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What exactly will be on offer when the new third-generation mobile phone
services are rolled out? Richard Wilson reports, revealing that we may have to
wait two or three years to find out.

Mobile video – just one new feature
that the new third-generation mobile phone technology makes possible, but

CIRCUIT IDEAS
• RS322-to-parallel data conversion
• FONC's using current converters
• EFFICIENT battery auto-charger
• 30W Class-A power follower

GETTING THE MOST FROM YOUR SCOPE
Oscilloscope noise, and making
measurements in noisy environments are the topics of Lee Green's third article.

SPEAKERS' CORNER
Your listening environment has a surprisingly significant effect on what
you hear from your headspeakers. John Watkinson explains why.

PHASE-LOCKED LOOPS
Revealing useful web sites along the way, Cyril Baierman explains the
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interested in this invaluable building block.

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Ian Hickman introduces you to an important initiative aimed at
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Fax 02476 650 773

355 COMMENT
Mobile Internet – who wants it?

357 NEWS
• Ashton or Peninsular III
• New substrate for high-speed
• Chip transistors shrink to 30nm
• Electronic tagging for consumer goods
• Self-assembling micro-wires for
• digital watermarking for OS mugs

362 VERIFY BATTERIES
To 7AH
This micro-controlled load tester for 12V sealed lead-acid and NICAd batteries
covers twenty of the most popular capacities from 0.8 to 7AH. Designed by
Dave Sanford and Ken Duggan.

373 THIRD-GENERATION
MOBILE PHONES
What exactly will be on offer when the new third-generation mobile phone
services are rolled out? Richard Wilson reports, revealing that we may have to
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Mobile Internet - who wants it?

As the turbocharged action for 3G licences went on and the prices rose into the billions, did anyone ask themselves: "Who wants mobile Internet?" Already people talk about "e-commerce", meaning mobile commerce, as the successor to e-commerce.

Will people really transact business deals and compose messages using the tiny keypads of mobile phones? Will people access the Internet using wireless connections which frequently cut off? Many wonder. Not least Sir Alan Sugar, chairman of Amstrad/Viglen, at one time the parent company of the Danish mobile phone company Digicall. "Who wants to send e-mails from the middle of a field?", asks Sir Alan.

Many agree with Sugar that fiddling around with tiny buttons is not going to be a popular pastime. Those who say speech recognition, not tiny buttons, will be the input mechanisms for portable Internet access aren't familiar with the inaccuracies of speech recognition. These require the frequent intervention of buttons for correcting the many errors.

With the technology at its current state of development, is Mobile Internet feasible? Undoubtedly billions are being spent pursuing it. Marketing "data" - often pretty spurious - abounds for supporting the proposition that "by 2003 or even sooner half the people accessing the Internet will be doing it from mobile terminals". How can these projections be believed? How can the people spending the billions sleep at nights? The reason could be that a very large number of people have a vested interest in making mobile data communications catch on. Not least the mobile phone manufacturers. How else can they escape the fate of the four-function calculator?

Back in the 1970s, the four-function calculator became a commodity. Its price tumbled from hundreds of dollars to ten dollars in a few years. The technical reason for that was the effect of the IC - the integrated circuit - then a ten-year-old invention but doubling in transistor count every year.

The mobile telephone could easily go the same way as the four-function calculator. The technical reasons for that happening are a thin line of SOC, or system-on-chip, which is fast becoming possible in most types of consumer product. When you can put the electronic innards of a mobile phone on one chip, the cost of a mobile phone will plummet. Though, of course, a way of avoiding the nightmare. You can add functionality to the mobile phone. When the makers of calculators were threatened by commoditisation, they added a host of increasingly sophisticated and exotic functions ending up with such esoteric capabilities as div, grad and factorial.

So complicated were some of HP's calculators that, it was said, even PhDs only used 30 per cent of its functionality.

And PhDs do not make a mass market. The mass market wanted only the original four functions: add, subtract, multiply and divide. The attempt to move the market to accept - and pay for - more sophisticated functions failed.

The PC fared better. Tertified that commoditisation would happen to it, the PC industry succeeded for a couple of decades in avoiding price declines by having Microsoft produce ever more code-heavy operating systems. These required Intel to produce faster and faster processors and the DRAM-makers to produce denser and denser DRAMs.

These strategies ensured that, for 20 years, the PC industry successfully avoided the commoditisation process as the consumer bought more and more of this increasingly sophisticated - and sometimes functionally superfluous - kit. Mainstream PCs were $1000 two years ago and are $1000 now. That's a very clever trick to have pulled off.

Now it is the mobile phones that stand at the cross roads. One road leads to simplicity, commoditisation and declining profits, the other to complication, added value and high profitability. I wonder which will it be?

David Manners
Athlon outdoes Pentium III in 800MHz benchmark tests

The processor war between AMD and Intel has intensified following benchmark results that confirm AMD's Athlon is up to twice as fast as Intel's Pentium III in certain situations.

The tests on 800MHz processors, carried out by Bert McComas of Inquest Research in the UK, also show that virtual-channel DRAM is far better in many cases than standard synchronous or Rambus DRAM. McComas tested several system configurations based on AMD's and Intel's 800MHz processors. Chip sets were from either Intel or VIA Technologies, the former supporting Rambus, 133MHz SDRAM (PC133) or virtual channel (VC133), the latter PC133 or VC133.

Using Linpack (see diagram) and StreamD benchmarks, McComas showed Athlos to be 50 per cent or more faster than Pentium III. 'Athlon's consistently high performance is related to its CPU bus characteristics. At 200MHz it is much more capable of extracting the unqueued performance (headroom) of PC133 and Virtual Channel SDRAM,' the report said.

Rambus and PC133 showed little difference on those metrics. The Inquest report also examined the bottleneck caused by the graphics accelerator. In his report, McComas said: 'As 3D benchmarks are used to evaluate CPU, chipset and DRAM performance, it has become common practice to crank down the screen resolution, colour depth and image quality features to their minimum. On the surface, this may seem logical, but in effect the hottest, fastest PCs on earth are being benchmarked at 1997 screen resolutions.' Therefore he tested the different systems using a high-end Creative Labs card based on nVidia's GeForce graphics chip. The 3D tests used a Quake3 test program, setting resolution and image qualities to both their highest and lowest settings. At the lowest settings, AMD comes out worst, due said McComas to its lower speed level two cache. At the highest resolution though, there was no difference between the various systems. Why? Because the bottleneck is that the graphics card completely chokes the system, says McComas.

Indeed, clocking either processor at 400MHz caused graphs frame rates to drop by just two percent. Overclocking the graphics chip — up to 140MHz from 120MHz — saw performance rise by 15 per cent, even though the CPUs were running at half speed, proof that graphics is a bottleneck.

The moral of this story — spend your cash on the graphics card and chipset, not the processor.

Richard Ball
Electronics Weekly

New substrate for high-speed processing

A group of ex-Intel workers has developed a method of reducing problems with electrical noise, clock skews, speed, and soft errors in high-speed microprocessors.

Their start-up firm, Primaron, plans to split a processor's power grid into small independent sections. The die is then bonded to another silicon substrate which provides power regulators for each section of the circuit.

Such a system would improve the quality of the power supply, reducing problems such as ground bounce. Response times to current changes could improve by a factor of 100, the firm claims.

Clocks would also be sent to the processor chip via the substrate, reducing clock skew, noise and crosstalk. Noise could also improve by 100.

Circuits on the substrate will be built using heterojunction bipolar transistors (HBTs) to improve the quality of power and clocks, which are essentially analog.

Primaron expects its technology will be in widespread use within five years.

In order to develop the technology, it has garnered $5.7m in venture funding, mainly from Intel's $8bn venture fund. The firm has also bought a bipolar fab from Lansdale in Arizona.
Chip transistors shrink to 50nm in the bid for faster, cheaper silicon

The incredible shrinking transistor has done it again, this time at the hands of Silicon Valley firm Numerical Technologies (NumeriTech) which has produced 50nm (0.05µm) transistors using conventional 248nm optical lithography.

The devices, claimed to be the smallest ever fabricated using optical lithography, were made at the Massachusetts Institute of Technology (MIT).

Using phase-shift mask (PSM) techniques, the previous limit for 248nm lasers was thought to be 100nm feature sizes. Getting to 70nm and below was the realm of 157nm lasers.

"People have been predicting the end of optical lithography for several years, saying that it can't extend beyond 100 nanometers," said Y.C. Pati, president and CEO of NumeriTech. "The MIT Lincoln Laboratory results prove that with prudent use of phase shifting, optical lithography can be extended much further than anyone ever thought was possible."

Beyond the 100nm mark, it was expected that new technologies such as ion-beam lithography would be used to pattern silicon features much closer together. Because of the interference fringes close to the desired transistor, you get false, but not necessarily compact, devices.

PSM relies on the fact that a coherent imaging system will create interference as the laser is diffracted as it passes through the mask. The effect can be used to reduce the spatial frequency of a given object or to enhance its edge contrast.

Both resolution and depth of field of the image can be improved. To shift the light phase, an extra layer of transmissive material with a different refractive index is needed on the mask.

NumeriTech designs the software that modifies the chip layouts to make use of optical proximity correction and PSM. It is already being used by firms such as Lucent and Motorola to produce features down to 120nm, or 0.12µm.

Electronic tagging for consumer goods?

RF tagging chips will be taking an active part in the fight against crime if a government Home Office initiative takes off.

"We must use every means at our disposal, including the latest technology, to see how it can best be used or developed to cut crime and make our communities safer," said Home Office minister Charles Clarke at the recent "Chipping the Goods" seminar.

The plan is to electronically tag equipment by embedding a passive RF tagging device into consumer goods such as TVs, computers and cameras. The ship would carry information about the equipment and its owner. The information stored in the device can be changed in situ using RF technology and can be read remotely when required.

The technology is referred to as RF ID and devices are being developed by several companies including Texas Instruments, Philips, Ocxy and Gemplus of France.

The technology should also allow companies to track goods more effectively and so reduce stock losses in the information written into it to what is legally allowed. "This is new technology which the Home Office is looking to encourage industry to make use of in protecting its property," said Martin Swedlow, chief executive of IT consultants Integrated Product Intelligence which is involved in organising trials of the tagging.

The first UK licence for spectrum for an Asset-Tracking Mobile Data Network has been awarded by the Radiocommunications Agency to QNL (UK) Ltd.

NumeriTech designs the software that modifies the chip layouts to make use of optical proximity correction and PSM. It is already being used by firms such as Lucent and Motorola to produce features down to 120nm, or 0.12µm.

• The HS801: the first 100 Mega samples per second measuring instrument that consists of a MOST (Multimeter, Oscilloscope, Spectrum analyzer and Transient recorder) and an AWG (arbitrary waveform generator). This new MOST portable and compact measuring instrument can solve almost every measurement problem. With the integrated AWG you can generate every signal you want.

• The versatile software has a user-defined toolbar with which over 50 instrument settings quickly and easily can be accessed. An intelligent auto setup allows the inexperienced user to perform measurements immediately. Through the use of a setting file, the user has the possibility to save an instrument setup and recall it at a later moment. The setup time of the instrument is hereby reduced to a minimum.

• When a quick indication of the input signal is required, a simple click on the auto setup button will immediately give a good overview of the signal. The auto setup function ensures a proper setup of the instrument, the trigger levels and the input sensitivities.

Diamond micromachines: Sandia National Laboratories in the US has created what it believes are the world's first diamond micromachines, The cord drive is constructed from etched amorphous diamond - the second hardest substance behind crystalline diamond. It is a better material than silicon because it is wear resistant, in addition, it is not rejected by the human body so it could be used for medical bioswaps. "Micromachines, for their marvellous tiny size, are still machines. It's a small leap, even if it's only at the micro level," said researcher Tom Friedmann. He believes second MEMS could last 10,000 times longer than silicon devices.

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Researchers develop self-assembling micro-wires for multi-chip modules

Self-assembling micro-wires could form the basis of a new interconnection system for multi-chip modules. Researchers at Leeds University formed the wires from stacks of disc-shaped molecules in a 'discrete' liquid crystal. These stack themselves under certain conditions to form columns like piles of plates, as in the diagram below. Stacking on any flat surface can be provoked predictably, forming a forest of independently-conducting wires like bristles on a brush. "The molecules will generally orient on anything," said Professor Richard Bushby of the Leeds team developing the technology.

Conductivity along the wires comes from a graphene-like six-atom carbon ring in the centre of each molecule. These can act as electron leaving a hole which, once the molecules are stacked, can migrated up the centre of the column. Surrounding polythene-like hydrocarbon chains form the wire's insulator.

If two chips are positioned on one chip will be connected to a corresponding conducting pad on the other once the space is filled with the liquid crystal. Insulating layers on the chip surface prevent conduction where it is not wanted. At the moment, pads 14nm across have been connected. Bushby expects this to be reduced to sub-micrometre levels in the future.

Researchers are also working on a "smart" way to ensure that wires can be connected only to corresponding pads above. "We have improved by a factor of ten the last two years and need a couple more powers of ten," said Bushby.

The Leeds team is to receive a share of a £1.5m grant from the EU as part of a 3D-chip programme. Other members are: the University of Debi, which is developing ways to produce conducting via through chips, CNRS in Paris, which is working on a conductivity polymer interconnection system to achieve the same ends as Leeds, and University College London which is looking at some related visual image processing techniques.

Steve Bush

Digital watermarking finds its way into maps

Signum Technologies has done a deal with Ordnance Survey to apply its digital watermarking technology to the OS’s library of digital maps.

"Some people think they can just copy a map, use it commercially and get away with it," said Calvert, from the OS’s intellectual property division.

While the OS is self-funded, any shortfall in revenue if made up from taxpayer’s money.

"It’s one thing to photocopy a map so someone can find you easily. It is quite another to use the information that costs us millions of pounds every year to provide and then use it commercially and unlicensed," said Calvert.

Signum’s ‘watermarks’ can show when an image has been copied, even if all the colours are changed and content is removed or added.

Now you see it... Similar technology from Signum to the one it is using in the Ordnance Survey watermarking technology is seen above being applied to a speeding bicycle (allegedly). The left-hand image shows how changes to the bike’s registration plate and speed, and removal of the car to the left have been spotted by the software.

