandgap, it must have approximately 1.1 eV of energy.** What light is capable of providing this energy?

Earlier in this century, Plank theorized that light came only in discrete amounts, or packets, of energy. These packets later came to be called photons. Each photon has energy E, where:

$$E = h\nu,$$

$$h = \text{Plank's constant } (6.626 \times 10^{-34} \text{ J}\cdot\text{sec}),$$

$$\nu = \text{Frequency of light (Hz, or sec}^{-1}\text{)}.$$

Recall also that the wavelength and frequency are tied together by the speed of light:

$$C = \nu\lambda,$$

$$C = \text{Speed of light } (2.998 \times 10^8 \text{ m/sec}),$$

$$\nu = \text{Frequency of light (sec}^{-1}\text{)},$$

$$\lambda = \text{Wavelength of light (m)}.$$

Combining the two and rearranging for wavelength gives:

$$\lambda = hc/E.$$

We're interested in finding the wavelength of light in the air before it hits the CCD detector, so it's appropriate to use the speed of light in air. Notice that 1.1 eV must first be converted to 1.76×10^{-19} J to keep consistent units.

$$\lambda = (6.63 \times 10^{-34} \text{ J}\cdot\text{sec})(3.00 \times 10^8 \text{ m}\cdot\text{sec}^{-1}) / (1.76 \times 10^{-19} \text{ J}) \rightarrow 1.13 \mu\text{m, or } 1130 \text{ nm}.$$

An actual spectral response curve is shown in **Figure 2**. Note that there is no response with wavelengths longer (lower energy) than 1000 nm. Considering we've used no knowledge of the actual device to predict

*EPROMs typically come in 24 and 28 DIP packages and have an approximate 1 cm diameter glass window on the top. Look inside almost any computer, TNC, or digital piece of equipment, and you'll probably see one.

**Energy, or equivalently work, can be measured with many units: calories, joules, watt-hours, etc. The work required to move one electron through a potential difference of one volt is defined as an eV (electron volt). Rearranging the definition of a volt ($V = W/q$, Joules per coulomb) to $W = V\cdot q$, we see 1 eV is $(1 \text{ J/coul})(1.6 \times 10^{-19} \text{ coul}) \rightarrow 1.6 \times 10^{-19}$ joule. A good reference for fundamental and simple, but essential, physics is S.A. Weissman, *Modern Concepts in Physics*, Oxford Book Company, 1973. Page 306 addresses the above issue.

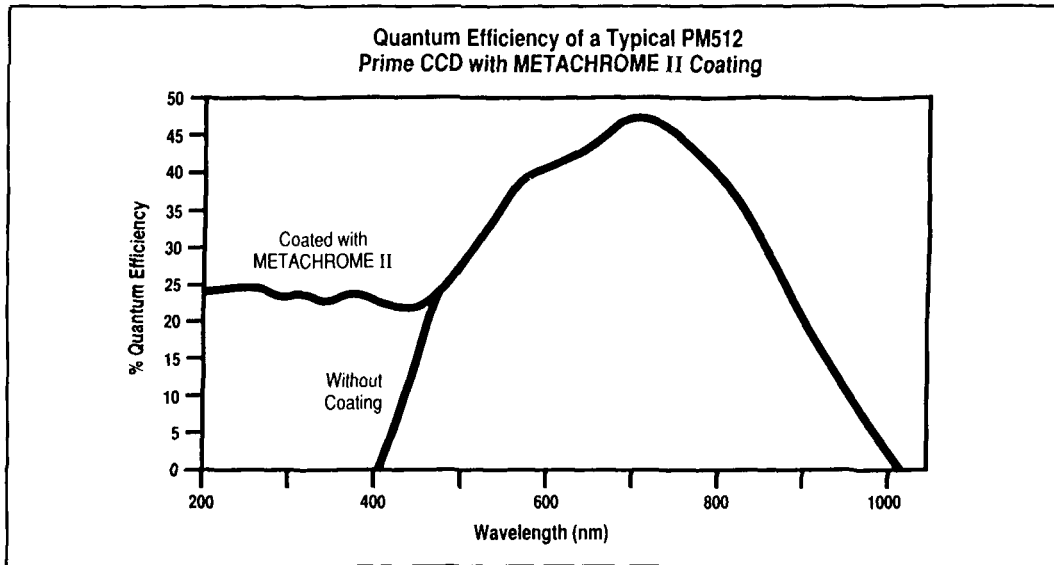


Figure 2. Ultraviolet (short wavelength) response enhancement is possible using a fluorophore that accepts the high energy photons and re-emits lower energy photons. Reprinted courtesy Photometrics Ltd.

the curve shown, and instead used only gross approximations, this is in excellent agreement!

The preceding discussion might lead one to believe that arbitrarily high energy photons would continue to have enough energy to generate e^-/h^+ pairs. Indeed they would, but another phenomena rolls off the response on the short wavelength side as shown in the “without coating” curve of **Figure 2**. The metal oxide semiconductor layers on top of the active region of a CCD exhibit a similar effect. Using wavelengths below (frequencies above) 200 nm, most of the light is absorbed before it ever reaches the active area. Correspondingly, wavelengths shorter than these don't give much response.

In the world of detectors, too much energy is rarely a problem (use an attenuator). Blocking out half the energy (half the photons) doesn't work in this case because *each* indivisible photon has too much energy. What chemists have done is to allow the high energy photon to be absorbed by a chemical that disperses part of the energy as vibrational or rotational motion (heat) and subsequently re-emits a photon of lower energy light. In the case of CCDs, this chemical fluorophore is coated on the top side of the CCD wafer, allowing high energy photons to be indirectly included in the count.

Some tradeoffs are inevitable. If the fluorophore absorbs photons in a spectral region that would otherwise have been detected, it decreases response at that wavelength. The fluorophore decomposes

over time and decomposition is accelerated by exposure to high light levels (room light). The fluorophore is just like a thinly sprayed layer of paint and it doesn't stick too well. If exposed to extreme temperatures, it may delaminate—just as plywood does if it gets too wet. The “Metachrome II” curve in **Figure 2** shows response of a CCD coated with a proprietary fluorophore of the same name.

Detector efficiency

Because CCDs exploit such fundamental mechanisms, efficiency is excellent. In the language of the field, peak quantum efficiencies (QE) are very high. For every 100 photons that arrive, up to 95 percent result in an electron trapped in a well. It's referred to as peak QE because, as shown in **Figure 2**, it varies depending on what energy the arriving photons have.

To give you an idea of what's acceptable, consider photomultiplier tubes (PMT) and diode arrays; they are often in competition with CCDs. Photomultipliers use vacuum technology to enclose multistage electron cascades. This gives excellent sensitivities (see **Figure 3**). Diode arrays offer spatial resolution (closely packed adjacent detectors) and capitalize on the inherent light sensitivity of a PN junction.*

PMT QE is strongly dependent on the exact chemical used to coat the electrodes, but does not peak above 25 percent. QE above 1 percent is available between approximately

*This effect can be seen with any glass-enclosed diode. Measure the forward resistance of a diode with a high-impedance ohmmeter at different distances from a bright desk lamp.

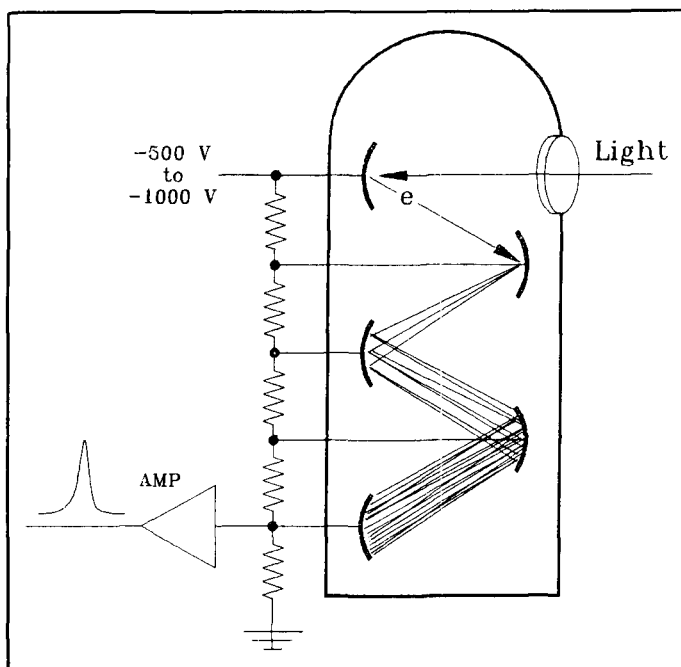


Figure 3. A simplified schematic of photomultiplier tube (PMT) operation. Depending on the flux of incoming photons, one can monitor output current or count individual pulses of current (a pulse is shown). A PMT detector, used in the current mode, was used to set the recent laser QSO distance record (see text).

200 nm to 800 nm, with QE above 10 percent in the range 200 nm to 450 nm.

Diode arrays typically offer spectral response (bandwidth at half of peak response) 570 nm to 1030 nm. Typically a few hundred mA/W is generated, with QE of 40 to 73 percent.¹³

For a complete comparative performance overview, see the two reference articles in *Applied Spectroscopy*.

Dynamic range

Two simple, but important, attributes of CCDs are their well-characterized response function and superb linear dynamic range. This means that if the device is exposed to a light source twice as bright, its output is exactly twice as large.

Linear dynamic range is the ratio of the strongest signal detectable to the weakest signal discernable. Simultaneous detection and linear response are also part of the definition. For example, the Tektronix chip in **Table 2** offers a usable range of $9 \times 10^5/12$ (S/N ratio of 2), or about 50 dB. Using variable integration times this can be extended to 100 dB. To appreciate this, consider the fancy new RF receivers boasting dynamic ranges of just over 100 dB when using very narrow CW filters. The radios have dozens of discrete components shaping the re-

sponse of the system. A CCD, in comparison, is not a designed *system* of components; it's only *one* component.

Linear dynamic range is important to spectroscopists who study individual atom emissions, where intensity ratios of emission peaks (varying several orders of magnitude) end up in the exponential part of equations, greatly enhancing any nonlinearity.

The theoretical lower limit of CCD detection is set by the simple fact that they use a detection scheme that counts photons. Any counting process is bound by the fluctuations (i.e., noise) in the observed Poisson distribution. The upper limit of the dynamic range is determined by full well capacity; when it's full, it's response goes nonlinear.

CIDs get around the upper limit by allowing nondestructive readouts. In other words, measuring the present electron accumulation doesn't necessarily mean it will be purged. In some applications, critical wells can be monitored and, when nearing capacity, can be read out and started over. Unlimited repetitions of this process push the effective well capacity way beyond other limits that come into play.

Once a CCD is manufactured, the basic well size is fixed, but many different sizes are available. If an image application needs superior resolution, very small well sizes can be fabricated. On the other hand, if large dynamic range is desired, CCDs can be manufactured with large wells that can contain many more electrons. **Table 2** shows the effect with several arrays available from different manufacturers.

Image defects

The outcome of the manufacturing process for any semiconductor wafer device can be contamination or incomplete etching and deposits. For CCDs, this shows up as defective cells or defective sequences of cells. These appear as hot spots or black spots—pixels or sequences of pixels that are permanently saturated or unresponsive. For instance, if there's an electrical short such that a well is filled by electrons leaking from a nearby conductor, it would fill immediately—regardless of the number of electrons formed by photon action. Manufacturers grade their production run of detectors and sell the more perfect units at higher prices.

I've spoken of containing and moving electrons. In more familiar language, this type of electrical character simply corresponds to high impedance. High impedance measurement systems are expected to show sensitivity to ambient electrical transients.

Device	Pixel Size (μm)	Format	Well Size (1000s)	Spectral Response	Read Noise (no. of e^-)
Kodak MIA	7		40		
TI 800 \times 00	15	800 \times 800	50	0.1-550(90)-1050	5
Photometrics PM512	20	516 \times 16	100	400-700(45)-1050	10
Thompson TH7882	23	384 \times 76	500	400-650(40)-1100	15
Tektronix TK512M-011		512 \times 512	900	450-750(35)-950	6
GE CID75	100	1 \times 1	100000	200-250(35)-850	80

Spectral response shows the wavelength (nm) range within which QE is above 10 percent. Peak QE (percent) is shown parenthetically after the associated intermediate wavelength. Information is accumulated from product literature, owner's manuals, and the two *Applied Spectroscopy* reference articles.

Table 2. Specifications for several devices.

Photo C shows a flat field (uniform illumination) picture acquired using a CCD. A spectroscopic spark generating apparatus¹⁴ was located several feet away, discharging several kilovolts in a unipolar, oscillatory waveform lasting tens of microseconds. The photograph shows the ability of a CCD to detect nonoptical electrical transients.

Fortunately, most CCDs are figuratively

buried inside an electrically controlled environment. Manufacturers are anxious to sell complete detector/amplifier boards rather than individual chips. In many portable battery devices, environmental noise concerns are greatly diminished (the greatest noise source in a handheld video camera is the tape transport motor). Careful design and careful cable shielding is productive in

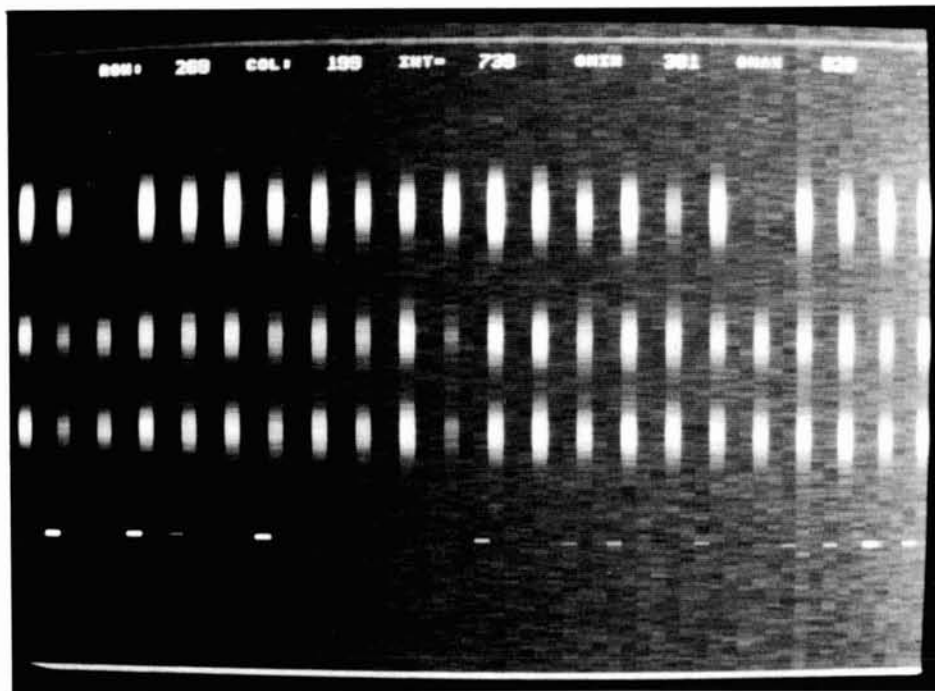


Photo C. Photograph of the CCD camera control screen, showing a highly asymmetrical (pixel data are visually stretched horizontally) flat field image. Electrical environment noise appears as bursts of "light." A single oscillatory waveform occurred as every third column of pixels was read out. Background read noise (speckled background) and dark current noise (fading to lighter on the right side of the picture) are also noticeable. Storage oscilloscopes would be pressed to compete with the variety of information comprehensible in one global "look" at this data (drop outs, amplitudes, trigger phasing, duration of recording, transients, etc.).

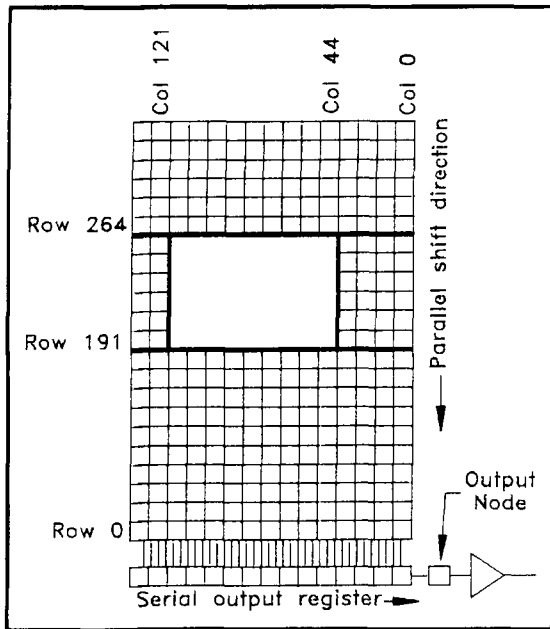


Figure 4. Readout times are greatly reduced by disposing of (not digitizing) areas of the array with no required information. Rows 0 to 190 are parallel shifted without digitization. Only columns 44 to 120 of rows 191 to 263 are digitized. Subsequently, rows 264+ are also quickly disposed of by parallel shifting them off the array without digitization.

larger laboratory systems. These concerns are familiar to amateur radio operators using computers and HF transmitters. They are not unsurmountable. The setup used to generate **Photo C** was subsequently used to collect megabytes of data, with linear sensitivities down to the CCD's inherent noise floor, with no discernible patterns.

Operating considerations

Image topography

So far, I've described the construction and character of these devices. Because of their unique qualities, CCDs have some distinctive operating procedures that may be unfamiliar to anyone unused to working with these devices in a maximum performance mode.

Using the integrating sensitivity of a CCD element always involves a balance between monitoring very dim light or only looking for a very short time. In the first case, the readout time is insignificant; after integrating for 30 minutes, who cares if it takes 30 ms to get the image off the CCD?!

In the second case, however, a distinction needs to be made between integration time

and minimum repetition time. A German company offers a complete camera capable of five nanosecond exposure times,* but the overhead associated with getting the image off the detector matrix can't keep up. It may take a second or more to digitize the thousands of packets making up the image. Of course, it's possible to manufacture a single-element CCD, but then the matrix advantage would be lost. A multidimensional array of detectors retaining single-detector sensitivity is key to the character of a CCD.

Schemes have been devised to deal with the limitations on read time. As packets of charge are shifted into a charge-to-voltage converter, more than one bin can be accumulated before shifting the packet to the amplifier. For example, an array 100×100 $20\text{-}\mu\text{m}$ pixels would normally provide 10,000 individual values. Alternatively, you could bin 2×2 squares and effectively read out 2,500 $40\text{-}\mu\text{m}$ square pixels. The readout time, which is often limited by the off-chip digitizers, would decrease proportionately. Noise advantages also accrue just because averaging is occurring.

A similar function offered by most off-chip periphery logic is the ability to collect information from only a sub-array of the entire available image area. Perhaps in some applications, computer software determines that only some subset of the full CCD image is of importance or is changing fast enough for repeated digitization. In this case, entire rows of information can be shifted off the chip until the chosen area is reached (see **Figure 4**). Only the desired columns of the necessary rows are digitized. Once it passes on to uninteresting rows again, the clocking logic quickly disposes of the charge with no digitization delay. Using this capability, frame acquisition rates can be increased to a speed even faster than would be indicated by comparing relative areas of the desired subset to the entire array.

Some devices are operated in a masked frame mode—another special technique used to maximize the exposure time without blurring an image during shifting. Part of the detector is masked from the light. When an exposure is done, the active area is quickly shifted over to the masked area and digitized at leisure, while the next image is integrating. This process should sound very familiar to those readers acquainted with computer screen video paging in the IBM-PC environment.

A recent NASA Tech Brief¹⁵ describes how interlaced scanning techniques can be

* PCO Computer Optics GmbH, Ludwigsplatz 4, 8420 Kelheim, Germany.

modified to minimize readout times and individual pixel saturation.

Shifting packets

I'd like to elaborate on my references to clocking and shifting. Refer once again to **Figure 1**, which shows a cutaway view of a CCD. **Figure 5** shows the waveforms necessary to move a column of charge packets across a CCD. **Figure 6** is the bird's eye view big picture.

There are other mechanical constraints and clocking schemes available to optimize parameters like speed or charge transfer efficiency. In each case, a voltage is lowered (repelling e^- or raising the potential energy required to stay at that location). This "squeezes" electrons into more energetically favorable neighboring sites, which may

or may not have been made more attractive, by raising the voltage on their corresponding conducting overlays. This is the image of herding rats under a blanket I referred to in earlier.

Of course, if a few electrons are lost in each shift, pretty soon none will be left! The farthest accumulation well on a 384×76 pixel array is $384 + 76 = 960$ shifts away from the amplifier. Charge transfer efficiency (CTE) measures the completeness of moving charge from one location to the next. CTEs generally exceed 99.999 percent—giving an accumulated efficiency for 960 shifts of 99.0 percent. If we started with a full well of 50,000 electrons, we'd lose 500 total electrons.

Notice that as the array size becomes larger, CTE becomes a more important

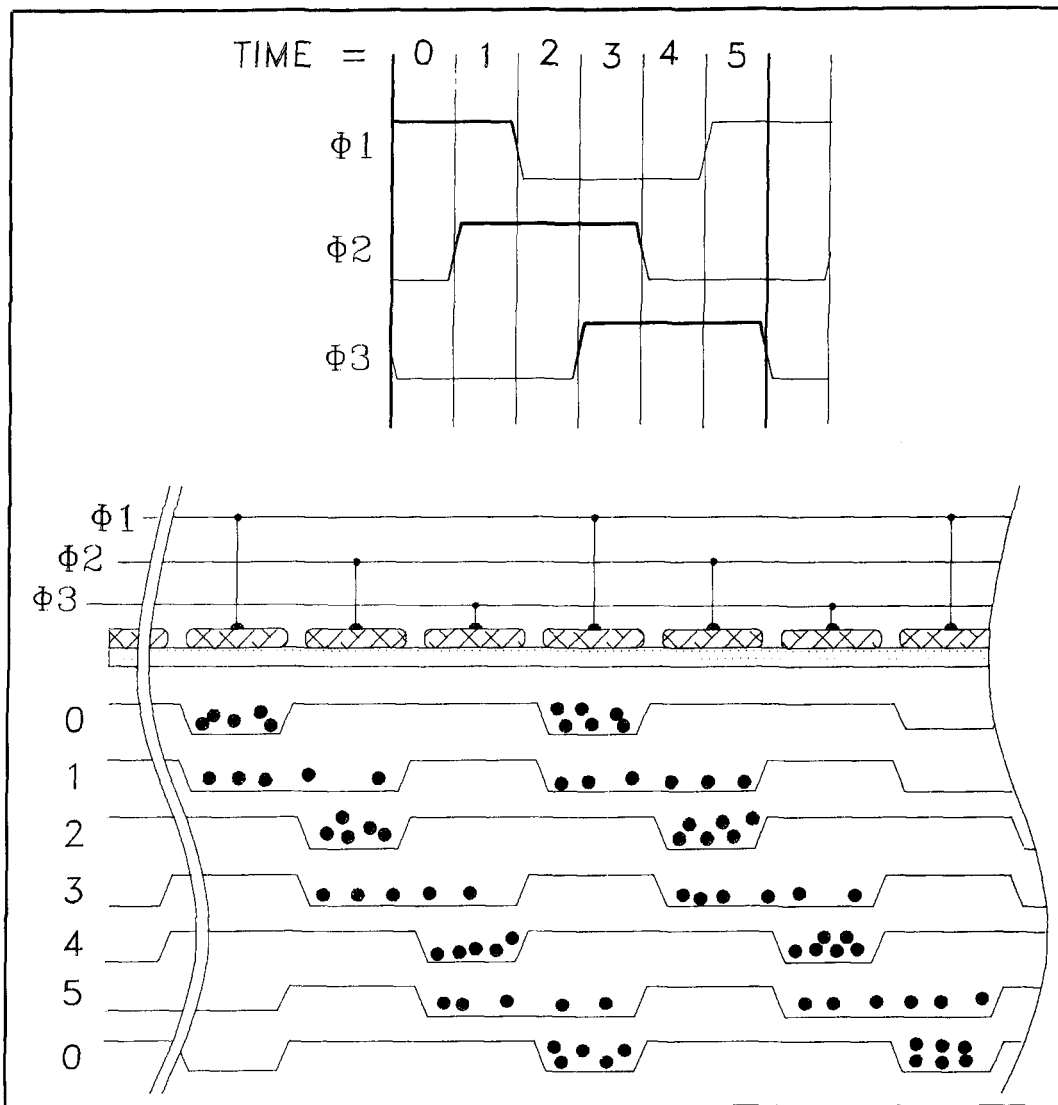


Figure 5. A side view of a CCD three-phase readout sequence. By manipulating voltages on the isolated gates, the charge can be squeezed toward an amplifier. To accomplish more complicated transforms, different voltage stepping schemes and different physical construction would be necessary.

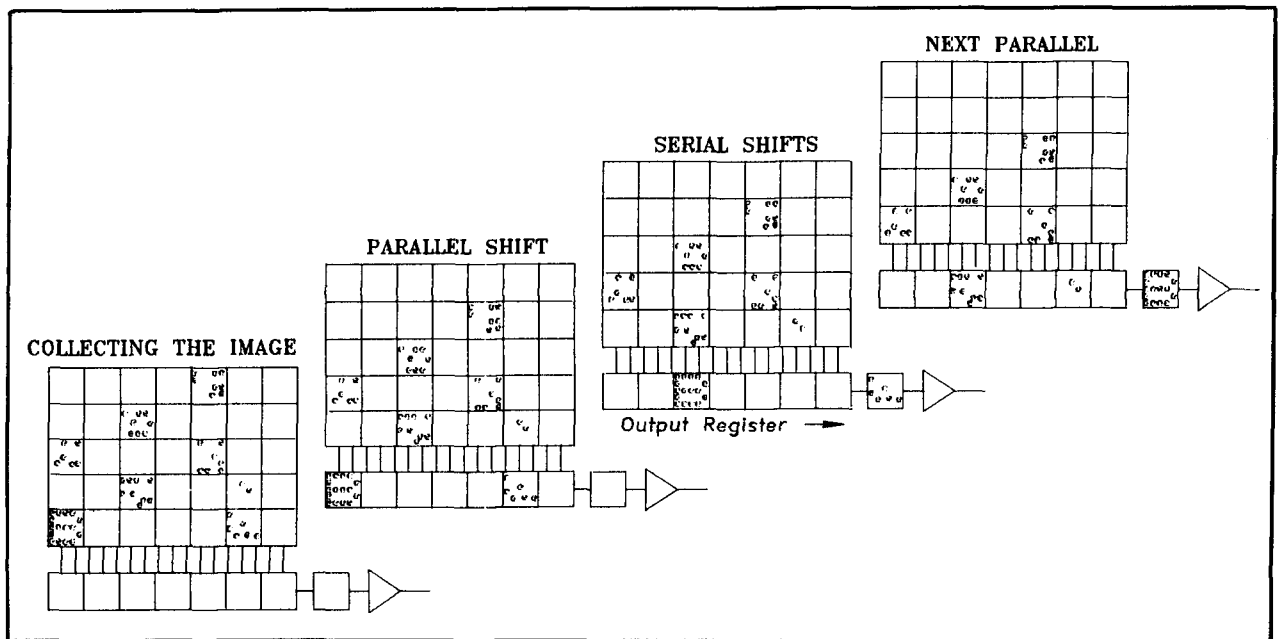


Figure 6. A top view of the CCD readout sequence showing how the elements are clocked in parallel to the single serial register, collected in the output bin and subsequently amplified.

number. Kodak makes one large array that provides a 2048×2048 active area. To retain 99 percent of the charge from the farthest pixel, individual CTE would have to be 0.999998. In other words, losses from individual shifts could not exceed 2 parts in a million.

Cooling the array

Inefficient charge transfer would cause a false low reading. On the flip side, thermally generated electrons would give a false high reading. Figure 7 illustrates this effect. This contribution to detector output is referred to as "dark current," because it's there even when the detector is in the dark. The number of electrons that contribute to this background level is modeled with a Boltzmann distribution of the form $N = Ae^{-E_g/kT}$, where A is a constant, E_g is the bandgap, k is Boltzmann's constant, and T is temperature in Kelyin.

With operating parameters that make scan time an appreciable fraction of integration time, the last pixel scanned off the array may have accumulated an unacceptably large number of dark-current electrons compared to the first. Or, in the other extreme, in applications requiring an array to integrate the effect of light over several seconds or hours, dark current would al-

ways cause well saturation at room temperatures. The obvious answer is simply to cool the device.

Solid-state coolers, or Peltier coolers, are often used. These are electrically operated heat pumps; a backwards version of the electric camping generators that give electricity when warmed on a fire. A three-stage heat pump available from EG&G* is capable of maintaining their array at -50°C (-58°F).

A process of exposing the array to liquid nitrogen, which boils at -196°C (-321°F), is typically used to press the solid-state packaging to its limits in order to obtain the maximum benefit. The CCD's small size makes it possible to cool the detector, using reasonable amounts of coolant, in a reasonable amount of time. Figure 8 shows the operating environment for an array I used. Subsequent researchers were able to double the cold time by improving liquid nitrogen transfer and storage geometry.

Remember that the CCD needs to obtain unperturbed light (spectrally and spatially) to detect an image accurately. A -130°C (-202°F) piece of glass condenses water out of the air more efficiently than will the coldest glass of lemonade sitting in the summer heat of Georgia. Water droplets running down the face of an array are not acceptable!

The entire CCD and preamplifier circuitry I used was secured inside an evacuated container. Figure 9 shows the assembly of-

*EG&G Princeton Applied Research, POB 2565, Princeton, New Jersey 08543. (609)452-2111.

ferred by Photometrics.* If you look closely, you'll see it's topographically the same as if the array were sealed inside the wall of a thermos bottle. This is not a perfunctory addition to the apparatus. It is a significant tradeoff, with operational concerns such as the ability to accurately focus the array, support the dewar, and retain the vacuum. At one point in my research, the vacuum seal was lost and it took three days on a specialized diffusion pump to reduce the pressure back to specifications.

Two other cold temperature concerns are worth mentioning. The mobility of electrons decreases at colder temperatures. Depending on the exact doping of the semiconductor, this effect ranges from a $T^{-1/2}$ proportionality to a function dominated by a proportionality to $e^{1/T}$.¹⁶ In either case, this is particularly undesirable on a device that is already pressing the limits of clocking speeds and CTE. Also, as alluded to before, thermal package concerns may come into

play. The manufacturers that sell fluorophore-coated arrays caution against use below -110°C (-166°F) due to fluorophore delamination.

A development now available commercially may negate much of the need for extreme cooling. Multipinned-phase (MPP) technology describes a procedure where the voltage on all clocking gates is adjusted simultaneously to make it less favorable to generate thermal electrons.¹⁷

Noise considerations

Assume that a perfect, noiseless signal has been applied to the CCD. What other noise is added prior to having a final digitized number for each pixel in an image?

Phenomena that contribute to the noise in a signal acquired from a CCD are numerous.¹⁸ However, a plethora of methods are

* Photometrics Ltd., 3440 E. Britannia Drive, Tucson, Arizona 85707. (602)889-9933.

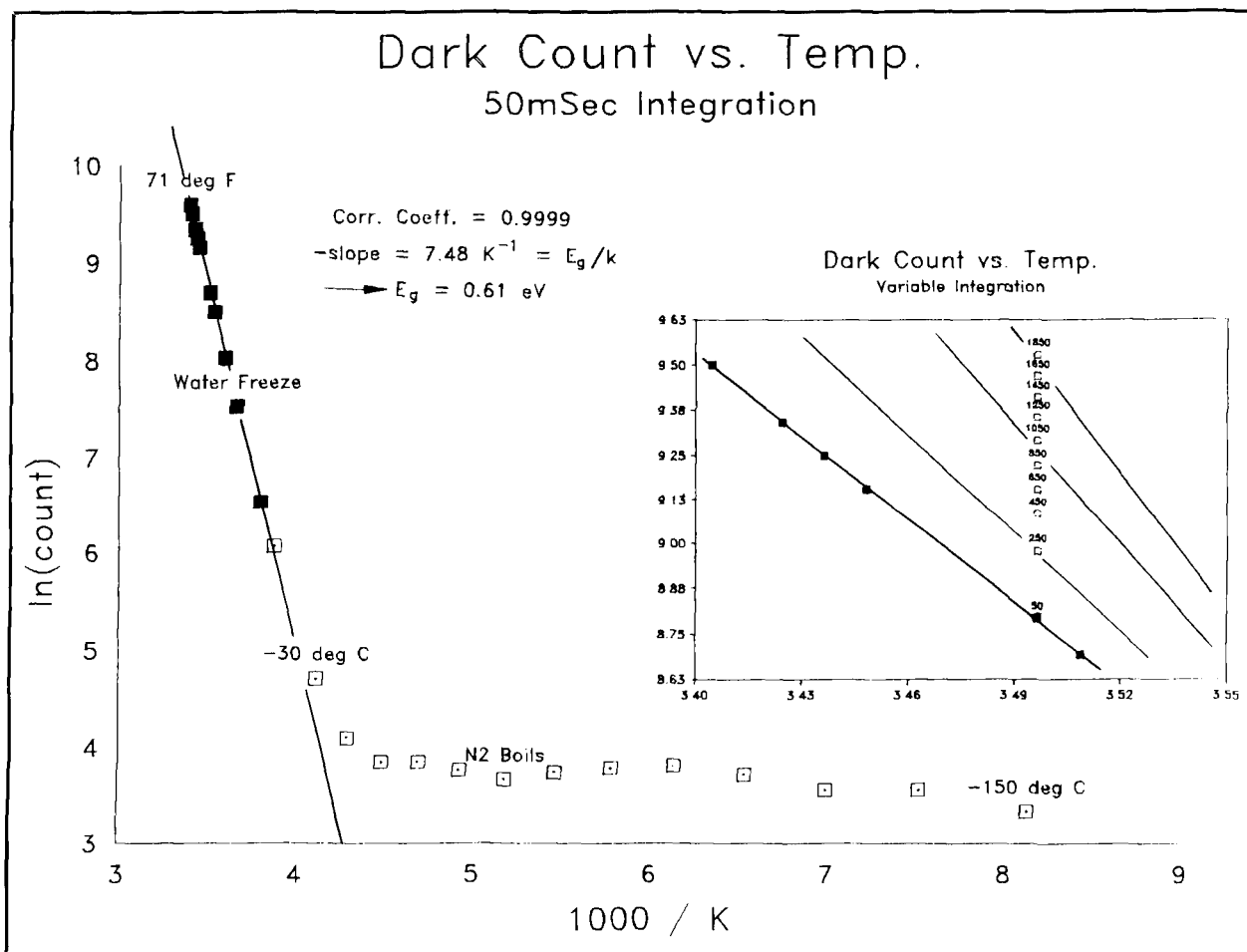


Figure 7. When data is taken at warmer temperatures, more thermally generated electrons ("dark current") are collected. The nonlinear axes more clearly show the relationships discussed in the text. Fitting a straight line to the colored-in points yielded a semiconductor bandgap of 0.61 eV (see text). The inset shows a closeup of one section with nine additional datum points. In this case, the additional lines show only the gross functionality (diverging at higher temperature), not experimental data.

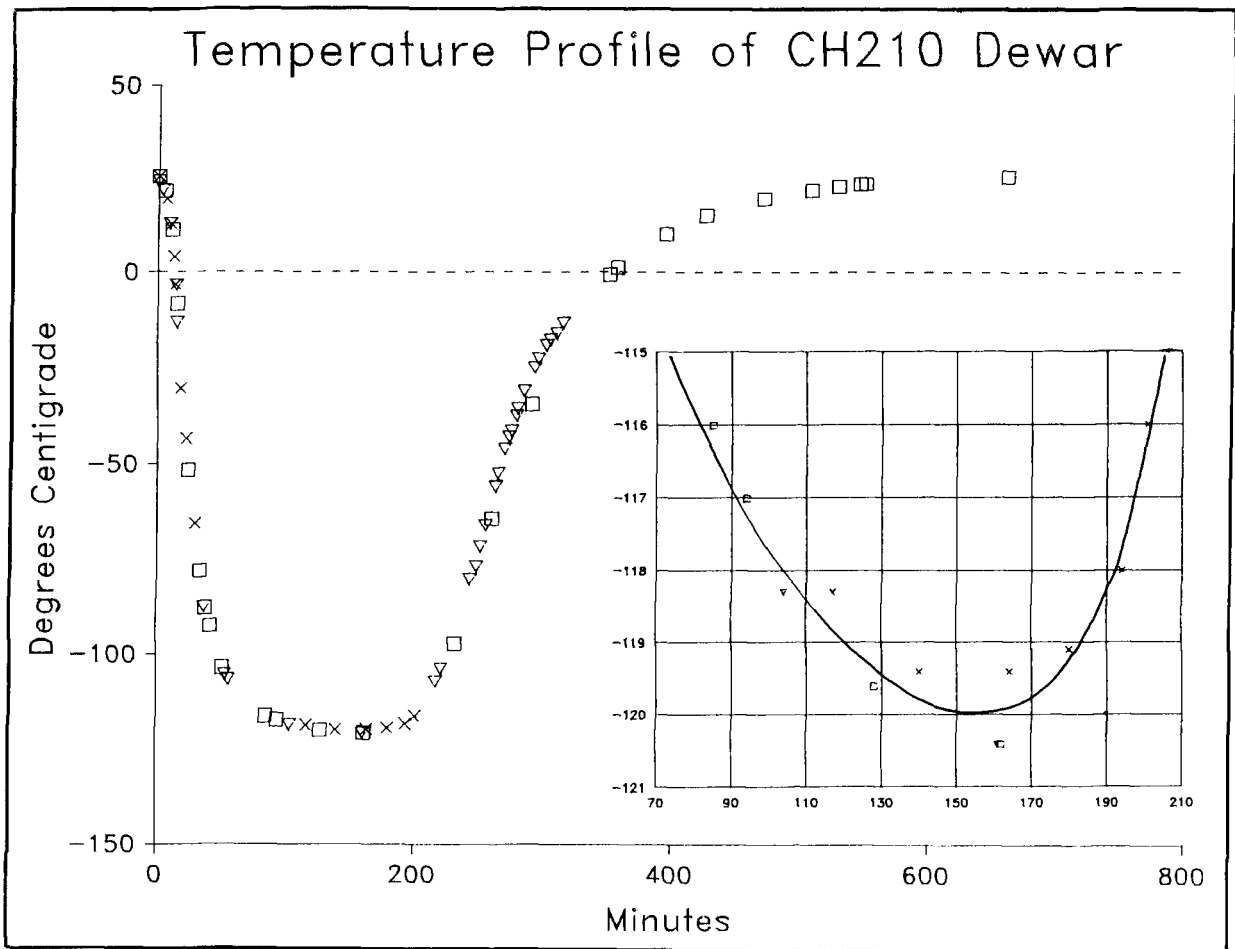


Figure 8. Superimposition of three cooldown/warmup cycles of the dewar shown in Photo B and Figure 9. A stable temperature (within 2 degrees) was available for about 1.5 hours with this setup.

used to control whatever noise each application is most sensitive to. A discussion of all the noise control methods for amplifier noise, thermal electron noise, readout noise, switching (KTC) noise, and so on would require a separate article. All I hope to do here is define each type of noise, so you'll be familiar with the terms as you read other material.

1/F or flicker noise is a catch-all phrase used to describe the fact you can't integrate forever to get rid of noise. After a while, power line fluctuations, temperature drifts, component drifts, battery voltage drops, or for that matter, aging of the universe will kick in. "1/F" gives you a hint to the model often used: The power contribution of this noise is inversely proportional to the frequency of the noise. Flicker noise is controlled by limiting measurement bandwidth away from DC.

Dark current is something I've already spoken about. It's really only noise if you ignore the effect. If the additional overhead doesn't threaten the required dynamic

range, subtracting a flat field image can make it seem as if the situation had never occurred.

Any radio operator has dealt with *amplifier noise*. The buried channel FET amplifier on a CCD chip always contributes some noise. Hopefully this small noise source is the largest source in the chain of analog processing prior to A/D conversion.

KTC noise gains its name from its proportionality to $(TC)^{1/2}$, where T is the absolute temperature and C is the capacitance of a control gate (see Figure 1). It's fundamentally dependent on the fact that one takes finite, or switched, samples of the charge in a well that have a Johnson noise source superimposed on them. A Johnson noise source, in turn, is a model of noise originating from thermally induced motion of electrons.

Photon, or shot noise, is based on the idea that any measurement that is photon sensitive is actually counting photons, and is only extracting samples from a statistical distribution. Be sure to read the sidebar at

the end of the article if you'd like more detail. Photon noise is the theoretical minimum noise, and in practice is rarely seen. This "white noise" source puts equal amounts of power into all regions of the spectrum (the power of the noise is not frequency dependent, only bandwidth dependent) and is often used in the increasingly popular noise bridges being built by amateur radio operators.^{19,20}

Photo C shows an example of *environmental noise*. Amateur radio operators have always dealt with variations on this theme.^{21,22}

Data handling

I've said nothing yet about the reams of data a CCD can generate. There are concerns that come into play only in the realm of digital, high-information bandwidth detectors. Applications for products such as video cameras never address these issues

since they always run in real time. As soon as a frame of information is off the CCD, it's sent to a view screen and record heads on a magnetic tape.

Viewing data

For single detector applications that don't require image capabilities, an array detector's output can be quickly reduced to a single number. Because the array of duplicate values can be averaged as many individual measurements, a "multichannel" advantage can be used to lower the measurement noise. For a cooled CTD, where the dominant read noise is independent of signal intensity, noise is expected to decrease proportional to N .²³ To appreciate this, consider the case where a single detector element gives a measurement of 426 ± 15 electrons. Averaging values from a 500×500 array would give an average of approximately 426 ± 0.00006 . The benefits of using a matrix detector are still present, but the

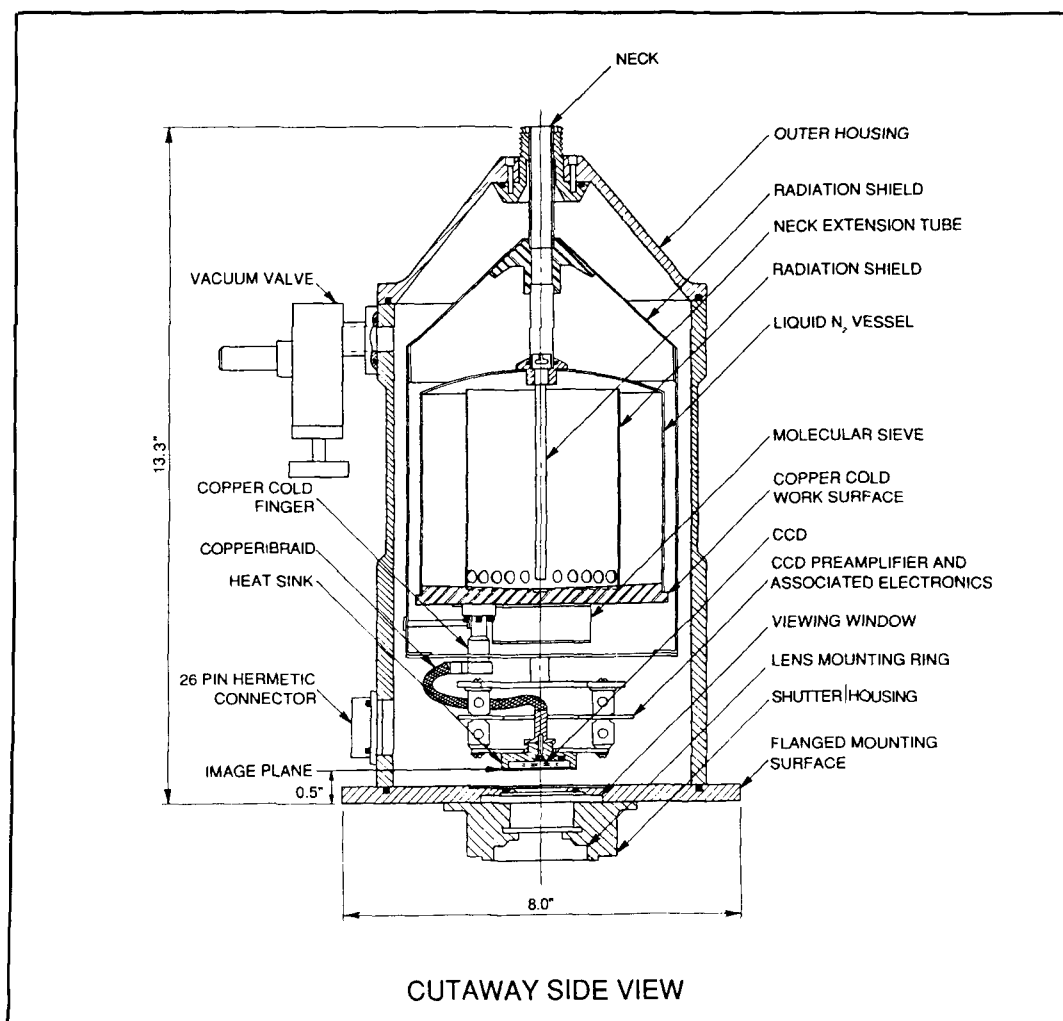


Figure 9. Cutaway side view of the dewar shown in *Photo B*. Reprinted courtesy of Photometrics Ltd.

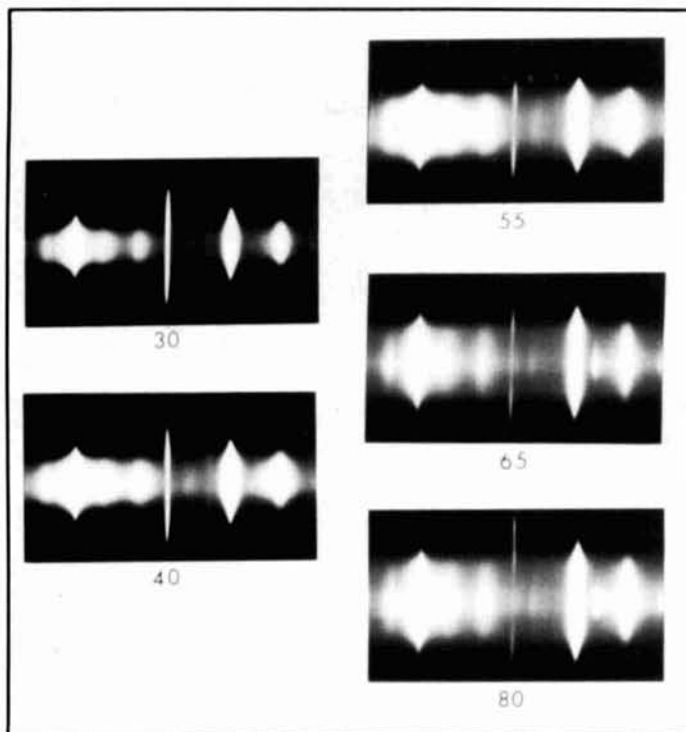


Photo D. These pictures show CCDs presented in a way most closely simulating classic photographic detection of atomic emission. This study was done to determine if line shapes changed as a function of current (they do). Labels are in amperes. The center, narrow line is light emitted at 510.55 nanometers when a copper atom's electron drops to a lower energy orbit.

data can be quickly reduced to low volume.

But consider situations when the full image is required. The real differences in viewing* CCD data appear when the full range and capacity is used to record varying intensities. I'll offer ten different ways of looking at an image or section of an image.

The easiest way to view an image is to look at a *numerical listing*. This option is often available directly from the image acquisition hardware. It has proved valuable in identifying peak intensity positions precisely.

Eight-bit, or 256-level, grey level images are again often available directly on a control console, without exterior computer power. Automatic scaling of pixel values to grey level is often done. This is by far the "workhorse" of most scientific systems.

Photographic simulation can be done by using grey-scale mapping with a larger dynamic range. **Photo D** shows what can be done by simply taking photographs of a computer screen. What is not shown here is that these digital images can be subtracted

*I use the term "view" loosely. I mean to view, or understand, or comprehend, or utilize, or report, or communicate, or convey, etc. The best book I've ever read on this topic is by E.R. Tufte, *The Visual Display of Quantitative Information*, Graphic Press, Cheshire, CN, 1983.

directly from each other, greatly simplifying the observation of *differential images*. This brings to mind the potential of optical NRZ digital modulation schemes.

Image cross sections can often be viewed directly with acquisition hardware. Simple scaling or averaging of adjacent cuts are typical capabilities.

Statistics are sometimes the only item of interest. Simple information on area subsections of an image are often available with acquisition hardware. For more complicated analyses a short program written in a familiar language can be used to extract from a full data file written by the acquisition hardware.

A *histogram* is a special type of statistic often of interest to image processing schemes. A typical histogram plots the number of pixels at a certain intensity rather than plotting those pixels as a function of the position where they were seen. Histograms are a classic aid to proper color or grey-scale mapping, but haven't been of analytical use outside of that function.

False color images similar to those seen in medical imaging applications have a strong visual impact. I've used these mostly for projection slide preparation. **Photo E** shows a four-color screen display (IBM CGA) reduced to black and white for publication.

Spreadsheet processing offers a host of options. After using an extraction program as described under Statistics, all the available facilities of these self-contained packages are accessible—particularly, multi-color publication quality cross-sectional plots. **Figure 10** shows an example of this type of data. Averaging adjacent cuts, special scaling, and simple functions are also possible. Processing starts to get noticeably slower when there are more than 3,000 pixels on the work sheet. Prospects of processing a full image are slim.

Contour (topographical) plots are useful for presenting large amounts of information in a quantitative manner. I used FORTRAN routines distributed by the National Center for Atmospheric Research (NCAR) to generate plots similar to **Figure 11**.

Three-dimensional surface plots, or "fishnet" plots, are also available via NCAR. They are excellent for seeing trends at a glance. Look at the sequence of **Figure 12**.

Acquisition hardware

Many computer systems can be used to control CCDs and reduce the data. In fact, because the computer price may be a minor portion of a new scientific system, its architecture is secondary to choosing high-quality

ty related hardware. The system I've used is a Motorola 68000-based computer with several megabytes of memory, connected to the outside world with an IEEE bus, an RS232 (serial) control link, and a black and white monitor. An 8-MHz MS-DOS computer with 4-Mbyte of memory and an 80-Mbyte hard drive was located on the receiving end of the IEEE. It is on this MS-DOS machine that I did all the custom programming. It's typical to put a familiar "front end" onto whatever architecture is sold with a system.

Many commercial computer systems equal the power of the arrangement I used. I think we've passed the point when a computer with sufficient power can be built economically from scratch; it should be viewed as a "black box" aid to the real goal. If you need one, buy one.

I think the real goals for contributing amateur radio operators should be: 1) discovering ways to use the high-information bandwidth of a million-element matrix of detectors and 2) providing electrical designs and/or software algorithms for powerful control of packets at a chip level.

Target applications

By now, you should have a feeling for what CCDs can do and what detectors they could replace. Many of the applications being taken over by CCDs used to be served by one of four detectors: PMTs, photodiode arrays, vidicon tubes, and photographic plates. To appreciate the versatile power of CCDs, I'd like to explain how each has contributed to CCD development.

Previously, PMTs had the corner on low light sensitivity. As noted in the sidebar, ultimate PMT sensitivity is obtained by counting photons. Researchers have shown CCDs to even exceed this capability.²⁴ PMTs use vacuum tube construction techniques and require lethal voltage for operation. They are also single channel detectors, whereas a CCD provides thousands of adjacent, independent detectors on a chip. CCDs offer spatial resolution or the "multi-channel" noise advantage—something PMTs just cannot do.

Photodiode arrays, like CCDs, provide digitized spatial resolution on the order of tens of microns. They offer the reliability of solid-state construction. However, they are real-time detectors, requiring external integration of a current to perform long-term observations. The CCD electron accumulation mechanism is intrinsically integrating, avoiding the need for extra noise-contributing external wiring, integrators, and ampli-

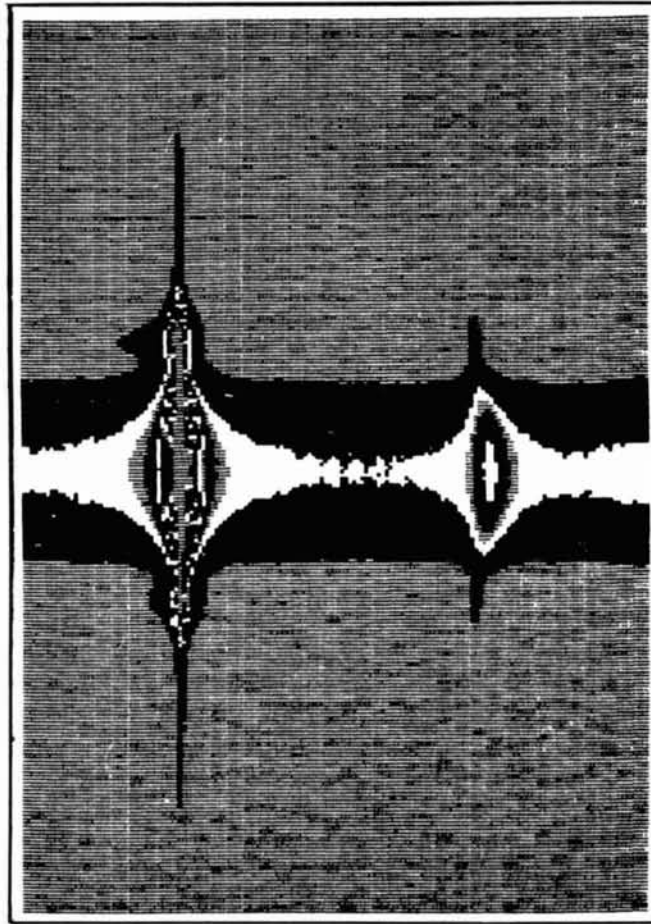


Photo E. A highly magnified section of the same spectral region shown in *Photo D*. The original was displayed in four colors on a CGA monitor using a short Pascal program.

fiers. Diode arrays are nearly universally available only in one-dimensional arrays. CCDs are available in formats ranging from one large accumulation well, to arrays of a thousand elements on a side. CCDs offer all the advantages and none of the liabilities. The only factors preventing them from becoming complete replacements for traditional components is their cost and lack of an established user base, but these obstacles will be removed in time.

When using a vidicon tube, the image is focused on the glass plate, energizing the chemical in a way similar to photographic film—except the process is electrically reversible. An electron beam is scanned over the glass plate and a current proportional to the incident light is drained off the coating of the glass plate. It's similar to a TV picture tube run backwards. In fact, vidicons were classically the heart of television cameras.

"Camcorders" can now be made the size of a large grapefruit because CCDs have virtually replaced vidicon tubes. Their long life span, low operating voltages, and small

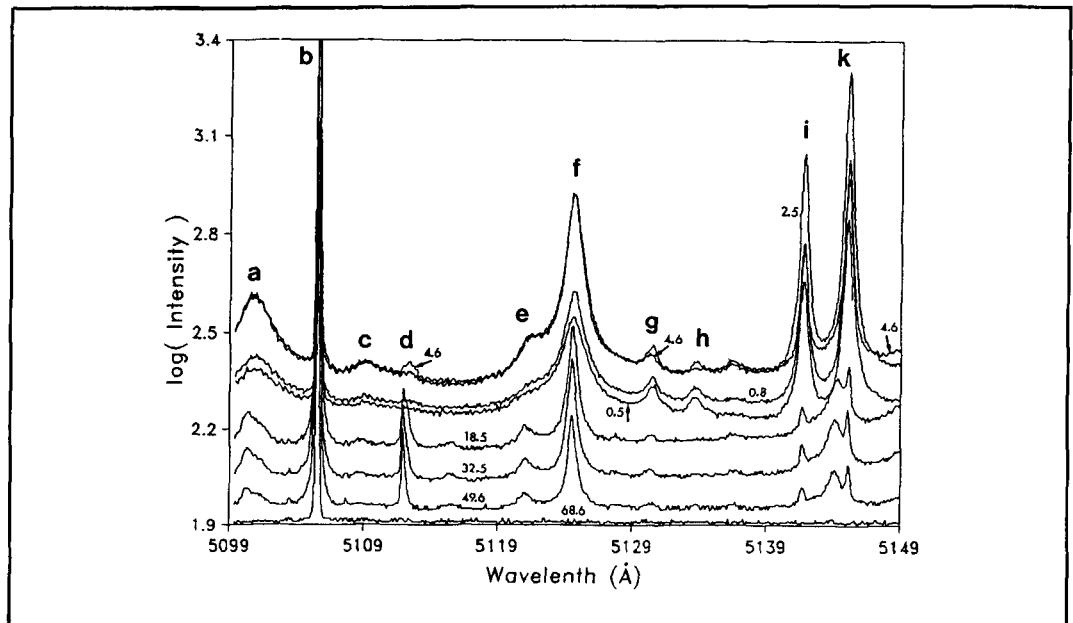


Figure 10. One of the simplest ways to look at CCD data, very familiar to atomic spectroscopists. A simple Pascal program was used to extract specified rows or columns of data. SuperCalc was then used to present the data as a function of wavelength. Line [b] is also exhibited in *Figure 12*.

size all contribute to the nearly universal replacement.

The video image acquisition market made the use of CCDs economically feasible. When I first started looking (1987) for a CCD array, a majority of them were specified with a scan rate of 1/30th second (TV frame rate). As the resolution went up, the electronic specifications were optimized only until the 1/30th scan rate could be maintained. Even the aspect ratios of most devices mimic the ratio of a television picture. Television and video applications have been, and continue to be, an economically imposed performance limitation.

Another echo of the vidicon heritage is software facilities—particularly in data *acquisition* (as opposed to processing) software. It seems that simply acquiring the image and doing bulk math has been accepted as the goal. Existing software has been more just mathematical muscle flexing rather than ergonomic use of detector capabilities. Articles on the powerful uses for CCD capabilities and image processing are necessary if we're to become comfortable with the basics and desire the advanced. One of the reasons I take the effort to write an article like this is that I hope to interest other technically creative amateur radio operators. I'm sure that placing CCDs in the hands of people who understand detection, electronics, and good old fashioned tinkering, would provide improvements just like we're seeing in the packet radio arena.

Lastly, consider photographic plates. This is, perhaps, foreign to the amateur radio and electronics-oriented readers, but be assured that these plates were *the* classic detector for atomic spectroscopists up until a few years ago. Nothing could compare with the ready availability and information bandwidth. Those who use photographic plates have no concerns about software compatibility—when dealing with a developed glass plate—and nothing to this day can compete with the spatial resolution available with photography.

But again CCDs have come to dominate. Computer data, properly backed up, is as permanent as the image on a photographic plate. The ability to acquire broad spectral regions is still important so researchers don't become "brain locked" into local spectral phenomena. This need for creative, searching familiarity with data on a variable global scale (little detail, all at once, or the exact function of how the light intensity falls off on one side of a spectral line) is meaningless in the controlled environment of a camcorder, but to a researcher it is a pure and simple necessity. As software matures, this capability will be regained in the realm of CCDs.

Contemporary CCD uses

In order to tie together some of the capabilities of these devices, I've chosen to high-

light two situations in which I know a CCD has or could make a significant contribution. I'll neglect the three biggest consumers: video recording equipment, the military, and government research labs. The use of CCDs in video recording equipment should be obvious, and is, frankly, relatively uninteresting. As for the other two major consumers of CCD technology—the military and government labs—little information is available. Consequently, I'll first present information on the use of CCDs in a commercial product anyone might appreciate, and then move on to a proposal for amateur use of a more technical nature.

The electric picture

I had cause to get a family picture taken for inclusion in an organizational directory. One of the big inconveniences inherent in these types of efforts is that a person must show up for a sitting, wait for proofs, and return at another time to select poses. United Photographics,* the company doing the photography for the directory, had leased a Kodak Prism XL system. The large-format portrait camera was no different than any other, except for a one-way, semi-transparent plate placed in front of the lens, which reflected light into another box. This setup is similar to a teleprompter system. Inside

the box, CCDs monitored the scene.

The CCDs downloaded their images to a computer in synchronization with each shutter release. The photographer could see instantly if anybody was caught with their eyes closed, or if the framing was bad.

The normal variations in pose were taken and each was recorded onto a computer diskette. After the photographer was finished, the assistant handed me a disk and directed me down the hall to the viewing room.

The room contained two tables holding computers consisting of nothing but a single disk drive and a monitor. I inserted the diskette and the first pose taken by the photographer appeared. I was able to page through more than half a dozen pictures at my leisure. Each was tagged with serial identification information. I chose the poses I liked and information was noted correlating the shots with their location on the roll of negatives in the camera. The disk was then erased and recycled.

This enabled me to select the poses that I liked immediately. Universal Photographics had invested in nothing but the negatives.

*United Photographics, Inc., 7916 Millsboro Road, POB 507, Galion, Ohio 44833. (800)521-4611 or (800)821-4365.

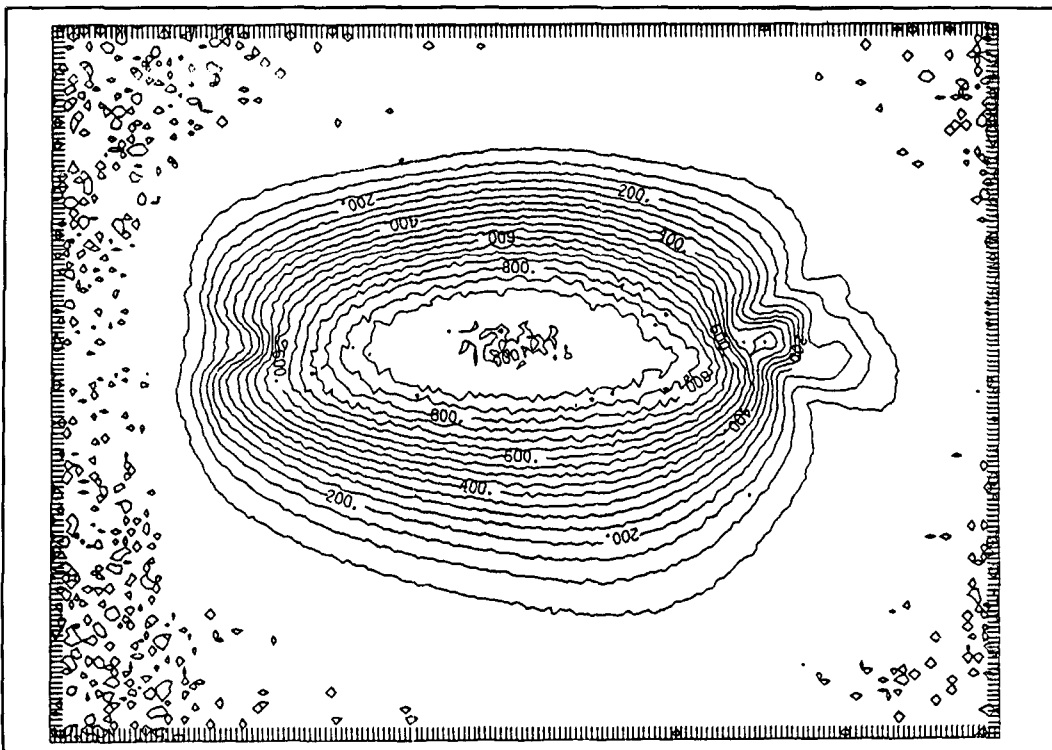


Figure 11. A topographical map of raw light intensity (all wavelengths) from a single 80-amp spark between two electrodes to the left and right. The electrodes were 2 mm apart, with 3.3-kV across them when the spark was fired.

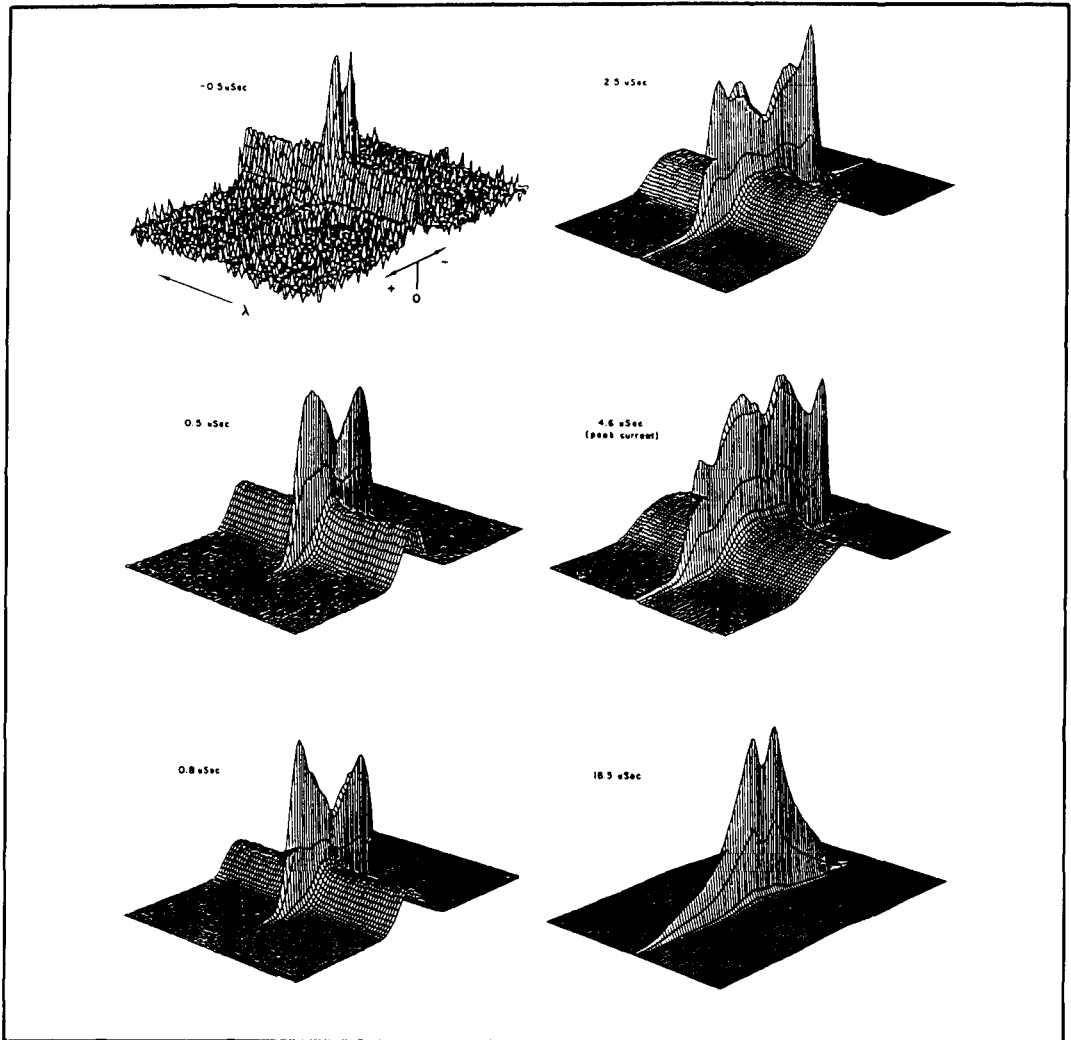


Figure 12. These graphical representations show data in a way impossible in the photographic age. The center, narrow, line from *Photo D* is shown in a perspective view as a function of time (0 to 19 microseconds). Each 105×67 pixel plot shows the same image area, giving a positional window of 2.39 mm, resolution $23\mu\text{m}$, and a spectral window of 0.576 nm , resolution 0.0087 nm .

They would print only the poses I desired, expanded to the size I ordered—eliminating the wasted time, processing chemicals, and paper involved when more traditional methods are used.

Laser QSOs

The recent report of a QSO on a laser beam over a distance of 157.7 miles, cited the use of PMTs as the detector. CCDs would fair very well in such an experiment. As I take you through the process, note how the predictive calculations are made for the different types of detectors.

KY7B and WA7LYI used a 0.015-watt Helium Cadmium at a frequency of 7.5×10^{14} Hz (7.5 teraHerz). They observed a beam spread of 250 feet at the detector, giving an area dispersion of 49,100 ft². They collected light with a 2.25 ft² Fresnel lens,

collecting only a portion of the generated laser light. PMTs typically provide about 15 mA/watt in the region of the laser (a specific type PMT was not mentioned). Assuming a new laser tube and clear optics, peak currents would be predicted to be:

$$(0.015\text{W})(15\text{mA/W})(2.25/49100) = > 10\text{ nA.}$$

An operational amplifier configured as a current-to-voltage converter with a gain of 1 million V/A would give 10 mV, with an average of about half of that. The modulation was in "real time," using standard CW Morse code.

How would a CCD fare in comparison? The 0.015-watt laser provides:

$$(0.015\text{ J/S}) \cdot (2.01 \times 10^{18}\text{ photons/J}) = > 3.0 \times 10^{16}\text{ photons/sec.}$$

Recall the energy of one photon, in Joules, is $h\nu$, where h = Plank's constant (6.626×10^{-34} J.sec), and ν = frequency of the light (7.5×10^{14} sec⁻¹).

Assuming only 30 percent QE, the CCD would record:

$$(0.3)(3.0 \times 10^{16})(2.25/49100) = > 4.1 \times 10^{11} \text{ electrons/second.}$$

That's a lot more than we need, considering a typical 50-electron detection limit and full well capacities of 5×10^5 .

The array could be scanned out hundreds of times per second and if the accumulated charge results in a voltage over a threshold value, an audio tone is generated. That would provide classic CW modulation sufficient for a WPM speed faster than most operators can copy.

The real problem evident during the QSO was not the raw detection limits, but rather the ambient noise from such sources as street lights, atmospheric refraction, haze, and portable power generators. If we were to change the focus of the problem from one of environmental noise to one of detector sensitivity, CCDs would have a definitive edge. To provide that edge, we could use optical interference filters matched to HeCd and HeNe lines.²⁵ Because of the greatly narrowed bandwidth, most interferences would simply disappear.