Andrea Hendra

READER Offer FROM NEWNES!

A reader is offering you a choice of two combinations of books on PICs for the price of one. You can choose either:

1. PIC Emulators from TechTools
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   - BASIC Stamp for Circuit Emulator
   - BASIC Stamp for Circuit Emulator

This offer is valid until the end of May 2000. To take advantage of this offer, please write to: Newnes Reader Offers, Butterworth-Heinemann, Linacre House, Jordan Hill, Oxford OX2 8DP.
**Verify batteries to 7Ah**

The function of backup batteries is to provide power to the system in the event of mains supply failure. In UPS, telecommunications and alarm systems, sealed lead-acid batteries are the most popular because they offer good combinations of size, energy density per unit volume and cost. However, batteries and related charging circuits remain common sources of failure — especially in alarms systems. Charging circuits are statistically more reliable than sealed lead-acid batteries, as correctly applied modern semiconductors typically last at least three times longer than even the most advanced batteries.

Testing such batteries gives multiple benefits, especially in the alarm industry; fewer call-outs for the installer, police, site owners’ etc., and fewer claims for the insurers. Testing identifies both weak and healthy batteries, reducing the chances of failure. It also allows you to make the best use of what is both a resource and, at the end of its service life, a source of pollution. Most batteries now being classified as recyclable could be dissipated could be a fire hazard.

There are only two methods of testing sealed-lead-acid batteries. Firstly you can measure the battery’s internal resistance. By inference, a battery with a high internal resistance cannot deliver power.

Alternatively, you can evaluate a lead-acid battery using load testing. Here, the battery delivers power to a load and the voltage is monitored. Demonstrating that a battery can deliver power for the required time increases confidence that it can perform to an almost identical level in the immediate future.

A testing problem

Taking the example of a 12V, 7Ah battery, such a battery could theoretically be tested by connecting a 12-7=171.7Ω resistor, which would allow 7A to flow, the 1C rate of this battery, hence a 1C test load. If the battery voltage fell below 12V during the test, the battery would be failed.

Any size of sealed-lead-acid battery can be tested in this manner; the load resistor value simply being calculated by Ohm’s law. However, for each capacity of battery, a different resistor is required. Also, a nominal ‘12V’ battery may have a start-of-test voltage of 12.9V causing, in this example, an initial current flow of 13.8+1.71=8.07A.

Taking in to account the 5-10% tolerance of the power resistor, the result is a worst case figure of 8.97A.

A PIC based solution

The tester described here enables twenty of the most popular capacities of sealed-lead-acid battery to be tested by applying an accurate constant current load. Yassa recommends a minimum test of 1 minute at 1C rate, and specify that the voltage should not drop below 12V.

The circuit is based on the cheap and versatile Microchip PIC16C74A. This device allows you to build a sophisticated but easy to use test instrument using very few components, thanks to features such as the on-board five-channel eight-bit analogue to digital converter. The block diagram of the tester is shown in Fig. 1.

As well as controlling the load, the PIC also directly controls four 7-segment multiplexed displays and three indicator LEDs to show what is being displayed — current, voltage or time. The controller also responds to select, stop and start controls, and monitors the voltage of the battery under test. In addition it checks its own battery and keeps an eye on the load temperature whilst it is active.

The adjustment links allow a 2.5% increase or decrease in the load current to counteract inaccuracies in the current measuring circuit. A buzzer gives an audible indication of the end of a test, or a problem with the load temperature. It is also used to make a click when a control key is pressed or if a held down key is auto-repeating.

Important safety issues

There are safety concerns that influenced the design of the circuit, and these are due to the nature of the batteries being tested. Although they might be tested at currents of up to 7A, the batteries involved here can deliver many times more.

Uncontrolled current flow could cause arcing, which might damage the test load clips. In a worst-case scenario, the power dissipated could be a fire hazard.

For these reasons, the connections were taken into account. Whenever the unit is switched off, the load must be inactive. This implies that the test load clips are connected before the unit is turned off during a test. At the first sign of a bad connection to the battery under test, the load must be swiftly de-activated.

As intuitively connecting the test leads with the wrong polarity must not cause any damage to either the tester or the battery under test.

Specifications of the battery monitor

<table>
<thead>
<tr>
<th>Battery types tested</th>
<th>12V sealed lead-acid and NiCd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery capacities tested (Ah)</td>
<td>0.8, 1.0, 1.1, 1.2, 1.8, 2.0, 2.1, 2.3, 2.5, 2.6, 3.0, 3.2, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0 Ah</td>
</tr>
<tr>
<td>Test type</td>
<td>Full floatload</td>
</tr>
<tr>
<td>Voltage measurement tolerance</td>
<td>±0.3%</td>
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<td>Voltmeter range</td>
<td>3-13.8V</td>
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<tr>
<td>Voltmeter resolution</td>
<td>0.05V</td>
</tr>
<tr>
<td>Load voltage range</td>
<td>9-13.8V</td>
</tr>
<tr>
<td>Load tolerance</td>
<td>Better than ±1.7% @ 7A, typically ±5-10mA</td>
</tr>
<tr>
<td>Power consumption, typical</td>
<td>11.75W</td>
</tr>
<tr>
<td>Internal battery low level warning</td>
<td>7.6V</td>
</tr>
</tbody>
</table>

Fig. 1. At the heart of the tester is a PIC microcontroller, which evaluates the battery being tested. Having a five-channel analogue-to-digital converter built in, this controller greatly simplifies the monitor’s design.
CONTROL & INSTRUMENTATION

Fig. 2. Principle of the constant-current battery monitor circuit. The PIC compares voltage over R1 to reference voltage against a reference and switches the transistor on or off depending on the reading, resulting in a pulse-width-modulated drive.

The battery monitor. As shown, the load device consists of a constant-current sinking device, the result would be a load that was activated by the low output from the PIC. If the test battery were connected before the unit was powered up, Tr3 would turn on hard, so the load would be turned on too. Using Tr4 as an inverter to make it active high makes sure that this does not happen.

Diodes D1 and D3 protect against current flow through the load transistors in the event of a reverse voltage being applied to the test loads. Diodes D2 and D4 make sure that the voltage applied to the PIC’s analog input pins never goes more than 0.6V above VDD or 0.4V below VSS. The PIC data sheet specifies that the voltage on any pin should not exceed 0.6V above VDD or 0.6V below VSS.

With this circuit, there is an added problem that a pre-power on voltage because the initial state of Tr10 is to be off. Diode D5 is used to monitor the temperature of the load components. If the load is sinking a current of 7A at 13.8V, the heat dissipated by it will be almost 100W, so it is essential that adequate heat sinking is provided for the components that do the dissipation.

Most of the heat is dissipated by R31, R32, Tr9 and D9. We recommend that they are mounted together on a separate heat sink with a good thermal connection to D9, to allow the PIC to accurately monitor their temperature.

An LM4040 AIM-4.1 voltage reference is used by the PIC’s 4-to-6 converter, which produces a voltage of 4.096V with 0.2% accuracy. This IC comes in a range of tolerances and packages but as all measurements made by the PIC are referenced to this voltage, using one with a different tolerance will affect the accuracy of all aspects of the tester.

All four 7-segment displays are common-cathode types. This allows them to be multiplexed, with the output from the PIC sourcing the current to drive them. The PIC can source up to 20mA, but we found that a drive current of 9mA per segment was sufficient with the type of displays used here. The buzzer used is a piezo-ceramic type that needs only 10mA to provide a surprising amount of noise!

The microcontroller

The PIC16C74A has 33 I/O pins, arranged as five ports. Any of the pins on a port can be configured as an input or output. Many can also be configured for a special function such as external interrupts (RB6, RB7) or asynchronous communication (RC0, RC1). In this circuit though, they are only used as straightforward I/O pins.

Data sheets for the PIC, available on the Microchip web site (www.microchip.com), give the full details but a brief summary of the ports and how they are used in this design is given in Table 1.

Table 1. A-to-D conversion routine.

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bsf ADCON0, GO</td>
<td>Enable A-to-D conversion</td>
</tr>
<tr>
<td>movf temp, ADRES, W</td>
<td>Load ADC result into temp</td>
</tr>
<tr>
<td>decfsz temp, F</td>
<td>Decrement counter</td>
</tr>
<tr>
<td>movf temp, temp</td>
<td>Store result into temp</td>
</tr>
</tbody>
</table>

Pins not shown in the table are concerned with the workings of the PIC.

Fig. 3. Full circuit of the battery monitor. As shown, the load device is a Darlington made up of two discrete devices, but you could see a MOSFET.
Table 1. The I/O pins of the PIC controller are designated as follows.

<table>
<thead>
<tr>
<th>Pin</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>R8</td>
<td>'Start' key</td>
</tr>
<tr>
<td>1</td>
<td>R7</td>
<td>'Select' key</td>
</tr>
<tr>
<td>2</td>
<td>R6</td>
<td>'Stop' key</td>
</tr>
<tr>
<td>3</td>
<td>R5</td>
<td>'Test' key</td>
</tr>
<tr>
<td>4</td>
<td>R4</td>
<td>'Select' key</td>
</tr>
<tr>
<td>5</td>
<td>R3</td>
<td>'Select' key</td>
</tr>
<tr>
<td>6</td>
<td>R2</td>
<td>'Select' key</td>
</tr>
<tr>
<td>7</td>
<td>R1</td>
<td>'Select' key</td>
</tr>
<tr>
<td>8</td>
<td>R0</td>
<td>'Select' key</td>
</tr>
</tbody>
</table>

**Fig. 4.** Flow chart setting up the PIC's ports and interrupts.

**Table 2.** For timing functions. The main program can use the bits of the interrupt register for its own timing requirements. 'Astable' bits toggle between 0 and 1 while 'monostable' bits need resetting by the main program routines.

<table>
<thead>
<tr>
<th>Bit</th>
<th>Function</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>a (s)</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>b (s)</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>c</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>d</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>e</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>f</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>g</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>h</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>i</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>j</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>k</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>l</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>m</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>n</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>o</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>p</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>q</td>
<td>1</td>
</tr>
<tr>
<td>17</td>
<td>r</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>s</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>t</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>u</td>
<td>1</td>
</tr>
<tr>
<td>21</td>
<td>v</td>
<td>1</td>
</tr>
<tr>
<td>22</td>
<td>w</td>
<td>1</td>
</tr>
<tr>
<td>23</td>
<td>x</td>
<td>1</td>
</tr>
<tr>
<td>24</td>
<td>y</td>
<td>1</td>
</tr>
<tr>
<td>25</td>
<td>z</td>
<td>1</td>
</tr>
<tr>
<td>26</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>27</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>28</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>29</td>
<td>D</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>E</td>
<td>1</td>
</tr>
<tr>
<td>31</td>
<td>F</td>
<td>1</td>
</tr>
</tbody>
</table>

The software can be broken down into four main areas.

1. **The 'pre-test' routine.** Referring to Fig. 4, this routine is where the interrupts and ports on the PIC are set up. Timers are initialised and the program goes into a loop where it waits for the user to press a key. The 'Select' key changes the test current, the 'Start' key toggles to the 'DVM' and the 'Stop' key disables the 'DVM'.

2. **The 'test' routine.** This is the actual test, where the current specified by the user in the 'pre-test' routine is drawn from the battery, Fig. 5. While this is happening the voltage, load temperature, time and keys are monitored. The user can change the display between 'Battery save' mode where the only thing displayed is a moving dot (resulting in the internal battery drain of about 15 mA), display the elapsed time, the voltage of the battery under test, the load current (set in the 'pre-test' routine) and the load current, the test took for the battery to pass or fail. The final voltage measured before the battery passed or failed, and the load current, Fig. 6.

3. **The interrupt-service routine.** This routine, Fig. 7, provides time-critical routines. These allow other routines to operate without worrying how they will affect factors such as the load PWM signal or the overall timing of the test.

4. **Ancillary routines.** There are other routines. These are used for setting up the PIC's ports and interrupts, etc.

The pre-scaler can be programmed so that the increments only happen every 2, 4, 8, 16, 32, 64, 128 or 256 instruction cycles. Communication between the interrupt-service routine and the main program is done through registers which the routine checks each time it is executed.
common routines used by different parts of the main program. These perform tasks such as doing the a-to-d conversion, List 1, and reading the keys. Fig. 8.

The complete code for the tester is too large to reproduce here, but is available on the internet from http://www.the-shed.demon.co.uk/tester or by post as a hard copy or on floppy disk. Details of how to obtain technical support are given at the end of the article.

At just over 1500 lines of assembly code, the program is fairly large. When writing programs of this size there can be problems which do not occur in smaller programs.

Controller usage notes

Stack depth. The stack of the PIC 16C74A is only eight levels ‘deep’. Each time a ‘CALL’ instruction is executed one of these levels is used up, meaning that calls can only be nested seven times before things start going wrong.

Bear in mind that an interrupt uses the stack to store its return address. Also, if the interrupt-service routine performs an a-to-d conversion another stack level is used when the a-to-d sub-routine is called.

These factors reduce the maximum number of nested calls the main program can use to five. It is very easy to accidentally go beyond this without noticing.

Page boundaries. Although the PIC 16C74A has a 13-bit wide address bus, only the lower 8 bits can be addressed when using computed look-up tables via the ADDWF PCL, F command. This command adds the contents of the W register to the program counter. The other 5 bits are loaded in from the PCLATH register when the ADDWF PCL, F command is executed. For look-up tables, this effectively divides the memory into 256-byte pages, which they must not cross.

Probably the easiest way to avoid crossing these boundaries is to put all the look-up tables at the beginning of the code, before the main program. This makes it easier to check that no boundaries are crossed.

For look-up tables that are after the first 256 bytes of program memory, the PCLATH register must be used to set the upper 5 bytes of the program counter.

More page boundaries. A ‘GOTO’ or ‘CALL’ in the program only loads the program counter with the lower 11 bits of the address, meaning that calls only have a 1024-byte range. The other two bits needed to complete the 13-bit address are loaded from bits 3 and 4 of the PCLATH register. If your program is over 1024 bytes long and uses calls to routines that are beyond the 1024/2048/3069 boundaries you must set the PCLATH 4:3 bits accordingly. The Microchip application note AN556 – available from the Microchip web site – has more details about these problems.