Alternatively, we must realize that CCDs are inherently integrating detectors—they accumulate the measurement over time. Normal PMT demodulation, on the other hand, provides an output signal proportional to the instantaneous input. Very low bandwidth detection schemes²⁶ that use integrating detection are a natural for CCDs and deal powerfully with situations where noise exceeds the desired signal. Other simple and fast algorithms can be incorporated easily.²⁷

How long range a QSO could CCD detection provide? To make a gross prediction, I'll assume the existing record just touched the limit. With coherent CW or any other synchronous scheme, we'd gain 3 dB. Assuming 1 mSec integration (bandwidth to provide approximately 100 WPM CW* or a 1000-baud digital channel) and an interference filter passing 50 percent of the light, the CCD would collect:

$$(4.1 \times 10^{11} \text{ sec}^{-1})(0.001\text{sec})(0.5) = > 2.1 \times 10^8 \text{ electrons.}$$

This is 66 dB more than the 50 electrons it needs with cryogenic cooling. Using a $1/r^2$ intensity decrease as a function of distance,

the extra electrons correspond to a distance more than 2000 times as far. This is absurdly far, and well past the visible horizon.

Miscellany

Information

I've tried to include a host of references in this article. Not many books cover the topic because it's still in a state of constant change and active research. Of the more obvious journals I've named, you will probably be able to locate one or two titles. I have three suggestions for those who wish to keep up with current developments.

First, contact manufacturers directly. Amateur astronomy journals often have advertisements for CCD products. The *Jane's* series of military compendiums referenced earlier often quotes contractors and manufacturers. These are some of the big names in the country, and a letter or phone call might easily get lost, but persistence usually yields good information.

You might also wish to contact the National Technical Information Service (NTIS).** The service is a clearinghouse for government-related publications and government-funded research reports from a number of different sources. Even small libraries often subscribe to the NTIS abstract service, which would let you determine which articles may be worth ordering.

Local university libraries might also be able to provide you with information. If you're fortunate enough to have one nearby, visit the Chemistry, Physics, or Electrical Engineering library and ask how to use forward referencing indexes like the *Science Citation Index*. Pick an article quoted here, and you'll find information about articles that have referenced that particular piece. This way you can ensure you've seen all the recent developments.

Availability

Even if you were to make a concerted effort to find suppliers, you'd find that CCDs are just beginning to appear on the secondary markets. I know of one supplier that started advertising a camera for \$200 last summer.* The ad's small print mentioned that kit forms might be available. However the CCD in the camera is a *video* quality CCD, and I suspect it will not handle the

*1000 samples/sec \times 1 WPM/(2.4 dots/sec) \times (1 dot)/(2 samples) \div 2 (Nyquist) \rightarrow 104 WPM.

**NTIS, 5285 Port Royal Road, Springfield, Virginia 22161. (703)487-4650.

*PMC Electronics, Box 11148, Marina Del Rey, California 90292, (213)827-1852, in *Nuts and Volts*, POB 1111, Placentia, California 92670.

extreme cooling necessary to kill dark current and obtain the lowest detection limits. I'm also sure the CCD was designed to scan out at a fixed 1/30th second rate. Most discouraging is that the camera, as sold, provides NTSC video output rather than providing an opportunity to digitize individual pixels.

I mentioned before that manufacturers grade their devices after production. Those that don't meet the minimum grades are not sold to public markets. It seems that individuals and for-profit organizations don't stand much of a chance of getting these chips. If a larger organization were to formally propose a use in an amateur radio function, I suppose they might be able to obtain a few chips with image defects that are otherwise functional.

The best chance I see for amateur radio operators to experiment with these devices is to scavenge home video-recording equipment as it appears on the used or nonworking second-hand market. You'd need to strip the CCD handling electronics and build custom circuitry. Video equipment is highly optimized for the single job it does. It is by modifying this "close-in" control circuitry that I see amateur radio operators able to make the greatest contribution to

ways these devices are used. Intelligent exposure, noise reduction, and masking algorithms all need access to this low-level logic, which would require the elimination of much of the camera's circuitry.

Just like CMOS devices, CCDs are easily destroyed with careless handling—so experimenting and disassembly shouldn't be done capriciously. I honestly can't say what one might do with the innards of CCD video equipment. I haven't had the chance to strip a camera yet!

Summary

CCDs are packaged like other ICs; however, special attention allows packages to withstand extreme pressure and temperature limits. An understanding of the simple mechanism of e^-/h^+ pair production lets us predict their wide spectral sensitivity, efficiency, and dynamic range. Depending on the predicted market, various packet-shifting geometries and mechanisms are used. Excellent sensitivity, inherently integrating design and high resolution matrix construction, make CCDs an excellent choice for many applications. To obtain the most from a scientific-grade CCD, one must be sure to consider noise contributions and the

STATISTICAL DISTRIBUTION MODELS OF CCDS

Poisson and Boltzmann distributions are an alternative to the familiar "bell-curve" Gaussian or Normal distribution. However, it's not as if one can choose which distribution he wants to use. Poisson distributions come into play when the problem at hand can be cast into a counting question like: "How many cars pass by my house in 10 minutes?" or "How many radioactive atoms decay in 4 seconds?" Normal distributions are appropriate to describe humans' attempts to quantify physical qualities: "How long is the wire?" or "How much breakfast cereal is in a box?"¹ Boltzmann distributions describe how a collection of items distribute available energy: "How many gas atoms at 100° are going faster than 327 feet/second?" or "How many electrons are heard as static in my low-noise satellite amplifier?"

The field of statistics recognizes an ideal truth and describes our attempt to measure it. For instance, a metal rod *does* have some definitive length. Our attempts with a ruler can, at best, estimate the real truth. **Figure**

S1 shows how 100 attempts to measure a 9.5-inch rod might be modeled. The average of all 100 measurements, \bar{X} , would be expected to be close to 9.5 inches. The actual spread of values would depend on how precise a method was used. Three different models are shown, with standard deviations of $\sigma = 1.0, 1.4,$ and 3.1 .

The experimental distribution ("distribution" of values, since they're not all the same) would be only an approximation of the Normal distribution we're using to model reality. Said in a different way, the actual measurements the experimenter obtains are samples from this ideal distribution. The model distribution has a mean of μ and a variance of σ^2 . People often interchange \bar{X} and μ , S , and σ , but this isn't formally correct.^{2,3} In fact, there is continuing disagreement between statisticians and experimentalists as to whether σ can be better estimated with a S calculated from "N-1" weighting or from "N" weighting. Experimentalists often N-1 weighting, supported by an argument that the degrees of freedom

opportunities to be realized with the large amounts of digital data. As the availability of these devices increases, I expect amateur radio operators will make significant discoveries about the ways in which CCDs can be used.

Acknowledgements

Thanks is due all the real experts that allowed me to take their time to research this article. Special thanks to Dr. Alex Scheeline and Dr. Paul Bohn at the University of Illinois for resurrecting research notes and product literature.

REFERENCES

1. Terry Wilkinson, WA7LYI, "New World Record Set for Amateur Radio Laser Communications—153.97 Miles," *CQ*, 47(9), September 1991, pages 46-52.
2. "Another Record Set," as reported in "VHF Plus" column, *CQ*, 47(10), October 1991, Page 62.
3. Bryan Bergeron, NU1N, "Digital Signal Processing: Image Processing," *Communications Quarterly*, 1(2), Spring 1991, pages 23-36.
4. Opening description of semiconductors in Chapter 4, or the appendix to Chapter 4, in a recent edition of *The ARRL Handbook*, American Radio Relay League, Newington, Connecticut.
5. R. B. Bilhorn, J. V. Sweedler, et al., "Charge Transfer Device Detectors for Analytical Optical Spectroscopy—Operation and Characteristics," *Applied Spectroscopy*, 41(7), 1987, pages 1114-1125.
6. "High-Performance Charge Transfer Device Detectors," *Analytical Chemistry*, 60(4), 1988, pages 282A-291A.
7. S.W. McGeorge and E. D. Salin, "Image Sensor Applications in Analytical Atomic Spectroscopy," *Progress in Analytical Atomic Spectroscopy* 7, 1984, pages 387-410.
8. J.R. Janesick, T. Elliot, S. Collins, and H. Marsh, "The Future Scientific CCD," *Optical Engineering*, 26(9), 1987.

9. "Electro-Optical Equipment (Air)," in *Jane's Weapon Systems*, published every two years by Jane's Information Group, Virginia.
10. J. Janesick and M. Blouke, "Sky on a Chip: The Fabulous CCD," *Sky and Telescope*, September 1987.
11. Table 6.1 in M. Ali Oman, *Elementary Solid State Physics*, Addison-Wesley, 1975, or page 461 of John Douglas-Young, "Properties of Materials," *Illustrated Encyclopedic Dictionary of Electronics*, Parker Publishing Co., New York, 1981.
12. Appendix to Chapter 4, *The Amateur Radio Handbook*.
13. Section 2.2, "Detectors," in H.H. Willard et al., *Instrumental Methods of Analysis*, 6th Edition, Wadsworth, California, 1981.
14. T. Thang and A. Scheeline, "Construction of a Compact Adjustable Waveform Spark Source," *Applied Spectroscopy*, 35(6), 1981, pages 536-540.
15. Edward M. Rentsch, "Altering Interline Transfer in a CCD to Reduce Saturation," *NASA Tech Briefs*, December 1991, pages 30-31. NTIS reference #NPO-17935.
16. Section 6.7 in M.A. Oman, *Elementary Solid State Physics*, Addison-Wesley, 1975.
17. J. Janesick et al., "CCD Pinning Technologies," *SPIE Proceedings*, 1989, page 1071.
18. "Solid State Imagers for Astronomy," Volume 9, *Proceedings of the International Society of Optical Engineering*, June 10-11, 1981, page 11.
19. "Noise Bridge for 160 through 10 Meters," *The ARRL Handbook*.
20. "QRM-Free Antenna Tuning," *73 Magazine*, August 1981, pages 40-42.
21. Ulrich Rohde, "Understanding and Handling Noise," *Ham Radio*, November 1986, pages 10-22.
22. Bradley Wells, "The Russian Woodpecker: A Continuing Nuisance," *Ham Radio*, November 1984, pages 37-45.
23. Equation (1) in R. B. Bilhorn et al., "Spectrochemical Measurements with Multichannel Integrating Detectors," *Applied Spectroscopy*, 41(7), 1987, pages 1125-1136.
24. R. B. Bilhorn, P. M. Epperson, et al., "Spectrochemical Measurements with Multichannel Integrating Detectors," *Applied Spectroscopy*, 41(7), 1987, pages 1125-1136.
25. *1991 Annual Reference Catalog for Optics, Science and Education*, Edmund Scientific, 101 E. Gloucester Pike, Barrington, New Jersey 08007. (609)573-6250.
26. Max Carter, "Super Narrow-Band Techniques Equalize Power Inequity on 1750 Meters," *Communications Quarterly* Premier Issue, Fall 1990, pages 99-113.
27. Lloyd C. Kwok, "Algorithm Reveals Sinusoidal Component of Noisy Signal," *NASA Tech Briefs*, 15(12), December 1991, pages 86-89.

is one less than the number of data points taken.⁴

Now to our charge counting problem on a CCD. Imagine 100 attempts to measure the number of accumulated electrons in a well. Potentially useful model distributions for less than 1 to more than 9 electrons are shown in **Figure S2**. For example, the PDF (probability density function) model with a mean of 5 should closely match the experimental distribution of measurements taken from a well in which there are 5 electrons. \bar{X} and S are the experimental estimates of the model's μ and σ . Notice that for a CCD, it is physically limited to only one measurement value (reading the amount of charge destroys the packet). Given only one measurement (not 100), how can one determine what the real μ is? You can't! The best course of action is to assume the distribution's mean is \bar{X} ($\mu = \bar{X}$), which in turn is equal to the one measurement that was taken.⁵ The unsurity in the value is another description of readout noise. In fact, a much better sample of this noise dis-

tribution can be obtained by recording an image of nothing (a totally flat field—all pixels the same value), and then reading out all pixels. If you assume that reading two identical pixels is the same as reading the same one multiple times, the plan works.

A CID actually allows nondestructive readouts. Thousands of measurements could be taken to estimate the true number of electrons. μ and σ could be accurately estimated. The common algorithm of "least squares fitting" defines the difference between \bar{X} and μ , S , and σ and then, using simple calculus similar to that shown in the sidebar of a previous *Communications Quarterly* article,⁶ fiddles with parameters until this difference is minimized. Readout noise can thus be eliminated with CID technology, depending only on a user's patience for taking more measurements.

I need to point out one last subtle difference relative to CCDs. Poisson distributions are the appropriate model to explain the noise associated with counting the electrons. However, the thermal origin of dark current

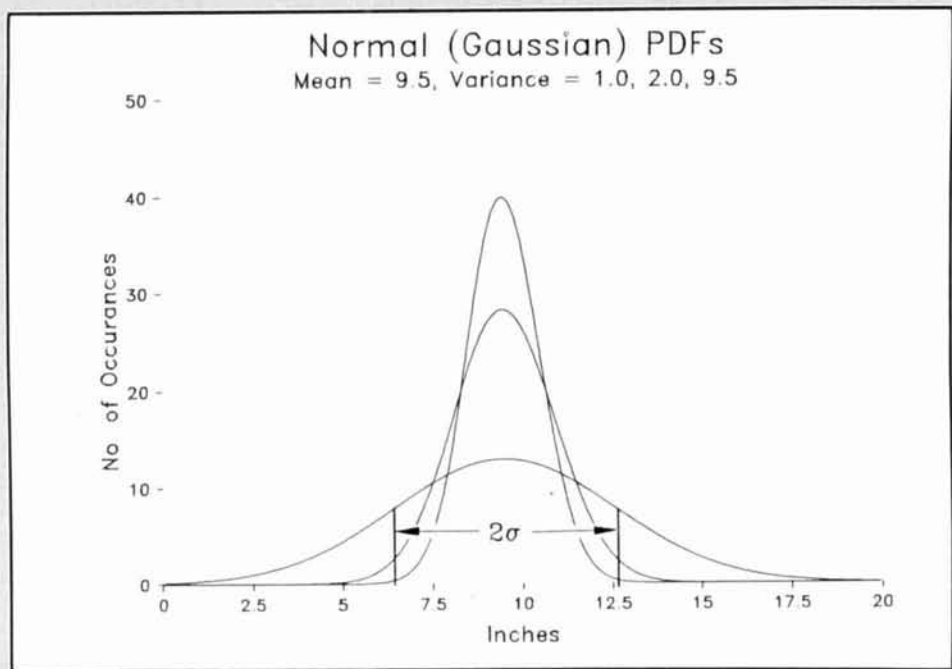


Figure S1. The area under each curve is 100 (100 samples). 68.3% of experimental measurements are expected to lie within one standard deviation of the mean if they are really samples from a Normal distribution with mean $\mu = \bar{X}$ and standard deviation $\sigma = S$. In the case of the Var = 9.5 curve above, this range is 6.4 to 12.6.

points to the use of a different distribution to predict how many electrons have accumulated prior to counting. Indeed, the Boltzmann distribution more accurately predicts how many electrons have enough

thermal energy to break loose and migrate to an electron well. One describes the accumulation of "noise" electrons; the other describes the "noise" associated with counting how many you have.

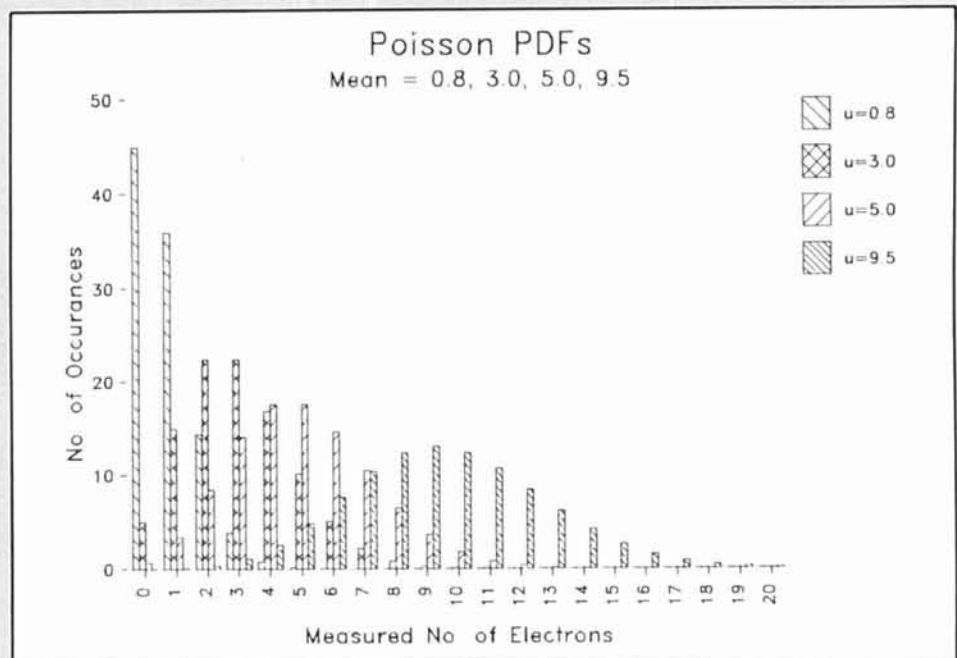


Figure S2. Notice that a Poisson distribution with a mean above approximately 10 looks very similar to a Normal distribution with mean = variance. Remember variance is the standard deviation squared.

I can't forego the opportunity to describe a certain irony in all this statistical approximation of reality. The very mechanisms we're describing (behavior of charge carriers on a solid-state device) are modeled sufficiently well by only Quantum Mechanical Theory (QM). QM abandons a search for truth independent of the measuring of the truth. For example, it's inappropriate to ask and impossible to measure the question: "Where's the electron?" You *must* ask only: "What's the chance that the electron is seen in this area?" Alternatively, you can't ask if *this* electron will become part of the dark current; you can only say there's a certain chance that *any* will.

"Chance," the way QM uses the word, is nothing more than the height of a PDF curve (or the area under the curve if your question is worded to include a range). The efforts of researchers go into calculating these distributions. An easy, reading and clear example of this search is narrated in the book *QED*.⁷

Earlier in the century, great minds fought

this issue of truth versus measurement of truth to an inconclusive resolution. In 1930, Albert Einstein's and Neil Bohr's disagreement over this issue came to a head at the sixth Solvay Conference.⁸ Eventually, the scientific community abandoned causality and absolute truth (they sided with Bohr), and went on to make significant discoveries using quantum models of reality.

REFERENCES

1. For mathematical specifics, see Section 2.6 "The Poisson Distribution" and Section 3.6 "The Normal Distribution" in R.V. Hogg and E.A. Tanis, *Probability and Statistical Inference*, second edition, Macmillan, New York, 1983.
2. P.R. Bevington, "Mean and Standard Deviation," Chapter 2, *Data Reduction and Error Analysis for the Physical Sciences*, McGraw-Hill, New York, 1969.
3. R.V. Hogg and E.A. Tanis, "Mean and Variance," Section 2.3, *Probability and Statistical Inference*, second edition, Macmillan, New York, 1983.
4. R.V. Hogg and E.A. Tanis, *Probability and Statistical Inference*, second edition, Macmillan, New York, 1983, page 67.
5. R.V. Hogg and E.A. Tanis, "Properties of Estimators," Section 5.2, *Probability and Statistical Inference*, second edition, Macmillan, New York, 1983.
6. Michael E. Gruchalla, "Optimizing Amplifier Gain-Bandwidth Product," *Communications Quarterly*, 1(4), Fall 1991, pages 68-72.
7. Richard Feynman, *QED*, Princeton University Press, New Jersey, 1985.
8. Read about the bantering at two consecutive conferences and the unresolved issue of the "half dead cat" in George Gamow, *Thirty Years That Shook Physics*, Dover, New York, 1966.

CORRECTION

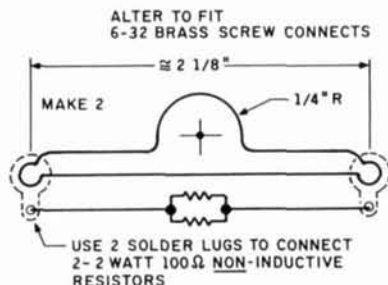
Please note these changes

George Carson, K4GDG, requested that we pass along the following corrections and additional references for his article "Modifying the Heath SB220 Linear Amplifier" (Summer 1991). George writes:

On page 91, column one, change "modified 3-1/8 inch connectors" to "1-inch diameter connector."

On page 91, column one, change "carefully bore 4-3/8 inch holes" to "carefully bore a 11/16-inch diameter hole to a depth of 13/32-inch." Note that the **Figure 3** drawing is correct and you can use 1-1/4 or 1-1/2 inch diameter aluminum stock if available.

In **Figure 2**, page 93: The drawing for the 10-meter tap on L-6 at 4-1/3 turns is in error. You'll find the correct modification of 4-1/8 turns from tuning capacitor C55 in the text on page 98. Note that if you use different tuning capacitor (C55), substituting a 10/300 vacuum variable, be aware that you do not increase stray capacitance of the LC circuit C55 and L6 or it will lower the ceiling of top tune capabilities at 29,700 kHz. If you can drop the stray capacitance further, you can tap farther out and increase the inductance tap of L6 for 10 meters. This will increase the Q and output, too. I limited modifications to the basic de-



sign merely to improve output and stability—which was very poor; meters jumped and the variable tune capacitor arced over before the modifications were made and power was reduced.

I put in two new tubes (3-500Z Eimac) and revised the parasitic suppressor configuration as shown in the figure, adding the parallel 100-ohm, 2-watt resistors. Use a piece of 0.051 Nichrome furnace heater resistor wire (no. 16) and *fold back*. I uncoiled two pieces from a 4500-watt, 240-volt element.

Here are some additional references:

1. R.L. Measures, AG6K, "Parasitics Revisited II," *QST*, October 1990, page 34.
2. R.L. Measures, AG6K, "Parasitics II," *QST*, December 1990, (input net), page 43.
3. R.L. Measures, "Circuit Improves SB220," *QST*, November 1990, page 25.
4. Bill Orr, W6SAI, "Loose Filament Pins on the 3-500Z," *CQ*, May 1991, page 80.

THE SOLAR SPECTRUM

Extended periods of quiet Sun

The Winter 1991 issue of *Communications Quarterly* contained an interesting article by Aaron Fishman which recounted what is arguably the best known period of low solar activity—the Maunder Minimum. Similar lulls (**Table 1**) are thought to have taken place prior to the event which English astronomer E.W. Maunder investigated during the latter part of the nineteenth century. As a result, we are occasionally asked if analogous events have occurred in more modern times. The answer to that question is symbolic of many which concern the Sun: yes... and no!

As Mr. Fishman outlined, the Maunder Minimum was a near century-long period during which few sunspots were observed and the 11-year solar cycle essentially disappeared, or operated at a very low amplitude. A lack of aurorae during this interlude appears to corroborate the pause in solar activity. (A large proportion of mid and low-latitude aurorae occur as a result of solar flares associated with sunspot regions, or with other spot-related phenomena.)

In addition to the traditional methods of monitoring the Sun's activity, the trend of

solar variations can also be determined indirectly, chiefly through the analysis of carbon-14 and beryllium-10 records which form distinct inverse relationships with the numbers of sunspots.¹ ¹⁴C is created as galactic cosmic rays strike nitrogen atoms in the Earth's atmosphere. The cosmic ray flux is modulated when the terrestrial environment is shielded from particle bombardment by magnetic fields frozen in the solar wind during periods of increased solar activity. Analyses of ancient tree rings, where ¹⁴C has been assimilated as CO₂ during photosynthesis, have allowed its annual abundance to be discerned for a period which extends back in time over 7000 years.² It is well known that ¹⁴C production was high during the Maunder Minimum.

On the other hand, ¹⁰Be concentrations are often measured in core samples taken from polar ice. Both ¹⁴C and ¹⁰Be are produced through interactions with atmospheric components. However, when these indices are compared with the sunspot record, the relatively brief (1 to 2 year) atmospheric residence time of ¹⁰Be results in a much shorter phase lag than the 10 to 50 year lag associated with ¹⁴C.¹ Since the short-term

Event	Probable Extent	
	Start	End
Maunder Minimum	AD 1640	AD 1715
Spörer Minimum	AD 1400	AD 1510
Medieval Minimum	AD 640	AD 710
Minimum	440 BC	360 BC
Minimum	820 BC	640 BC
Minimum	1420 BC	1260 BC
Minimum	3220 BC	3110 BC
Minimum	3430 BC	3330 BC
Minimum	3690 BC	3470 BC
Minimum	5320 BC	5110 BC

Table 1. Prolonged periods of low solar activity prior to 1715, as indicated by the ¹⁴C record.²

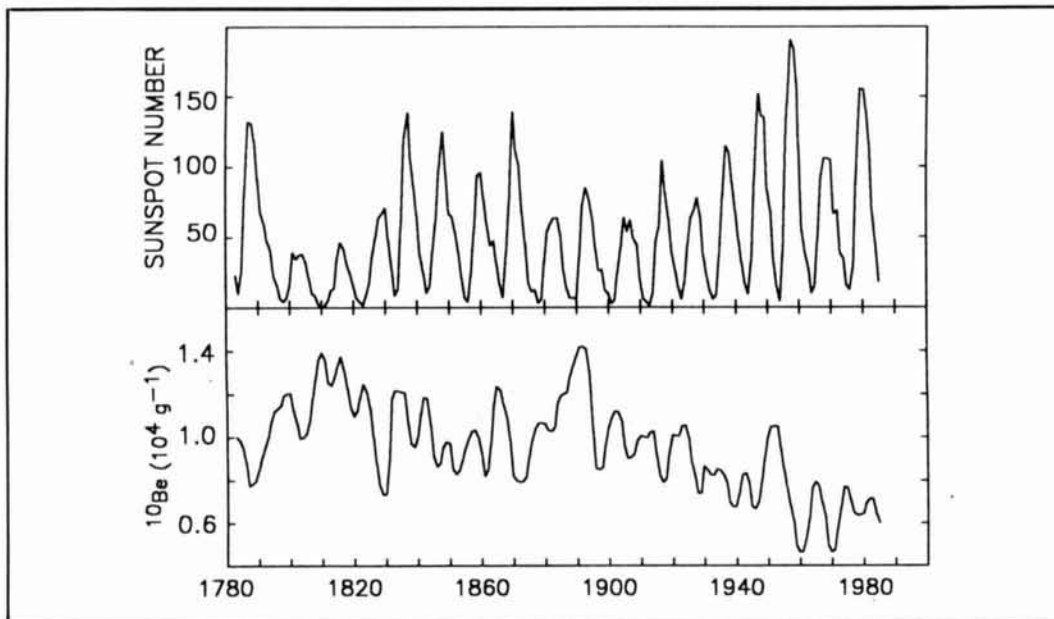


Figure 1. The smoothed ^{10}Be and annual sunspot records between 1783 and 1985. Note the well-defined inverse relationship between these indices. (Values for the ^{10}Be index were taken from a graph originally presented in Beer et al.¹)

damping effect is less, ^{10}Be can be used to study the historical trend of the 11-year sunspot cycle (Figure 1). Both indices are fairly pronounced: cosmogenic isotopes display average global rate changes on the order of ± 20 to 25 percent as abundances rise at solar minimum and fall at maximum.

If we apply these measurements—sunspot numbers, auroral rates and radio-isotope abundances—to search for extended periods of low solar activity after the Maunder Minimum ended around 1715, will instances be found? Although sunspot activity was higher, a recent study by Hoyt and Schatten³ clearly defines one such episode which occurred at the beginning of the nineteenth century.

In reaccessing what has been regarded as the longest recorded cycle (17 years) of the 11-year cycle series, Hoyt and Schatten find its more likely length to be 13 to 14 years, which is more consistent with recent cycles. Moreover, their investigation confirms that the adjacent years, an interval known as the Dalton or Modern Minimum, is the weakest period of solar activity to occur since the Maunder Minimum. ^{14}C and ^{10}Be indices for this interval substantiate the low level of activity demonstrated by the sunspot index, as do auroral records.

It is worthwhile to note that the time frame studied by these two scientists was one of the colder-than-normal temperatures in many parts of the world. In fact, Landsberg⁴ has determined that the year 1812 was

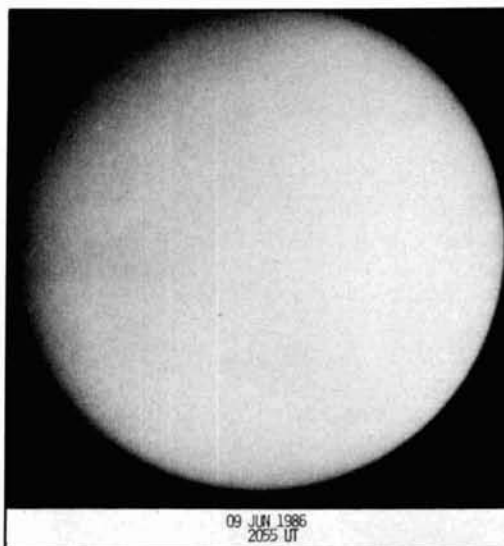


Photo A. The quiet Sun is shown in this photograph taken by Thomas G. Compton on 9 June 1986, just three months before sunspot cycle minimum. Contrast this view with the full-disk photograph shown in this column in the Winter 1992 issue of *Communications Quarterly*.

the coldest single year of the last four centuries.* Therefore, the cool climate during this interlude may, as Eddy suggests for the Maunder Minimum, be related to variations in the Sun's level of activity.

The ^{10}Be index peaked again in the period

*It should be noted that Landsberg does not rule out a volcanic "dust veil" as a source of at least a portion of this cooling.

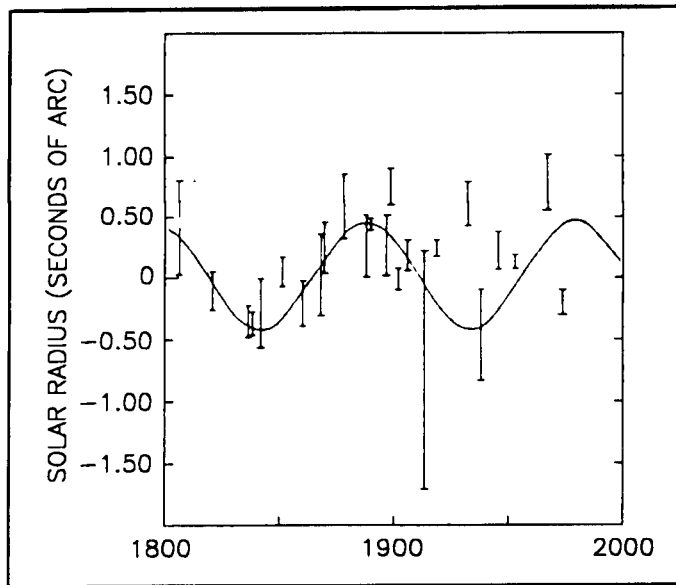


Figure 2. Cyclical change in the Sun's radius as determined by Sabatino Sofia and his colleagues.⁵ The solar radius appears to vary according to a period of around 90 years.

1880 to 1910, at a time when the average amplitude of the sunspot cycle was only slightly greater than at the beginning of the nineteenth century and auroral activity was again at a low level. Unfortunately, the advent of fossil fuels into the environment blurs the solar information in the ¹⁴C record after about 1850, and the Sun subsequently entered a period of increased activity which continues today.

What, if any, physical changes to the Sun accompany—or perhaps usher in—such apparently anomalous solar behavior? Recent information suggests that the solar luminosity, and therefore its irradiance, may fluctuate, accompanied by a change in the Sun's radius and effective surface temperature.

Observations seem to show that solar irradiance varies with the cyclic trends of solar activity, indicating that a prolonged interval of low activity could be associated with a low level of irradiance and increased radius. The findings of Sofia et al.⁵ offer evidence in this regard. Sofia and his colleagues have shown that the solar radius appears to vary according to a period of about 90 years (Figure 2), and that it was nearly 0.5 second of arc larger than average at the beginning and end of the nineteenth century. A similar period, related to the amplitude variation of solar cycles—the Gleissburg Cycle—has long been suspected.

In the past, measurements which trace the transit of Mercury or the Moon's passage across the solar disk at total eclipse have often been used to monitor the Sun's di-

ameter. Changes on the order of 400 kilometers (0.6 second of arc) to a "normal" solar radius of some 700,000 kilometers have been well-documented.⁵ Unfortunately, until the advent of space technology (specifically, concurrent observations by instruments aboard the *Nimbus 7* and *Solar Maximum Mission* satellites), precise measurements of solar irradiance were much more difficult to obtain. Even though ground-based monitoring equipment was frequently placed high above sea level on mountaintops, it is necessary to apply an atmospheric correction on the order of 25 to 40 percent to the acquired data.⁵

It is somewhat ironic that irradiance can now be measured from spacecraft with a greater accuracy than the Sun's diameter. This situation will improve as more accurate instruments such as the *Solar Disk Sextant*⁶ are placed in space. For the moment, however, a definitive resolution is not in hand, and solar pulsation continues to be an intriguing aspect of the Sun's evolution.

Recent activity and near-term outlook

The number of strong flares recorded in December was nearly three times that for November, but the Earth's magnetic field was far less disturbed. Just one day of minor storming occurred at mid-latitudes, and that was attributed to coronal hole activity. Solar and geomagnetic indices for January were comparable to those for December, although the number of energetic events fell by some 50 percent.

As predicted, solar activity increased during February and the Earth's magnetic field responded accordingly. Several periods of severe storming were instigated by a variety of sources including flares, coronal holes, and disappearing filaments. The more disturbed intervals took place during the first and last weeks of February, when aurorae were observed from mid-latitudes and polar radio propagation paths were affected.

The outlook for the next several months continues to call for a gradual decline in active solar phenomena, punctuated by intervals of enhanced activity. Prediction models currently indicate that increased activity may occur in June.

REFERENCES

1. J. Beer et al., *Nature*, 347, 164, 1990.
2. J.A. Eddy, *Climatic Change*, 1, 173, 1977.
3. D.V. Hoyt and K.H. Schatten, *Astrophysical Journal*, 384, 361, 1992.
4. H.E. Landsberg, *Climate and History*, R.I. Rotberg and T.K. Rabb, Editors, Princeton University Press, 51, 1981.
5. S. Sofia, et al., *American Scientist*, 73, 326, 1985.
6. Currently under developmental testing at the NASA Goddard Space Flight Center. (Private communication from S. Sofia.) An excellent description of this instrument and its purpose is contained in S. Sofia, et al., *Advanced Space Research*, 11, 123, 1991.

LOW-PASS FILTER PERFORMANCE

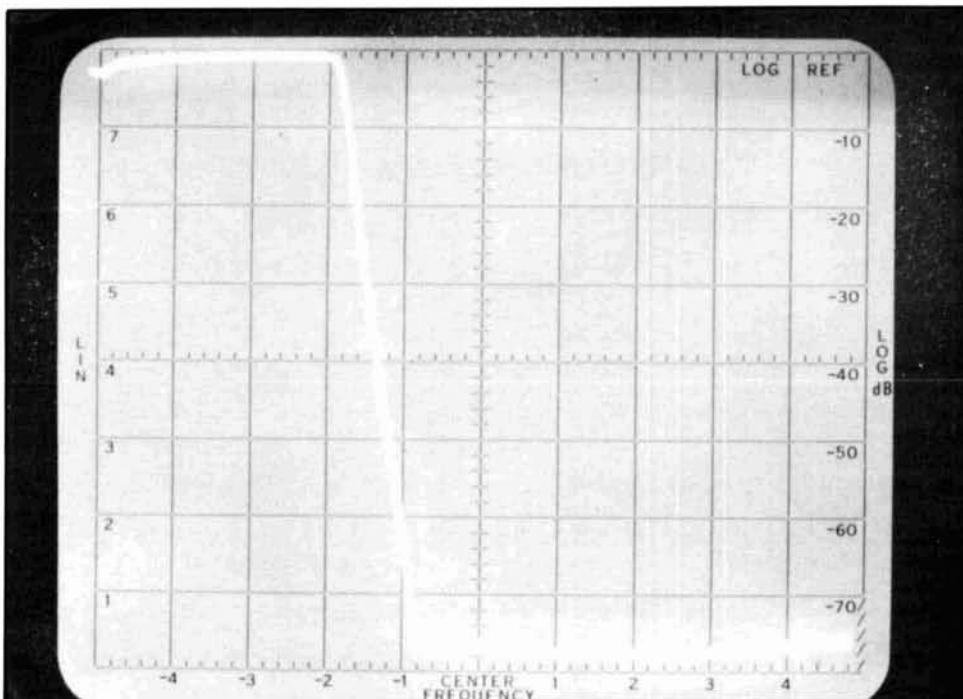
A survey of the characteristics of commercial filters

Experience dictates that *every* transmitter benefits from the addition of a low-pass filter as a means of reducing harmonic radiation. Modern wide-band HF transmitters, generally employing push-pull solid-state amplifiers, perform relatively well in minimizing, but not eliminating, *even* harmonics due to cancellation. Conversely, *odd* harmonic generation does not benefit from this phenomenon. No one operating in an urban area should take any consolation, as there isn't any real safety or comfort in

either of these harmonic conditions. One would find these facts particularly germane after reviewing the chart of amateur frequencies relative to the VHF and UHF spectrum.¹

Background

After the return of their frequencies at the end of World War II, amateur radio operators returned to the airwaves. Most hams used transmitters with Class C amplifiers, that were good harmonic generators. At the



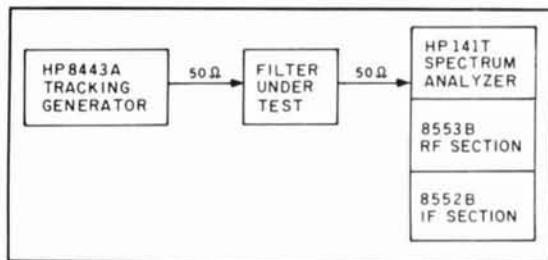


Figure 1. Filter test setup.

same time, there was a rapid increase in number of television broadcast stations and TV sets became fixtures in many people's homes. Consequently, radio amateurs found themselves dealing with high incidences of TVI. Manufacturers hurried to develop low-pass filters (LPF) that would minimize the interference caused by these amplifiers. A number of well-known brands came into prominence immediately. Collins, Barker & Williamson, Johnson, and Drake were among those highly respected for their quality. Most filters of this period exhibited good harmonic attenuation *above* 50 MHz, with cut-off frequencies (f_c) in the range of 40 to 50 MHz. These characteristics were considered pretty good at the time. Television IF frequencies were generally much lower and, much to our deep regret, many were in the middle of the 21-MHz band! Today, almost universally, color television IFs are in the low 40-MHz region, which, for example, is the third harmonic of the

20-meter band. This makes the construction of an LPF considerably more challenging because it may be necessary that the filter pass 29.5 MHz, yet provide respectable attenuation above 40 MHz. As this is considerably less than one octave of separation, good notches and multi-elements in an overall superior design are necessary to achieve a very steep slope for good success. More on this subject later.

IF or video interference is evidenced by a blanketing of all TV channels, along with color suppression, even at very low power levels. In one case, which involved a manufacturer's video circuitry design deficiency, I found that as little as 10 watts at 14 MHz caused serious interference from a transmitter at a distance of 300 feet! In such situations, established techniques should help determine which piece of equipment is causing the disturbance,² and proper filtering usually substantially alleviates or eliminates the IF problem. As far as I know, with respect to video interference, it's possible that only the manufacturer can help. Fortunately, this was true in my case. The set was exchanged for a later version in which the problem had been eliminated.

Some early filter evaluations

I decided to do a survey of commercial filters to learn about their design criteria, performance characteristics, components, and construction techniques. The previously



Photo A. A photographic representation of Figure 1.

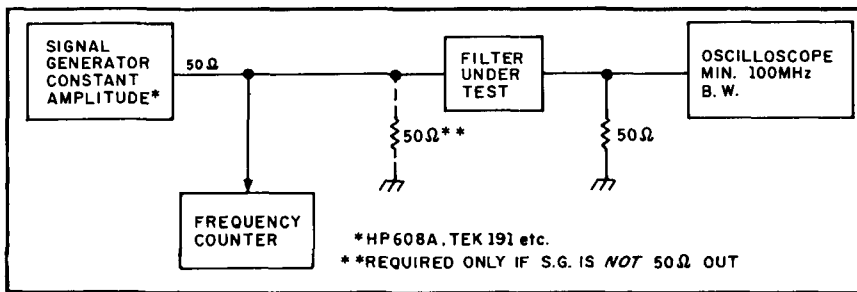


Figure 2. Alternative test setup.

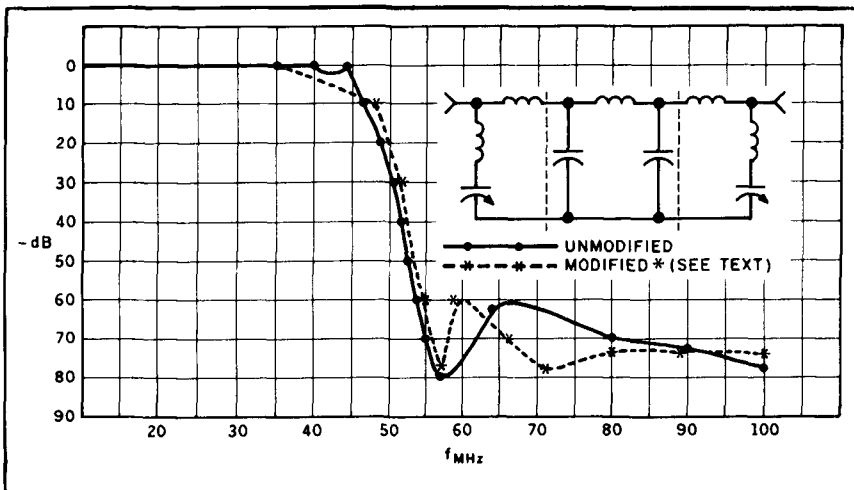


Figure 3. Johnson 250/20 filter.

mentioned, post World War II composite-type commercial LPFs were my first subjects. Using the test setup described in **Figure 1** and shown in **Photo A**, I obtained some rather revealing and interesting results. All my data are based on 10 dB and 10 MHz per division. I arbitrarily established -80 dB as the noise floor of my system for reliable testing.

Figure 2 depicts an alternative test setup that should be more commonly available for those who want to try their hand at making some filter measurements. This method will work quite effectively, but not as quickly or conveniently as the one shown in **Figure 1**—and it is potentially less accurate.

The popular Johnson 250/20 filter exhibited very good performance *above* 50 MHz. The schematic diagram of this filter and related performance is found in **Figure 3**. It conforms to the majority of the basic designs common in the post-war period; that is, good attenuation of the frequencies from 50 MHz. That, of course, was aimed at channel 2 and above. It was built, consistent with the best engineering practice, using sandwich-type capacitors for low inductance. These were fabricated on the sheet

metal partitions that form part of its 2-1/2 inch diameter tubular aluminum enclosure.

I moved on to the R.L. Drake-type TV3300LP, which yielded far superior results. Its performance and schematic are shown in **Figure 4**. The internal construction of this filter, using a compression-type finger stock to isolate the shield sections, was impressive. It, no doubt, contributed to its superb performance. Note that both the Drake and Johnson filters were designed for 1 kW of average power—the FCC limitation in effect at that time. Under current regulations, these filters will be operating within their margin of safety. The Drake filter uses mica as its capacitor dielectric material and the Johnson uses what appears to be Mylar.TM More modern designs might use TeflonTM which, of course, wasn't in existence when these filters were designed. The Johnson filter offers a very interesting bit of flexibility in that its two terminating half-sections are tuneable from the exterior using double spaced APC-type air variable capacitors. I found it advantageous to retune one of them to provide a notch at 71.0 MHz for improved harmonic suppression on channel 4 (see **Figure 3**). Padding one of the half-section's variable capacitors

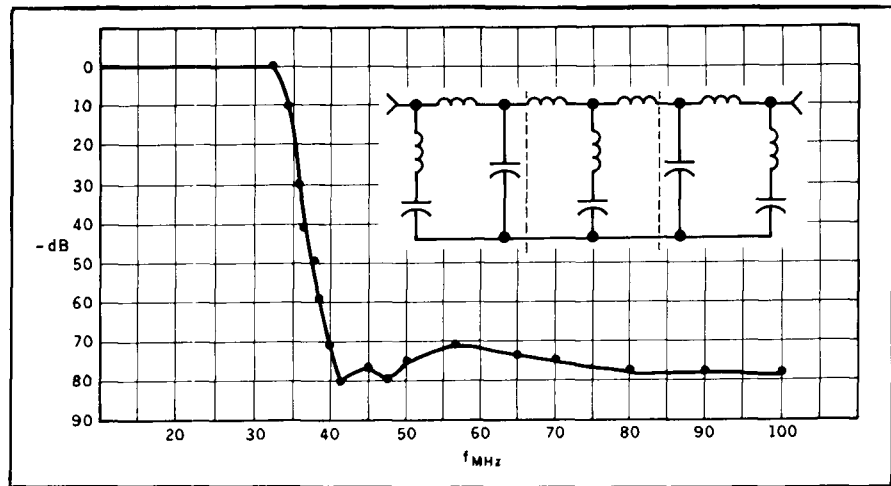


Figure 4. Drake TV-3300-LP.

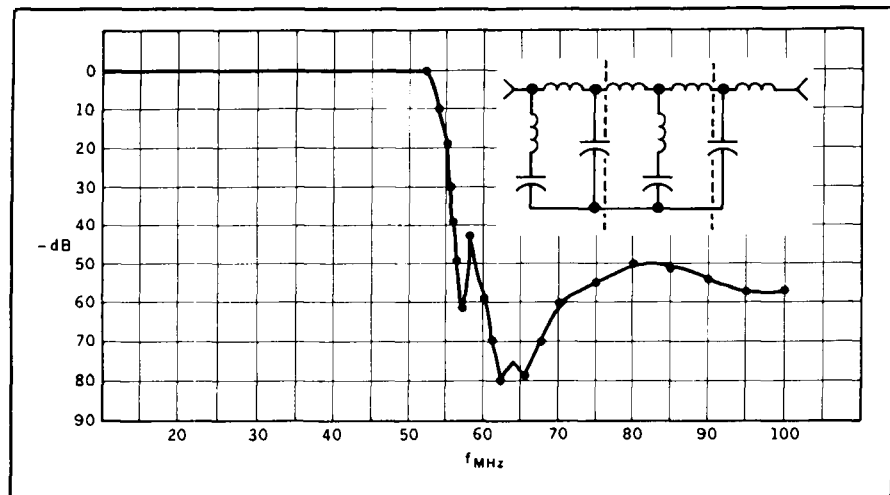


Figure 5. Drake TV-1000.

with 47 pF causes it to alternatively notch reject 42.6 MHz. However, the slope following the f_c is altered, as expected, with any movement of either of the original terminations. Both the three Drake and three Johnson filters I tested yielded similar results. Fortunately, they can still be found in the flea markets at reasonable prices.

The TV1000LP was an earlier version of the Drake TV3300LP. It was well constructed, employing low inductance, sandwich-type capacitors attached to the bulkheads and outside walls. Its configuration and response curve are shown in Figure 5. The capacitor dielectric appears to be Mylar. These, too, are still available at reasonable cost in the flea markets but, obviously, the TV3300LP takes preference. Unfortunately, Drake no longer produces LPFs.

I evaluated one imported filter—a Mars. Its performance data and schematic appear in Figure 6. I did this primarily out of curiosity, hoping to learn something valuable

about this filter's design and components. I felt its enclosure might have the potential for modification into a homebrew filter, as well. It was undoubtedly designed for their domestic frequencies, so after I saw the results, I put it aside to look at another time!

The Bud Manufacturing Company also marketed a tuneable LPF. Unfortunately, I couldn't obtain any for test purposes. If anyone has one of these filters, and is interested in its performance characteristics, I would be pleased to test it and provide the results.

I tested the Collins kW level 35C-1 Model 2 filter next. Its schematic and performance data are shown in Figure 7. The construction employed the use of Centralab type 850 ceramic capacitors. The filter is housed in a 3-inch diameter silver-plated tubular brass enclosure with appropriate shield baffling. It used the type N fittings so typical of Collins quality. With that relatively large diam-

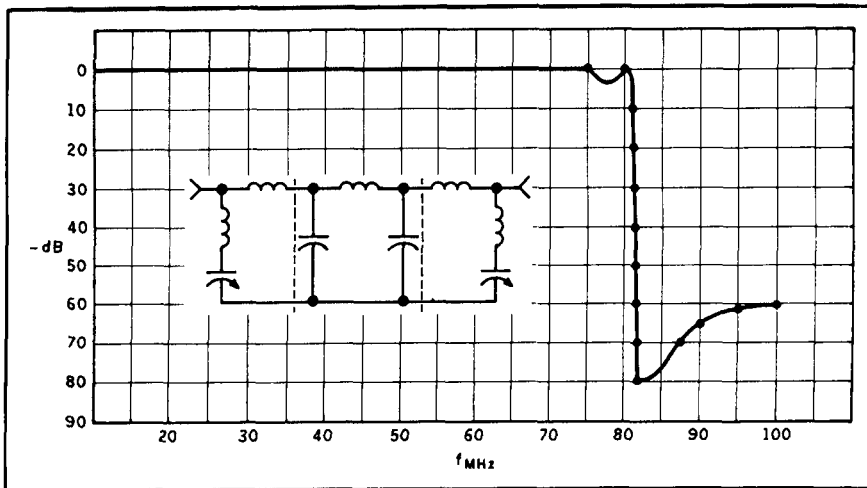


Figure 6. Mars filter.

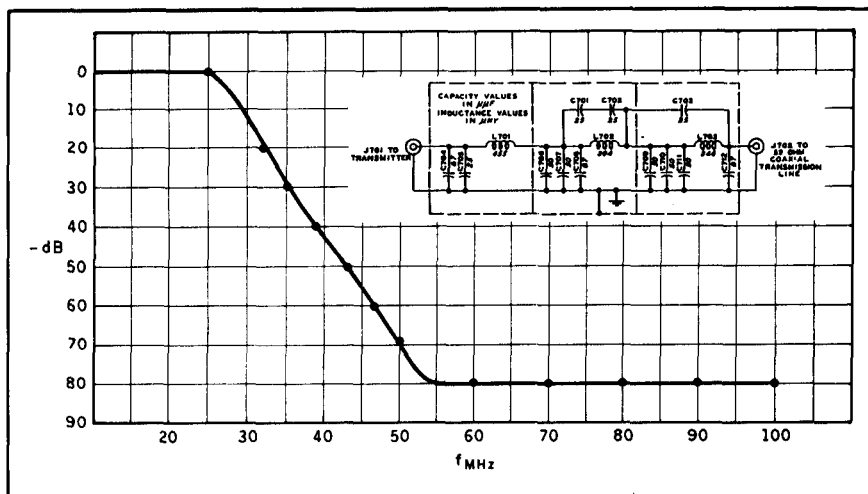


Figure 7. Collins 35C-1 Model 2.

eter housing, the capacitance effects were undoubtedly minimized. Although its performance specifications weren't available, the test results speak for themselves. It was the class filter in its day, as was all Collins equipment, and the operators who had one were envied by those of us who couldn't afford it!

Next, I tested the J.W. Miller kW model C-514-T, which is specified to attenuate up to 80 dB above 50 MHz. Its measured performance and schematic are shown in **Figure 8**. Mica insulation was used for the bulkhead-type low inductance capacitors. Its configuration is similar to quite a number of filters manufactured and shown in the handbooks of its day. These, too, are still available at flea markets at relatively reasonable prices.

Homebrew filters

Having looked at a number of older com-

mercial units, I decided to build a relatively simple filter to add to the knowledge I'd acquired from building other such devices years earlier. The difficulties of constructing the homebrew filter lie in performing the sheet metal work or finding a suitable enclosure, securing the components, and testing the unit. My experience has led me to believe that it's relatively difficult to compete with the commercial units.

I used double-spaced 25-pF APC-type air variables and Centralab type 850 fixed capacitors. These low inductance units are often found in the local flea market at reasonable prices. The schematic of my augmented, shunt-derived filter and its performance characteristics, are shown in **Figure 9**. There was considerable frequency interaction between the adjustment of the two notches, so I exercised some patience. I found only minor interaction when adjusting the m-derived terminating half-sections in the Johnson filter. With the

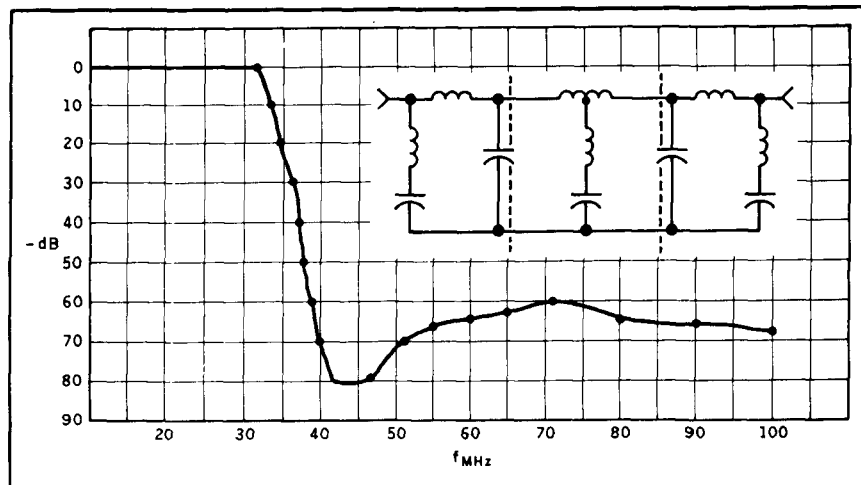


Figure 8. J.W. Miller C-514-T.

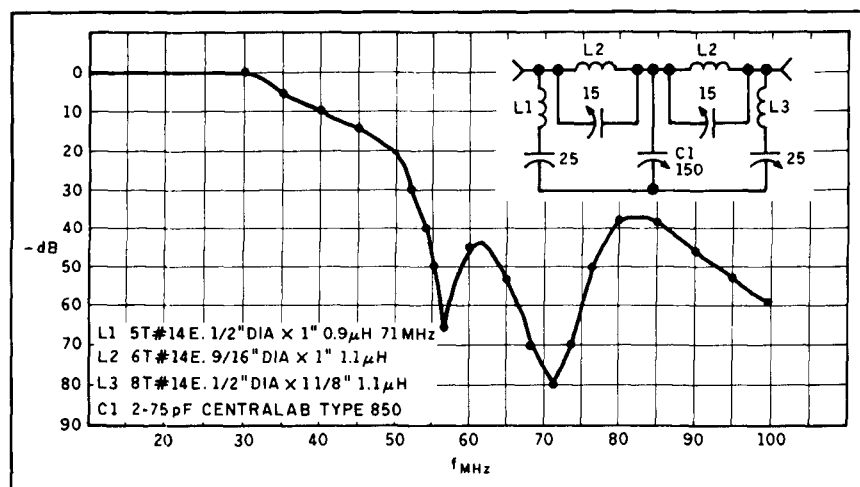


Figure 9. Homebrew filter.

Johnson filter and my homebrew design in cascade, the notches were so deep that they were well below the noise floor of my analyzer.

Some time ago, I constructed another simple filter for use with a 20-meter mono-band linear amplifier. Its characteristics are much different than those described above. The f_c is approximately 18 MHz, so it would be useful only to those operating below that frequency. However, its attenuation is reasonably good at 42 MHz and above. The filter is easy to build using the Centralab type 850 capacitors. I employed no internal shielding, although the coils were mounted at right angles to each other and well isolated from the enclosure, and I used strap copper leads. The schematic and attenuation data recorded then, on an exotic HP automated tester, are shown in **Figure 10**. Two of these filters in cascade would yield considerably better results, and could be built in two shielded boxes bolted together.

Some general notes

When testing a completed filter, I've found it's *extremely* difficult to grid dip the elements accurately with the enclosure cover off and then obtain the same performance with the cover on! However, the larger the enclosure, the less change that takes place. Calculated values, strays, and manufacturing tolerances may take their toll, as well. I have concluded that, whenever possible, externally adjustable air variable capacitors are near mandatory—but their inclusion requires test equipment. I've found this to be especially true with the series resonant, terminating elements. Also, as all the handbooks dictate, sandwich-type fixed capacitors are preferable—principally attached to the bulkheads for operation as three-terminal capacitors for lowest inductance. These are generally difficult to build; the low inductance Centralab transmitting-type 850 capacitors are the next best alternative,

as long as one takes all the proper precautions (short strap-type copper leads, etc.). Good shielding and/or isolation between filter elements, in addition to adequate spacing between the coils and the enclosure are also a must. For higher power construction, the Centralab type 858 capacitors provide a generous amount of safety. Bear in mind that all sharp corners should be radiused, as high voltages will likely develop at these points and may cause failure.

It is significant to note that there exists an engineering design premise which dictates that the basic absorptive filter yields approximately $6n$ dB per octave above its f_c^3 , but only when removed from it due to the general characteristic slope of the curve thereafter. In this case, n is the number of reactive elements; that is, each inductor and capacitor in the low-pass portion of the filter. Using this rule, one may quickly calculate the approximate attenuation of a filter by inspection, but parallel resonating capacitors are generally not counted in this calculation.

Current filter evaluations

Having looked at a number of early filters, I wanted to see what was presently available on the market. The first type I tested was designed for high power. Its published specifications indicated an f_c of approximately 32 MHz with 70 dB of attenuation at 40 MHz, which would be extremely desirable. However, I was unable to duplicate the manufacturer's performance data on the three units tested. From a strict engineering design standpoint, the specified slope of 70 dB in much less than one octave is a very technically challenging job. I base this assessment on the background and cal-

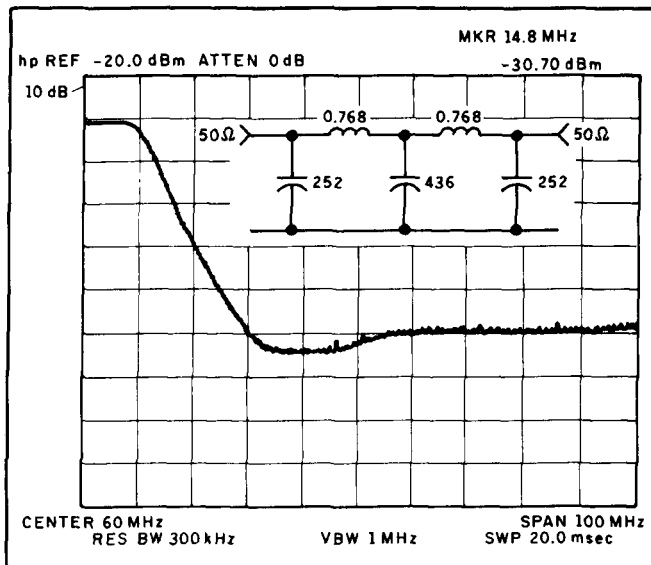


Figure 10. Early homebrew filter.

culational previously noted. Because the manufacturer has produced a number of distinct versions of this filter, all carrying the same model number and specifications, I felt that publishing my test data was unwarranted at this time.

My investigation of commercial filters continued with a 1500-watt LPF manufactured by MFJ—their model 704. This is a moderately priced unit whose characteristics aren't specified. Its performance is shown in Figure 11, along with its schematic. If you aren't concerned with IF interference, this filter would be fairly adequate. It's interesting to note that MFJ used printed circuit board (PCB) construction for this filter's capacitors—a very good method for providing the lowest inductance and a good ground plane for isolation. The filter employs nine reactive elements and follows

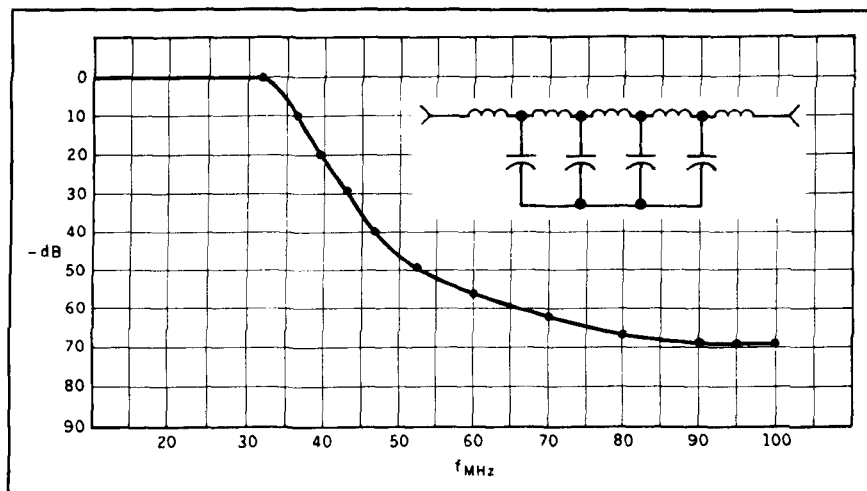


Figure 11. MFJ-704.

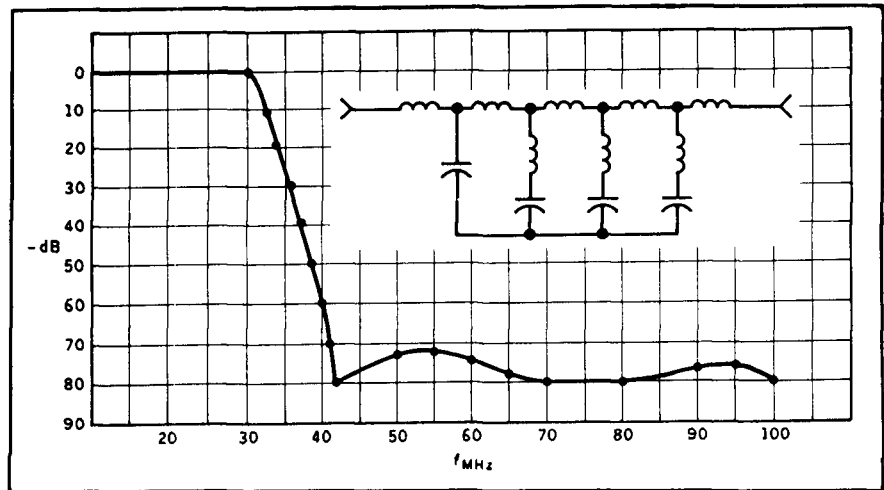


Figure 12. Vectronics LP-30.

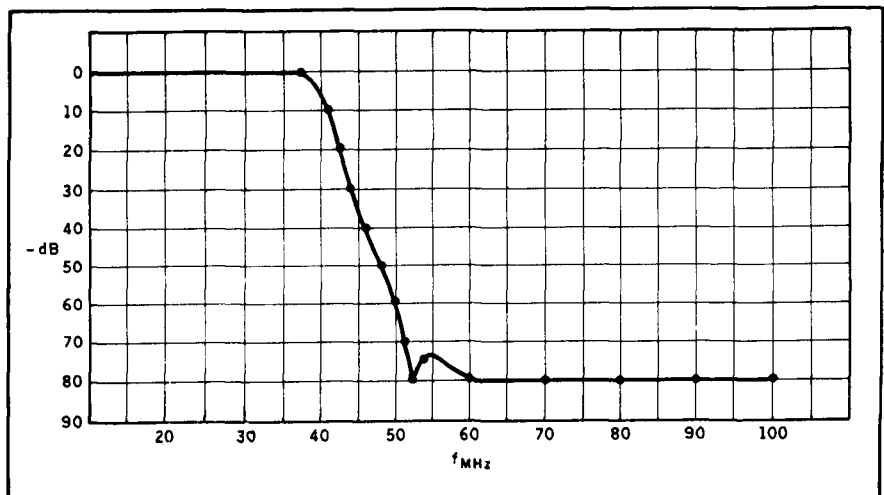


Figure 13. Bencher YA-1.

the attenuation that one would expect, as previously noted.

I went on to test a very interesting LPF manufactured by the Vectronics Company, Inc. of Canada—their 1500-watt model LP-30. It, too, is moderately priced, and its performance was exceptionally good (see the data and schematic diagram in Figure 12). It consists of twelve reactive elements so, as expected, its harmonic absorption is significantly enhanced over lesser designs. I was particularly interested in the company's innovative use of toroidal inductors in this application. This was the first time I had seen these inductors used in this kind of commercial production for an amateur application. Because they are self-shielding, toroidal inductors have the distinct advantage of minimal interaction with the surrounding metal enclosure. I verified this with an open unit attenuation curve, which I held in the memory of the spectrum analyzer, sweeping it again with the unit

closed. As a result, the two traces were essentially superimposed; the lower knee of the curve was degraded slightly, but the ultimate attenuation was unchanged. Toroids, in amplifier L sections, etc., and other filters, have been used for a long time, so I don't believe that this application would present any problem with normal use. This filter employs PCB construction. That factor and the use of toroids, minimize the space requirements for layout isolation and the lead inductance, and essentially minimizes the need for internal shields.

Next, I tested a higher-priced unit—the Bencher 1500-watt LPF model YA-1. Its performance data is shown in Figure 13. As it is a sealed unit, I can't comment on the design, other than to note that its ultimate attenuation was good compared to some others. However, it does not significantly attenuate the television IF frequency; partially, I presume, because its f_c is rather high. If that particular aspect isn't critical

in your application, this filter will perform well at the higher frequencies.

An innovative LPF

An article in the November 1968 issue of *QST* put forth a very creative and interesting concept for LPFs.³ It concerns some absorptive filters that use a novel design approach. Some exceptionally steep attenuation curves are obtained by using two filters in parallel—one high-pass and one low-pass. This happens because the high-pass filter is passively terminated into 50 ohms, dissipating the harmonic energy. What is achieved is a relatively low VSWR across its entire bandpass—a result which is otherwise unattainable for harmonics in the conventional LPF. The cross-over of the two filters offers a shape that, under other circumstances, is extremely difficult to obtain. By using this approach, which was specifically aimed at high rejection close in to the cut-off frequency, the authors were able to create a filter which dropped 55 dB in 26 MHz

with a very simple, four-pole configuration. From the -10 dB point, the attenuation was a startling -45 dB, or an almost vertical line in about 5 MHz! A six-pole version of the filter shows slightly better shape. The four-pole version of this filter is briefly described in *The ARRL Handbook*.⁴ The schematics of the four and six-pole filters are given in **Figure 14**. The authors provide complete design data for filters from two to six poles. I suspect that the ultimate attenuation of this filter was much greater than that which was shown, when one considers the type of test equipment that may have been available at that time. This is a deduction on my part, because the noise floor of their best measurement was shown at -60 dB! The authors' termination concept gave me some concern that the usual LPF, being essentially unterminated at the harmonic frequencies, would be subject to the same loss of performance. It would be nice to be able to test for this, but the permutations are so great that I concluded it wouldn't be possible.

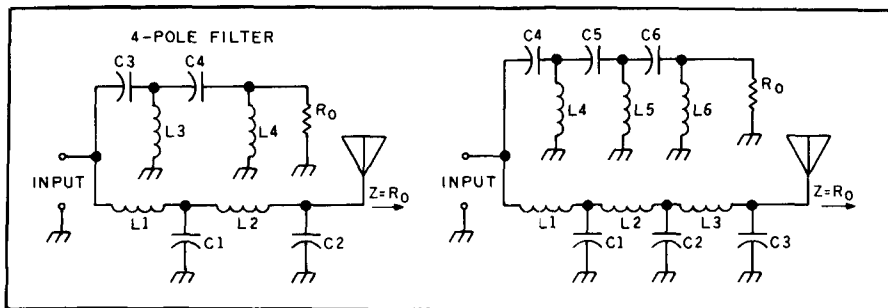


Figure 14. Schematics of four and six-pole absorptive filters.

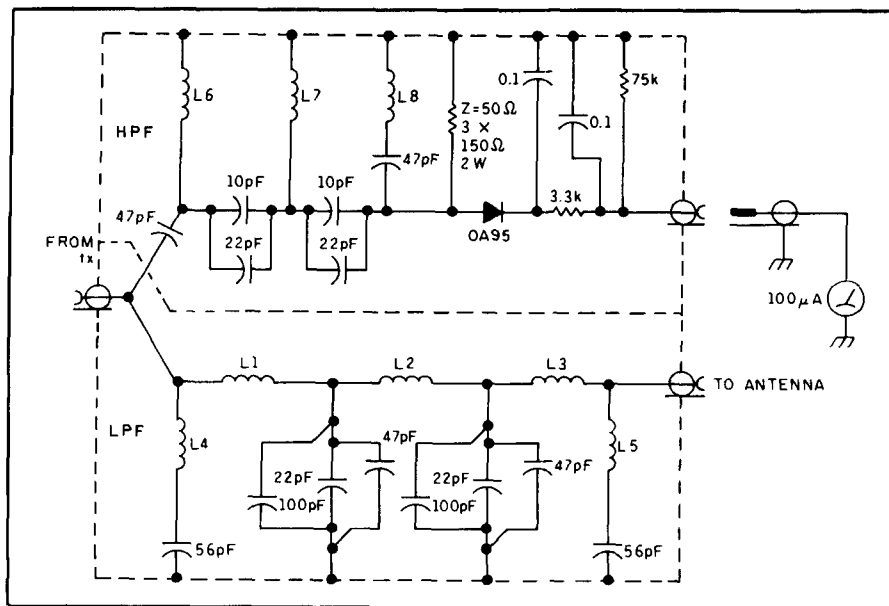


Figure 15. DJ2NN filter.

I have learned that several ads for a commercially available absorptive filter appeared in the Japanese *CQ* magazine some years ago. Unfortunately, I was unable to obtain any more information.

A very brief article in a book titled *Amateur Radio Techniques*,⁵ described DJ2NN's absorptive filter—which strongly resembled the design just discussed. The article was first published in the *CQ-DL* magazine in August 1976. His circuit, shown in **Figure 15**, contains a novel metering capability. He claims harmonic reduction in the 70 to 100 dB region! In 1976, let alone now, measuring 100 dB, if accurate, was a significant triumph! I plan to build one of these filters and learn more about them. Assuming that they are as effective as it appears, it's difficult to understand why they haven't been universally adopted.

Summary

I'd like to point out that a number of my measurements have reluctantly been made on a sample of one for obvious reasons. However, because the filters I tested were commercially manufactured, it's reasonable to assume that, within small deviations, the data taken are generally valid.

Basic amateur-type low-pass filter designs haven't appeared to have changed significantly during the past 40 years. Only the

implementation has changed, a result of the development of better materials and test equipment. Because of this, we should expect improved performance within allowable cost constraints.