The analogue to digital converter

One of the most useful features of the 16C74A is the on-board a-to-d converter. Although it only has a resolution of 8 bits, used in conjunction with a precision voltage reference it allows accurate monitoring of many different parts of the circuit.

The reference voltage for the a-to-d – i.e. the voltage that a digital value of 255 from the a-to-d converter represents – can either be set up in software as the VREF supply voltage to the PIC or an external source.

As the tolerance of most 5V regulators is only 5%, an external 4.096V, 0.2% tolerance voltage reference, namely DR, is used in this circuit for improved accuracy in voltage measurements.

To convert a voltage to its corresponding digital value the following can be used,

\[ D = \frac{V_{\text{in}}}{V_{\text{REF}}} \times 2^8 - 1 \]

where \( D \) is the digital value, \( V_{\text{in}} \) is the sampled voltage and \( n \) is the number of bits of resolution of the a-to-d converter.

For the PIC 16C74A in this application, \( V_{\text{REF}} = 255 \times 4.096 \)

4.096

This circuit uses four of the PIC’s a-to-d channels to monitor the following parameters:

RA0: Current flow through the load. For example, at 7A the voltage at RA0 is, 

\[ 7 \times 10^3 \times 0.47 \Omega = 3.29 \text{V} \]

So the value returned by the a-to-d conversion will be, 

\[ D = \frac{3.29}{4.096} \]

4.096

Note that as the PIC can only use integers, the actual value returned would be 204.

RA1: The voltage of the battery under load.

\[ 7 \times 10^4 \times 0.47 \Omega = 3.29 \text{V} \]

So the voltage returned by the a-to-d conversion will be, 

\[ D = \frac{3.29}{4.096} \]

4.096

Table 3. The ADCON0 register is used to manage a-to-d conversion.

<table>
<thead>
<tr>
<th>Bit</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function ADCON1</td>
<td>ADCON0</td>
<td>CH5</td>
<td>CH4</td>
<td>CH3</td>
<td>CH2</td>
<td>CH1</td>
<td>CH0</td>
<td>GO/DONE</td>
</tr>
<tr>
<td>Description</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Analog channel select</td>
</tr>
<tr>
<td>ADON</td>
<td>Setting this bit turns on the a-to-d conversion module</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not used</td>
<td>Setting this bit turns on the a-to-d conversion module</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reset the TMRO counter for 500us

Check the load feedback voltage

Update the next display

Do timing functions (Table 2)

Enable interrupts

Fig. 7. All time-critical operations are carried out during the interrupt-service routine.
CONTROL & INSTRUMENTATION

To provide a measuring voltage range of up to 13.8V, R1 and R2 (precision 0.1% tolerance components) are used as a potential divider,

\[ \text{13.8V} \times \frac{10k\Omega}{23.7k\Omega+10k\Omega} = 4.095V \]

at RA1.

RA2: The voltage of the tester's own battery. Resistors R3 and R4 are used to give a measured voltage range of up to 9V.

RA5: Drive-transistor temperature. The LM35 used here provides a voltage output of 10mV multiplied by its temperature in kelvin, so for a temperature of 55°C there would be a voltage of

\[(273+55)x0.01 = 3.28V\]

present at RA5. Line RA3 is the input for the external voltage reference.

Technical support

A complete set of instructions on how to use the tester is available from http://www.theshed.demon.co.uk/tester, where the complete code is also available. The instructions are also distributed with hard copies of the code, pre-programmed PICs and kits of parts.

To obtain details about how to get the code sent by mail, buy a pre-programmed PIC or a complete kit of with hard copies of the code, pre-programmed PICs to obtain details about how to get the code sent by mail, buy a pre-programmed PIC or a complete kit of with hard copies of the code, pre-programmed PICs.

Implementing the tester

Our prototype battery tester was constructed in an extruded aluminium case, with the heat-dissipating components mounted on a piece of sheet aluminium. Fig. 9 They were bolted to the case using a hole in the heat-sink block using high-temperature epoxy to give a good thermal contact.

Because there was a direct thermal path from the heat-sink to the case, we chose 55°C as the temperature at which to suspend the test with an error message. The components on the heat-sink can stand higher temperatures, but the operator holding the case might not be able to!

In this configuration, we found that three successive 7A tests could be performed before the unit started giving the 'too hot' error message. If a different build technique was used to allow a higher running temperature, the maximum test temperature could be raised by changing a value in the PIC code.

We stuck the temperature sensor into a hole in the heat-sink block using high-temperature epoxy to give a good thermal contact. All other components were mounted on a PCB that was bolted via the 'B' hole to the heat-sink with insulating pillars. There's a rectangular slot in the front of the case for the display. The leads, 4mm test-lead sockets and on/off switch were mounted on the front. The battery compartment was in the base of the unit.

The choice of test leads is an important factor when it comes to accuracy. Not only must they be rated at 7A or more, but they must also have a known resistance.

Our tester has leads with a resistance of 0.054Ωm, which makes for a total resistance of 0.027Ω, which balance the total current used. This is due to the fact that power resistors such as those used for the current sensor, R1, typically have a tolerance of 5%.

Cutting link 1 adds 2.5% via a look-up table to the reference voltage that the pulse-width-modulated load signal generating routine will use for each test setting. This is the easiest way to use a current of, say 2A from a power supply through the resistor and measure the voltage across it. As the resistance is voltage divided by current, it is easy to calculate R1, and cut the appropriate link if need be.

On a final note, it should be easy to apply the loading method to other current ranges and voltages.

Fig. 8. The keypad interface routine is interrupt based so there are no time-wasting software delays.

Fig. 9. Layout of the heat-sink mounted components in our prototype.
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- No power supply required
- Ultra compact design
- Oscilloscope and data logging software included
- Write-to-disk on trigger function standard

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The ADC42 has 12-bit resolution making it suitable for applications where detection of small signal changes is needed.

Specifications
Scope timebases 50μs/div to 60μs/div
Spectrum analysis 100Hz to 1kHz
Max sampling 15kSamples/s
Voltage range ±5V
Resolution 12 bit
Channels 1 BNC
Impedance 1MΩ, DC coupled
Accuracy 1%
PC connection D2S to PC parallel port
Power supply Not required

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Third-generation mobile phones

The consumer will probably not get the benefits of 3G mobile phones for another two or three years, but what exactly will be on offer when the services are rolled out?

Richard Wilson takes a look

As you can see from the table on the right, the UK, like the rest of Europe, is about to get its first third-generation mobile phone operators. But if like me you're wondering what third-generation mobile communications will offer in sexy new services then we should start to find out before the end of the year.

By Christmas 2000 each of the new third-generation (3G) operators will only be starting to build their network infrastructure. True 3G services are probably two years away at the earliest.

Some even suggest 3G will not happen in a significant way until 2002/03. One reason for this is that mobile-phone users will not have to wait until 3G is ready to get some of the anticipated new services like wireless Web browsers and video. If GSM is second generation and UMTS is third generation mobile communications, then somewhere in between comes the 2.5 generation system known as general packet radio service (GPRS). This is more than a half-way house mobile technology to full 3G. In fact its capability to carry packet-switched data at aggregated rates up to 384kbit/s may even persuade operators to put off investment in full-blow and expensive 3G networks a little longer.

Evidence suggests that UK operators are racing to upgrade their GSM networks to support GPRS and we could see first commercial general packet radio services by the end of the year.

There is a strong desire for the rollout of GPRS," says Lance Hiley, a strategic marketing manager for wireless at Lucent Technologies Microelectronics. "Every operator will have commercial GPRS services in 2000 — most likely the second half of the year."

But how does GPRS improve on existing GSM mobile systems? The key is data transmission. The GSM mobile phone is essentially a voice communicator. GSM data transfers are literally in the dark ages being limited to 9600b/s. This is less than 20 per cent of the rate of the modem in your PC, or 1000 times slower than the slowest office LAN.

The experts tell us that the 3G mobile phone will be defined as a mobile video. Samsung shows what a 3G handset will look like.

3G licences in Europe

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of licences awarded being scheduled</th>
<th>Award date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finland</td>
<td>4</td>
<td>March 1999</td>
</tr>
<tr>
<td>UK</td>
<td>5</td>
<td>March 2000</td>
</tr>
<tr>
<td>Spain</td>
<td>4</td>
<td>March 2000</td>
</tr>
<tr>
<td>Netherlands</td>
<td>4-5</td>
<td>Q1 2000</td>
</tr>
<tr>
<td>Germany</td>
<td>4-6</td>
<td>Q2 2000</td>
</tr>
<tr>
<td>Norway</td>
<td>3-4</td>
<td>Q2 2000</td>
</tr>
<tr>
<td>Switzerland</td>
<td>3-4</td>
<td>?</td>
</tr>
<tr>
<td>Portugal</td>
<td>4</td>
<td>?</td>
</tr>
<tr>
<td>Denmark</td>
<td>4-5</td>
<td>?</td>
</tr>
<tr>
<td>France</td>
<td>4</td>
<td>Q3 2000</td>
</tr>
<tr>
<td>Belgium</td>
<td>3-4</td>
<td>Q3 2000</td>
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<td>Sweden</td>
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<tr>
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<td>Q3 2000</td>
</tr>
<tr>
<td>Austria</td>
<td>4</td>
<td>Q4 2000</td>
</tr>
<tr>
<td>Ireland</td>
<td>3-4</td>
<td>Q4 2000</td>
</tr>
<tr>
<td>Greece</td>
<td>4</td>
<td>Q1 2002</td>
</tr>
</tbody>
</table>

Source: Netcom Consultants, UK
Mobile phone operator Orange has already shown us what a 3G video phone could look like.

The telecoms industry is robust for its use of acronyms, so when third-generation mobile systems become known as 3Gs systems hardly an eyebrow was raised in disbelief. However, 3G is just the start. Already there are 2G+-3GPP and 2GPP2 to tax our powers of understanding.

To help the acquisition of one's wits, I am listing all sorts of mobile radio systems associated with the next generation of mobile phone technology. Perhaps I will give you a chance to impress your office in the business or don't bank on using the knowledge at the local pub quiz night.

**3G+** Second generation mobile communication with spreading spectrum techniques will be taking high-speed data rates from EDGE, HSCSD and GPRS.

**3G** Third generation, 3G is used in a single radio slot (as the so-called fallback generation) of mobile phone systems. These are also operated by high-speed data capacity alongside voice carriers for up to 384kbit/s. It does not stop there. A further GSM data enhancement technology known as EDGE is being developed by Nokia and Ericsson amongst others. This could increase mobile data rates up to 115.2kbit/s. A 10-fold increase on today's GSM tendons.

However we as users are only starting out on the 3G road, despite how quickly manufacturers may wish to push us along. A full 115kbit/s GSM mobile data terminal requires eight radio slots, for both transmit and receive. That requires a minimum of 16 slots and is known as a Class 18 GPRS system. Class 18 mobiles offering 115kbit/s.

**TETRA** European Telecommunications Standards Institute.

**PLMTS** Future Public Land Mobile Telecommunication System, the ITU's single global 3G standard, that agreement could be found, replaced by the IMT-2000 family. The project is expected to accelerate IMT-2000 family members.

**3GPP** Third Generation Partnership Project. An organisation between 27 European American radio and ITU national members. According to 3GPP, the 3GPP standards will be forwarded to the ITU and will support interworking between IMT-2000 family members. The project is expected to accelerate IMT-2000 family members.

**3GPP2** CDMA2000 equivalent to 3GPP, members are ARIB (Japan), CTS (China), ETSI (Europe), ITS-136, ITIA (Japan) and TCT (Japan) are members. According to ARIB, the 3GPP standards will be forwarded to the ITU and will support interworking between IMT-2000 family members. The project is expected to accelerate IMT-2000 family members.

**GSM** Global System for Mobile Communications, formerly General Packet Radio Services, has a data rate of up to 11.2kbit/s. Data rates to 115.2kbit/s will also be able to extend the data rates on GSM networks. GPRS works by transmitting data packets. Each packet has an "address" for where it is being sent so that all the data packets that make up a particular message do not necessarily have to be transmitted in sequence on one radio channel, as is the case with GSM at present. With GPRS, data transmission can be increased above the capability of a single radio channel because packets can be sent on any of a number of different radio channels for up to the air interface. GPRS systems allow a data rate of up to 14.4kbit/s to be transmitted in each of GSM's eight time slots. This gives an aggregated system data rate of 11.5kbit/s. A 10-fold increase on today's GSM tendons.

However we as users are only starting out on the 3G road, despite how quickly manufacturers may wish to push us along. A full 115kbit/s GSM mobile data terminal requires eight radio slots, for both transmit and receive. That requires a minimum of 16 slots and is known as a Class 18 GPRS system. Class 18 mobiles offering 115kbit/s.

**WAP** Wireless Web browsing will complicate considerably the business of selling mobile communications to operators and manufacturers because user access to services through wireless application protocol (WAP) standard to help companies through the minefield of the wireless Internet.

WAP is a set of hardware and software interfaces which will be implemented on mobile handsets and Web site servers should allow mobile phones to be used much like a PC, to send and receive e-mail messages and access the Web.

But the performance of the WAP applications will inevitably put demands on the bandwidth of the mobile's radio channel. So the development of WAP, its performance and the impact on the radio link this year of higher bandwidth radio systems like GPRS (general packet radio service) which theoretically offers data rates up to 11.5kbit/s.

WAP itself incorporates data compression to make the most of the slowly data transfer rate of today's GSM networks. It also uses error correction techniques to ensure that browsing and data transmissions are not necessarily affected by changes in the quality of the radio link.

The other important feature of the WAP is it is designed to run applications on different radio network architectures, such as GSM, CDMA, DECT and even TETRA.

**ETSI** European Telecommunications Standards Institute.

**PLMTS** Future Public Land Mobile Telecommunication System, the ITU's single global 3G standard, that agreement could be found, replaced by the IMT-2000 family. The project is expected to accelerate IMT-2000 family members.