It is my expectation that this survey will provide users with some further insights into low-pass filter performance. With that knowledge, I hope they will better be able to research the detailed, specific performance data from reputable manufacturers. This, in turn, should enable them to make improved cost-effective purchase decisions, as they would in the case of any other product.

Acknowledgements

To N6FL, VE3UP, W0IAK, W6JAZ, NG6W, N6RJ, WA9NVN, N5AR, and W6GNX, I extend my sincere appreciation for their valued suggestions and their willingness to make available many of the filters that I tested.

REFERENCES

1. *The ARRL Handbook*, Amateur Radio Relay League, 1989 edition, page 40-4.
2. *The ARRL Handbook*, Amateur Radio Relay League, 1989 edition, page 40-15.
3. Weinreich and Carroll, "Absorptive Filter for TV Harmonics," *QST*, November 1968, page 20.
4. *The ARRL Handbook*, Amateur Radio Relay League, 1989 edition, page 40-9.
5. Pat Hawker, G3VA, *Amateur Radio Techniques*, RSGB Publishing, Radio Society of Great Britain.

PRODUCT INFORMATION

Modular Oscilloscope Probe Kits

Pomona Electronics has a new family of oscilloscope probe kits with interchangeable oscilloscope probes and accessories. The kits are available in three configurations 100 MHz, 200 MHz, and 300 MHz. Each kit is packaged in a reusable plastic case.

The 100-MHz standard modular oscilloscope probe kits can be used with any scope up to 100 MHz and are available in three attenuation ranges: Model 5792, $\times 1$; Model 5795 $\times 10$; and Model 4550A, $\times 1$ to $\times 10$ switchable. The 100-MHz kits are modular and feature flexible cable and a wide variety of accessories. Replacement parts are available.

The 200-MHz professional modular oscilloscope probe kits can be used with any scope, offer bandwidths up to 200 MHz, have stainless steel probes, and replaceable parts. There are four models with different attenuation available: Model 5800, $\times 1$; Model 5803, $\times 10$; Model 5806, $\times 1$ to $\times 10$ switchable; Model 5827, $\times 100$.



The 300-MHz high-frequency professional modular oscilloscope probe kits can be used with any scope. They feature bandwidths up to 300 MHz, 1.2 nanosecond rise time, and a wide range of accessories. Two models are available: Model 5809 with $\times 10$ attenuation, and Model 5812 with $\times 10$ attenuation and readout actuator.

For a free copy of the new 1992, 140-page catalog, contact Customer Service, ITT Pomona Electronics, 1500 East Ninth Street, P.O. Box 2767, Pomona, California 91769. Telephone: (714)469-2900. FAX: (714)629-3317.

QUARTERLY DEVICES

Low-power audio amplifiers

Choosing the right audio amplifier for your next communications project may involve nothing more than a quick trip to Radio Shack. However, some projects may beg for something more—perhaps a chip with greater output or special features. These days, the consumer-electronics marketplace offers designers and builders many choices. This installment of “Quarterly Devices” looks at recent entries into the low-power audio category that provide new options for builders.

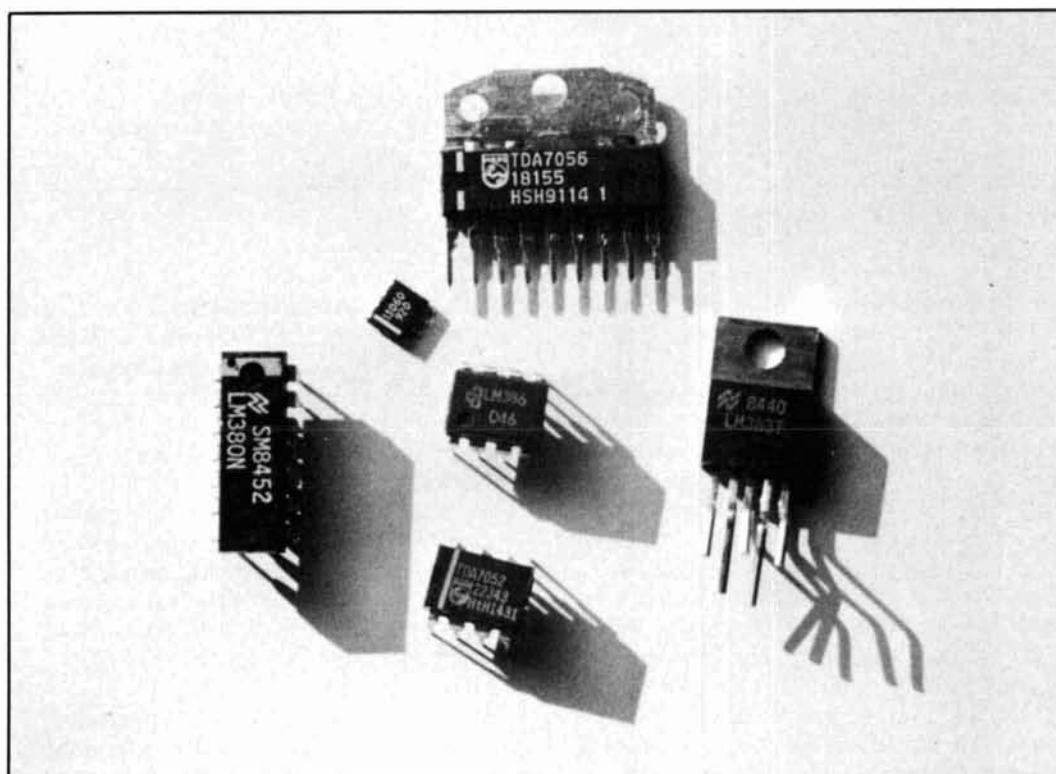
The devices featured here are especially suited for bench projects like small desk-top radios, test equipment, QRP transceivers,

and battery-powered portables. In general, these devices will:

1. Drive a small 8-ohm speaker.
2. Operate with few external parts.
3. Function without a heat sink.
4. Provide at least 35 dB gain.
5. Operate on low V_{cc} .

The venerable LM386

The baseline for comparing low-power amplifiers is the LM386, an extremely popular chip most of us have used at one time or another. Although the LM386 has been



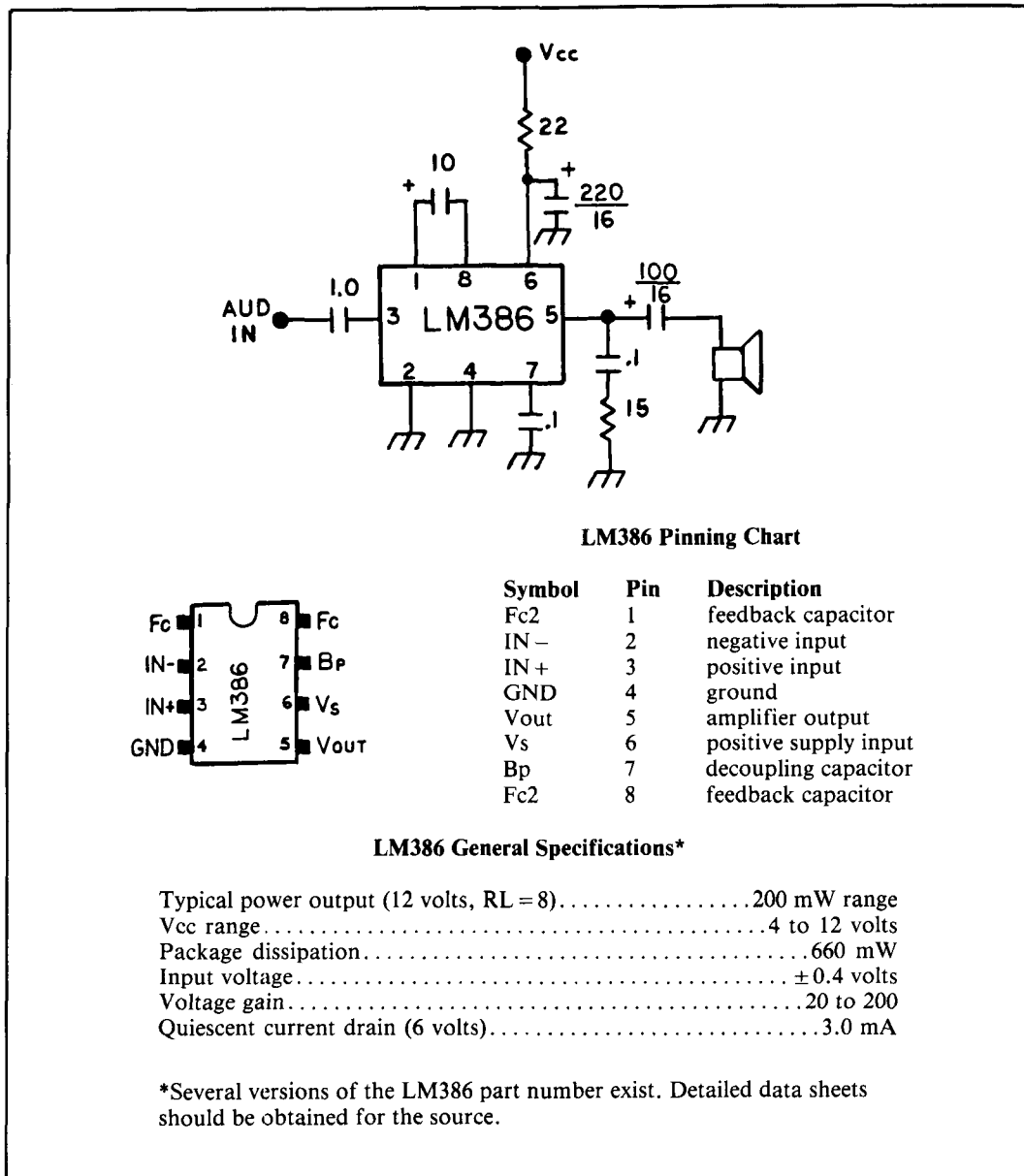


Figure 1. Practical circuit, pin outs, and basic specifications for the LM386.

around for several years, it's still the most widely available audio device going, proving itself in countless applications from home construction projects and kits to a wide range of commercial products.

Figure 1 shows a practical circuit and outlines the basic specifications for the LM386. Output power is in the 250-mW class (some versions slightly higher), with plenty of gain for detector-to-speaker receiver applications. The LM386 is an op-amp design with external access to the feedback loop. This means you can tailor gain and frequency response to suit your particular application.

The LM386 is a great device, but it does have a few shortcomings when compared with some recent designs. For one thing, it's

configured as single-ended amplifier with the output working against ground. When connecting a speaker, you must install a relatively large blocking capacitor to isolate the amplifier's DC offset voltage from the low-resistance path to ground created through the speaker voice coil. This requirement adds a relatively large (and expensive) electrolytic to the parts list. Careful Vcc decoupling is also required, adding a second hefty electrolytic to your design. The storage capacity of these capacitors makes it nearly impossible to mute the chip silently by removing Vcc.

In addition to the DC blocking requirement, the LM386 may not deliver enough output swing to drive a speaker when oper-

ated at very low V_{cc} levels (2 to 5 volts). In some battery-powered applications, this may limit the chip's usefulness.

A different approach to low-voltage audio power amplifiers

Before scoping out specific part numbers, here's an overview of what audio chip designers are doing to make our lives easier these days. In order to provide greater output swing at low battery voltage, most manufacturers now offer an alternative to the traditional single-ended amplifier like the LM386. These designs place two identical op amps on a single chip and configure them to work as a team.

The specific approach adopted by Motorola is shown in **Figure 2A**. Note that Op amp 1 is configured to amplify incoming audio in typical fashion; the device's loop gain is established by an external resistor network. However, instead of working against ground (i.e., single-ended configuration), Op amp 1 feeds one side of the load

and simultaneously sends a sample signal to the input of Op amp 2. Op amp 2, configured for unity gain, then reproduces an exact mirror image of that signal (180 degrees out of phase) which drives the opposite side of the load. The two op amps, working together, produce differential output; when Op amp 1 pushes on one side of the load, Op amp 2 pulls on the opposite end. This complementary action results in more voltage swing through the load than a single-ended amplifier could provide working against immovable ground.

Another scheme, employed by Philips/Signetics, is shown in **Figure 2B**. This approach uses two identical op amps working in parallel with their gains set to equal values by internal feedback networks. The incoming audio is divided, then fed to the inverting input of Op amp 1, and to the noninverting input of Op amp 2. The resulting output signals, which are equal in amplitude and 180 degrees out-of-phase, feed opposite sides of the load.

Both configurations achieve the same outcome in slightly different ways. The scheme used by Motorola allows designers

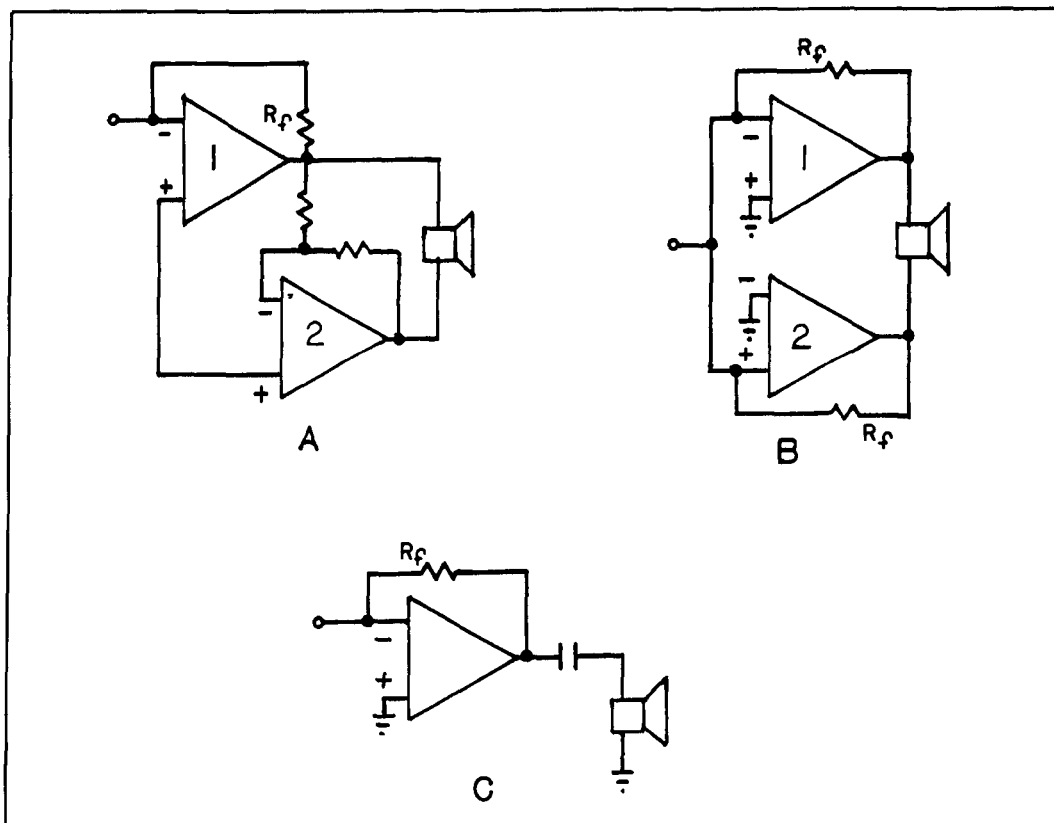


Figure 2. In (A), Op amp 1 drives one side of the load. Op amp 2 samples the output of Op amp 1 and delivers equal but inverted output to the opposite side of the load. In (B), Op amps 1 and 2 are set for equal gain but driven on their opposing inputs. Both produce differential output. (C) illustrates single-ended output with amplifier working against ground.

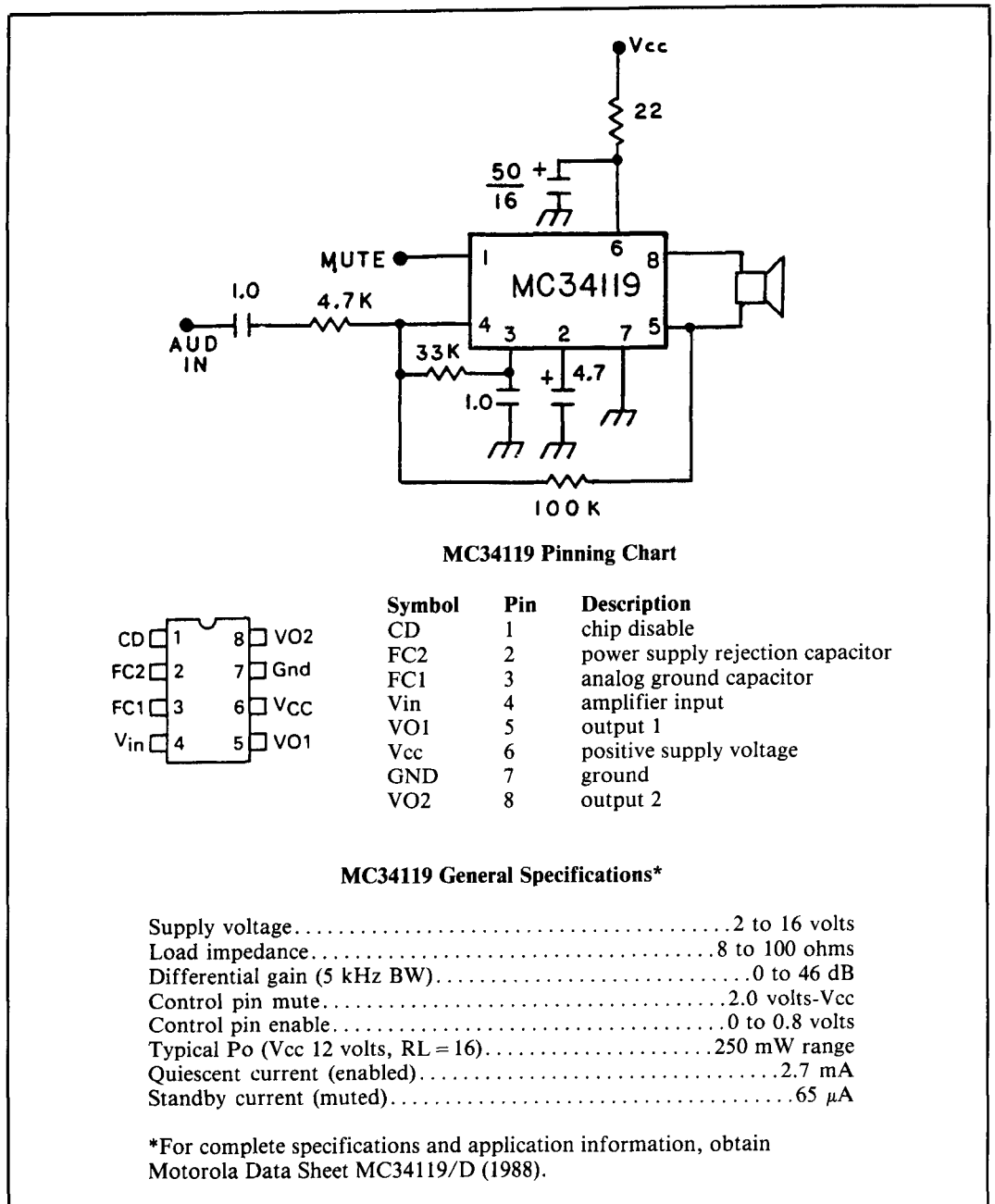


Figure 3. Technical specifications, pin outs, and practical circuit using the MC34119.

to tailor gain and frequency response of the amplifier externally, while the Philips/Sigmetics approach does not. On the other hand, the Philips/Sigmetics approach requires fewer external parts.

Other advantages of differential output

In addition to providing a greater output-voltage swing at low V_{cc}, chips designed for differential output typically require fewer external parts than their single-ended cousins. One reason is because the offset voltage

of both op amps are equal. This means you can tie each output to opposite sides of the speaker voice coil without DC blocking—and eliminate that big electrolytic capacitor used in single-ended designs. Philips application literature refers to this practice as employing a bridge-tied load, or BTL configuration.

Decoupling the amplifier from its voltage source is also easier when differential output is used. This is because any ripple created on the V_{cc} line will be twice the frequency of the signal you are amplifying rather than equal to it. This allows you to reduce

significantly the value of the Vcc decoupling capacitor.

Only one word of caution when feeding an external speaker or headphones with this type of amplifier; be sure to insulate both sides of the audio line from your chassis. If you mount a standard grounded-ring type jack directly to the front panel, you'll short the offset voltage of both op amps to ground.

The disable input: A new approach to standby mode

Eliminating DC blocking from the speaker line, and reducing Vcc decoupling, help differential audio chips to power up and power down more cleanly than their single-ended predecessors. However, many "new-age" audio chips go one step further—providing a special control function which makes shutdown or turn-on virtually silent and instantaneous. This feature may be called a remote disable, mute or gate function, or simply be referred to as a DC attenuator circuit. But the idea is the same; you can literally put your audio chip to sleep or wake it up in a matter of milliseconds via a small logic-level DC control input. This is especially good news when your project calls for a simple squelch circuit, a fast and silent T/R switch, or a built-in battery saver.

Exhibit 1, the Motorola MC34119 low-power audio amplifier

In my last column, the MC34119 appeared in a supporting role to the MC13135 "receiver-on-a-chip" FM receiver. In this issue, the MC34119 steps into the limelight as a quarterly device. This amplifier was originally designed for line-powered speaker phones—a demanding application where Vcc can vary widely and fall to as low as 2 volts under load. The "disable" or "gate" function was included as a convenient way to shut down the phone's speaker whenever the local microphone was keyed open. In addition to this somewhat specialized application, the MC34119 has found popularity with designers of other communication projects because it provides differential output and muting in a small, inexpensive package.

Technical specifications and a practical circuit employing the MC34119 are shown in **Figure 3**. This device is available in stan-

dard 8-pin DIP packaging (MC34119P), or in surface mount (MC34119D). It operates over the incredibly wide Vcc range of 2 to 16 volts, which means you can hook it up to almost any power source and it will play. Gain is adjustable from less than 0 dB to over 46 dB in voice-band applications by means of an external feedback resistor. The feedback network may also be tailored for customized roll-off or bandpass characteristics with some reduction in overall gain (differential gain = 36 dB). Audio output is specified as exceeding 250 mW into a 32-ohm load. In practical receiver circuits (i.e., Vcc = 12 volts, RL = 2.5-inch imported 8-ohm speaker), the chip delivers sufficient output for residential use—but probably not enough output for mobile or industrial environments.

The chip disable function is accessed via pin 1. Any time this input sees a "logic 1" state (2.0 volts or greater), the chip will be gated off. When the input is at "logic 0" (0.8 volt or less), the chip activates. For transceiver applications, you would normally key the gate with the +T line to mute the amplifier during transmit. If you don't intend to use the disable function, Motorola suggests setting the input level to "logic 0" by grounding pin 1 rather than by leaving the pin open.

No special pc board layout considerations are indicated for the MC34119 beyond normal analog audio practices. There's no need for the "snubber" circuit used on many single-ended designs to prevent high-frequency oscillation. However, Motorola does advise that speaker leads should be limited to a few inches in length, and even short speaker wires should be tightly twisted together. Finally, in some applications, you may find enabling the chip after an extended period of shutdown produces an annoying "pop" in the speaker. If this occurs, add a 33-k resistor between pins 3 and 4 (see Motorola application note AN1081).

The MC34119 has been on the market for some time, and should be available from most Motorola distributors. To obtain the MC34119, contact your local Motorola sales office. Data sheets and application note AN1081 may be obtained by calling (800)521-6274 and placing your request.

In addition to the MC34119, Motorola has several other receiver-type audio chips available, including the powerful little MC13060. This tiny 8-pin SMT package is a single-ended design without a gate, but it can deliver over 2-watts output under the right operating conditions (Vcc = 32 Volts, RL = 32 ohms).

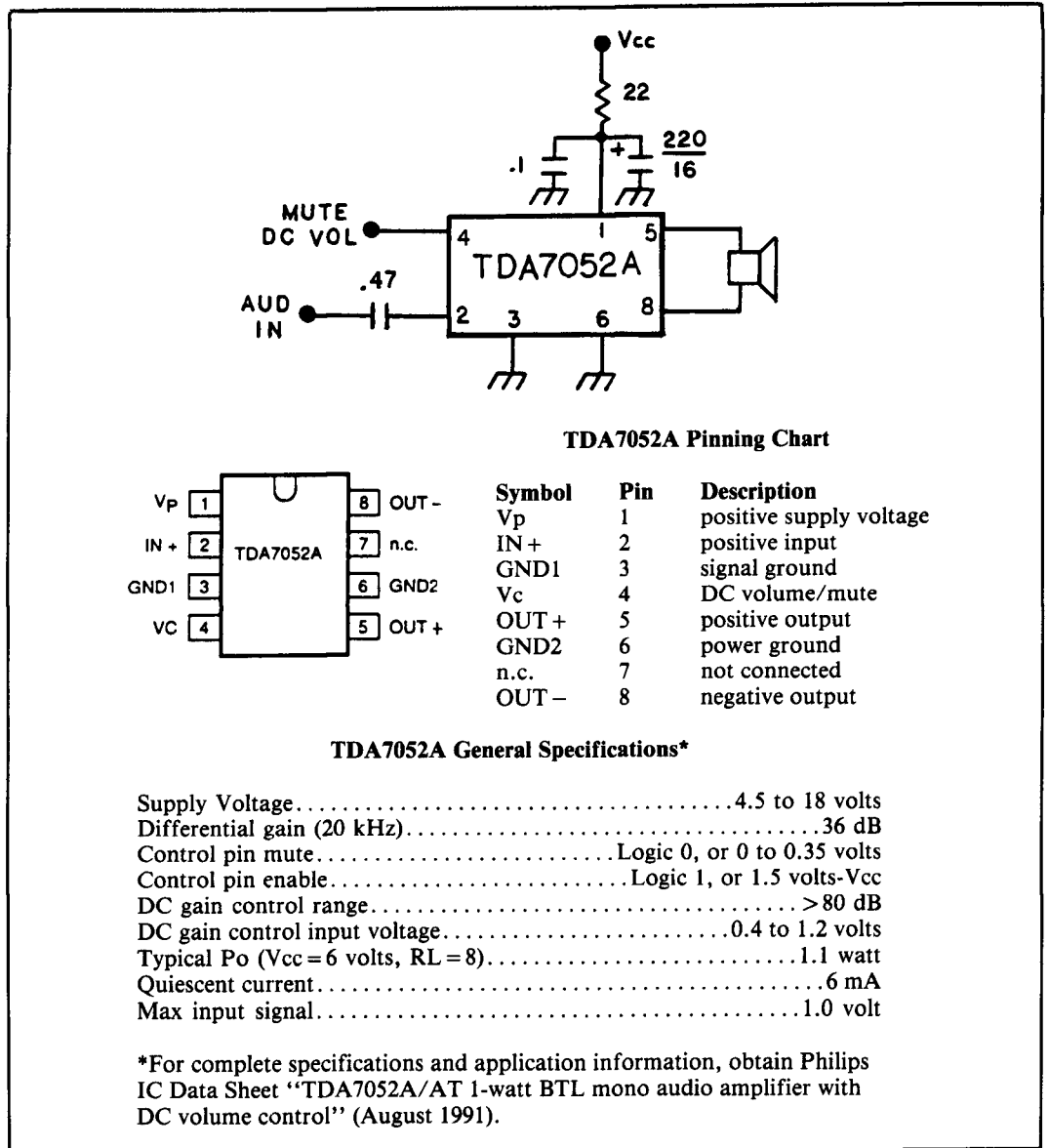


Figure 4. Practical circuit, pin outs, and technical specifications for the TDA7052A.

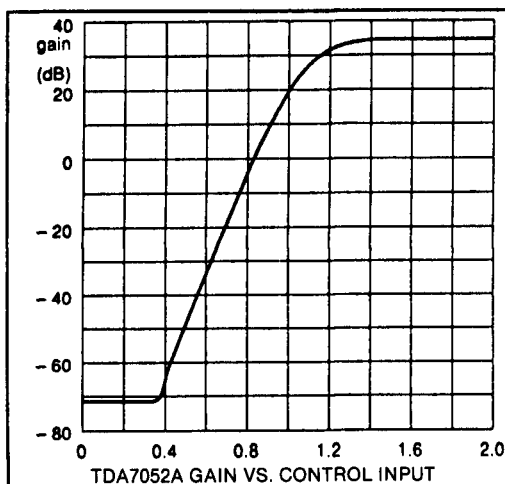


Figure 5. Gain of the TDA7052A as a function of DC control-voltage input to pin 4.

Exhibit 2, Philips TDA7052A 1-watt audio amplifier

The TDA7052A is a very new device which has only become available to Signetics distributors within the past month or so. It's a 1-watt differential output-type audio amplifier that was designed primarily for TV receivers and monitors. However, the TDA7052 has a long list of features that also make it ideal for communication-type radios.

The TDA7052A has all of the basic features we've discussed so far, plus a few more. For example, it delivers a bit more power, which is an obvious plus in noisy surroundings. Other features include short-

Type No.	Po(W)	Vcc	Package	Comments
TDA1015T	0.5	3.6 to 18	SO8	Preamp/Amp stages
TDA7050	150 mW	1.6 to 6.0	DIL8	DC Vol/mute
TDA7050T	150 mW	1.6 to 6.0	SO8	DC Vol/mute
TDA7052	1.0	3.0 to 18	DIL8	No peripheral parts
TDA7052A	1.0	4.5 to 18	DIL8	No parts; DC Vol/mute
TDA7052AT	0.5	4.5 to 18	SO8	No parts; DC Vol/mute
TDA7056	3.0	3.0 to 18	SIL9MP	No peripheral parts
TDA7056A	3.0	4.5 to 18	SIL9MP	No parts; DC Vol/mute

SO8: 8-pin dual in-line surface mount
DIL8: 8-pin dual in-line
SIL9: 9-pin single in-line with tab

Table 1. Philips/Signetcs low-power audio amplifiers

circuit proof outputs, silent shutdown, and a need for very few external components (the feedback network is internal). A practical circuit and technical specifications are provided in **Figure 4**.

Circuit disable and DC volume control

The mute circuit in the TDA7052A has some unique features that distinguish it from the MC34119. While the amplifier portions of the chip are preset for maximum gain, the TDA7052A employs a shared preamplifier section that doubles as a wide-range logarithmic gain control and signal gate. Signetics applications literature refers to this feature as "DC gain control."

Referring to **Figure 5**, note that when DC control input is at "logic 0" (0.4 volts or less), attenuation through the chip is at maximum. Between 0.4 and 0.8 volts, this attenuation level decreases from as much as -72 dB to zero. As control input increases from 0.8 to 1.2 volts, the chip begins to amplify from unity gain to +36 dB gain. At "logic 1" (2.0 volts or more), amplification is solidly established at full gain. Note that this is the exact opposite of the MC34119, which is disabled at "logic 1" and activated at "logic 0." The logarithmic DC gain-control feature in the TDA7052A not only provides a relatively soft shutdown during muting (no abrupt transients), but also opens up intriguing possibilities for AGC or audio output limiting in simple receivers.

A family of audio amplifiers

The TDA7052A is only one member of a family of Philips/Signetcs low-power audio ICs that may be of interest to designers and builders. For example, the TDA7052 (plain vanilla) is identical to the "A" version, except it doesn't provide the DC gain and mute function. Several other family members are listed in **Figure 6**. These are suited for applications ranging from driving cellular telephone headsets to powering speakers in noisy mobile environments. Some amplifiers have muting capability while others do not. A complete catalog of Philips/Signetcs audio power amplifier ICs with outputs ranging from 150 mW to 100 watts is available by calling (800)227-1817 and asking for the "Audio Power Amplifier IC" application book. According to Signetics marketing representatives, you may purchase TDA-series chips in small quantities from Digi-Key Electronics.

Conclusion

I hope this discussion of "new-age" low-power audio chips inspires you to give them a try. I suspect we'll all be using this type of device in the various construction projects, kits, and commercial products that emerge from our kitchen tables and places of employment in the future. In the mean time, if you wish to share your particular application of a quarterly device with other readers, please write (care of *Communications Quarterly*) and let me know.

TECHNICAL CONVERSATIONS

Roy Lewallen and Dave Barton shared these comments with us regarding Dave's article "The Wonderful Transformer Power Splitter" (Summer 1991). We thought we'd pass them along to you. Ed.

Dear Editor:

Congratulations on a fine magazine! *Communications Quarterly* is living up to its promise of being a quality technical publication. But it just hit a sore point.

This letter is a plea to you to take better advantage of the extremely knowledgeable and qualified people on your Editorial Review Board. That you're not using them to full advantage is shown by the article in the summer 1991 issue entitled "The Wonderful Transformer Power Splitter." While well-written and generally accurate, it promotes the concept of feeding phased-array antennas with power splitters, and the mistaken idea that some integer ratio of powers should be fed to array elements. The power splitter discussed in the article won't provide integer power ratios as claimed except in very special cases and, in any event, doing so won't produce expected patterns in arrays of a few elements. I've worked hard for years to dispel these mistaken ideas, and was feeling some success, when I saw them again—in a magazine which enjoys high and increasing credibility. Ouch!

I know, *I know*, that neither Forrest Gehrke nor Walt Maxwell saw this article. They never would have let these mistaken notions past. Yet they're shown on your Editorial Review Board. Please use them!

Keep up the good work with the magazine, but—one more time—please use your review board!

Roy Lewallen, W7EL
Beaverton, Oregon

P.S. My references are: G. Hall, Editor, *The ARRL Antenna Book*, 16th edition, page 8-12ff, "The Wilkinson Divider;" and the excellent series on phased arrays in *Ham Radio*, 1983-1984 by Forrest Gehrke.

Dear Editor:

I'm responding to Roy Lewallen's letter about my article in the summer 1991 *Communications Quarterly*. He graciously copied me. Clearly, I hit a sore point and that wasn't intended. Neither did I intend to promote the use of power splitters general-

ly. The article's purpose was to explain a little about broadband splitters, their uses, and how to build low-power ones.

It isn't easy, especially in a short article, to show exactly when and how something should be used. Like nearly everything, splitters are useful in some situations but inappropriate in others. I would not (and did not) claim splitters should be used in every antenna array. But they *are* useful in some. Please consider two cases.

Case 1: a two-antenna narrowband array, such as a stack of two Yagis. The conventional feed uses a quarter-wave (or three-quarter wave) matching section (usually coax) from each antenna to a common feedpoint, where the two matching sections are themselves fed in parallel. This arrangement deserves its popularity. By forcing equal voltages one quarter (or three quarters) of a wavelength from each antenna's feedpoint, it forces *equal currents at the feedpoints*—exactly what's wanted. This inherently narrowband method is the best approach available for stacked monobanders. I have no argument with Roy, or any of his cited references, within that context.