**3GSC** The successor to IS-136 mobile standard. This is EDGE (the GSM phase 2+ standard).

**IMT-F** The DEC'T standard.

**IP** Internet Protocol

**IPv6** Forum an organisation promoting internet access on 3G mobile networks.

**IS-95** Second generation narrow-band CDMA system, used predominantly in the USA.

**IMT-136 Enhanced IS-95**

**IS-2000** CDMA2000 2nd generation 3G air interface standard.

**IMT** International Telecommunication Union.

**3GPP2** CDMA2000 equivalent to 3GPP. Members are ARIB (Japan), CTS (China), ITIA (Japan) and TCT (Japan). www.3gpp2.org

**ARIB** Association of Radio Industries and Businesses. (Japanese radio standards body. ARIB specifies were developed to be interoperable at a national level.

**CDMA** Code division multiple access. A spread spectrum communication system, the basis of most 3G systems.

**CDMA2000** 3G air interface standard, a Qualcomm created standard. Comes in 1X (1.25MHz development resources leads to more data whether user is traveling or not.

**HSCSD** High Speed Circuit Switched Data, data over GSM up to 110 kbit/s by concatenating data packets to achieve 2864 kbit/s.

**WCRT** Chinese Wireless Telecommunications Standards organisation. www.cwts.org

**EDGE** Enhanced Data rates for GSM Evolution. GSM's own 8-bit modulation scheme has been abandoned when none of the vested interests could have it any other way. See: IMT-DS, IMT-MC, IMT-IC, IMT-SC and IMT-FC.

**EFR** Enhanced Full Rate. A speech codec for better speech quality, also sold to be more tolerant to interference.

**ETSI** European Telecommunications Standards Institute.

**PLMTS** Future Public Land Mobile Telecommunication System, the ITU's single global 3G standard, that agreement could be found, replaced by the IMT-2000 family. The project is expected to accelerate IMT-2000 family members.

**FDD** Frequency division duplex, part of 3G WCDMA with separate T and R frequencies for up to 2Mbit/s.

**GCF** GSM Certification Forum. An industry body defining a set of tests to supplement European self-certification type-approval tests to ensure functional compatibility to GSM networks. A 3G equivalent of this is expected to be formed.


**GSM** Global System for Mobile Communications, formerly General Packet Radio Services, has a data rate of up to 11.2kbit/s. Data rates to 115.2kbit/s will also be able to extend the data rates on GSM networks. GPRS works by transmitting data packets. Each packet has an "address" for where it is being sent so that all the data packets that make up a particular message do not necessarily have to be transmitted in sequence on one radio channel, as is the case with GSM at present. With GPRS, data transmission can be increased above the capability of a single radio channel because packets can be sent on any of a number of different radio channels for up to the air interface. GPRS systems allow a data rate of up to 14.4kbit/s to be transmitted in each of GSM's eight time slots. This gives an aggregated system data rate of 11.5kbit/s. A 10-fold increase on today's GSM tendons.

However we as users are only starting out on the 3G road, despite how quickly manufacturers may wish to push us along. A full 115kbit/s GSM mobile data terminal requires eight radio slots, for both transmit and receive. That requires a minimum of 16 slots and is known as a Class 18 GPRS system. Class 18 mobiles offering 115kbit/s.

**IMT** International Telecommunication Union.

**3GPP2** CDMA2000 equivalent to 3GPP. Members are ARIB (Japan), CTS (China), ITIA (Japan) and TCT (Japan). www.3gpp2.org

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**EFR** Enhanced Full Rate. A speech codec for better speech quality, also sold to be more tolerant to interference.
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Don't forget to say why you think your idea is worthy.

Clear handwritten notes on paper are a minimum requirement: disks with separate drawing and text files in a popular form are best - but please label the disk clearly.

RS232-to-parallel data conversion

Here, standard ICs convert RS232 format to eight-bit parallel data with one start and stop bit. Total cost and power consumption is less than that of any standard chip available.

The circuit can be used as part of a PC-based serial interface through the COM1 or COM2 port.

A general purpose timer, IC1, is used as the clock generator, producing clock pulses only on receipt of serial data. Data is shifted into a serial-to-parallel shift register, and along with each byte data (DATA) a latch pulse (LATCH) is generated for the parallel destination port.

No initialization other than the bit-rate setting from the PC is required. The rate is equal to the clock, C, generated by timer IC1. Setting the divider value for bit rate 'R' sets the baud value of the PC.

The divisor value for the PC is,

\[ CL = \left( \frac{R_4 + 2R_5}{R_6} \right) \times C \]

The divisor value for the PC is, 1843200/168

It is possible to program the PC for any bit rate by putting the corresponding divider value in 16-bit format using statements in turbo-C below, for COM1:

- \( \text{outport}(0x2F8, 0xMSB) \)
- \( \text{outport}(0x2F9, 0xLSB) \)
- \( \text{outport}(0x2FB, 131) \)

Any data in eight-bit format can be sent to pin 3 of the nine-pin D-type connector using statement outport(0x2F8, word).

For COM2 use 3F8, 3F9 and 3FB.

S. Vijayan Pillai
Kerala
India
C74

National Instruments sponsors Circuit Ideas

Over the next 12 months, National Instruments is awarding over £3500 worth of equipment for the best circuit ideas.

Once every two months throughout 2000, National Instruments is awarding an NI4050 digital multimeter worth over £500 each for the best circuit ideas published over each two-month period. At the end of the 12 months, National Instruments is awarding a LabVIEW package worth over £700 to the best circuit idea of the year.*

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- AC Measurements: 20mV rms to 250V rms; 20mA rms to 10A rms
- True rms, 20Hz to 25kHz
- Up to 60 readings/s
- UL Listed
- 5? Digit Multimeter for PCMCIA

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May 2000 ELECTRONICS WORLD
FDNCs using current conveyors

Using two current conveyors, the circuit of Fig. 1 realises the function \( \frac{N(V)}{V} \). The equivalent circuit consists of a parallel connection of the ideal frequency-dependent negative conductance, \( D \), capacitance \( C \), and conductance \( G \). Parasitic components \( C \) and \( G \) are due to the non-ideal nature of the current conveyors. The stable condition of the circuit requires positive signs for \( C \) and \( G \). Figure 2 shows computer simulations of the negative conductance \( \omega D \) and \( \omega C \) dependencies versus frequency. These were carried out for current conveyors constructed according to the Haertas concept using two TL081s, four 100kΩ resistors and two 1kΩ resistors for each current conveyor. Component values used were \( C=10 \mathrm{pF}, 1 \mu \Omega, 10 \mu \Omega, C_2=1 \mu \Omega \) and \( R_2=1 \mathrm{k} \Omega \).

In Fig. 2, the stable operation region of the circuit is marked by continuous lines. If capacitance \( C \) is negative the circuit becomes unstable. The frequency-dependent negative conductance circuit forms a resonant circuit with resistance and can be used in resonant bridges capable of measuring capacitance with high losses, like the frequency-dependent negative resistance circuit used for measuring inductances with high losses.

L. Tomaszewski, M. Marka, M. Sławiec
Poland

References

Electronic circuits using current conveyors.

Efficient battery auto-charger

This efficient automatic battery charger commences charging when the battery voltage reaches the set lower limit and ceases charging when the upper level is reached. Adjustments are provided for both limits, which are best set up using a variable dc power supply. With the mains supply disconnected, the 'fully charged' voltage of 14.5V dc is applied at the circuit's battery terminals, and VR, adjusted so that the relay is energised, cutting off the charging supply.

Next, the variable dc power supply is set to the lower limit of 12.5V dc, and VR, adjusted so that the relay de-energises, reconnecting the charging supply. Settings for VR1 and VR2, interface, so the adjustments should be iterated as necessary.

An op-amp forms a pseudo window comparator. Its supply is stabilised at 9.1V and a 3.9V reference is applied to its inverting input.

Battery voltage is sensed by divider chain \( R_1, R_2, R_3 \) and applied to the non-inverting terminal. Positive feedback to the non-inverting terminal sets the lower limit at which charging recommences. The circuit can be used for charging various battery types.
£75 Winner

30W Class-A power follower

At first glance, this circuit may seem familiar. Essentially, it is a typical source follower working in pure Class-A with a constant-current generator forming the load. Features that differentiate it are its negative power supply and small power supply reservoir capacitor.

The current generator has a DC feedback through the BD139 to prevent thermal effects on quiescent current. Note that this circuit works only in class A, so it needs enough bias current for the required output power.

To keep the power dissipated under static and dynamic conditions the same, I have used identical devices for the follower and current source.

Class-A power amplifiers normally involve a large reservoir capacitor. This causes very high current peaks in the diodes, which is undesirable.

My circuit has a relatively small capacitor after the bridge. It is followed by a MOSFET voltage regulator featuring a very low-frequency CR filter of 220µF/100Ω.

Components used in the power supply have been simulated and optimised for a 3A quiescent current and with a capacitor value of 3300µF. The 50Ω1 trimmer should be set to 2000µΩ, 63V

Complete Class-A power follower and its regulator/smoothing circuit. Note the bias switch to save power at low listening levels, and the relatively small reservoir capacitor.

Features typical so source follower working in reservoir capacitor. That differentiate it are its negative power supply and small power supply prevent thermal effects on quiescent current.

I suggest using a heat sink of at least 50 by 42 by 16cm, or a smaller one in conjunction with a fan. In my view, the input capacitor, the 470µF input bypass and the output capacitor affect the sound quality.

I prefer to use ELNA Cerafine paper or oil. Input impedance of the buffer is 3300µF/63V.

A few suggestions for mounting the circuit board on the heat sink.

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Oscilloscope noise, and making measurements in noisy environments are the topics of Les Green's third article explaining how to make more reliable measurements using your scope.

The noise levels of DSOs and real-time oscilloscopes are not easy for the user to compare. All else being equal, one could reasonably expect a basic real-time scope to be quieter than a DSO because there are no noisy microprocessors and A-to-D converters to corrupt the trace. So how do you measure the noise of your scope? If it is a DSO, it is really easy; select a slow time-base, turn on the max-min function and measure the noise band.

If you are the unlucky owner of one of those hand-held reducing scopes that I mentioned in my last article, make sure that you compare the noise level with a scope of the reduced bandwidth.

To measure the noise of your real-time scope you can use the Tektronix 'tangential noise' measurement technique. This involves putting the oscilloscope in add-mode and applying a small amplitude quiet square wave to the other channel. The trigger is set to auto so that the untriggered square-wave-plus-noise pattern causes two bright bands to appear on the screen.

By adjusting the square wave amplitude the two bands can be made to merge in a very repeatable manner - when the dark band in the middle just disappears - and the square-wave amplitude is a measure of the noise of the first channel.

At first glance, anyone would complain that the DSO was very noisy compared to the real-time scope; the trace is much narrower on the real-time instrument. The problem here is the conversion from rms to peak-to-peak. Estimating the peak-to-peak value of a real-time scope trace by eye may well obtain a value that is twice the rms value. This is as far as statistical tables are concerned.

Now look at the DSO result: it may be taking 100MS/s over a one-second measurement period and displaying the max-min values. Tables of the Normal/Gaussian distribution do not generally go above 5σ. However, even for this value the tabulated answer is 0.99999733.

This says that on average 1 acquisition in 3.5 million will exceed the 5σ positive peak. I have used MathCad to generate a graph of rms to peak-to-peak conversion factors for Gaussian noise, Fig. 1. In the case of 100MS/s for one second the number of samples is 1EB. Reading the graph it says that 95% of the time the peak-to-peak noise level will be greater than 110 and less than 127/6; 0 being the rms value.

Clearly, for a DSO running at this speed a more reasonable conversion factor from rms to peak-to-peak is 12 – a conversion factor of 6σ for general purpose work is often used, i.e. a σ.35

Conclusion: a DSO with the same rms noise level as an opto bandwidth real-time scope can have a max-min trace width six times as large!

Noisy measurements

Regardless of the type of scope used, there is often a problem measuring the actual noise of the circuit. This is due to the connection between the scope and the equipment being probed.

Unless you are using an isolated-input scope, the BNC connectors on the front panel have to be earthed. In order to meet safety standards like EN61010-1, the BNC outputs have to be able to take 25A at the supply frequency and present an impedance of less than 0.1Ω.

As soon as you connect your scope probe earth-lead to the system being probed, a common-mode current flows down the outer braid of the coaxial cable. If the circuit being probed has much high speed logic on it, or a switched-mode power supply, there will be a significant high-frequency content to this common-mode current.

Before connecting your probe to an actual circuit node, try to connect a simple test clip; the probe tip to the earthing crocodile-clip and touch the pair onto a convenient OV point in the circuit to be probed.

If the noise measured on the scope becomes too large for comfort then you have a noise problem to resolve. This could be due to common-mode current alone or there could be an element of magnetic pickup, as the path from the coaxial cable screen via the probe earth-lead back to the probe tip has quite a large area.

Fortunately both pickup mechanisms are handled by the same technique. Removing the probe signal clip reveals the probe tip and a metal earthing ring. If the probe earth-lead can be unclipped, so do, if not then just clip it to the probe lead out of the way, so that it cannot dangle around and short-out parts of the circuit.

Wind several turns of insulated copper wire – 6 turns of 22SWG for example – around the metal earthing ring of the probe and leave a short tail at the end – not more than an inch ideally. You can now solder the free tail to a signal earth and probe nearby points.

It is also possible to use a finer coil of wire to contact the probe tip in order to make a hands-free connection to the circuit. Oscilloscope manufacturers all know about this but the information does not always get through to the user. Tektronix actually sells a little socket to plug probes into, which makes a nice semi-automatic probe.
permanent probing point for development work. It is manufactured by Specialty Connector Co., of Franklin, Indiana.

There is also such a thing as a spring-loaded probe head that plugs onto the end of a probe with an ATE type of sprung pin for the earth contact. Even connecting pieces of equipment via BNC-BNC leads can cause additional noise. Different types of BNC cable can significantly affect common-mode earth contact. They can cause additional noise.

Typically, the probe is bulk loaded by the flyback converter and the line-output transformer in the centre of the picture is another flyback converter. Fig a), the 10:1 probe is reasonable well positioned, but in b) it is too close to the line-output transformer. The best solution is to solder a coaxial cable on the underside of the board, c).

Fig. 5. Power supply and video drive assembly under test. The supply is a flyback converter and the line-output transformer in the centre of the picture is another flyback converter. In a), the 10:1 probe is reasonable well positioned, but in b) it is too close to the line-output transformer. The best solution is to solder a coaxial cable on the underside of the board, c).

The best of both worlds
This is the pulse response of an amplifier in development. It is being driven with a 200ps edge and being measured on an analogue sampling oscilloscope system, namely a Tektronix S-2 sampling head in a 7511 sampling unit. To get cleaner results and a stored trace, the analogue output of the 7511 is fed into a Gould 6100 storage oscilloscope. Using averaging and measurement scaling, the 6100 is calibrated to give the correct rise time.

Please supply the following:

<table>
<thead>
<tr>
<th>Name</th>
<th>Address</th>
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Switch position 1

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>DC to 10MHz</th>
</tr>
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<tbody>
<tr>
<td>Input resistance</td>
<td>1MΩ (if oscilloscope input)</td>
</tr>
<tr>
<td>Input capacitance</td>
<td>40pF (oscilloscope capacitance)</td>
</tr>
<tr>
<td>Working voltage</td>
<td>600V DC or pk-pk AC</td>
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</tbody>
</table>

Switch position 2

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>DC to 150MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise time</td>
<td>2.4ns</td>
</tr>
<tr>
<td>Input resistance</td>
<td>10MΩ (if oscilloscope input)</td>
</tr>
<tr>
<td>Input capacitance</td>
<td>12pF (if oscilloscope input)</td>
</tr>
<tr>
<td>Compensation range</td>
<td>10-60pF</td>
</tr>
<tr>
<td>Working voltage</td>
<td>600V DC or pk-pk AC</td>
</tr>
</tbody>
</table>

Switch position 'Ref'

| Probe tip grounded via 9MΩ, scope input grounded |

Product: Classic 6000 S/S/N: __________
Printed: 12 Jan 2000: 09.22.48

Over:

TRC1M: 10MΩ, 100nS/div, 200mV/div, 1.176nS/div
TR1M: 10MΩ, 100nS/div, 200mV/div
TR1M: 10MΩ, 100nS/div, 200mV/div

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INSTRUMENTATION

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ELECTRONICS WORLD May 2000

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386
Room for improvement II

The listening room has a surprisingly significant effect on the loudspeaker. Last month, John Watkinson considered its effects at low frequencies. Here, he discusses how the room affects the rest of the spectrum.

A real sound source in a real environment produces a combination of direct sound and reflected sound.

The human hearing mechanism has evolved to locate the sound source accurately, despite the reflections, and to assess the nature of the environment from the reflections. If either the source or its reflection is absent, there will be a lack of realism.

In principle, a stereo recording can capture sound from any direction, but the conventional stereo pair of speakers can only create virtual sound sources over an arc between the speakers. The 360° sound field will be mapped into that arc in the real listening room. The human hearing mechanism is not the same as listening to a 360° sound field.

Clearly, listening to a sound field of restricted angle is not the same as listening to a 360° sound field. Fortunately the reverberation of the listening room can to some extent make up for the loss. Thus reverberation is essential in the listening room to create a natural result.

More than any other single factor, the reverberant field is responsible for the low-frequency sound we hear. Thus it is surprising how much of the sound we hear is reverberant. This is very easily demonstrated with any dipole loudspeaker - a Quad electrostatic for example.

In Fig. 1(a) the speakers are in a normal listening position. In Fig. 1(b) a large pair of cushions has been placed in front of the speakers and in Fig. 1(c), they have been placed behind the speakers.

The results are non-intuitive. In practice positions Fig. 1(b) sounds better than position Fig. 1(c). This is because blocking the front radiation allows the rear radiation to excite the reverberation in the room. Blocking the rear radiation makes the speaker sound dull.

One of the great advantages of the electrostatic speaker is that it is inherently a dipole and the excitation of the room comes free. However, the same results will be obtained if the speaker contains two tweeters working in phase as an omnidirectional radiation pattern simply by swapping the wires on the rear driver.

Despite the theories put forward about the massive differences in the excitation of the room between these two configurations, the simple fact is that in practice the skilled listener is hard pressed to tell which configuration is in use. There is no effect at all on the stereo image heard between the speakers; in fact this is still retained if one of the rear speakers is anti-phase and the other is in-phase.

For a moving coil system, having the tweeters working in phase as an omnidirectional source has the advantage that the low-frequency roll off due to cancellation is avoided. This means that a lower and less audible crossover frequency can be used.

Another surprising result using dipole speakers is shown in Fig. 2(b). Here, a pair of dipoles has been placed at either side of the listening position and adjusted so the listener's ears are in a null.

No direct sound at all reaches the listener from the speakers. A virtual stereo image will be heard in the opposite wall as shown in Fig. 2(b).

Both of these examples illustrate just how much of the sound we hear is reverberant. As a result, it follows that an additional criterion for a precision loudspeaker is that as well as creating an accurate waveform on a direct path to the ear, it must also create a sufficiently accurate reverberant field.

This critical aspect of loudspeaker design has been obvious from psychoacoustic considerations for many years but the traditional loudspeaker industry, with a few notable exceptions, has passed it by.

Why do loudspeakers sound so different?

It is well known that loudspeakers with identical specifications sound different. There is only one conclusion to be drawn from that, which is that the specifications are incomplete.

In short, the traditional ways of testing loudspeakers only give part of the picture. It's like testing cars in a straight line and then wondering...
The aerial consists of an outdoor head unit with a control performance: SOIP +90dBm, TOIP +55dBm. For the first time this permits full use of an active system around the IF and power unit and offers additional intermodulation of broadcast stereo codecs.

Listener outside door

why they corner differently.
in any other industry, a disparity
between theory and practice results
in research to advance the theory
and close the gap. Why the audio
industry should make itself a
conspicuous exception could be the
subject of a long discussion.

There is a trivially easy way of
demonstrating the aspect of
loudspeakers which makes them
sound different. This is to listen
from the next room via an open door
and compare the total quality or
timbre outside the room with that at
the ideal listening position. Figure 3
shows the principle.

Without exception, the
loudspeakers that sound the most
totally balanced in the next room
are the ones that sound most
realistic in the ideal listening
position. Also, without exception,
the loudspeakers that perform best
are those that have had some
thought given to the quality of the
to-axis sound that they produce.

The constructional philosophy of
the speaker seems to be more
important here than the amount
spent or the transduction principle.

The importance of off-axis sound
quality in a loudspeaker cannot be
underestimated. In my next article, I
will explore the consequences of
getting it wrong.

Fig. 3. Listening from the next room tells a lot about loudspeakers

Speakers

Listener outside door

why they corner differently.
in any other industry, a disparity
between theory and practice results
in research to advance the theory
and close the gap. Why the audio
industry should make itself a
conspicuous exception could be the
subject of a long discussion.

There is a trivially easy way of
demonstrating the aspect of
loudspeakers which makes them
sound different. This is to listen
from the next room via an open door
and compare the total quality or
timbre outside the room with that at
the ideal listening position. Figure 3
shows the principle.

Without exception, the
loudspeakers that sound the most
totally balanced in the next room
are the ones that sound most
realistic in the ideal listening
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Phase-locked loops

Revealing useful web sites along the way, Cyril Bateman explains the phase-locked loop and discusses the options and design tools available for those involved with this invaluable building block.

Three years ago while researching for a phase-meter design, I surveyed the Internet for information on phase-locked loops. Since then, the drive to provide ever faster computer systems has resulted in an explosion in the use of phase-locked loop integrated circuits. This is reflected in the much increased amount of phase-locked loop information and design aids now available for downloading.

A search of the Philips Semiconductors site alone brought up 407 matches for the phrase "PLL". But why search Philips first? Perhaps a brief look at the history of phase-locked loops will explain.

Phase-locked loop roots

The phase-locked loop concept was first proposed in 1922. Probably the first ever general use of a phase-locked loop was in a 'hommodyne' radio receiver in the 1930s. It was in the 1950s though that the rapid expansion of television receivers saw the universal adoption of phase-locked loops. PLLs were used in tv sets to synchronise the 'frame' and 'line' oscillators to the incoming signals - the so-called 'flywheel sync' circuit.

Signetics claims to have produced the first ever dedicated phase-locked loop integrated circuits in the spring of 1970. These were selected as one of the hundred most significant technical products by the Industrial Research Institute in 1971.

Two other notable facts that I recall were a phase-locked stereo decoder and a phase-locked-loop fm tuner. Both were published by Wireless World.

Today, phase-locked loops can be used to modulate and demodulate AM, FM, FSK and BPSK signals. They can detect the presence of specific frequencies buried in noise and produce voltage controlled frequencies or precise clock signals.

Phase-locked loops can also restore signal waveforms that have been distorted using fibre optic links and they can precisely control the speed of electric motors. In addition, PLLs are useful for restoring the timing waveforms when reading floppy and hard disk drives, the list is endless. Figure 1 is an example of a precise motor drive.

Designing with PLLs

The 'flywheel' analogy is used to explain phase-locked loop behaviour in application note AN177. Entitled 'An overview of the phase-locked loop', this note downloads relatively quickly. I commend this as a first read for those of you wanting a simple, readable introduction to the topic. A much longer 123 page technical article, which is complete with all needed equations and called 'Dean's PLL Loop Filter Design Program', can be downloaded from National's web site.

The phase detector used in the original Signetics phase-locked loop designs was based on the double-balanced mixer circuit. When this method of phase detection is used, the complete integrated circuit is labelled as an 'analogue' phase locked loop, even though it may also include many digital stages.

Analogue phase detectors can be used with both small and large input signals and at very high frequencies. A good detailed description of the analogue phase detector, entitled 'Modelling the PLL double-balanced mixer' can be downloaded as application note AN178. Figure 2 is an example of an analogue phase-locked loop from inside an Exar XR2212.

Many of the most popular integrated phase-locked loops use a digital phase detector. For this reason, they are labelled as 'digital' phase-locked loops, even though analogue stages may be included. Perhaps the best known and widely used is the CMOS 4000 series 4046 integrated circuit. While the maximum operating frequency of this particular circuit is restricted, other designs can be used at 100MHz and above.

Three types of digital phase detector

Three common types of 'digital' phase detector circuits are in use.
Sometimes all three types are included in the one integrated circuit. Since it includes all three, I will use the 74161/4046 as an example here. This device is usable to some 15MHz. The simplest digital phase detector is based on the exclusive-or circuit, and is similar to a 74HC06. This detector, which should be driven by 50-50 mark-space input waveforms, provides an output zero when the input waveforms are exactly 90° out of phase. Its output is a square wave at double the frequency of the input signal and with a duty cycle of 50%. The actual duty cycle of this output waveform varies according to the phase difference of the input signals.

The second style of phase detector is effectually a digital memory network comprising four bistable devices, some gate logic and a tri-state output. These bistable devices act only on the rising edges of the input signals, so this detector works independently of the input signal's duty cycle. When both input signals have the same phase, the tri-state output becomes a high impedance. Its output becomes a logic high or logic low only while the signal phases differ.

The third type of phase detector is again positive-edge triggered, so is also independent of the input signal duty cycles. Based on an RS flip-flop, it outputs a square wave at the input signal frequency with a duty cycle that varies with phase difference. When the input signals have a 180° phase difference, this detector output waveform has a 50% duty cycle.

Designing loop filters
You can see from the above that for most applications, the phase detector output must be filtered. This filter may be active, or more simply can be based only on passive components.

Correct filter design however is most important for successful circuit operation. Filter design can prove time consuming if done iteratively. Solving the mathematical design equations can prove tedious.

Three years ago I found only one design aid available for downloading. This was version 2 of the 'HCMOS phase-locked loop design program', which I downloaded from the Philips site.

When I looked again this January, I was unable to locate it, but I did manage to find an earlier version. This is a DOS-based program that allows you to explore 'what if' designs for the Philips HC145170 and HC14906 phase locked loops by answering a few simple questions. With little effort, I managed to find several other design and simulation aids. One particularly helpful page I found is the University site. It covered many other topics besides phase locked loops. In fact, it was so useful that I bookmarked it.

On-line design aids
Some sites now offer on-line design aids for phase-locked loops. I found the first one on the Berkeley site. It provided an easy to use on-screen representation of a phase-locked loop, especially suited to first time users, Fig. 3.

I also found an interesting and interactive on-line package on the UK's University of York web page. Written in Java code, this provides performance graphs in addition to calculating design values. Many designers though will prefer the convenience of having their design tools stored within their own computer environment.

National Semiconductor offers three software packages as part of its series of application notes for the design of wireless systems. The first is a Windows program, titled 'Windows Loop Filter Design'. This 3Mbyte download helps with the design of loop filters. The second is a smaller DOS program, entitled EasyPLL, which assists with component selection and designs and simulates the loop filter performance.

National's final offering is a number of miscellaneous phase-locked loop models to aid loop design and simulation. Many of these can only be run via Mathcad. Since I only have an older version of Mathcad, I was unable to try these out.

High-frequency applications
Within the various Spice time-domain based simulators, as the output.

One phase-locked loop design module dedicated to rf design is Genesis from the EagleWare Corporation. The EagleWare system is a complete package of design tools, targeted to RF designers' needs. These can be purchased either as separate modules or as a complete package.

Using PSpice analogue behavioural modelling techniques, a method of simulating the performance of digital phase-locked loop systems running at several hundred megahertz has been devised by Spanish RF engineer Orlando Pena. This routine was developed using the PSpice simulator in version 7.1 of the Microsim DesignLab.

I have found this version of PSpice is particularly useful. While aimed at Windows 95 or Windows NT, it will run on a modest 486PC with Windows 3.1 operating systems.

The particular phase-locked loop model was based on a digital phase-frequency detector, as used in the Motorola MC4044 integrated circuit. It has an analogue charge pump, which Orlando based on the Spice models for 2N2222 and 2N2907 transistors, as the output.

Potentially even more useful is the 'MC145170 PSpice Modelling Kit' because the full Spice models used in this application note are specific to this Motorola part, it does include sufficient backbones.
Ian Hickman introduces you to an important initiative aimed at encouraging a greater number of promising electronic engineering undergraduates to aim for a career in the fascinating – and burgeoning – field of radio frequency engineering.