Case 2: a stacked pair of broadband antennas (log periodics or even tribanders). Here you can't use resonant matching sections. You could run equal lengths of coax to a common feedpoint and just accept the mismatch. You could match the common point with a broadband transformer. But, except at certain frequencies, you won't be forcing equal currents in the antennas. In fact, at frequencies where the individual feedlines are an integer number of half-waves, you'll force equal feedpoint voltages instead, resulting in feedpoint currents exactly as different as the feedpoint impedances—and ground reflections or other non-symmetrical effects may make them quite different. A broadband power splitter would keep the currents *more nearly equal* than a simple parallel (or series) connection—over a broad range of frequencies. No, the splitter can't guarantee equal feedpoint currents. But, the current imbalance variation over a frequency with a splitter, expressed in dB, will be half that of a simple parallel or series connection.

Does a splitter waste reflected power?

(Continued on page 104)

Joseph J. Carr, *K4IPV*
P.O. Box 1099
Falls Church, Virginia 22041

RADIO RECEIVERS OF THE PAST

From early detectors to super hets

Although I'm thoroughly excited by modern technology, I'm also more than a little enamored of early radio apparatus. One of my "sub-hobbies" in amateur radio is collecting antique radio receivers, both amateur and broadcast, as well as visiting the various antique radio museum displays (see **Photo A**) of early equipment. In this article, I'll take a look at the basic forms of radio receivers from the earliest time up to the development of the now ubiquitous superheterodyne. Some receivers are broadcast models, but their designs paralleled those of ham receivers of the same era.

Early receivers

The very earliest radio receivers aren't even recognizable as such by today's standards. One early 19th century "receiver" consisted of a magnetic induction coil placed in proximity to a compass. Deflection of the compass needle provided an indication of a radio wave from a nearby spark-gap transmitter. Range was limited to only a few meters—from one laboratory bench to another or, as was true of radio pioneer Guglielmo Marconi, across the backyard garden. Other early detectors included sensitive spark-gaps connected to resonant



Photo A. Portion of the antique amateur radio equipment museum in the lobby of the ARRL headquarters building (Newington, Connecticut).

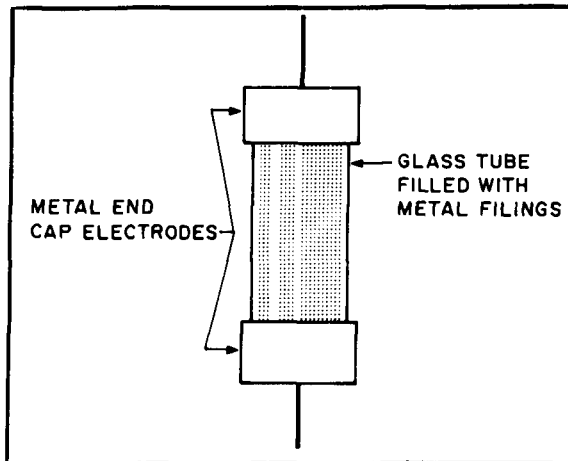


Figure 1. The Branley coherer was an early form of radio signal detector.

wire loops (Hertz, 1887) and telegraphic electromechanical tappers.

The first attempts at improving radio receivers involved finding better detectors. A device that will do the job of detecting radio signals will exhibit a nonlinear impedance over cyclical excursions of the applied signal. The range of telegraph clicker detectors was extremely limited—hundreds of feet at best—so alternatives were sought. Earphones (which require only a small amount of signal power to operate properly) replaced the clicker, while devices such as the Branley coherer (Figure 1) and liquid barretter were used for the detector. The coherer is now attributed to Branley, but it was originally invented in slightly different form by a professor named Hughes in 1878. Unfortunately for Branley, Marconi adopted the coherer and patented it himself, leaving Branley bitter for many years to come.

The coherer shown in Figure 1 consisted of a cylindrical glass tube filled with metal filings, usually iron. The radio signals from the antenna were coupled to the coherer. The metal filings provided the nonlinear impedance needed for detection. Unfortunately, the signals tended to magnetize the metal

filings in the coherer, causing them to adhere to each other. The recovered signal soon became weak and distorted, until mechanical stimulation restored the coherer to proper operation. Consequently, a tapper or decoherer was often built into the receiver to reset the detector. When the output began to distort or dropped in sensitivity, the operator would use the tapper to “reset” the coherer.

Crystal sets

It was soon discovered that certain natural minerals, such as the bluish-gray crystalline lead ore galena (lead sulphide or PbS), had a property that allowed them to detect radio signals. Galena can pass current in only one direction if the correct points on its surface are found. We now know that galena forms a natural PN junction diode at certain points on its surface. These crystals are a naturally occurring semiconductor diode, and can detect both radiotelegraph and radiotelephone signals. Because galena is a cubic crystal, the galena detector was called a crystal detector, and radio receivers using them were called crystal radios or crystal sets.

Figure 2A shows the construction of a crystal detector. The galena crystal was set into a cup and held fast by setscrews or a spring clip. The cup forms one electrode. Because the rectification property needed for radio detection is only found at certain spots on the surface of the crystal, a cat’s whisker probe (the other electrode) was used to find the correct spot. Because it was often difficult to find the correct spot for the cat’s whisker electrode, undue vibration of the radio could provoke . . . errr . . . justified hostility on the part of the radio operator.

Crystal set sensitivity

The crudest form of antique crystal set radio receiver is shown in Figure 2B. A long wire antenna is connected to one side of the crystal, while a ground is connected to the other. A pair of high-impedance earphones receive the demodulated radio signal. Even today, a very crude crystal set can be fashioned by using a germanium PN junction diode like the 1N34, 1N60, or ECG-109, shunted across the earphones (Figure 2C).

The crude crystal set of Figure 2 works well only with relatively strong local signals. Improved sensitivity was obtained with circuits such as Figure 3A. In this crystal set, the RF signal flowing between antenna and ground is developed across an inductor (L). This design resulted in a stronger available

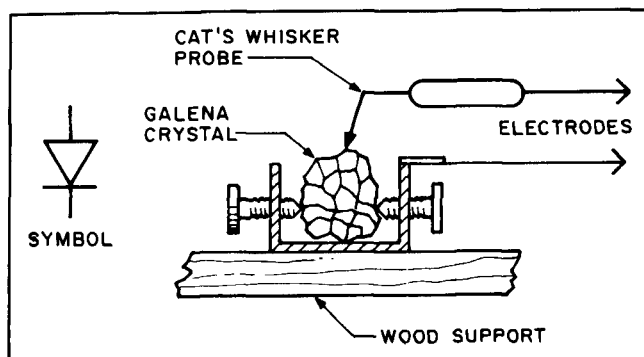


Figure 2A. Cat’s whisker crystal detector.

signal for detection. The crystal is connected to a sliding tap on the inductor coil. This arrangement served two basic purposes. Perhaps the most important is that the tap allows the low crystal impedance to be matched to an impedance point on the coil. Maximum power transfer always occurs in electrical systems when the source and load impedances are matched.

A further refinement (Figure 3B) made the coil into an RF transformer—the addition of a small winding (L1) to the main coil (L2). Using transformer terminology, L1 is the primary winding and L2 is the secondary winding. The antenna and ground circuit is connected to the small coil (L1). When RF current flows in the primary winding, it sets up a magnetic field that induces a signal in the secondary winding (L2). Because there are more turns in the secondary than in the primary, the voltage across the secondary is higher than the primary voltage received from the antenna.

Even in the early days of radio, interference mounted rapidly, so some means was needed for selecting signals of different frequencies. The earliest crystal sets could select desired signals and discriminate against unwanted signals, only by virtue of antenna dimensions. A resonant antenna (for example, a 1/4 or 1/2 wavelength) naturally works better on its resonant frequency than on other frequencies. Nonetheless, the antenna also will pass all frequencies to some extent.

The use of the antenna to select signals is woefully inadequate. It was found that combining an inductor with a variable capacitor formed a tunable resonant circuit that could select one radio frequency (or a narrow band of frequencies), while attenuating frequencies away from the resonance point. The circuit in Figure 4A is the simple version, while that in Figure 4B offers a matched impedance to the detector diode.

Enter the vacuum tube

The Fleming valve was the first diode vacuum tube. The tube's significant property was that it passed current in only one direction. So, the Fleming valve was suited to service as a radio detector (Figure 5). This circuit is essentially a crystal set, but has a vacuum diode as the detector, for the galena crystal. A rheostat in the filament circuit controlled sensitivity. Although the vacuum tube represented a step forward, it was expensive in the early years and it wasn't always clear that the tube was superior to the natural crystal.

Although the various crystal sets were a

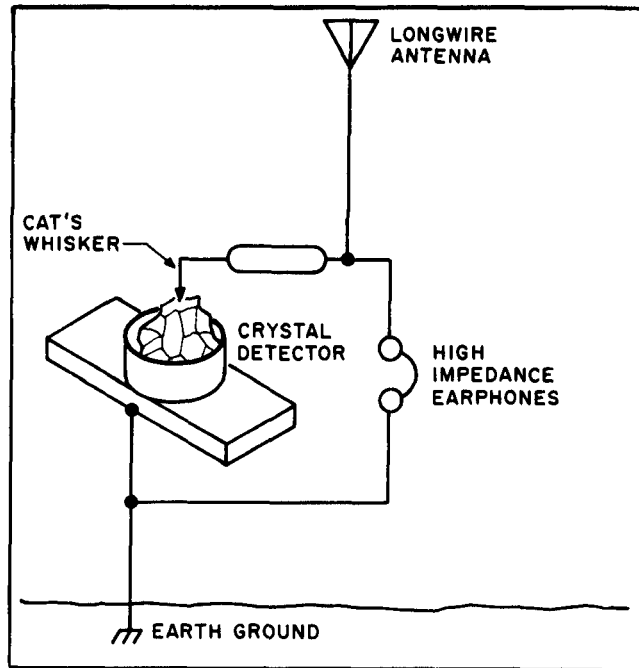


Figure 2B. Crude, untuned crystal set based on the galena crystal.

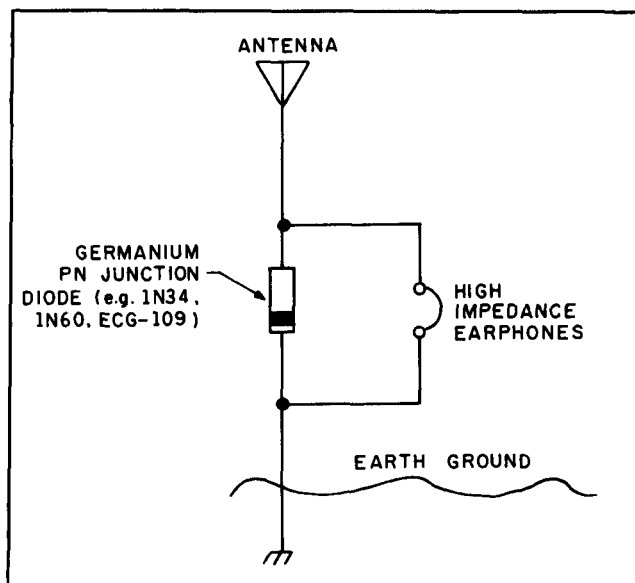


Figure 2C. Modern equivalent of Figure 2B uses germanium diode (1N34, 1N60, etc.) to replace the galena crystal.

great improvement over the coherer receivers, they still suffered badly on weak signals. There were many cases where a signal was strong enough to overcome natural losses in the crystal, but was too weak to drive the earphones to audible levels effectively. In 1906, a new invention by Dr. Lee DeForest greatly improved radio receivers. DeForest added a control grid to the diode (two electrode) vacuum tube previously invented by Fleming in England. Fleming had based his work on a discovery made in the 1870s by Thomas Edison. The grid was a third

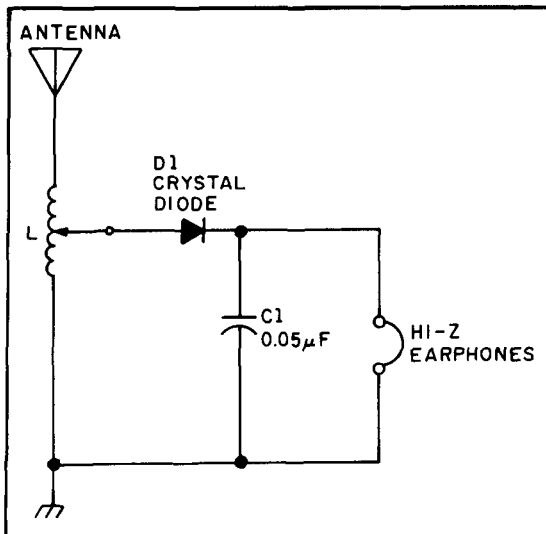


Figure 3A. Impedance matched crystal set using a slider "tuned" inductor.

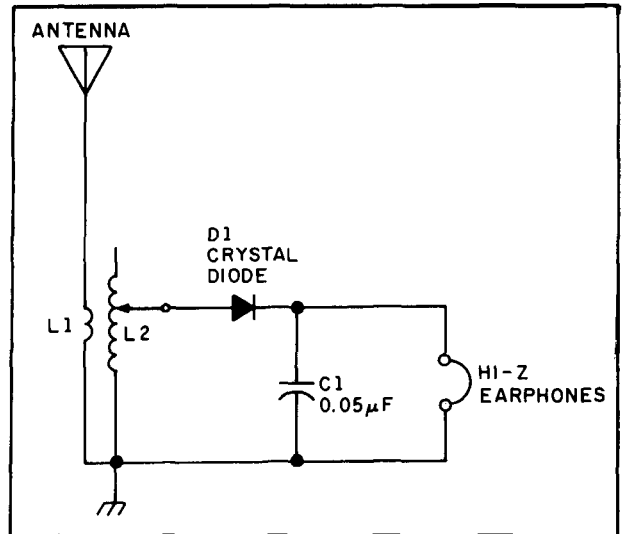


Figure 3B. Addition of transformer primary increases sensitivity.

element in the tube, so these tubes were called triodes (three electrodes). The advantage of the triode was that it allowed the amplification of weak signals. The earliest triodes worked only at low frequencies, but could amplify audio signals. Though the earliest tubes were inefficient and costly, the De-Forest triode was often used as a post-detection audio amplifier (Figure 6). The amplified audio crystal sets were a great improvement over the nonamplified versions. **Photo B** shows an amplified crystal set; **Photos C** through **D** show early vacuum tubes.

Regenerative detector receivers

Another limitation on earlier designs was that both vacuum tube (diode) and galena crystal detectors were inefficient, especially on weak signals. But a Columbia University (New York City) engineer named Edwin

Armstrong invented a startlingly sensitive detector based on the principle of feedback. Called the regenerative detector (Figure 7), Armstrong's circuit coupled a little of the RF amplifier output signal back to the input circuit. When the degree of coupling was adjusted properly, either by a series-connected variable resistor ("X" in Figure 7) or mechanical proximity, the circuit would be just on the verge of oscillation. An input signal would force the circuit even closer to oscillation, resulting in the conditions needed for detection.

Unfortunately, because maximum sensitivity occurred at the point of oscillation, regenerative receivers oscillate easily. The radio would then become a little transmitter, and cause interference to other receivers in the vicinity. Some early amateur transmitters were Armstrong oscillators, which were essentially the same as a regen-

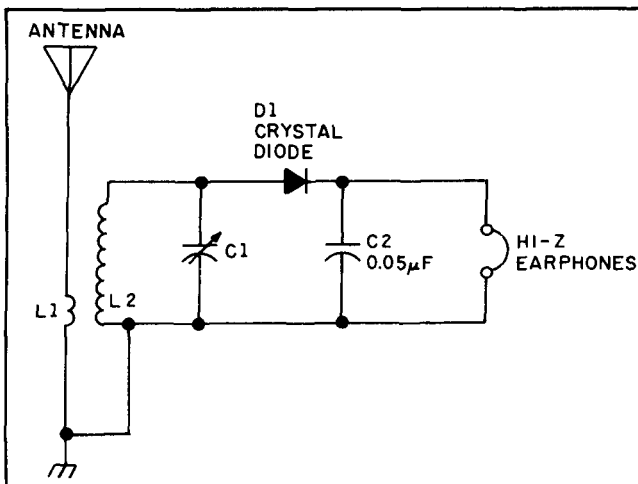


Figure 4A. Simple tuned crystal set.

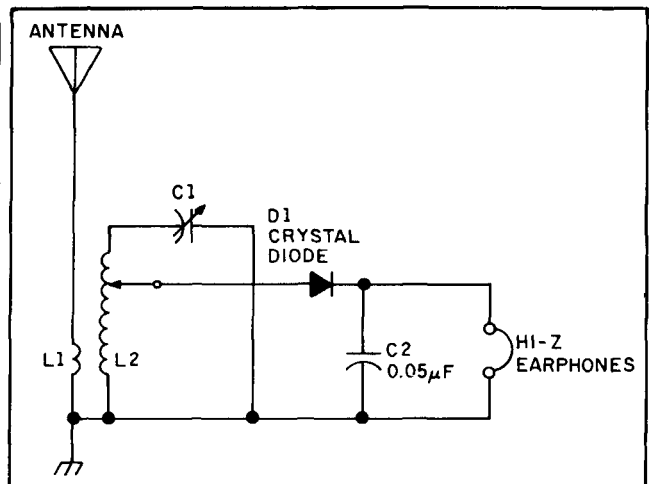


Figure 4B. Impedance-matched version of simple tuned crystal set.

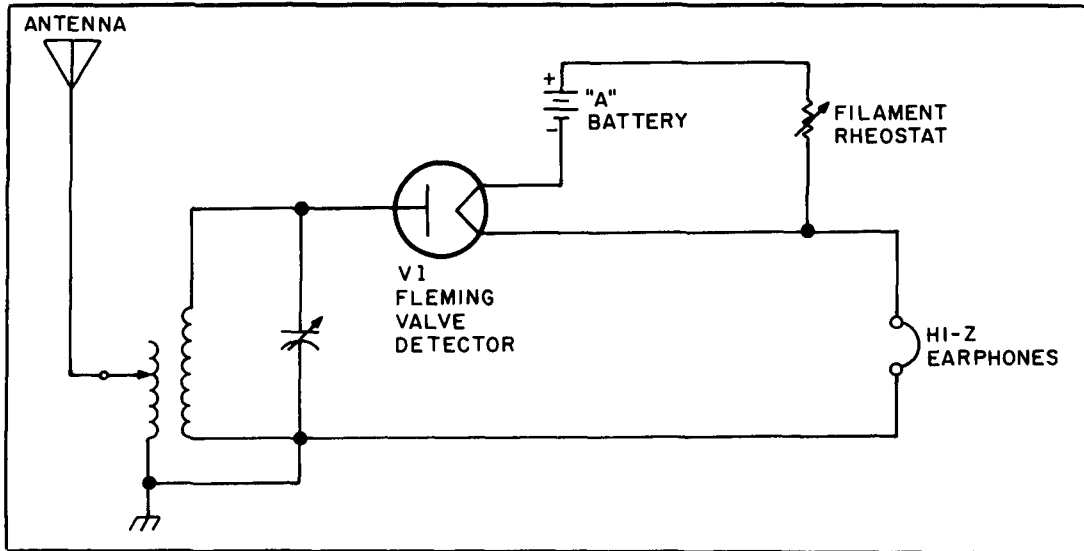


Figure 5. Fleming "valve" (diode) tube detector replaces the galena crystal.

erative receiver detector but deliberately allowed to oscillate. By the mid-1920s regenerative radios were no longer made by the major manufacturers. Only small manufacturers and kit suppliers offered the regens commercially (although amateurs still built many of these sets).

Tuned radio frequency (TRF) receivers

Because vacuum tubes were refined enough to amplify radio frequencies as well as audio, they were rapidly pressed into service as radio frequency amplifiers (Figure 8). If tuned LC circuits were used on at least

the input of the tube (they were also used on the output of the tube circuit when instability could be controlled), then the amplifier would selectively amplify only the frequencies of interest. A receiver with such a tuned RF amplifier ahead of the detector was called a tuned radio frequency (TRF) receiver.

Cascading two or more RF amplifiers (Figure 9) produced the classic design usually called "TRF." It offered much better sensitivity and selectivity than single stage designs. However, there was a cost inherent in the new cascade designs. Either several tuning knobs were required (one for each variable capacitor; see Photos F and G), or all the variable capacitors had to be "gang-

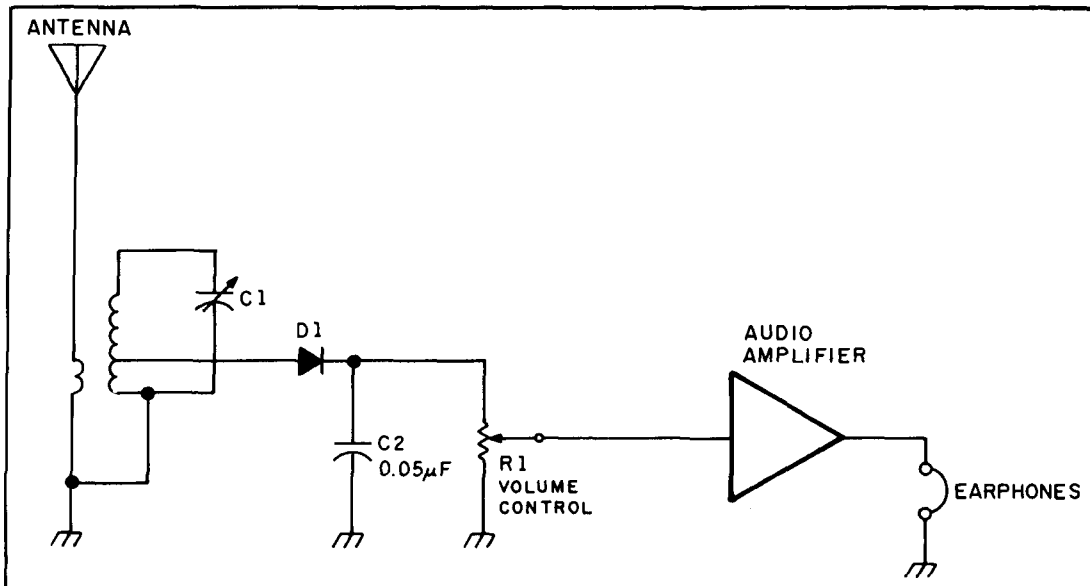


Figure 6. Amplified crystal set used a DeForest triode to amplify the audio signals at the output of the crystal set.

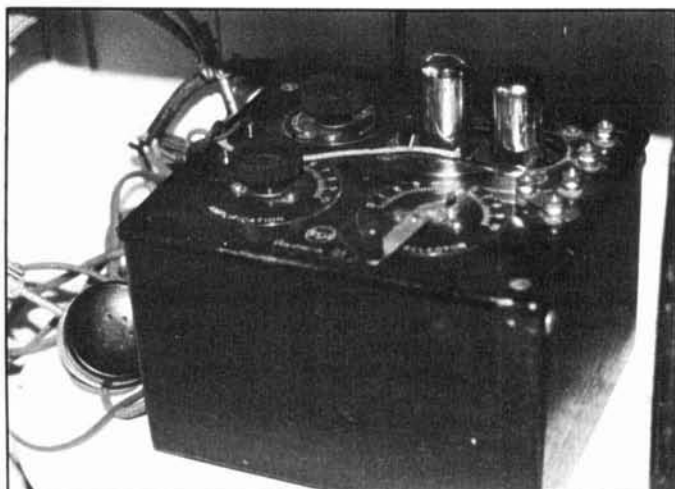


Photo B. Early amplified crystal set.

ed" together on a common tuning shaft to form a "single-knob tuning" radio receiver (Photo H). Also, unneutralized triode RF amplifiers tend to oscillate on or near the resonant frequency of the LC tuned circuits. When such instability occurred, the oscillation signal heterodyned with the received RF signal (or with oscillations from other stages) to produce a howling shriek in the earphones. In many households, only one member of the family had a sufficiently deft touch to adjust the classic TRF radio correctly. It was also true that dial settings were unreliable, and stations often could

not be relocated at the same spot on the dial because of circuit instability.

Neutrodyne receivers

The serious instability of the TRF radio was reduced in part by a modified version of the design called the neutrodyne receiver. This design was patented by Professor Hazeltine of Stevens Institute of Technology. The neutrodyne design was based on the knowledge that improved stability resulted when a small amount of degenerative or negative feedback was introduced to counter the regenerative or positive feedback that was inherent in the TRF design (the positive feedback results from interelectrode capacitances within the vacuum tube, as well as unintended coupling external to the tube).

Hazeltine's neutrodyne receivers proved very stable, and for the first time, dial calibrations had practical meaning even on low-cost receivers. Station dial settings were actually repeatable. Between 1924 and 1927, companies such as F.A.D. Andrea (Model FADA-160) and Freed-Eisemann (Model NR-5) produced and sold many neutrodyne receivers.

Broadcast-band receivers were difficult to produce, and shortwave receivers even more so. Because of the prices, only a few people could afford radio receivers, and most hams were forced to build their own. At \$300 to \$700, models cost several month's salary for

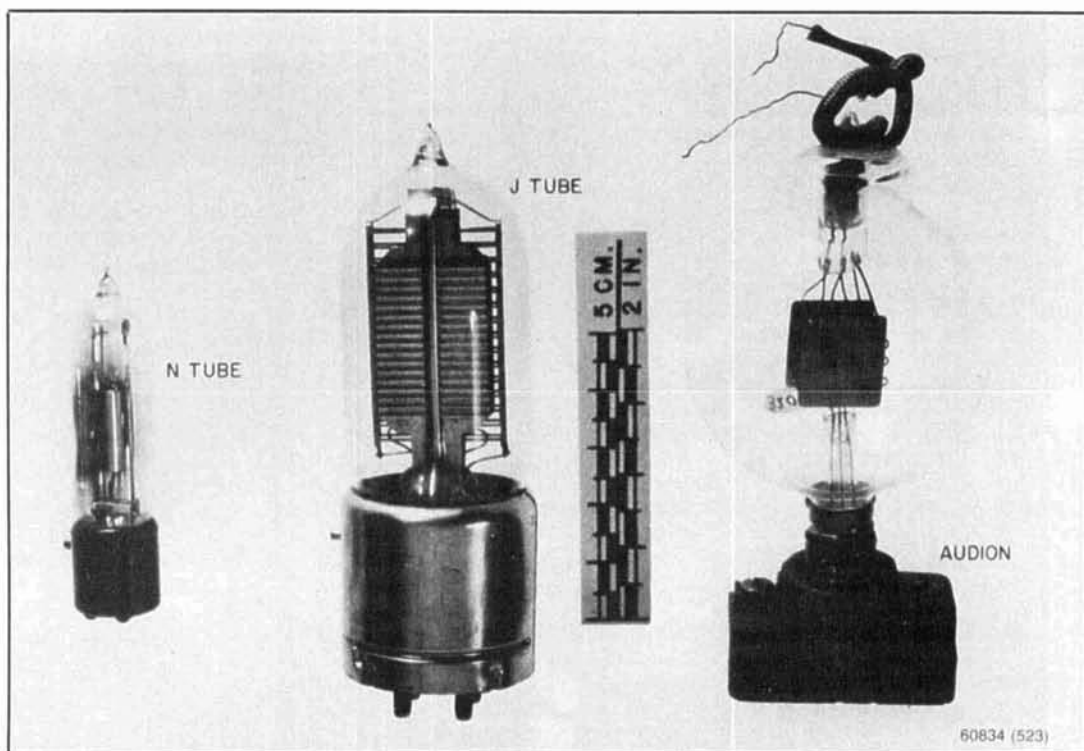


Photo C. Early vacuum tubes used in Navy radio receivers (Photo Naval Research Laboratory, Washington, D.C.).

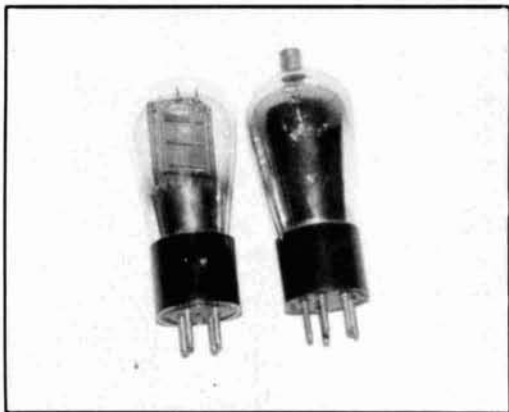


Photo D. Two early receiver tubes (1920s vintage).

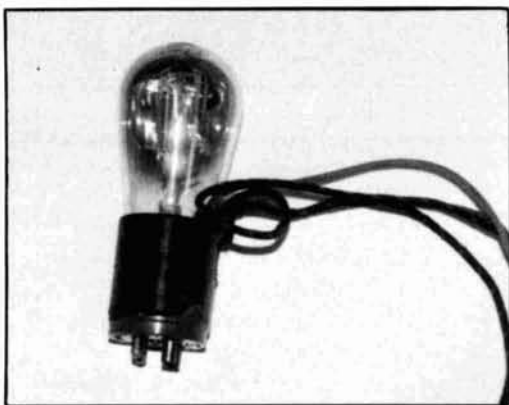


Photo E. "Long pin" tube with special adapter to make it fit into a "short pin" socket (circa 1926).

a typical 1920's worker. In 1919, vacuum-tube broadcast radios carried price tags on a par with small houses, but within a few years they were more affordable. By the 1930s, radios were within the reach of large

numbers of families, as the mass market era began. It was at this time, that increasing numbers of amateurs started buying receivers ready-made from companies like Hallcrafters, National, Hammarlund, and others. Still, receiver construction projects were popular in ham magazines of the era. Reprints of early shortwave receiver projects can be found in the *1934 Official Shortwave Radio Manual* (Lindsay Publications, Inc., Bradley, Illinois 60915).

Second generation TRF radios

Starting about 1927, radio tube manufacturers offered tubes with a fourth element called a screen grid. Much of the instability (oscillations) seen in triode tube circuits is attributable to the interelectrode capacitance between the cathode-grid and grid-plate elements. By placing a screen grid between the control grid and anode, the tube makers effectively reduced the interelectrode capacitance to a point where it could almost be ignored. The tetrode tube led to a type of radio design called the second generation TRF. These sets were produced between 1927 and 1932, and were a somewhat low-cost alternative to the expensive superheterodyne radios also on the market at that time.

The superheterodyne

The old TRF radios were a dog to tune, and emitted a shrieking cacophony of howls and screams if improperly adjusted. The new TRF designs were better than the old designs, but they still suffered, at least

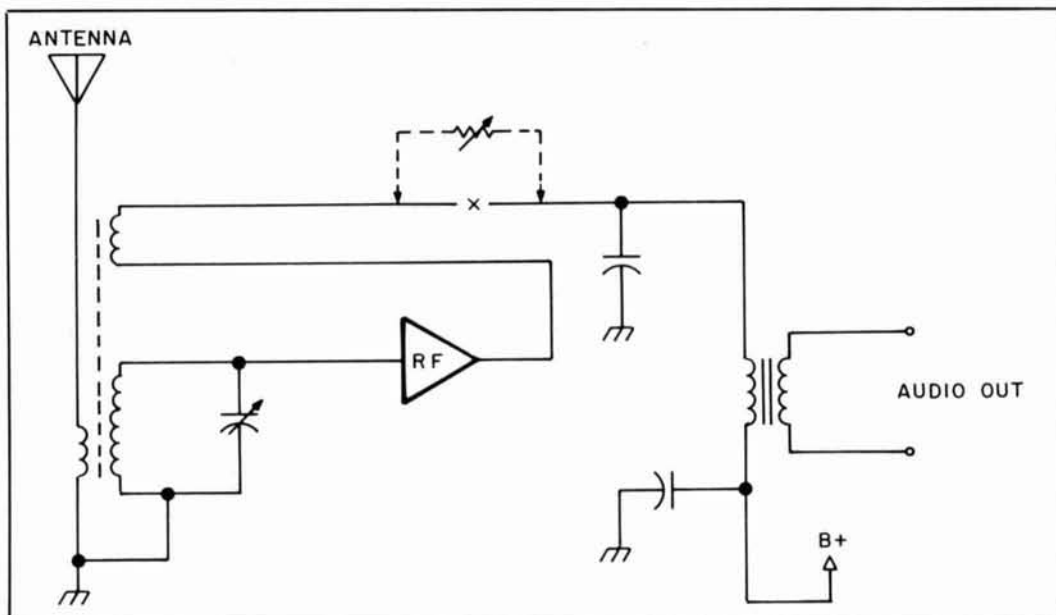


Figure 7. Armstrong's regenerative detector used a feedback "tickler" coil to produce regeneration.

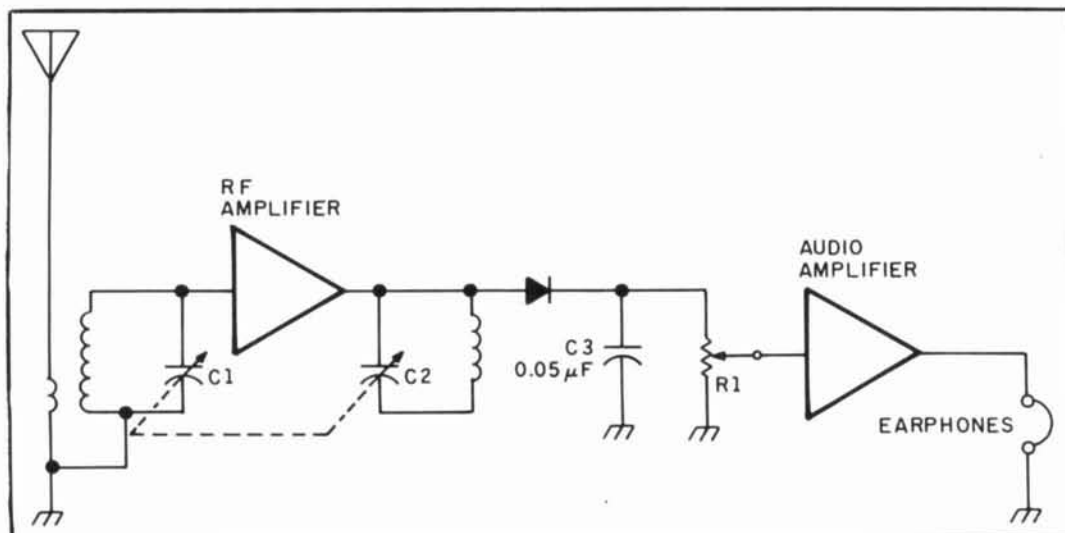


Figure 8. Single-stage tuned radio frequency (TRF) receiver.

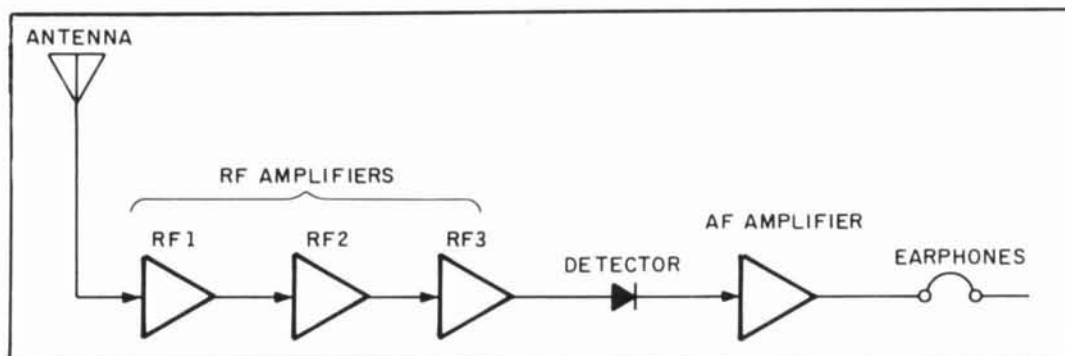


Figure 9. Cascade multi-stage TRF radio receiver.

somewhat, from the defects of other TRFs. As he would do several times over, Professor Edwin Armstrong came up with a fundamental invention (1920) that solved the problem. The new Armstrong receiver, dubbed the superheterodyne (the “super” probably came from the “marketeers” rather than the engineers), is still the design of choice today. Although a single integrated circuit (IC) can replace the several vacuum tubes used in the 1920 designs, the essential principle is the same.