The Institution of Electrical Engineers started life in 1871 as the Institution of Telegraph Engineers. What they have thought, I wonder, when along came others, pioneering the transmission and reception of messages without wires?

Natural, this new technique was called Wireless Telegraphy, WT or radio, as also TSF– other fields – telemetry, remote meter reading etc. and of course, most notably, mobile phones.

Radio engineering

All these current applications, together with others forthcoming, such as UMTS – universal mobile telephone system – are creating an ever increasing demand for engineers skilled in radio frequency engineering. This is a demand that at present cannot be filled. The situation can only worsen, unless suitable steps are taken.

It is with this need in mind that the Department of Trade and Industry has launched the RF Engineering Education Initiative, or RFEEI. Under this, the electronic-engineering departments of universities receive a three year award aimed at encouraging interest in a career in RF engineering.

The scheme is being sponsored by a number of companies and Government departments.

Ride the wave

Organisers of the RFEEI have produced a pack of literature called 'Ride the wave'. It contains a booklet about careers in radio engineering and leaflets describing the activities of the various companies supporting the Initiative are included. It is privileged to be assisting with the Initiative at one of the participating universities, the University of Portsmouth, just a dozen miles from my home. The university has made a room in one of the Electronic Engineering labs available for use by any student. The club even lays on snacks and leaflets describing the activities of the Initiative are included.

The usual arrangement has two have already done so, but at least one such scheme has fallen by the wayside. This is due to lack of enthusiasm, not on the part of the students or of the organisers, but of the teachers.

A university wishing to start such a home-grown scheme need not incur any great expense. While a bespoke club room is a nice luxury, the afternoon activity can always be accommodated in one of the electronic engineering labs. And the projects can use the copious amount of equipment already available, which will in any case already be in stock.

As an assistant to any department wanting to run such a scheme, I hope – given the Editor’s welcome enthusiasm for the Initiative – to publish simple projects, suitable for a variety of readers, suitable for such a wide audience as these pages in the forthcoming months.

Groff Lewis’s comprehensive book provides a basic understanding of a wide range of topics and concepts encountered in the field of communications technology. Whether you are looking for a simple explanation, or need to go into a subject in more depth, the Communications Technology Handbook provides all the information you need in one single volume.

This second edition has been updated to include the latest technology including:
- Video on demand
- Wi-Fi distribution systems
- High speed data transmission over telephone lines
- Smart cards and batteries
- Global positioning systems

The contents are ordered initially by communications systems. This is followed by an introduction to such topics as radio and go on to provide more detailed information in alphabetical order. Each section contains an explanation of common terminology, and further references are provided. This handbook also gives a variety of readers.

The book addresses an international audience by referring to all systems and standards throughout.

CONTENTS
- Analog systems and concepts; Antenna or aerials; Audio signal processing; Bar code technology; Codes and coding formats; Computers in communications; Digital communication systems; Digital pulse code modulation; Electro magnetic compatibility; Interference; Encryption and decryption; Error control; Facsimile systems; Filters; Frequency bands in use; Image processing; Information theory; Logic; Measurement of systems parameters; Memories; Microwave devices; Mixer signal processing; Myriads and modulating; Networks; Noise; Optical communications, devices and systems; Photo detectors/receivers; Power supplies; Propagation; Quality and reliability; Radar and navigation systems; Radio frequency receivers; Satellite systems; Semiconductor devices and technology; Signals; Sputter spectrum techniques; Standards organisation; Test equipment; Telemetry and associated systems; Television signal processing and systems; Transmission lines and waveguides; Valves; CCITT recommendations; Abbreviations and acronyms; Index

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Marconi 2022c

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Claude Lyons 100A 240/415V 3 phase auto. voltregs £2900

Sony 5¼" 2½" 5¼" for sale

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399
The board can be used without a power connector. It is fully configured with display, touch screen, bios and cabling. Able to support 100MHz Ethernet, it has USB, I/OA and two serial ports. There are also a bidirectional parallel port, two IDE ports and Dimm support for SDRAM up to 1GByte. The device can be configured with two floppy drives. Discounting to 144MHz memory is possible. The board includes a PISA (PCI+ISA) connector for background expansion.

Asics Electronics
 Tel: 020 7377 7514
 Enquiry No 507

RF power transistor
Ericsson has introduced the PT1010/11 RF transistor for the 900 to 960MHz band. It uses Gallium technology. With an output power of 70W, it is suitable for GSM mobile phone base station transmitters. Gain is 13dB, linearity ±0.25dB and efficiency 50 per cent. It operates from 65V. The n-channel enhancement mode FET has a drain-source breakdown voltage of 40V, an on-state resistance of 0.05Ω, a maximum output current of 20A and has a current fall time of 70ns typical at 125°C. It is MOS gated.

Tel: 01244 350250
Enquiry No 515

Power Innovations
Tel: 01908 231555

Two-stage voltage inverters
The BOV503 and SG503 are one and two-stage voltage inverters from Infineon. Their output is a positive supply voltage between +5 and +5V or a typically corresponding negative output voltage of -3.16 to -4.6V and -4.4 to -9.6V, respectively. The BOV503 has a integrated regulator for biasing GaAs FETs and depletion high-electron mobility transistors. An integrated oscillator has a typical frequency of 230kHz. The high output voltage ripple is typically 20mV at output currents of dm (AV1). Shutdown input supply current is less than 5µA between +5 and +10°C. Both come in TS55CP-1.1 packages.

Infineon Technologies
Tel: 0149 89 234 32767
Enquiry No 510

120V ISDN/Slice protector
Power Innovations has introduced the TISPAN TP820 surface-mount ISDN protector. The 120V maximum rating makes it suitable for providing overvoltage protection on up to four ISDN (GC power supply lines at two Slices. It contains four programmable and independently triggered protectors in a SOC package, with each protector having an International protection ratings (ISSA TGL-EG-0107B and 240V-1089-Core 10). The trigger voltage is automatically programmed by reference to the system main supply voltage. In operation, negative surges are initially clipped close to the power supply rail, followed by a fast turn-off action, retarding voltage stress for downstream electronics. Positive surges are clamped to ground by an integrated inverse parallel diode for each line. It comes in 56pin or 56pin- and-inlet format. Offline capacitance is 540pF – 50nF to ensure transparency in normal use and it has a 150kHz holding current, Trigger current is 5mA.

Power Innovations
Tel: 01244 350250
Enquiry No 515

The DrDAQ is a low cost data logger from Pico Technology. It is supplied ready to use with all cables, software and example science experiments.

DrDAQ represents a breakthrough in data logging. Simply plug DrDAQ into any Windows PC, run the supplied software and you are ready to connect and display data. DrDAQ draws its power from the parallel port, so no batteries or power supplies are required.

Tel: 01480 395395, Fax: 01480 395296, Email: post@pico-tech.com, Web: www.drdaq.com

DrDAQ is a low cost data logger from Pico Technology. It is supplied ready to use with all cables, software and example science experiments.
Piezoelectric actuators

Took piezoelectric actuators are available from Siemens. Using the piezoelectric longitudinal effect to transform electrical energy into mechanical energy, these devices are suitable for mechatronic systems with high accuracy and repeatable positioning.

Applications include pick and place assembly tasks, tracking control of magnetic heads for hard disc drives and positioning of mirrors or prisms in laser systems.

Siemens
Tel: 01797 822024
Enquiry No 516

SVGA colour

STN display

Hitachi has announced an SVGA colour STN display for PC and internet browsing. The 25.4cm display has a contrast ratio of 50:1, brightness of 200cd/m² and power consumption of 2W. It is suitable for point-of-sale, point-of-information and internet terminals.

The SGE5303 uses multi-lens bi-linear technology and has a resolution of 800 by 600 pixels with 262,000 colours. There are 15 versions - 3 and 5 VDC, 250, 200 and 150V AC models. They are encapsulated in a stainless steel case. For PC systems, the front plate is removable and a glass panel, made from 113.15 or 113.16, is used to make the injector and extractor handles accessible. The zero-injection, single-chip STN polarized display adds versatility to the flexible panel, enabling text and graphics to be displayed simultaneously.

Hitachi
Tel: 01223 462244

Inverse multiplexer

The Hitachi MR0200 is an eight-port ATM physical layer inverse multiplexer providing a multi-vendor PCM interface and is for systems that implement ATM access over existing T1 interfaces. These cards fit into standard 19" or 23" frames and can handle T1 and E1 interfaces. In mixed mode, T1 and E1 lines can be programmed to operate as inverse multiplexed on Uni lines for ATM over T1 and E1 lines. More than 10,000 such boards have already been used in practical applications, including access over existing trunk interfaces, for systems that implement ATM-based switching. The ATM layer supports the T1 and E1 interfaces and is based on the Hitachi MT90220 data processor.

Hitachi
Tel: 01223 462244
Enquiry No 516

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Enclosures

APW has introduced the Vitecse 700 EMC-screened cabinet, 19" or 23" rack sizes, suitable for one or more boards. The enclosure provides a supply voltage of over 250V, 750V basic accuracy 1.2 %, 200, 2k, 20k, 200k, 2Mohm basic accuracy 0.8%, 2uA, 2mA, 20mA, 200mA, 10A. Weight is about 8g and the device incorporates a closed rectangular case and a closed polycarbonate former with four sections. It is for systems that implement ATM access over existing trunk interfaces, for systems that implement ATM-based switching.

APW
Tel: 01223 462244
Enquiry No 516

Security processor

Philips has introduced the VM1427 single-chip microprocessor that can handle more than 25MHz's instruction processing (1000x100x1000) (64Kx64x64) instruction processing. It is based on the company's Velocity RSP7 subsystem. It has an integrated Arm™ processor, integrated bus connections and memory, and a software development kit. It will be available in the spring.

Philips Semiconductors
Tel: 020 74 270 297
Enquiry No 516

D-core choke

Epcos has introduced the EB8771-M D core choke, a current-compensated double choke for interference suppression in electronic power supplies for lighting baskets and TV sets. Inductance is between 3.3 and 47mH. Pin grid size is 12.5 by 12.5 by 0.5mm. Pin size is 0.8mm. With rated voltages of 250V AC or DC, the EMC component covers rated currents from 0.5 to 1.6A. Weight is about 5g and the device incorporates a closed rectangular ferrite core and a closed polycarbonate case with four sections. The coil former is flame-resistant to UL94-V0. The choke is made without encapsulation or adhesive materials.

Epcos
Tel: 01944 398699
Enquiry No 821

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PCB applicator

Donprint has developed a device for printing and applying PCB labels. The Appli-Print 915 uses the Zebra 905i printer with Zebra 600 dpi resolution. It can be Initialled to test most production line equipment such as conveyors. It can also be combined with the firm’s barcode software, data capture products and customised programming services for work in progress tracking. Cycle times are less than 0.1 second, repeatable ±0.5mm.

SM relay

Rohm Components has introduced a solid-state relay in a surface mount package for modern and data communications applications. The GC-D140 is a dual-form A device with 1000 volt isolation rating and no EMI, typically – that can handle continuous load current of 100mA and peak load voltages of 350V. Input to output isolation is 2500V, minimum height of 0.22cm. No EMI or FRI is generated by the relay unit so solid state construction eliminates arcing and contact bounce. No snubbing circuits are needed. UL and CE is recognised, the relay is certified to IEC61800 and VDE 0975.

Application specific tools

Engineers and scientists can create measurement applications in Visual C++, using National Instruments. The set of integrated measurement tools includes Measurement Studio, which provides a foundation for text-based programming languages. The package includes user interface controls, mathematical analysis and statistical tools, data acquisition and high-level data visualization directly into Visual C++. National Instruments sells this equipment, 01763 297396

Application note

FXA-298 monolithic GaAs power amplifier from LMR is for use as a driver stage in base station equipment for cellular (CDMA and narrowband) wireless applications. Made by Standard Microsystems, it uses Darlington pair topology to provide broadband performance from 50MHz to 20MHz, while drawing 130mA from a ±5V supply.

FM transmitter and receiver

For the 88MHz band, Low Power Radio Solutions has introduced the Radiometer 800 transmitter and RIO receiver. These module operate at 880MHz-C. Internal filtering gives the user selectable, providing immunity against the latest generation of electronic warfare systems at 800MHz. Data rate is up to 56Kbps. The STS200-220 compliant transmitter provides a third order output of 45mW into a 75 Ohm load and inserts hot, 400mA at 1000mW into a 75 Ohm load.

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Range. Noise is 50dB in the 800 to 2000MHz and 1800 to 2000MHz bands. Power gain is typically 20dBm in the cellular band and more than 14dB in the PCS band. Packed with features, it is housed in a SOT49 surface-mount plastic package. Evaluation board, development kits and application circuits are available.

Lisa Micirek
Tel: 01226 667711
Enquiry No 631

66W switching regulator

UK has available the STR-66G1 offline quasi-resonant flyback switching regulator from Allegro Sanken. The switch-mode power-supply regulator is for industrial, telecoms, datacomms, white goods, lighting, medical, and security applications. Capable of handling up to 66W, the device comes in a four-pin over-moulded TO-220 package and incorporates the primary control and drive circuit with a discrete available rated power MOSFET. The MOSFET has a Vds of 650V, and is constant voltage soft gate driven. It can be used at switching frequencies of 20 to 100kHz and has built in cycle by cycle programmable current protection, latched overvoltage protection, latched thermal shutdown, integrated programmable soft start and under voltage lock out.

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Enquiry No 632

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Enquiry No 633

60mm square fan

The San Ano 60 fan is available from SAQ. The fan measures 60mm diameter by 25mm thick, and has a claimed operating life of 100,000 hours at 60°C ambient temperature. The unit is available in 5, 6, and 24V versions. Nominal acoustic noise level is 29(dBA). Alarm functions are available for remote monitoring, and locked-rotor protection is provided by an overcurrent limiting circuit.

Tel: 01444 236000

Enquiry No 634

3U Eurocard controller

HM Computing has launched a 3U Eurocard combining a Pentium processor with functions and interfaces for real-time embedded systems. This card can be expanded to handle up to 32MB of memory and includes PCI, ISA, and EISA interfaces and a LCD display. It is available with a Pentium M3 processor operating at up to 400MHz. Also onboard is a 4MB DRAM, 6.5MBID synchronous L2 cache. 1MBbyte solid-state disk, watchdog and real-time clock and floppy disk and keyboard controllers. HM Computing

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- Provides a link to the Wiley tip site for the use of associated MATLAB exercises
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CONTENTS: Introduction; The Elementary Phase-Locked Loop; Sidebands and Noise Spectrum; Frequency Dividers; Phase Detectors; Higher Order Loops; Sampling Effects; Architectures; Large-Signal Performance; Natural Acquisition; Large-Signal Acquisition; MATLAB exercises

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IF filter options

Over the years, a variety of intermediate-frequency filter arrangements has evolved. Joe Carr looks at a variety of the techniques available and discusses their merits.

A number of different types of IF filters are used in radio receivers today. In addition to LC filters, there are various types of crystal filter, monolithic ceramic filters, and mechanical filters to consider. In this article, I take a look at the various types of IF filter, their characteristics and their applications.

Before delving into the topic, it is helpful to consider how these filters are used. Figure 1 shows a generic IF amplifier with the filters in place. The IF amplifier provides most of the gain in a superheterodyne receiver, as well as the bulk of the selectivity of the receiver.

Selectivity is the function of the IF filter. It has the narrowest bandwidth of all the filters in the receiver. Its main function is to supply the selectivity of the receiver by narrowing the bandwidth to accommodate the type of modulation being used.

The IF amplifier may or may not use two or more filters, depending on the type of design. In cases where only one filter is used, then the filter will usually be placed at the input of the amplifier in order to eliminate the mixer products that can affect the IF amplifier performance.

Noise produced by the IF amplifier can be significant. This means that an output IF filter is indicated in order to eliminate that noise.

**LC IF filters**

The basic type of filter, and one of the most common, is the LC filter, which comes in various types Fig. 2. The type shown in Fig. 2a) contains two parallel tuned LC sections. Although it is not apparent here, the input and output sides of the LC network need not be the same impedance, although that is usually the case.

Once the most common form of IF amplifier filter, this type has largely been eclipsed by other types, except in certain LC amplifiers.

A more common form today is shown in Fig. 2b). This form has a low impedance tap for transistor or IC applications, with the high impedance portions still available. In Fig. 2c) is a common form of IF filter in which the low impedance tap is available to both input and output sides, but one side of the high impedance portions of the transformer is not.

In Fig. 2d) you can see a single-tuned IF filter. It has a standard IF filter input side, but it has only a low impedance link on the output side. The IF filtering is performed by the tuned LC circuit. This low impedance link is for impedance matching.

In Fig. 2e) you can see a double-tuned IF filter that is not magnetically coupled (so it is not a transformer), but rather is coupled through a common impedance. In this case a small value capacitor is used as the common impedance, but inductors can also be used as well.

**Crystal filters**

The quartz piezoelectric crystal resonator is ideal for IF filtering because it offers high Q - resulting in narrow bandwidth - and it behaves as an LC circuit. Because of this feature, it can be used for high quality receiver design as well as filter type single-sideband transmitters.

Quartz has a dielectric constant of about 3.8, a schematic symbol for a crystal is shown in Fig. 3a), while the equivalent LCR circuit and the device's impedance curve are shown in Figs. 3b,c). The equivalent circuit shows that there is a series inductance, Lc, and capacitance, Cc, as well as a series resistance, Rc.

Series inductance and capacitance of a crystal are sometimes called the motional reactance values. There is also a parallel capacitance, Cp.

The parallel capacitance resonates with the inductor to form a parallel resonance, while the series capacitance resonates with the inductor to form a series resonance. Figure 3c) shows capacitive and inductive reactance against frequency. The frequency marked Fc is the series resonance point. The anti-resonance is officially the parallel resonance, but in practical terms there is a range of parallel resonance.

Figure 3a) shows a typical crystal package and its mounting on a printed circuit board. The basic package is shown in Fig. 3a). Note that the pins might be actual pins, or they may be wire. A cut-away view is shown in Fig. 4b). This gives you a better idea of how the crystal works.

Figure 3c) shows how the crystal is usually mounted on a double-sided printed circuit board. An insulator is placed on the board to prevent short circuiting the board tracks with the crystal package.

Figure 3a) shows a simple crystal filter that has been around since the 1930s in one form or another. Figure 3b) shows the attenuation graph for this filter.

There is a 'crystal phasing' capacitor, adjustable from the front panel, that cancels the parallel capacitance. This cancels the parallel resonance, leaving the series resonance of the crystal.

Although the 1930s vintage filters didn't use it, this filter is built in trilfilar form. This means that the windings of F1 are wound together, interlaced with each other.

Figure 3c) shows the circuit for a half-lattice crystal filter, while Fig. 4b) shows its attenuation curve. This type of crystal filter is used in lower cost radios. The simple crystal filter described above, this version uses a trilfilar coil for F1. But instead of the phasing capacitor there is a second crystal in the circuit.

The frequency relationship between the two crystals, Fig. 4b) shows that they have overlapping parallel and series resonance points. This makes the parallel resonance of crystal No 1 the same as the series resonance of crystal No 2. However, you can use the half-lattice filter to build a cascade half-lattice filter, Fig. 7, and a full-lattice crystal filter, Fig. 8.

The cascade half-lattice filter has increased skirt selectivity. It also gives fewer spurious responses compared with the same passband in the half-lattice type of filter. It is a back-to-back arrangement on a trifilar transformer, T1. In practice, close matching is needed to make the cascade half-lattice filter work properly.

The full lattice crystal filter of Fig. 8 uses four crystals like the cascade half-lattice, but the circuit is built on a different basis. It uses two tuned transformers, T1 and T2, with the two pairs of crystals that are cross-connected across the tuned sections of the transformers. Crystals Y1 and Y2 are of one frequency, while Y3 and Y4 are of another frequency in the pair.

The principal advantage of the full-lattice filter is the use of two different frequencies instead of one frequency for the crystals. It is more difficult to match four crystals than two.

---

**Fig. 2. Various LC IF filter circuits.**

(a) and (c) are all tuned on either side of the transformer and vary primarily in drive impedance. Filter (a) is used to build the conventional IF filter, but it is no longer widely used. Filter (b) has low-inductance taps on both sides to increase its usefulness in solid-state circuits. Filter (c) is identical, except that the high-inductance taps are no longer available to the outside world. Filter (d) is single-tuned and has low-inductance output for impedance matching. In filter (e), the filter coils are not magnetically coupled. Instead, the signal is transferred by common reactance. Here, the resistance is a capacitor, but it could equally well be an inductor.

**Fig. 3. The quartz crystal.** In a) it is a crystal schematic symbol, b) an equivalent circuit and c) the crystal's impedance curve.

---

*Figure 4a) Crystal package; b) in-cut-away form showing inside; c) Mounting on a printed wiring board.*
A different sort of filter is shown in Fig. 9a), with its asymmetrical attenuation curve shown in Fig. 9b). This filter has a more gradual fall-off on one side than on the other, Fig. 9b).

The filter has the advantage that the frequencies of crystals Y1 and Y2 are the same frequency. Capacitor C1 is included in the circuit to allow tuning of the desired pass band. The bandwidth of this filter is only half what is expected from the half-lattice crystal filter above.

Crystal ladder filters
Figure 10 shows a crystal ladder filter. This filter has several advantages over the other types.
- All crystals are the same frequency – no matching is required.
- Filters may be constructed using an odd or even number of crystals.
- Spurious responses are not harmful – especially for filters over four or more sections.
- Insertion loss is very low.

Both Butterworth and the equi-ripple or Chebyshev responses can be created using this design. Ideally, in Chebyshev designs the number of peaks should be the same as the number of crystals. Response should also be of equal magnitude over the pass band of the filter. In reality, fewer peaks than that are found, some being merged with each other. Additionally, the amplitude of the ripple increases towards the edges of the band.

Designing this filter can be simplified by using a test fixture to determine the problem first. The value of the end capacitors is,

\[
C_{END} = \frac{1.59 \times 10^4}{R_{FE}} \left( \frac{R_{END}}{R_{FE}} - 1 \right) \cdot 5
\]

The value of the coupling capacitors is,

\[
C_{JP} = 1320 \left( \frac{M}{R_{FE}} \right)^{-10}
\]

And the value of \( R_{END} \) is,

\[
R_{END} = \frac{6B}{C_{JP}} - R_{F}
\]

Where:
- \( B \) is the bandwidth in hertz.
- \( C_{JP} \) is the end capacitance in picofarads.
- \( C_{JP} \) are the shunt capacitors in picofarads.
- \( M \) is the bandwidth measured in a test fixture.
- \( R_{FE} \) is the normalised end section.
- \( R_{END} \) is the end termination of the filter. This is the end termination to be used without matching capacitors.

A special version of the crystal ladder filter is the Cohn filter or 'minimum-loss' filter of Fig. 11.

This filter rotates the end capacitors, and makes the shunt capacitors equal value. It preserves a reasonable shape factor, whilst minimising loss when built with practical resonators.

Like the crystal ladder filter, the Cohn filter uses the same frequency crystals throughout. The error in frequency between the crystals, \( \Delta f \), should be less than 10% of the desired bandwidth of the filter.

The design procedure given by Hayward (1987) is simplified:
- Pick a crystal frequency in the range 2 to 12MHz.
- Choose a bandwidth, \( B \).
- Pick a capacitance for the filter. A good start is 200pF – higher capacitance yields narrower bandwidth but higher insertion loss.
- Vary the end termination impedance to obtain a ripple-free pass band while providing sufficient stop band attenuation.

Table 3 gives various Cohn filter bandwidths, termination impedances and capacitor values for a three-crystal filter.

Monolithic ceramic crystal filters
Figure 12 represents a monolithic crystal filter. The principal benefit of this type of filter is its price, which is low enough to allow its use in low-cost consumer radios. Only a few monolithic filters have the shape factor needed for high-performance receivers though.

These filters are often used with synthetic piezoelectric resonators, rather than quartz. They are made in small packages, some being made in crystal packages and some being made in special packages. Some of the special packages are smaller than crystals, and some are larger.

Mechanical filters
Considerable improvement in filter action is possible with the use of the mechanical filters. These filters were once used in Collins high-end radio receivers and SSB transmitters. They are now more widespread, although the Rockwell/Collins company still makes the filters.

The basic principle of operation is the phenomenon of magnetostriction, that is the length or circumference of a piece of material will change when it is magnetised. Nickel changes in this way when magnetised, but only by about one part in about 20,000.

Other materials, such as ferrites or powdered-iron (types 61, Q1 or Q4), provide much stronger magnetostriction effects. In addition, these materials have a high electrical resistivity, so radio currents are minimised, and they

| Table 2. Normalised \( k \) and \( q \) values for Chebyshev response. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| \( N \)  | \( k_1 \)  | \( k_2 \)  | \( k_3 \)  | \( k_4 \)  | \( k_5 \)  |
| 1  | 1.61  | 0.701  | 0.702  | 0.703  | 0.704  |
| 2  | 1.93  | 0.301  | 0.451  | 0.601  | 0.751  |
| 3  | 1.0  | 0.707  | 0.708  | 0.709  | 0.710  |
| 4  | 0.785  | 0.849  | 0.912  | 0.975  | 1.038  |
| 5  | 0.616  | 1.000  | 0.956  | 0.912  | 0.870  |

| Table 3. Cohn three-crystal filter. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| \( B \)  | \( C (pF) \)  | \( R_{END} \) |
| 600  | 200  | 150  |
| 1000  | 70  | 431  |
| 1500  | 30  | 1500  |
| 2500  | 17  | 3300  |
have a mechanical $Q$ on the order of several thousand. They make far better filters than nickel! The typical ferrite material is formed at 1300 to 1400 degrees Celsius, and has a $Q$ determined by the proportions of oxides used in the formation of the ferrite material.

Figure 13a) shows a magnetostrictive resonator, while Fig. 13b) shows the equivalent circuit. The ferrite rod is wound with a coil such that it is a slip fit. It is biased magnetically with either a permanent magnet or a DC component to the electrical signal applied to coil $L$.

Over a temperature range of $-25^\circ$C to $+85^\circ$C, the change in resonant frequency is as little as 1.5 parts per million. In one test, the frequency shift for eight months was one part per million.

The mechanical filter consists of three basic parts: a) the transducers, b) the magnetically resonant discs, and c) disc coupling rods. The transducer is a magnetostrictive device that converts electrical energy to mechanical vibrations, and vice versa. The resonant discs form parallel resonant circuits, so increasing the number of discs decreases the bandwidth of the circuit.

Further reading

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During the 1950s, a new type of amplifying device emerged in fits and starts—and in some strange shapes—from the semiconductor manufacturers’ laboratories. By the end of the decade, reasonably reliable and workmanlike components were readily available.

I had begun to introduce low-power dual-transistor gain blocks of the type shown in Fig. 6 in my domestic ‘hi-fi’. These blocks were low-noise small-signal circuits with a low distortion of typically less than 0.01% at 1kHz and 1V RMS.

In this application, the freedom from heater-circuit wiring, the relatively low noise and the almost complete absence of mains-frequency hum in filter and frequency-correction circuits was welcome. Also, due to the fact that the devices gave off little heat in low-power use, one could, at last, make drift-free FM tuners.

However, there were electronic circuit design engineers who were at home with these components, and they soon turned their attention to audio applications.

Transistor audio amplifiers

From the late 1950s, circuit designs for transformer-coupled audio amplifiers, based on germanium p-n-p diffused voltage, operated device. All its electrodes presented internal conductive paths, whereas in a valve such inter-electrode paths were usually virtually open-circuit.

However, there were electronic circuit design engineers who were at home with these components, and they soon turned their attention to audio applications.

**Fig. 6. Low distortion gain block.**
Transistors had been presented by transistor manufacturers. These germanium devices were the only ones commercially available at the time. However, in the case of valve-operated audio output stages, the challenge that remained was to eliminate the inter-stage coupling transformers.

These transformers were sources of distortion and they limited the frequency and phase linearity of the system. Moreover, even loudspeaker coupling output transistors shouldn’t be needed with low impedance output loads such as a loudspeaker.