The first commercial superhets were produced by RCA in 1924 (Model AR-812), and later as the Radiola Super VIII. A story that circulated among radio buffs concerning the superhet claimed that Armstrong, who was then affiliated with Columbia University in New York City, invited David Sarnoff to his laboratory one evening to see a new radio. The superhet was so sensitive and selective that Sarnoff—a visionary himself (among other things that are said of him)—almost salivated over the sealed

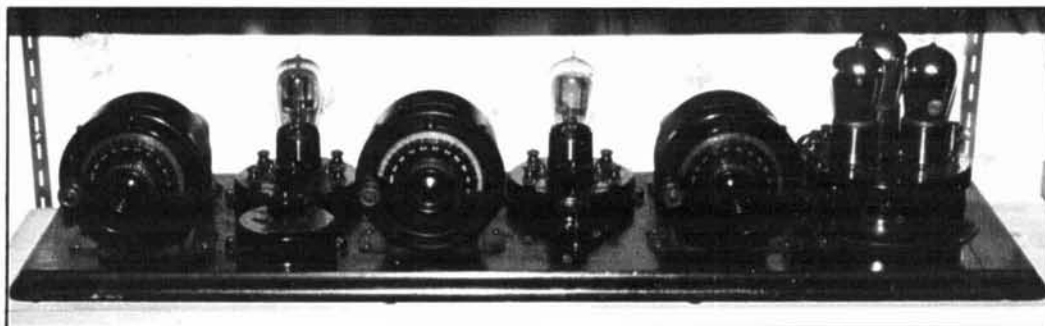


Photo F. Breadboard construction, TRF radio (early 1920s).

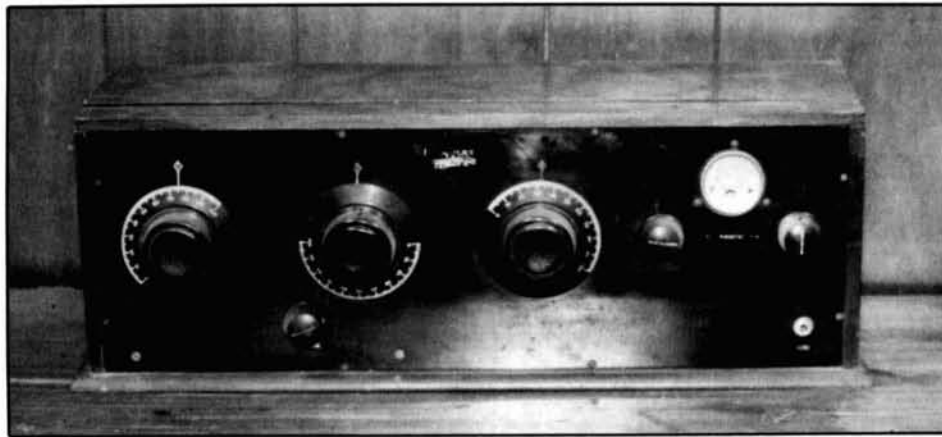


Photo G. Early 1920s TRF receiver with three tuning knobs.

wooden box. According to this possibly apocryphal story, Armstrong wouldn't reveal the secret of the box until Sarnoff paid for it.

The intermediate frequency

The principal defect of TRF designs was the instability of the RF amplifiers, especially high-gain cascade amplifier chains. It was this problem that the superhet solved nicely. Still, one could build such amplifiers for only a single frequency and achieve good stability. Variable-frequency RF amplifiers would almost invariably oscillate—at least on some frequencies. The variable-frequency TRF radio was either very complicated or very unstable. Armstrong's great idea, and the basis for the superhet design, was that he redistributed the amplification and selectivity to one frequency (called the intermediate frequency or IF). All received frequencies were converted to this one fre-

quency, where a very stable high gain amplifier could process them.

Figure 10 shows the basic "superhet" block diagram. The key to superhet operation is the conversion of the RF signal (frequency RF) to the intermediate frequency (IF). This job was done by nonlinearly mixing the RF signal with a signal from a local oscillator operating on frequency LO. The frequency LO can be above the RF frequency, or below it. The oscillator signal is produced inside the receiver. The main tuning dial of the superhet receiver is connected to the capacitor that tunes the local oscillator.

When two frequencies, like RF and LO, are nonlinearly mixed, the output of the mixer will contain at least four frequencies: RF, LO, RF + LO (sum), and RF - LO (difference). The IF can be either the sum or the difference frequency, although for practical reasons at the time only the difference frequency from the mixer was used. Thus, the mixer - LO stage (sometimes

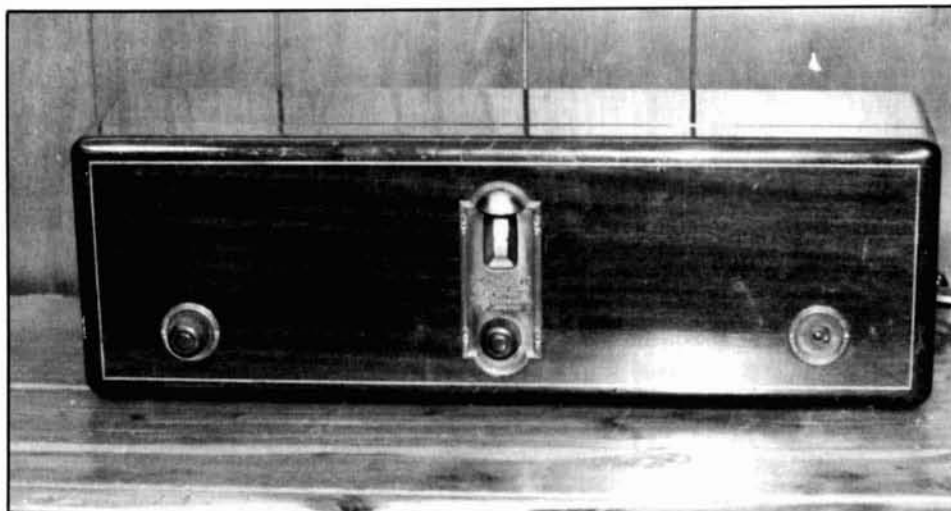


Photo H. Late 1920s TRF receiver with single knob tuning.

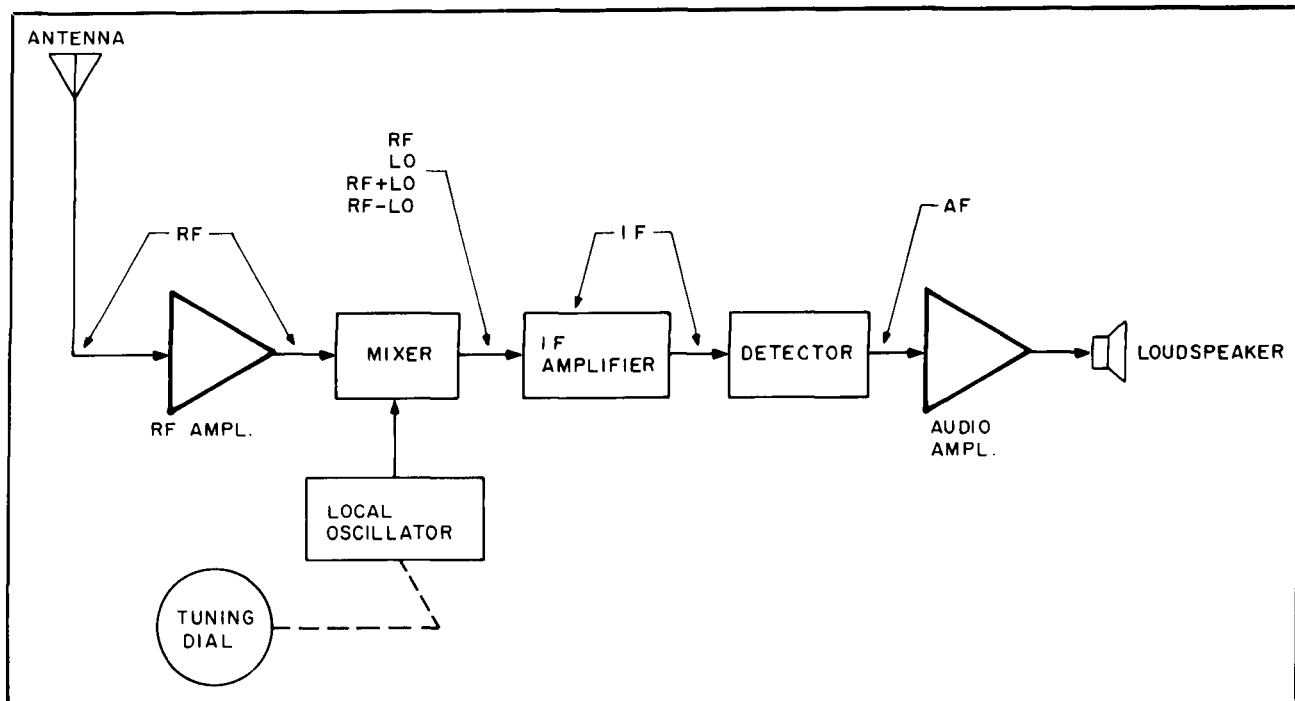


Figure 10. Superheterodyne receiver block diagram.

called either the first detector or converter stage) converts the RF frequency of the incoming signal to the lower IF frequency (which equals $RF - LO$). Incidentally, modern superhet receivers can use either the sum or the difference product of the mixer, and many shortwave receivers use the sum instead of the difference frequency. In Armstrong's time, however, using the sum frequency was often too difficult given the existing technology.

The Preselector

Many superheterodyne receivers use an RF amplifier ahead of the mixer. This stage was sometimes called the preselector. It serves a couple of different functions, even though it provides only a small amount of gain. First, it tends to unilaterize the receiver. That is, it allows signal to flow in only one direction—from the antenna into the radio. Signals inside the radio can't flow back out to the antenna, which might radiate and cause interference with nearby receivers. The particular offending internal signal that needed such unilateralization was from the very local oscillator that made the superhet work.

Second, the preselector serves to eliminate strong out-of-band signals that can interfere with the desired RF signal. Although the principal selectivity function is in the IF amplifier stage(s), the IF selectivity does

nothing to improve the image response of the receiver.

Image response

The image frequency in a superheterodyne receiver is a normal (albeit unwanted) response that must be suppressed. There are at least two manifestations of image response that cause problems. First, there is the response to unwanted strong signals. **Figure 11A** illustrates the problem. Normally, the LO frequency is spaced away from the received RF signal by an amount equal to the IF (that's how we get $IF = RF - LO$). In **Figure 11A**, the LO is on the high side of the RF signal. If there is another signal present at a distance equal to the IF on the other side of the LO, then it, too, produces a difference frequency equal to the IF, and will pass right through the IF

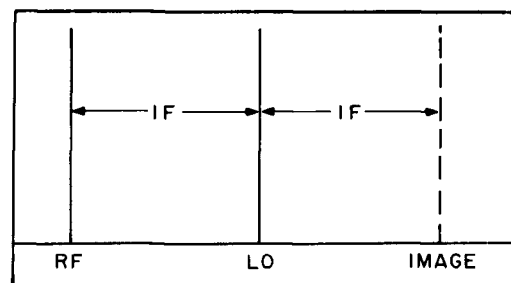


Figure 11A. Relationship between the image and received RF frequencies.

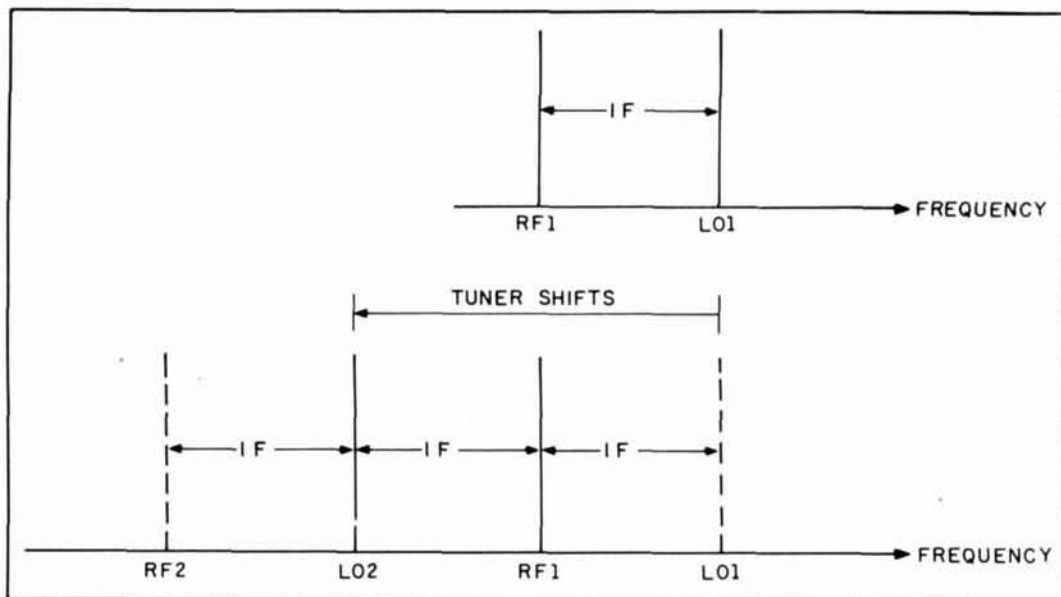


Figure 11B. Image interference scenario.

amplifier as a valid signal. The preselector improves rejection of these image frequencies by sharply attenuating them.

The other manifestation of image response problems is that the same signal might appear on the dial at two different points. Consider **Figure 11B**. Initially, the radio is tuned to RF1, so the local oscillator will be at LO1 (which is equal to $RF + IF$). Because a signal is present at RF1, the receiver detects a station, and everyone is happy. But suppose the receiver is retuned away from RF1 to a new frequency, RF2. If RF2 is $2 \times IF$ away from RF1, the new LO frequency (LO2) is still displaced from RF1 by the frequency of the IF, so a "valid" signal is produced for the IF amplifier. Again, the answer is to preselect the RF signal to attenuate all but valid signals.

The IF amplifier provides the bulk of the overall receiver gain, as well as the best selectivity. It's relatively easy to provide these features in a single frequency amplifier, especially when the frequency is low. Thus, the superhet radio reached the pinnacle of performance available to any particular class of radio receiver. The design was so successful for its time that it endures even today. ■

If you wish to read more about radio receivers of the past, the author recommends these books:

1. Clinton B. DeSoto, *Two Hundred Meters and Below*, American Radio Relay League, Newington, Connecticut. Reprint of the 1936 original. A history of amateur radio.
2. Robert E. Grinder and George H. Fathauer, *The Radio Collector's Directory and Price Guide*, Ironwood Press, Scottsdale, Arizona, 1986.
3. Edward A. Herron, *Miracle of the Airwaves: A History of Radio*, Julian Messner, New York, 1969.
4. Morgan E. McMahon, *Vintage Radio 3rd-Edition*, Vintage Radio, publishers, Rolling Hills Estates, California, 1980.
5. *1934 Official Shortwave Radio Manual*, Lindsay Publications, Inc., Bradley, Illinois, 60915.
6. Joseph J. Carr, K4IPV, *Restoring Classic Radios*, TAB Books, 1991.

To learn more about DeForest, Armstrong, and Sarnoff, read:

1. Tom Lewis, *The Empire of the Air*, Edward Burlingame a Division of Harper Collins Books, 1991.

CORRECTION

It's better than it looks!

We inadvertently left out an important number at the beginning of K6JPO and N6UEZ's article, "Loran C Frequency Cali-

brator" (Fall 1991). The heading directly below the title should read: Calibrate frequency sources to better than 1 part in 10^{11} easily and inexpensively, and not: Calibrate frequency sources to better than 1 part in 10. . . Sort of puts a totally different slant on things. Sorry guys! Ed.

Yes, half of it. Does this make the signal weaker at the other end? It depends on the cause of the reflected power. Consider a rhombic's terminator. Without it the antenna would have a back lobe. Similarly, power that contributes to imbalance from the ideal current distribution in an array doesn't add to its main lobe—it just fills in nulls elsewhere in the pattern. Clearly, power reflected because the antennas are individually and equally mismatched is wasted. But this isn't very significant unless the antenna is very poorly matched indeed. With a 2:1 SWR, the antenna only reflects 10 percent of its incident power and the divider would burn only half of that. With well-tuned antennas, the loss would be truly negligible.

The arguments *The ARRL Antenna Handbook* uses when it rails against the Wilkinson divider are flawed. A matching-section feed is the best choice for a mono-band array because it keeps antenna feed currents equal in the presence of imbalance—period. All else is beside the point or simply wrong.

The ARRL book does not specifically impugn *transformer* splitters; it avoids broadband array feeding altogether! My article mentions Wilkinson dividers (as opposed to broadband splitters) as a “good choice for single-band arrays, especially in the VHF/UHF range. . .” I should have pointed out the superiority in single-band HF arrays, where ground reflections usually cause substantial feed-impedance imbalance, of matching-section feeds. The subject of the article—the transformer splitter—shines in *broadband and multi-band* systems, including antennas. For broadband arrays, I believe it offers clear advantages over anything else that's been invented.

Dave Barton, AF6S
San Jose, California

Those of you who tried the FT-ONE modifications suggested by Cornell Drentea in his article “Upgrading the FT-ONE Transceiver” (Summer 1991), might find the following letters of interest. Ed.

Dear Mr. Drentea:

This is a follow-up letter in regards to your excellent article on the Yaesu FT-ONE upgrading in the Summer 1991 issue of *Communications Quarterly*. I found it most

interesting and eventually decided to pursue the effort.

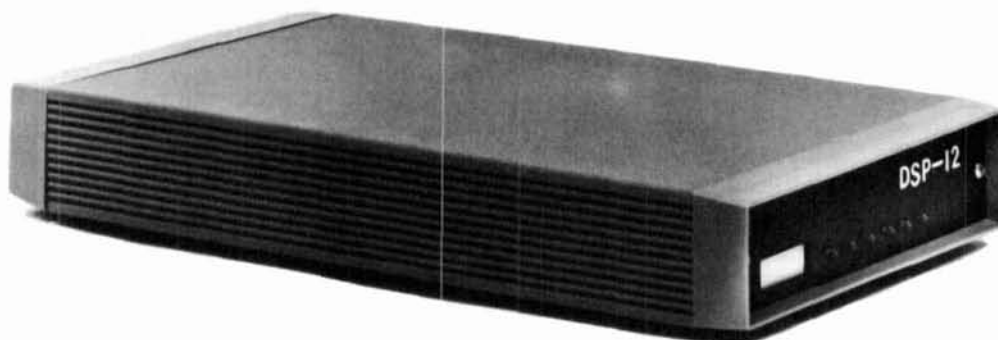
I'm sure you are aware that the partial schematics shown with **Figures 2 and 4** were reversed. I was not aware of the difficulty I would have in locating a few components; though perhaps your discussion on pages 52 and 53 should have clued me in. Eventually, I found the home address of Johanson Manufacturing Corporation and obtained one of their catalogs. After much comparison between the catalog and your discussion and **Figure 5**, I decided it was not the Standard Air Capacitors JMC P/N 5400 PC25J140 that I wanted. The item that I selected was the Vertical Mount Air Capacitors JMC P/N 8053 PC32T140. These latter units are PC mountable and I only had to enlarge one of the existing holes on the PLL board slightly to accept the stud on the capacitor. (These “look” like the unit shown in **Figure 2 and 5** of your article.) The only extra I added was to also replace the trimmer on the 48.615-MHz oscillator. It was during final testing that I became aware of how warm the PLL box becomes under normal operating conditions.

You discussed various implementations of the “extra digit.” I decided that I would match the seven-segment readouts of the existing dial with another amber HP-display of the same type. Of course, this meant that I had to add a decoder/driver chip and decided to use the CMOS 5411. It can be easily constructed on a small piece of perf-board and this then mounted on the back of the meter bracket. There happens to be a tab there with a predrilled /tapped hole and there is ample space for the board to mount horizontally. Short wires are then connected to the BCD-input, 5-volt power and ground lines, and somewhat longer wires to the seven-segment display. I placed the LED current-limiting resistors on the perfboard.

There you are then, a little feedback that your article was appreciated by at least one reader. Thanks again for taking the time to share it with the amateur radio community. Now that I have this FT-ONE stable, I'm going back to the drawing board and work on my older CX7B by Signal/One and see if I can't tame it too. It's 1-MHz range on the LMOs are also known to drift.

John Jan Jellema, Ph.D., W8SWN
Eastern Michigan University
Ypsilanti, Michigan

VERSATILITY PLUS +



L.L. Grace introduces our latest product, the **DSP-12 Multi-Mode Communications Controller**. The DSP-12 is a user programmable, digital signal processing (DSP) based communications controller.

FEATURES

- Multi-tasking operating system built in
- PC-compatible (V40) architecture allows development of custom applications using normal PC development tools and languages
- Motorola DSP56001 DSP processor
- Serial interface speeds from 110 to 19200 bps
- Optional 8-channel A-to-D & DAC for voice and telemetry applications
- 12-bit conversion architecture
- V40 source code and schematics available
- RAM expandable to one megabyte. Useable for mailbox feature, voice mail and development
- EPROM expandable to 384k bytes
- Low power requirements: 10-15vdc, 750ma
- 3 analog radio connectors. RX & TX can be split in any combination. Programmable tuning outputs are available on each connector
- Many modems available in the basic unit, including Packet, RTTY, ASCII, and PSK modems for high speed packet and satellite work
- Both V40 and DSP programs can be down-line-loaded from your PC or a bulletin board. You can participate in new development!
- Built in packet mailbox
- V40 and DSP debuggers built in
- Open programming architecture
- Free software upgrades
- Low cost unit
- Room for future growth

APPLICATIONS

- HF Packet
- HF RTTY & ASCII, including inverted mark/space and custom-split applications
- VHF Packet
- 400bps PSK (satellite telemetry)
- 1200bps PSK (satellite & terrestrial packet)
- V26.B 2400bps packet
- 9600bps direct FSK (UO-14)
- Morse Code

CUSTOM APPLICATIONS

- Voice compression
- Telemetry acquisition
- Message Store-and-Forward
- Voice Mail

COMING ATTRACTIONS

(Remember, software upgrades are free!)

- WEFAX and SSTV demodulators
- NAVTEX
- AMTOR and SITOR
- Multi-tone Modems
- ARINC ACARS

Commercial inquiries are welcomed. We offer rapid prototyping of custom commercial, civil, and government applications including intelligent radio, wireline, and telephone modems.

DSP-12 Multi-mode Communications Controller	\$ 595.00
One Megabyte RAM Expansion Option	149.00
Date/Time Clock Backup Option	29.00
8-Channel A-To-D Telemetry/Experimentation Option	49.00
Wall-Mount Power Supply for DSP-12 (110 vac)	19.00

We accept MasterCard & VISA and can ship C.O.D. within the USA. All orders must be paid in US Dollars. Shipping & Handling: \$5 (\$20 International).

L. L. Grace Communications Products, Inc.

41 Acadia Drive, Voorhees, NJ 08043, USA

Telephone: (609) 751-1018

FAX: (609) 751-9705

CompuServe: 72677,1107

1/91

L. L. Grace also manufactures the Kansas City Tracker family of satellite antenna aiming systems. Call or write for more information.

TECHNICAL CONVERSATIONS

Dear Dr. Jellema:

Thank you for the letter describing your experiences with the FT-ONE modifications. Several other individuals have also been modifying their radios.

With your permission, I would like to share the information you provided with the magazine for the good of all radio amateurs.

Also, you may want to know about an additional modification which considerably improves the phase-noise performance of the radio. Although the FT-ONE is relatively quiet, the lowpass filter in the 100-Hz loop can be additionally and safely dampened to a certain point without impacting the QSK and other switching characteristics of the radio—improving the FT-ONE's phase-noise performance in receive and transmit.

The results are spectacular in the sense that an additional 3 to 5 dB spurious free dynamic range (SPDR) can be gained in the MDS. The modified rig will sound at least as good as the more modern radios involving DDS technologies.

All that needs to be done is to replace the 0.01 pF, C144 in the Local Unit assembly with a 0.047-pF ceramic capacitor. This can be easily accomplished by either paralleling a capacitor on the solder side of the board, which together with the existing capacitor would not exceed the prescribed value, or by removing the existing capacitor and replacing it with the 0.047 value.

In any case, the 0.047 value should not be exceeded because the synthesizer would become too slow. To test your radio after the modification, depress the "Fine" push button (10 kHz per revolution) and tune the main dial back and forth at an accelerated rate (with sudden stops in between). Also switch between two "VFOs" far removed from each other (like 1.8 MHz and 28 MHz). The radio should follow without any problem. If the value exceeded the recommendation, the radio will go out of lock, and the display will blink indicating this until the radio is powered down and up again. This modification also smoothes out the settling time of the 100 Hz switching improving on the bugling tendency of the radio.

I am sure you will enjoy this latest modification. The reward will be improved intelligibility of many weak (S-1 and 2) amateur and broadcast signals that just didn't sound right before.

Cornell Drentea, WB3JZO
Minneapolis, Minnesota

48 HOUR SHIPPING

ELENCO & HITACHI PRODUCTS AT DISCOUNT PRICES

TO ORDER
CALL TOLL FREE
1-800-292-7711
1-800-445-3201 (Can.)

Hitachi RSO Series
(Portable Real-time Digital Storage Oscilloscopes)

VC-6023 - 20MHz, 20MS/s	\$1,695
VC-6024 - 50MHz, 20MS/s	\$1,995
VC-6025 - 50MHz, 20MS/s	\$2,195
VC-6045 - 100MHz, 40MS/s	Call
VC-6145 - 100MHz, 100MS/s	Call

RSO's from Hitachi feature real mode averaging, save memory, smoothing, interpolation, pretriggering, cursor measurements. These scopes enable more accurate, simpler observation of complex waveforms, in addition to such functions as hardcopy via a plotter interface and waveform transfer via the RS-232C interface. Enjoy the comfort of analog and the power to digital.

25MHz Elenco Oscilloscope

S-1325
\$349

- Dual Trace
- 1mV Sensitivity
- 6" CRT
- X-Y Operation
- TV Sync

• (2) 1x, 10x Probes included

SPECIAL BUY

V-212 - 20MHz Scope \$409

Hitachi Portable Scopes
DC to 50MHz, 2-Channel, DC offset function, Alternate magnifier function

V-525 - CRT Readout, Cursor Meas	\$995
V-523 - Delayed Sweep	\$975
V-522 - Basic Model	\$975
V-422 - 40MHz	\$775
V-223 - 20MHz delayed sweep	\$695
V-222 - 20MHz deluxe	\$625

HITACHI COMPACT SERIES SCOPES
This series provides many new functions such as CRT Readout, Cursor measurements (V-1085/1085A/865A), Frequency Ch. (V-1085), Sweeptime, Autotrigger, Delayed sweep and Trigger Lock using a 6-inch CRT. You don't lose the compactness in terms of performance and operation.

V-860 - 60MHz, Dual Trace	\$1,149
V-665A - 60MHz, DT, w/cursor	\$1,345
V-1060 - 100MHz, Dual Trace	\$1,395
V-1065A - 100MHz, DT, w/cursor	\$1,649
V-1085 - 100MHz, QT, w/cursor	\$1,995
V-1100A - 100MHz, Quad Trace	\$2,195
V-1150 - 150MHz, Quad Trace	\$2,695

PRICE BREAKTHRU

20MHz Digital Storage Oscilloscope

• Analog Digital Scope	
• 2K word per channel memory	DS203
• 10MS/s sampling rate	\$775
• State-of-art technology	
• Includes probes	
S-1360 60MHz Delay Sweep \$775	

Elenco 40MHz Dual Trace

Good to 50MHz **\$495**

S-1340

- High Luminance 6" CRT
- 1mV Sensitivity
- 10KV Acceleration Voltage
- 9ns Rise Time
- X-Y Operation

• Includes (2) 1x, 10x Probes

All scopes include probes, schematics, operators manual and 3 year (2 yrs for Elenco scopes) world wide warranty on parts & labor. Many accessories available for all Hitachi scopes. Call or write for complete specifications on these and many other fine oscilloscopes. 1x, 10x Scope Probes: P-1 65MHz \$17.95, P-2 100MHz \$21.95

Digital Capacitance Meter

CM-1550B

\$58.95

9 Ranges
1pF-20,000pF
5% basic acy
Zero control w/ Case
Big 1" Display

Digital LCR Meter

LC-1801

\$125

Measures:
Coils 1uH-200H
Caps 1pF-200uF
Res. 0.1-20M

Multimeter with Capacitance & Transistor Tester

\$55 CM-1500B

Reads Volts, Ohms
Current, Capacitors,
Transistors and
Diodes w/ case

FLUKE MULTIMETERS
(All Models Available Call)

Scopemeters	Model 93 \$1,095.00	70 Series	Model 701i \$65.00
	Model 95 \$1,395.00	Model 771i	\$145.00
	Model 97 \$1,695.00	Model 791i	\$189.00
	10 Series	80 Series	
	Model 10 \$62.95	Model 87	\$289.00
	Model 12 \$79.95		

B + K TEST EQUIPMENT
All Models Available
Call for special price

Soldering Station Temperature Controlled

SL-30 \$99

Digital Display
Temp Range: 300F-900F
Grounded Tip
Overheat Protect

Video Head Tester

HT-200

\$44.95

Tells you if VHS head is defective or worn.
A must for VCR work

COMPUTER INTERFACE TRAINER

XX-450

\$139.95

Convert your IBM PC/XT or compatible computer into a trainer

Color Convergence Generator

SG-250

\$89.95

Kit \$69.95

Finest in the industry
10 rock steady patterns
RF & Video output

Quad Power Supply

XP-580

\$69.95

2.20V @ 2A
12V @ 1A
5V @ 3A
5V @ 5A

Fully regulated and short circuit protected

Triple Power Supply

XP-620

Assembled \$75
Kit \$50

2 to 15V @ 1A,
2 to 15V @ 1A
(or 4 to 30V @ 1A)
and 5V @ 3A

All the desired features for doing experiments.
Features short circuit protection, all supplies

AM/FM Transistor Radio Kit with Training Course

Model AMFM 108

\$26.95

14 Transistors • 5 Diodes
Makes a great school project

True RMS 4 1/2 Digit Multimeter

M-700T

\$135

65% DC Accuracy
1% Resistance
with Freq. Counter
Data Hold

GF-8016 Function Generator with Freq. Counter

SL-30

\$249

Sine, Square, Triangle
Pulse, Ramp; 2 to 2MHz
Freq. Counter; 1 to 10MHz
Int'l. operation

GF-8015 without Freq. Meter \$179

Function Generator Blox

#9600

\$28.95

Provides sine, triangle, square wave from 1Hz to 1MHz
AM or FM capability

LASER KITS

Build your own laser. This great kit includes all parts needed to build a class II laser. Safe to use, output is under one milliwatt. Kit includes a new He-Ne 1.125 dia x 5.75" long laser tube. Comes with building instructions, schematic and all parts.

Model LK-1 \$79.95

Learn to Build and Program Computers with this Kit

Includes: All Parts, Assembly and Lesson Manual

Model MM-8000

\$129.00

Wide Band Signal Generators

SG-9000 \$129

RF Freq 100k-450MHz AM Modulation of 1MHz Variable 10-40dB

SG-9500 w/ Digital Display & 150MHz built-in Counter \$249

Specifications LK-1

Input voltage	12VDC @ 1.25 amp
Output voltage	2.3KV @ 3-4.5mA
Trigger voltage	0-8KV
Laser power	1 milliwatt
Laser tube type	helium-neon
Laser tube size	1.125" dia x 5.75" long

Mirror & Motor Kit

This unique kit allows you to project laser patterns on the ceiling or walls. You change the patterns by varying the speed of the motors. The kit comes complete with 2 motors, 2 front surface mirrors, 2 motor brackets and 1 power master control to vary speed of the motor.

Model LM-1 \$19.95

WE WILL NOT BE UNDERSOLD
UPS SHIPPING - IN STATES 5%
IL RES 7.5% TAX (53 min \$10 max)
OTHERS CALL

C&S SALES INC.
1245 ROSEWOOD, DEERFIELD, IL 60015
FAX: 708-520-0085 • (708) 541-0710

106 Spring 1992

ASTRON POWER SUPPLIES

• HEAVY DUTY • HIGH QUALITY • RUGGED • RELIABLE •



MODEL VS-50M

SPECIAL FEATURES

- SOLID STATE ELECTRONICALLY REGULATED
- FOLD-BACK CURRENT LIMITING Protects Power Supply from excessive current & continuous shorted output
- CROWBAR OVER VOLTAGE PROTECTION on all Models except RS-3A, RS-4A, RS-5A, RS-4L, RS-5L
- MAINTAIN REGULATION & LOW RIPPLE at low line input Voltage
- HEAVY DUTY HEAT SINK • CHASSIS MOUNT FUSE
- THREE CONDUCTOR POWER CORD except for RS-3A
- ONE YEAR WARRANTY • MADE IN U.S.A.

PERFORMANCE SPECIFICATIONS

- INPUT VOLTAGE: 105-125 VAC
- OUTPUT VOLTAGE: 13.8 VDC ± 0.05 volts (Internally Adjustable: 11-15 VDC)
- RIPPLE Less than 5mv peak to peak (full load & low line)
- All units available in 220 VAC input voltage (except for SL-11A)

SL SERIES



MODEL	Colors Gray Black	Continuous Duty (Amps)	ICS* (Amps)	Size (IN) H x W x D	Shipping Wt. (lbs.)
SL-11A	• •	7	11	2 3/4 x 7 3/8 x 9 3/4	11

- LOW PROFILE POWER SUPPLY

RS-L SERIES



MODEL	Continuous Duty (Amps)	ICS* (Amps)	Size (IN) H x W x D	Shipping Wt. (lbs.)
RS-4L	3	4	3 1/2 x 6 1/2 x 7 1/4	6
RS-5L	4	5	3 1/2 x 6 1/2 x 7 1/4	7

- POWER SUPPLIES WITH BUILT IN CIGARETTE LIGHTER RECEPTACLE



RM SERIES

MODEL RM-35M

MODEL	Continuous Duty (Amps)	ICS* (Amps)	Size (IN) H x W x D	Shipping Wt. (lbs.)
RM-12A	9	12	5 1/4 x 19 x 8 1/4	16
RM-35A	25	35	5 1/4 x 19 x 12 1/2	38
RM-50A	37	50	5 1/4 x 19 x 12 1/2	50
RM-60A	50	55	7 x 19 x 12 1/2	60

- 19" RACK MOUNT POWER SUPPLIES

- Separate Volt and Amp Meters

RS-A SERIES



MODEL RS-7A

MODEL	Colors		Continuous Duty (Amps)	ICS* (Amps)	Size (IN) H x W x D	Shipping Wt. (lbs.)
	Gray	Black				
RS-3A	•	•	2.5	3	3 x 4 1/4 x 5 3/4	4
RS-4A	•	•	3	4	3 3/4 x 6 1/2 x 9	5
RS-5A	•	•	4	5	3 1/2 x 6 1/2 x 7 1/4	7
RS-7A	•	•	5	7	3 3/4 x 6 1/2 x 9	9
RS-7B	•	•	5	7	4 x 7 1/2 x 10 3/4	10
RS-10A	•	•	7.5	10	4 x 7 1/2 x 10 3/4	11
RS-12A	•	•	9	12	4 1/2 x 8 x 9	13
RS-12B	•	•	9	12	4 x 7 1/2 x 10 3/4	13
RS-20A	•	•	16	20	5 x 9 x 10 1/2	18
RS-35A	•	•	25	35	5 x 11 x 11	27
RS-50A	•	•	37	50	6 x 13 3/4 x 11	46

RS-M SERIES



MODEL RS-35M

MODEL	Continuous Duty (Amps)	ICS* (Amps)	Size (IN) H x W x D	Shipping Wt. (lbs.)
RS-12M	9	12	4 1/2 x 8 x 9	13
RS-20M	16	20	5 x 9 x 10 1/2	18
RS-35M	25	35	5 x 11 x 11	27
RS-50M	37	50	6 x 13 3/4 x 11	46

- Switchable volt and Amp meter

- Separate volt and Amp meters

VS-M AND VRM-M SERIES



MODEL VS-35M

- Separate Volt and Amp Meters • Output Voltage adjustable from 2-15 volts • Current limit adjustable from 1.5 amps to Full Load

MODEL	Continuous Duty (Amps)			ICS* (Amps)	Size (IN) H x W x D	Shipping Wt. (lbs.)
	@13.8VDC	@10VDC	@5VDC			
VS-12M	9	5	2	12	4 1/2 x 8 x 9	13
VS-20M	16	9	4	20	5 x 9 x 10 1/2	20
VS-35M	25	15	7	35	5 x 11 x 11	29
VS-50M	37	22	10	50	6 x 13 3/4 x 11	46

- Variable rack mount power supplies

RS-S SERIES



MODEL RS-12S

MODEL	Colors		Continuous Duty (Amps)	ICS* Amps	Size (IN) H x W x D	Shipping Wt. (lbs.)
	Gray	Black				
RS-7S	•	•	5	7	4 x 7 1/2 x 10 3/4	10
RS-10S	•	•	7.5	10	4 x 7 1/2 x 10 3/4	12
RS-12S	•	•	9	12	4 1/2 x 8 x 9	13
RS-20S	•	•	16	20	5 x 9 x 10 1/2	18

- Built in speaker

1992 Antenna Buyer's Guide

Antennas for newcomers!
Antennas for oldtimers!
Antennas for all smart hams!

The 1992 Antenna Buyer's Guide is crammed full of information on all the latest antennas, towers and accessories. Plus, there's detailed information on how to approach the town, who to see, what to say—and it is written by a top legal expert. VHF antennas? We'll show you what to look for and what to avoid! Lew McCoy, W1ICP, tells you which simple wire antennas really work. Great articles with advice you need! Pages and pages of antenna charts! Pictures and descriptions of all the great antenna accessories! Order today before it is too late!



YES, please send me _____ copies at \$4.95 each:
(plus \$2.50 shipping & handling; \$3.50 foreign)

Name _____ Call _____

Address _____

City _____ State _____ Zip _____

Send only \$4.95 each today. Foreign: \$6 U.S. funds. Check Money Order

MasterCard VISA Amex Card No. _____ Expires _____

Signature _____ (required on all charge orders)

Mail to: CQ Communications, Inc., 76 North Broadway, Hicksville, NY 11801/FAX: 516-681-2926

TOROID CORES



- Iron Powder
- Ferrite
- Shielding Beads
- Ferrite Rods
- Split Beads

Small orders welcome. All items in stock for immediate delivery. Low cost experimenter's kits: **Iron Powder, Ferrite.** The dependable source for toroidal cores for 25 years.

Call or write for free catalog and tech data sheet.

PALOMAR ENGINEERS

Box 462222, Escondido, CA 92046

Phone: (619) 747-3343

Fax: (619) 747-3346

Low Cost RF Software

Computer programs from *RF Design* magazine,
by some of the best RF engineers in the world

— a few of our most popular programs —

RFD-1291 Analysis Program for Coaxial Cable

RFD-1091 RF Calculations for DOS

RFD-0791 A Comprehensive Filter Design Program

RFD-1090 Microstrip CAD Program

RFD-1189 ACANAL Nodal Network Analysis Program

RFD-0589 A Mixer Spurious Plotting Program

Programs are priced at only \$15.00 each. This low cost is possible because the authors have offered them as an exchange of ideas among colleagues. We supply a copy of the *RF Design* article describing the program, plus any additional author's notes. We must advise you that this is not commercial software; programs are offered "as-is" without technical support.

Call or write for a listing of all available programs

RF Design Software Service
P.O. Box 3702
Littleton, Colorado 80161-3702
(303) 770-4709

We accept checks, money orders, VISA, MasterCard or American Express

HIGH-ACCURACY ANTENNA SOFTWARE

MN 4.0 is the fastest, most powerful, and most accurate MININEC antenna-analysis program available. MN corrects fundamental problems in the MININEC algorithm for improved accuracy. MN features 3-D views of antenna geometry and wire currents, presentation-quality polar and rectangular plots, automatic wire segmentation, automatic frequency sweep, symbolic dimensions, skin-effect modeling, near-field calculation for TVI and RF-hazard analysis, up to 254 pulses for complex models, simple definition of sources and loads, and pop-up menus. MN 4.0, \$85. MNC 4.0 (1.6-2.4 times faster, coprocessor required), \$110. MNH 4.0 (huge-model option), \$25.

YO 4.0 automatically optimizes Yagi antennas for maximum forward gain, best pattern, and minimum SWR. YO handles designs from HF to microwave. YO models stacked Yagis, Yagis over ground, skin-effect, dual driven-elements, element tapering, mounting plates, and matching networks. YO runs hundreds of times faster than MININEC. YO is calibrated to NEC for high accuracy and has been extensively validated against real antennas. YO is intuitive, highly graphical, and fun to use. YO 4.0, \$100. YOC 4.0 (1.7-2.7 times faster, coprocessor required), \$130.

NEC For Yagis 1.0 provides highest-accuracy analysis of Yagi designs with the professional-standard Numerical Electromagnetics Code. NEC For Yagis 1.0, \$50. Coprocessor, hard disk, and 640K memory required.

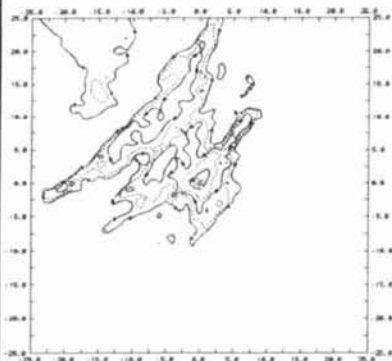
MN and YO come with comprehensive antenna-design libraries and include both coprocessor and extra-fast no-coprocessor versions. All programs include extensive documentation and an easy-to-use, full-screen text editor. Add 6% CA, \$5 overseas. VISA, MasterCard, U.S. check, cash, or money order. For IBM PC, 3.5" or 5.25" disk.

Brian Beezley, K6STI, 507-1/2 Taylor, Vista, CA 92084
(619) 945-9824, 0700-1800 Pacific Time

Terrain Analysis and VHF Propagation Software

Unlike HF propagation which is primarily determined by the ionosphere, non-enhanced VHF propagation is determined by the local terrain. SoftWright's Terrain Analysis Package (TAP™) is a comprehensive system of programs which performs functions for retrieving and manipulating topographic elevation data, and for using that data for VHF/UHF radio path and coverage analysis. Among its many features, this software allows you to:

Coverage Map



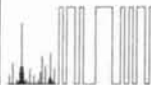
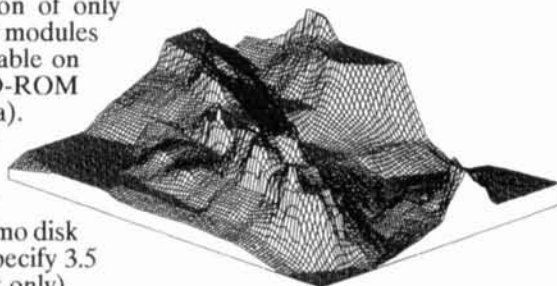
- Plot a cross section of the terrain between two sites to identify major obstructions and fresnel loss areas
- Plot shadowing studies
- Compute field strengths.
- Plot field strength contour maps to show coverage areas
- Calculate Height Above Average Terrain (HAAT)
- Compute FM/TV FCC Field and plot computed contour (part 73)
- Compute Carey Curve Values and plot (FCC part 22)
- Compute distance and bearing
- Model terrain in 3-D to aid in site selection and evaluation
- Draw topo maps
- Plot field strength in 3-D to easily identify coverage holes
- Generate signal threshold plots to show base, mobile and handheld coverage areas

The TAP system is divided into numerous modules which allow selection of only those functions needed. Other modules

can be added as required. The necessary terrain data is available on floppy disk in 1 x 1 degree blocks for use in limited areas, or on CD-ROM for larger areas. Data is available for the entire US (except Alaska). This data contains sample points approximately every 300ft and has been derived from the USGS 3-second database.

We also offer a low cost plotting service. For more information on this software and/or our services, please call or write. For a demo disk please send \$3.00 and specify 3.5 or 5.25 disk (IBM format only).

3-D Terrain Model



NX2P Electronics

321 East Shore Trail, Sparta, NJ 07871 (201) 729-6927

AMATEUR TELEVISION

GET THE ATV BUG



Transceiver
Only \$329
with 50 Watt
D26 Amp \$539
Value + Quality
from over 25years
in ATV...W6ORG

With our all in one box TC70-1d, ATV Transceiver, you can easily transmit and receive live action color and sound video just like broadcast TV. Use any home TV camera or VCR by plugging the composite video and audio into the front VHS 10 pin or rear phono jacks. Add 70cm antenna, coax, 13.8 Vdc and TV set and you are on the air - it's that easy!

TC70-1d has 1.5 Watt p.e.p. with one xtal on 439.25, 434.0 or 426.25 MHz & properly matches Mirage D15, D26, D100 amps for 15, 50, or 70 Watts. Hot GaAsfet downconverter varicap tunes whole 420-450 MHz band to your TV ch3. Shielded cabinet 7x7x2.5". Req. 13.8 VDC @ .5A Transmitters sold only to licensed amateurs, for legal purposes, verified in the latest Callbook or send copy of new license. Call or write now for our complete ATV catalog including downconverters, transmitters, linear amps, and antennas for the 400, 900 & 1200 MHz bands.

(818) 447-4565 m-f 8am-5:30pm pst.

Visa, MC, COD

P.C. ELECTRONICS

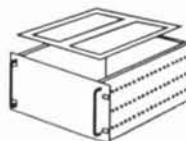
2522-CY Paxson Ln Arcadia CA 91007

Tom (W6ORG)

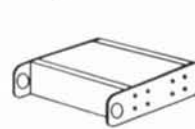
Maryann (WB6YSS)

ELECTRONIC ENCLOSURES

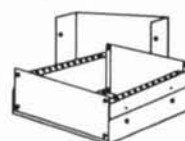
Everything to complete your project -
From initial concept to finished product!



Rack Mount



Universal



Split Case

Complete line of Enclosures in Aluminum, Steel or ABS, Hardware, Silkscreening, Tools, Custom Fabricating
Call for our **FREE Full Color Catalog**
(800) 800-3321 or (216) 425-8888 (216) 425-1228 Fax



Cage & Preamp
Enclosures



Knobs & Parts



Linear



ABS



Die Cast

Project Pro

1710 ENTERPRISE PKWY. TWINSBURG, OHIO 44087

SATELLITE TRACKING MADE EASY

WITH SOFTWARE FROM
AMSAT



Line representation of QuikTrak 4.0 World Map

QuikTrak 4.0

Whether you want to identify the next time Oscar 13 will provide communications between two cities or if you just want to know the next time you can visually sight the Soviet space station MIR, QuikTrak will let you plug in the latest Keplerian elements for up to 100 satellites using a new full screen editor. QuikTrak also supports autotracking. *Hardware requirements*, IBM PC, AT, PS/2, or clone with a minimum 512K memory. CGA or EGA graphics required. Numeric coprocessor not required but recommended.

InstantTrack 1.0

For those concerned with greater speed and capability, InstantTrack offers all of QuikTrak's features plus instant visibility for your "favorite" satellites before you issue the first keystroke. More than 200 satellites and 1754 cities are on the menu and will be in full-color high-resolution EGA or VGA modes. *Hardware requirements*: IBM PC, AT, PS/2 or clone with at least 512K memory. EGA or VGA graphics required. Numeric coprocessor not required but recommended. Mouse not required but can be used on the map screens.

These are only a few of the features of QuikTrak and InstantTrack. The figures below reflect suggested donations to defray production expenses and benefit AMSAT's non-profit, educational activities.

Recommended Donations:

	Member	Non-Member
QuikTrak 4.0 5-1/4"	\$55	\$75
InstantTrack 1.0 5-1/4"	\$50	\$70

AMSAT membership \$30/yr U.S.; \$36/yr Canada & Mexico; \$45/yr Foreign

AMSAT PO Box 27 Washington, DC 20044

301-589-6062 Voice, 214-784-3871 Fax

K.V.G. CRYSTAL PRODUCTS



9 MHz CRYSTAL FILTERS

MODEL	Appli- cation	Band- width	Poles	Price
XF-9A	SSB	2.4 kHz	5	\$ 75.00
XF-9B	SSB	2.4 kHz	8	105.00
XF-9B-01	LSB	2.4 kHz	8	145.00
XF-9B-02	USB	2.4 kHz	8	145.00
XF-9B-10	SSB	2.4 kHz	10	185.00
XF-9C	AM	3.75 kHz	8	110.00
XF-9D	AM	5.0 kHz	8	110.00
XF-9E	FM	12.0 kHz	8	120.00
XF-9M	CW	500 Hz	4	80.00
XF-9NB	CW	500 Hz	8	165.00
XF-9P	CW	250 Hz	8	199.00
XF-910	IF noise	15 kHz	2	20.00

10.7 MHz CRYSTAL FILTERS

XF-107A	12 kHz	\$105.00
XF-107B	15 kHz	105.00
XF-107C	30 kHz	105.00
XF-107D	36 kHz	120.00
XF-107E	40 kHz	125.00
XF-107S139	100 kHz	175.00

41 MHz CRYSTAL FILTER

XF-410S02	\$199.00
-----------	----------

Write for full details of crystals and filters.
Shipping: \$6.00 Shipping: FOB Concord, MA
Prices subject to change without notice.



si

Spectrum International, Inc.
P.O. Box 1084 Dept. Q
Concord, MA 01742 U.S.A.
Phone: 508-263-2145
FAX: 508-263-7008

SURPLUS SALES OF NEBRASKA

Visit our new 6,000 ft² showroom, the largest one of its kind.... anywhere. It's where the hard-to-find parts are found and on hand!

New SPECIALS

TURNER	LMB-1 Desk Microphone	\$ 35
TURNER	LMB-2 Desk Microphone	\$ 39
TURNER	LMB-3 Desk Microphone	\$ 45
TURNER	LMB-5 Gooseneck Mic	\$ 99
SG-230	SMARTUNER Auto-Tuner	\$ 459
AEA	ISOLOOP (14-30 MHz)	\$ 250
AEA	AT-300 Antenna Tuner	\$ 139
IP-8 Coax	RG-8 style, 50Ω	35¢/ft.
SRA-22	Collins Antenna Coupler	\$ 129

Jennings RF5A Vacuum Relay	\$ 22
TWT, 10 GHz, 10 watt, Rantec	\$125
HF-380 conversion kit	\$475
KWM-380 Filters, 360Hz, 1.7 KHz, 6 KHz	\$ 99
KWM-380 Speech Processor	\$250
PAINT... Any color Collins paint	\$ 10
RCA APT & Monitor Package	\$195
DL75-1.5 Dummy load, 1.5 GHz, 75 watt	\$110
Mechanical Filter, 2.1 KHz, 455 KHz (526-9897-010)	\$ 49
Jennings CHV1-45 Vac cap, 1.5-45pf, 5kv	\$ 75

CATALOG 6

Available Now! In the USA FREE via bulk mail or send \$3 for your copy via First Class Mail. DX please send \$5 for Airmail. Payment is refundable with your first \$25 catalog purchase.

SURPLUS SALES OF NEBRASKA
1502 Jones St. • Omaha, NE 68102
402-346-4750 • fax: 402-346-2939

SIGNAL-TO-NOISE Voting Comparator



Improve coverage by adding receivers

- Expandable to 32 Channels
- Continuous Voting
- 19" Rack Mountable
- Select/Disable Switches for Manual Override
- Can be used with RF Links or Dedicated Lines
- LED Indicators
- Hundreds in Service
- More

— Competitively Priced —
For more information call or write:

Doug Hall Electronics
815 E. Hudson St.
Columbus, Ohio 43211 • (614) 261-8871
FAX 614-261-8805

ELNEC

Advanced Antenna Analysis Program

Fast to learn and easy to use, ELNEC lets you analyze nearly any type of antenna in its actual operating environment. Describe your antenna with ELNEC's unique menu structure and spreadsheet-like entry system and watch it make azimuth and elevation plots, report beamwidth, f/b ratio, takeoff angle, gain, and more. Save and recall antenna files. Print plots on your dot-matrix or laser printer.

ELNEC uses the full power of MININEC code but makes description, analysis, and changes worlds easier and faster. With ELNEC there's no messing with "pulses" - just tell it where on a wire you want a source or load to go, and ELNEC puts it there. And keeps it there, even if you change the antenna. ELNEC has a host of other features to make analysis fast and easy. The MaxP option extends ELNEC's capability to very complex antennas (up to 260 "pulses").

ELNEC runs on any PC-compatible computer with at least 512k RAM, CGA/EGA/VGA/Hercules, and 8/9 or 24 pin Epson-compatible or HP LaserJet/DeskJet printer. (The MaxP option requires a hard disk, coprocessor, and 640k RAM.)

There's no copy-protection hassle with ELNEC - it's not copy protected. And of course there's extensive documentation.

ELNEC is only \$49.00 postpaid. MaxP is \$25.00. (Please add \$3.00 per order for airmail outside N. America.) VISA and MasterCard orders are accepted - please include card number and expiration date. Specify coprocessor or noncoprocessor type. Order or write for more information from:

Roy Lewallen, W7EL
P.O. Box 6658
Beaverton, OR 97007

Measure Up With Coaxial Dynamics Model 83550 Digital Wattmeter

The "Generation Gap" is filled with the "new" EXPEDITOR, the microprocessor based R.F. AnaDigit System.

The EXPEDITOR power computer...you make the demands, it fills the requirements.

- Programmable forward AND reflected power ranges.
- Can be used with the elements you now have.
- Compatible with all Coaxial Dynamics line sizes and power ranges.
- 18 scales from 100 mW to 50 kW.

Contact us for your nearest authorized Coaxial Dynamics representative or distributor in our world-wide sales network.



**COAXIAL
DYNAMICS, INC.**

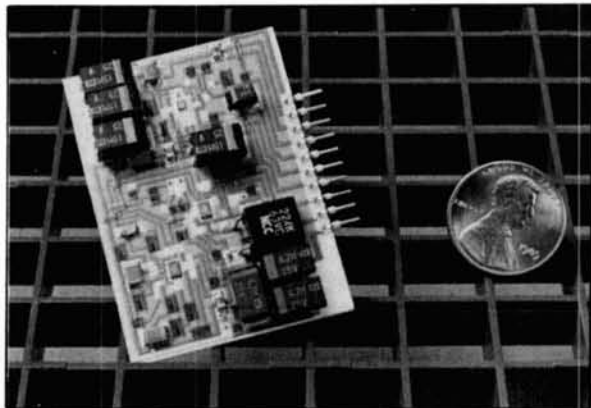
15210 Industrial Parkway
Cleveland, Ohio 44135
216-267-2233 1-800-COAXIAL
Telex: 98-0630

Service and Dependability...A Part of Every Product



SIDEBAND SQUELCH

(VOICE OPERATED)



- Fits inside most HF-SSB transceivers.
- Requires human voice to activate.
- Ignores static, noise and heterodynes.
- On/off switch only—no adjustments!
- Connects to audio leads and 9/12 VDC.
- Fully assembled and tested \$129. Deluxe \$149.
- Complete with comprehensive manual.
- Used worldwide in commercial and military transceivers.

NAVAL ELECTRONICS, INC.
5417 Jetview Circle, Tampa, FL 33634
(813) 885-6091 FAX: 813-885-3789

Doug Hall Electronics



Announcing the RBI-1

Now you can control any of the 16 Kenwood® TM—XX1 series mobiles with any advanced computer controls, inc. repeater controller.

Simply connects to the Kenwood® through the mike jack. Controls frequency, power, RF power, CTCSS, Shift, etc. Supports up to four radios and four bands. Expands user function output. No computer interface required. Just plug in and play!

For more information call or write:

Doug Hall Electronics
815 East Hudson Street
Columbus, Ohio 43211
Voice: 614/261-8871
Fax: 614/261-8805

DIGITAL METERS



DMM 2360
\$129.95
DMM + LCR Meter
Most Versatile DMM

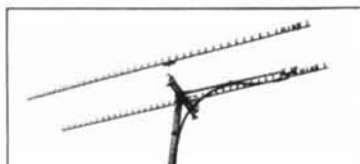
- Inductance: 1 μ H - 40H
- Capacitance: 1pF - 40 μ F
- Temperature: -40 - 302°F
- Frequency: 1Hz - 4MHz
- Logic test: 20MHz
- Diode test
- Continuity beeper
- Volt, current, ohm
- 3999 count display
- Peak hold
- Auto power off



DMM 175A
\$79.95
20MHz
Frequency
Counter

- Frequency
1 Hz - 20 MHz
- Logic test 20 MHz
- C: 1pF - 20 μ F
- .1 Ω - 2000 M Ω
- Volt, current, continuity
- LED, diode, hFE tests

DOWN EAST MICROWAVE



MICROWAVE ANTENNAS AND EQUIPMENT

- Loop Yagis • Power Dividers • Dish Feeds
- Complete Antenna Arrays • Linear Amps
- Microwave Transverters & Kits • GaAs FET Preamps and Kits • Microwave Components
- Tropo • EME • Weak Signal • OSCAR • FM
- Packet • ATV
- 902 • 1269 • 1296 • 1691 • 2304 • 2400 • 3456 • 5760
- 10,386 MHz

ANTENNAS

2345 LYK	45 el	Loop Yagi Kit	1296 MHz	\$95
1345 LYK	45 el	Loop Yagi Kit	2304 MHz	\$79
3333 LYK	33 el	Loop Yagi Kit	902 MHz	\$95
1844 LY	44 el	Loop Yagi Assembled	1691 MHz	\$105
3B Feed	Tri Band Dish Feed 2.3, 3.4, 5.7 GHz			\$15

Many others and assembled versions available. Shipping extra.

LINEAR AMPS AND PREAMPS

2303 PA	1.2 to 1.3 GHz	3w out	13.8 VDC	\$130
2318 PAM	1.24 to 1.3 GHz	20w out	13.8 VDC	\$205
2335 PA	1.24 to 1.3 GHz	35w out	13.8 VDC	\$325
2340 PA	1.24 to 1.3 GHz	high gain 35w out	13.8 VDC	\$355
2370 PA	1.24 to 1.3 GHz	70w out	13.8 VDC	\$695
1302 PA	2.2 to 2.5 GHz	3w out	13.8 VDC	\$430
13 LNA	2.3 to 2.4 GHz	preamp	6 dB NF	\$140
23 LNA	1.2 to 1.3 GHz	preamp	6 dB NF	\$95
33 LNA	900 to 930 MHz	preamp	6 dB NF	\$95
1691 LNA WP	1691 MHz	mast mounted preamp	8 dB NF	\$140

Kits, Weatherproof Versions and other Frequencies Available

NO-TUNE TRANSVERTERS AND TRANSVERTER KITS

900, 1269, 1296, 2304, 2400, 3456, 5760 MHz	
SHF 902K	902 MHz Transverter 40mW, 2m IF Kit \$139
SHF 1296K	1296 MHz Transverter 10mW, 2m IF Kit \$149
SHF 2304K	2304 MHz Transverter 10mW, 2m IF Kit \$205
SHF 3456K	3456 MHz Transverter 10mW, 2m IF Kit \$205

OSCAR and other frequencies available, also Amps and package versions wired and tested.

Write for more information. Free catalog available.



DOWN EAST MICROWAVE

Bill Olson, W3HQT

RR1 Box 2310, Troy, ME 04987

(207) 948-3741 Fax: 207-948-5157



ALFA ELECTRONICS

P.O. BOX 8089, PRINCETON, NJ 08543
 (800) 526-ALFA / FAX: (609) 275-9536

QUALITY DMM, GOOD RELIABILITY
 15 DAY MONEY BACK GUARANTEE
 1 YEAR REPLACEMENT WARRANTY

Visa, MasterCard, C.O.D., Purchase Order Welcome

ATV CONVERTERS • HF LINEAR AMPLIFIERS

DISCOVER THE WORLD OF FAST SCAN TELEVISION



HF AMPLIFIERS per MOTOROLA BULLETINS

Complete Parts List for HF Amplifiers Described in the MOTOROLA Bulletins.

AN758 300W	'160.70	AR305 300W	'383.52
AN762 140W	'93.25	EB63 140W	'88.65
AN779L 20W	'83.79	EB27A 300W	'139.20
AN779H 20W	'93.19	EB104 600W	'371.85
AR313 300W	'403.00		

NEW!! 1K WATT 2-50 MHz Amplifier

600 Watt PEP 2-Port	\$ 60.95
1000 Watt PEP 2-Port	\$ 79.95
1200 Watt PEP 4-Port	\$ 89.95

UNIVERSAL DIGITAL FREQUENCY READOUT

TK-1 (Wired/Loaded) \$149.95

HEAT SINK MATERIAL

Model 99 Heat Sink (8.5 x 12 x 1.6)	..... \$24.00
CHS-4 Copper Spreader (8 x 8 x 1/8)	..... \$22.00

We also stock Hard-to-Find parts

CHIP CAPS - Kemet/ATC

METALCLAD MICA CAPS - Unico/Semco	
RF POWER TRANSISTORS	
MINI-CIRCUIT MIXERS	
SBL-1 (1-500MHz)	..... \$ 6.50
SBL-1X (10-1000MHz)	..... \$ 7.95

ARCO TRIMMER CAPACITORS

VK200-20/4B RF Choke	..... \$ 1.20
56-590-65-3B Ferrite Bead	..... \$ .20

Broadband HF Transformers

Low Pass Filters for Harmonics (Up to 300W)	
10m, 15m, 20m, 40m, 80m & 160m	



AMATEUR TELEVISION CONVERTERS

ATV3 420-450	\$ 44.95 Kit
ATV3 420-450 (GaAs-FET)	\$ 49.95 Kit
ATV4 902-928 (GaAs-FET)	\$ 59.95 Kit

AUDIO SQUELCH CONTROL for ATV

SIL	\$ 39.95 Kit
-----	--------------

2 METER VHF AMPLIFIERS

35 Watt Model 315A	\$ 79.95 Kit
75 Watt Model 875A	\$ 119.95 Kit

Available in kit or wired/tested

For detailed information and prices, call or write for our free catalog.

CCI Communication Concepts Inc.

508 Millstone Drive • Beavercreek, Ohio 45434-5840
 (513) 426-8600 • FAX (513) 429-3811

Add \$3.50 for shipping and handling



Iron Powder and Ferrite Products

Fast, Reliable Service Since 1963

Millions of Parts in Stock for Immediate Delivery.
 Low Cost Experimental Kits.

Small Orders Welcome

Ask For Our FREE 78 Pages
 Handbook/Catalog



Toroidal Cores,
 Shielding Beads,
 Shielded Coil Forms,
 Ferrite Rods,
 Pot Cores, Baluns, Etc.

AMIDON
Associates



2216 East Gladwick Street, Dominguez Hills, California 90220

Telephone: (213) 763-5770 FAX: (213) 763-2250

ADVERTISER'S INDEX

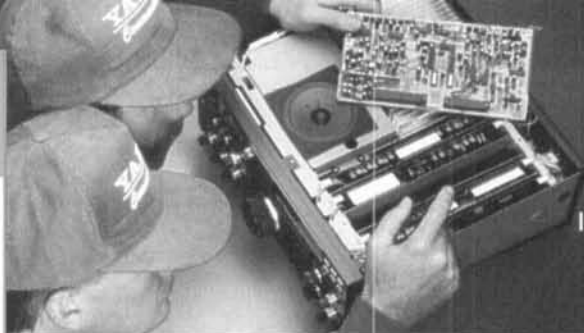
AEA/Adv. Elec. Applications	..... 5
AMSAT	..... 110
Alfa Electronics	..... 112
Alinco Electronics	..... 6,7
Amidon Associates	..... 112
Astron Corporation	..... 107
Beezley, Brian, K6STL	..... 108
C & S Sales	..... 106
Coaxial Dynamics	..... 111
Communications Concepts, Inc.	..... 112
CQ Antenna Buyer's Guide	..... 108
Down East Microwave	..... 112
HAL Communications	..... 8
Hall Electronics	..... 110,111
ICOM America, Inc.	..... COV.II,1
Interactive Image Tech.	..... 9
Kenwood USA	..... COV.IV,2
L.L. Grace Comm. Products	..... 105
Lewallen, Roy, W7EL	..... 111
N.X.2.P. Electronics	..... 109
Naval Electronics	..... 111
OPTOElectronics	..... 10
PC Electronics	..... 109
Palomar Engineers	..... 108
Project Pro	..... 109
R.F. Design Software Service	..... 108
Spectrum International, Inc.	..... 110
Surplus Sales of Nebraska	..... 110
Yaesu	..... COV.III

We'd like to see your company listed here too. Contact Arnie Sposato, N2IQO, at (516) 681-2922 or FAX at (516) 681-2926 to work out an advertising program to suit your needs.

FT-990

All-Mode HF Transceiver

- **Frequency Coverage:**
100 kHz – 30 MHz RX
(160–10 m TX)
- Built-in Dual Digital Switched Capacitance Filters
- Built-in High Speed Antenna Tuner w/39 Memories
- RF FSP (RF Frequency-Shifted Speech Processor)
- Dual VFOs with Direct Digital Synthesis (DDS)
- 90 Memories which store Frequency Mode and Bandwidth
- Full and Semi Break-in CW Operation
- Band Stacking VFO System
- Multi-mode Selection on Packet/RTTY: Easy interface to TNCs
- Adjustable RF Power
- Variable Threshold Noise Blanker
- Optional Digital Voice Recorder (DVS-2)
- Front Panel RX Antenna Selection
- **Accessories:**
FT-990DC Available without power supply
XF-10.9M 2nd IF SSB Narrow 2.0 kHz Filter
XF-445K 2nd IF CW Narrow 250 Hz Filter
TCXO-2 High Stability TCXO
SP-6 External Desk-top Speaker
MD-1CB Desk Microphone
DVS-2 Digital Voice Recorder Unit
YH-77ST Lightweight Headphones
LL-5 Phone Patch Unit for SP-6 Speaker



"Yaesu did it again!"

"This is the only HF rig with a dual digital SCAF. It's incredible on a crowded band. Look inside, motherboard and plug-in board design. Un-be-liev-able!"

The innovative technology of the FT-990 is inside, not outside. Like the exclusive dual digital SCAF (Switched Capacitance Audio Filter). And for long term reliability, the motherboard/plug-in module construction eliminates inter-board wiring. The FT-990 also has the same undisputed receiver performance of the FT-1000 as well as other features such as a high-speed, built-in antenna tuner with automatic storage. And, multiple DDS (Direct Digital Synthesis) for quick lock-up time and low level noise. What's more, for maximum efficiency, the FT-990 is a self-contained base station with its space-saving, built-in AC power supply.

Outside, the very functional HF front panel is simple and uncluttered with a large amber display. Easy to use, easy to see. Pure and simple QSO enjoyment – with muscle when you need it! Yaesu makes "high-tech" effortless. Now it works for you, not against you. Have your dealer show you the FT-990 today and see what we mean.

YAESU

Performance without compromise.SM

High-tech innovation isn't miniature knobs, switches, and tiny labels.



© 1992 Yaesu USA, 17210 Edwards Road, Cerritos, CA 90701 (310) 404-2700

Specifications subject to change without notice. Specifications guaranteed only within amateur bands. Some accessories and/or options are standard in certain areas. Check with your local Yaesu dealer for specific details.

TS-450S

All This and More!

Building on a proven performer, Kenwood continues its H.F. superiority with the new TS-450S!

No other compact H.F. transceiver can offer you all the features of the popular TS-440S plus an impressive new set of deluxe features designed to give you that "Kenwood Edge" in H.F. operations.



- ▼ 100 Watts on all nine Amateur bands - SSB, CW, FM, FSK modes.
- ▼ General coverage receiver. 150kHz-30MHz.
- ▼ 108 dB Dynamic Range with Advanced Intercept Point (AIP).
- ▼ 100% Duty Cycle Transmitter allows continuous transmission (Key Down) at full power output for periods up to one hour with PS-53 heavy duty power supply.
- ▼ Direct Digital Synthesizer (DDS) allows fine-tuning in 1 Hz steps.
- ▼ Digital Signal Processor (optional) DSP-100, another Kenwood exclusive!
- ▼ New CW REVERSE MODE and PITCH CONTROL.

- ▼ Primary Function Control.
- ▼ Selectable IF Filter with Memory.
- ▼ Transceiver-to-Transceiver Data Transfer.
- ▼ IF Shift.
- ▼ Special circuit design, including Triple Conversion.
- ▼ 100 Memory Channels.
- ▼ New Ten-Key "Telephone Pad" Layout.
- ▼ Digital Bar Meter and Multi-function Display.
- ▼ Internal Automatic Antenna Tuner (optional).
- ▼ Three Scan Modes.
- ▼ Switchable AGC (slow/fast) Circuit. Front Panel VOX Control All-Mode Squelch Circuit.

KENWOOD

... Pacesetter in Amateur Radio

KENWOOD U.S.A. CORPORATION, Communications and Test Equipment Group, P.O. Box 22745, 2201 E. Dominguez Street, Long Beach, CA 90801-5745
KENWOOD ELECTRONICS CANADA, 6070 Kestrel Road, Mississauga, Ontario, Canada L5T 1S8

Kenwood meets or exceeds all specifications. Contact your dealer for a complete listing of specifications and accessories. Specifications are subject to change without notice. Complete service manuals are available for all Kenwood transceivers and most accessories. One year warranty in the U.S.A. only.