### The Lin design

An almost complete answer to the demand for a transformerless audio power amplifier was proposed by HC Lin in 1956. At that time the only available power transistors were p-n-p by the way.

Lin’s design is principally remembered for the introduction of the ‘quasi-complementary’ output stage layout. This involves a p-n-p-p-n and n-p-n-p arrangement used to simulate a symmetrical polarity pair of emitter-followers as the output group. However, Lin’s real contribution to amplifier design lay in his use of a low-power voltage amplifying stage followed by a low or unity-gain impedance conversion stage. This layout has been adopted for almost every power output stage design since then—never forgetting some thousands of op-amps. Lin’s design is shown in Fig. 7.

This circuit gave some 6W output with around 1% distortion, and covered the audio range of 20Hz-15kHz within ±1dB. At that time, for reference, the better high power valve amplifiers could give 25 watts at less than 0.05% and with a 5Hz-50kHz bandwidth. However, these were early days, and I was quite content with my Williamson mono set up—the tag lying in the ‘mono’ bit.

### Turntable trauma

When my old friend, the Seascale carpenter, made the cabinets for our two radiograms, he fitted each with a Decca turntable and its XMS sapphire-stylus pick-up. This seemed quite a good choice in 1950, before the advent of stereophonic LPs, even though the playing weight of the spring counter-balanced head was 40g or thereabout.

Sadly though, there was no way that the Decca system would play a ‘stereo’ disc without jumping up and down during the loud bass.

Replacing the turntable and pick-up would have presented little difficulty, though any new system would probably not have fitted as snugly as the original joiners installation.

The real problem was what to do about the single Williamson power amplifier. Quite apart from the cost and difficulty of buying and installing another Williamson, with its separate 450V power supply, there simply wasn’t room in the cabinet to accommodate it.

So my thoughts turned to constructing two equivalent transistor power amplifiers. This solution could certainly save space, but it had to sound as good too.

I treated the requirement as if it were for a typical industrial control system. The emphasis would be on simplicity—on the premise that “what you don’t put in won’t go wrong”. I designed and made up the experimental four transistor power amplifier circuit shown in Fig. 8.

### Why was it n-p-n throughout?

At that time, 1965, silicon n-p-n transistors were not very good, so the design used only n-p-n power devices. The opposite was the case with germanium devices, where it was the n-p-n ones which were relatively poor in performance.

This design operated in class A, which removed any problems which might arise with class ‘A’ output bias level settings.

On being tested with a 35V supply line, this amplifier worked very well. It had an output power of a little over 10W, a THD figure rather better than 0.1%, and a bandwidth of 16Hz to 100kHz, ±0.5dB. This was very encouraging—especially when I compared its sound quality against the Williamson, and concluded that it was at least as good.

On seeing these results, I built a tiled-up stereo version as a Christmas present to myself in 1967. Some time later, I replaced the output transistors with Motorola ‘ epitaxial base’ 2N6055s.

With an increase in the supply voltage to 45V, the new transistors allowed an output power of more than 15W. This was equivalent to the Williamson, though I am unconvinced that I ever needed or used more than two watts.
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What is Bluetooth?
Soon it will be possible to connect peripherals to your PC via an rf link using a wireless local network technology called Bluetooth. Geoff Lewis outlines how it works.

Bluetooth is the title used for an open specification system designed to provide a fast and secure short range radio interconnection between portable devices and a local area network (LAN) through the use of spread spectrum techniques. The services provided for include internet, e-mail, image and data transmission together with voice applications extending to three simultaneous 64kb/s PCM channels.

The concept has been adopted by about 2000 diverse user organisations and is supported by many of the major semiconductor chip manufacturers. These include Intel, Toshiba, VLSI, Texas Instruments, Ericsson, Thomson (ST), Lecent and Siemens. In addition, the Bluetooth standards have gained the approval of the FCC (Federal Communications Commission), ETSI (European Telecommunications Standards), the IEEE (Institute of Electrical and Electronic Engineers) and the IxDA (Infrared Data Association) for global use.

The 'user portable terminal devices' involved can include mobile phones, headsets, printers, digital cameras, PDAs (personal digital assistants) and lap/palm top and notebook computers. The emphasis is to provide a robust worldwide system capable of acting as a captive type of replacement at low cost with plug and play capabilities.

The transmission system
The system operates in the licence-free (industrial, Scientific and Medical, or ISM) band from 2.4GHz to 2.45GHz and employs frequency-hopping spread-spectrum (FHSS) technology. For this application, FHSS is preferred to the more common direct sequence spread-spectrum (DSSS) system.

This FHSS is somewhat slower in operation, it is much simpler to implement through the use of a frequency synthesiser. The power output of the transmitters ranges from 1 to 2.5mW (0 to 4dBm) to provide a coverage of at least 10 metres – a range that can be increased to 100 metres by the use of radio-frequency power amplifier.

A prime number (79) of sub-carriers, spaced by 1MHz, occupies the band 2.402MHz to 2.480MHz. Each sub-carrier is frequency modulated with a deviation of either −140kHz to −175kHz for binary 0 or +140kHz to +175kHz for binary 1. This modulation method is referred to as Gaussian frequency-shift keying (GFSK) because the base-band digital signal is filtered to provide a Gaussian bell-shaped response with at least 90% of the pulse energy contained within ±100kHz bandwidth.

The resulting signal has a good spectrum efficiency and resilience to co-channel interference (CCI).

Each sub-carrier can be switched at the rate of 1600 frequency hops per second to provide a spread spectrum signal with a hop period of 625μs. The maximum bit rate is currently set to 1Mbit/s but because each sub-carrier can carry multiple bits during...
each time slot, this figure might be doubled in the near future. A bandwidth bit period (BW_Tps) product of 0.5 has been set for Bluetooth. For a maximum bit rate of 1Mbps, this yields a signal bandwidth of 0.5x0.5, which is 0.25kHz. Under these conditions, the system has an adjacent carrier interference (ACI) ratio of better than -20dBc. If the bit rate is increased to 2Mbps then this ACI protection ratio will be reduced.

Bluetooth's radio module

As currently configured, each Bluetooth terminal is constructed around two highly integrated modules. Each contains an application-specific integrated circuit (ASIC) designed to handle the radio functions and the baseband signal processing.

The basic module is constructed on a laminated substrate consisting of seven layers of metal interleaved by six layers of ceramic. This is then connected to a PCB via ball grid array (BGA) mounts. The lower metal layer acts as a ground plane while the component side carries a pair of metal access to complete the electromagnetic shielding. In order to maintain good interference rejection, the various earth points are distributed around the ground plane.

As Fig. 1 illustrates, the radio system ASIC carries out all the functions associated with the generation and control of the sub-carrier frequencies. This is achieved through the use of a voltage controlled oscillator, or VCO, linked to a phase-locked loop circuit. In turn, the PLL is locked to the output of a 1.5MHz crystal oscillator.

A VCO tank circuit forms part of the PLL circuit. Its tuned load is then laser trimmed for accuracy. A loop filter is used to remove any ripple from the output of the PLL circuit. For receive purposes, this IC employs a heterodyne technique to generate a low IF at 5MHz.

Spread-spectrum frequency-hopping modulation is performed directly on the VCO. A pair of balun circuits convert the balanced signals used within the ASIC into the unbalanced form used externally for transmission and reception.

An antenna switch directs the signals between the baluns and the antenna inputs/outputs for the transmit/receive functions. The antenna filter reduces the harmonic radiation from the terminal device during transmit and helps to minimize the unwanted interference effects during receive. The antenna feed is designed to match a 50Q impedance load.

Baseband signal processing module

Figure 2 is a simplified block diagram of the baseband signal processor. The ASIC in this stage contains an embedded reduced instruction-set computer core that controls the operation of the radio section and the inputs from either of the input/output interfaces.

A flash reprogrammable memory carries the software that provides the radio module. The code stored within the flash memory provides control for both host controller interface and the local link manager for the USB, UART and PCM ports. The operational protocol provides for link set up and configuration together with authentication.

To maintain a secure transmission system and a high data rate in what might well be a noisy environment, Bluetooth operates with a packet switching protocol that includes both forward error control and encryption.

Networking Bluetooth

Bluetooth terminals are organised into small groups referred to as 'piconets'. These consist of up to eight peer devices with one acting as a master for the group. The simplest network is just two devices linked by a virtual cable.

Piconets may be linked together via a terminal device that is common to two groups, but this must not be one of the masters. Each piconet has a different frequency hopping sequence and a collection of piconets is known as a 'scatternet'.

Finally, I should like to acknowledge the help received from Ericsson Components AB in preparing this article. The company's Bluetooth data sheets and extensive information on the web site, www.ericsson.com/bluetooth have been particularly helpful.

The universal asynchronous receiver/transmitter, or UART, interface operates as a 'data circuit equipment', or DCE, device under the control of the request to send clear to send signals RTS and CTS. In turn, these handshaking signals control the data flow lines TXD (transmit data) and RXD (receive data). This interface can handle all the standard data rates from 300b/s up to 460.8kb/s.

Apart from the universal serial bus standard bi-directional ports D+ and D-, two additional inputs are provided for the control of a laptop/telephone computer. The 'wake-up' signal advises the host computer that the terminal has become operative and the 'detach' signal indicates a suspending operation mode. While the USB port is capable of running at 12Mbps, the Bluetooth operation is limited to 1Mbps.

The PCM interface operates at the standard sample rate of 8kHz and can handle linear PCM from 13 to 16 bits, plus both µ-law and A-law 8-bit compressed samples.

Software and protocol

The code stored within the flash memory provides control for both host controller interface and the local link manager for the USB, UART and PCM ports. The operational protocol provides for link set up and configuration together with authentication.

To maintain a secure transmission system and a high data rate in what might well be a noisy environment, Bluetooth operates with a packet switching protocol that includes both forward error control and encryption.
A novel inductance meter

Combining high-speed phase detection circuitry with microcontroller data processing, Michael Silfkin and Alexander Gornstein have developed an inductance meter capable of displaying accurate measurements from 20µH to 200mH on an LCD module.

- Phase-shifting. Here you would use the reactance as the variable element in a phase-shifting circuit and then measure the change in phase of an oscillator working at fixed frequency. There are different ways of measuring phase change. You could use a pulse-counting technique as described in our article on a power-factor meter in the February issue. Alternatively you could use the phase detector described in the April 1999 issue on page 312. It would be possible to devise a range of methods for such measurements.

- You could use the reactance as a frequency determining element in a tuned circuit and obtain the new frequency or change in frequency caused by the reactance. If the change in frequency were too small, you would probably find a linear relationship between the change and the value of the reactance.

Methods exist that are specific to the type of reactance being measured. You could measure capacitance by charging to it to a known voltage and then find the discharge time. Or you could try to measure inductance by finding the back EMF when a pulse is applied to it. Standard radio techniques can be used to measure reactance. This is not as far fetched as it sounds. For example, a radio receiver with a BFO would detect the shifting of a carrier wave due to reactance added to the tuned circuit. You would not need to use an actual radio receiver to do this, although I once saw a radio receiver used in this manner about 45 years ago.

Nowadays you can buy chip sets comprising a transmitter and receiver in frequency and phase modulation modes that can be readily adapted to reactance measurements. This is not the subject of this article, but perhaps one of the future.

Finally, you could try to measure the reactance directly by finding the current through the reactance at some voltage. This is the method we chose. Although this would appear to be an obvious method, it does not seem to have been used before, probably because of the 90° phase shift between the current and the voltage introduced by the reactance. The ohmic loss also has to be included.

The instrument in detail

Figure 1 is a block diagram of our instrument and Fig. 2 is its full circuit diagram. The meter involves a simple analogue circuit in which the inductance is measured in five series with an alternating constant current generator as the input to a high impedance FET op-amp. A voltage is produced across the inductance. This voltage is amplified. By using suitable values of gain, the amplified voltage is found to be numerically equal to the inductance.

At this point, the voltage is converted to a digital form. A processor now calculates the value of inductance according to the range and sends the reading to a 16-character by 2-line liquid-crystal display module. The best form of detection of a sinusoidal voltage signal is the phase-sensitive detector, as mentioned above. As explained in the earlier article, the phase-sensitive detector is just a multiplier and a low-pass filter.
Adjust $P_2$ for stable oscillation

Phase-shift adjust
Assuming 10kV,
$R_7+P_2=12k$ ($R=1/\mu A$)

Fig. 2. Complete circuit of the four range inductance meter, with the Wien-bridge oscillator upper left, the switches of the phase-sensitive detector upper right and the microcontroller bottom left. The display is a generic 1620 matrix type with 16-by-2 characters such as the Sanyo C1620S.
INSTRUMENTATION

Michael Sifkin is in the Department of Electronics at the Jerusalem University of Technology. The authors have opened a website at: http://optics.jct.ac.il/~slifkin/nim.htm. It contains URLs to all the devices used in this instrument.

If you want the object code in electronic form, e-mail jac.howell@bt.co.uk and I will be forwarded to you as text embedded in an e-mail. Please use L meter on the subject heading.

If you want the object code on disk, again free of charge, send us a PC formatted 3.5in floppy with a protective self-addressed envelope and enough stamps to allow us to return the disk to you. Post it to the Quadrant House address below.

The source code is available on disk for £15, or as an e-mail attachment for £10 fully inclusive. E-mail the above address with your credit card number, expiry date and cardholder address or fax 020 8662 8555 with the details. Alternatively, send your order to L meter, Electronics World Editorial, Quadrant House, The Quadrant, Sutton, Surrey SM2 5AS.

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Technical support
Michael Sifkin is in the Department of Electronics at the Jerusalem University of Technology. The authors have opened a website at: http://optics.jct.ac.il/~slifkin/nim.htm. It contains URLs to all the devices used in this instrument.
Everything but the sink

Two significant breakthroughs in isolated modular dc-to-dc converters have been made by a relative newcomer in this field. The company, SynQor, has introduced synchronous rectification – increasing efficiency to such an extent that the new converters are the first of their kind to do away with heat sinking. Secondly, planar magnets have been used, reducing weight and lowering board height.

In the interests of increasing reliability, and to ease the problem of conveying power to electronic equipment in racks, it's common to have regulators on cards distributed throughout the system. Each individual regulator is fed by a relatively high voltage, allowing the cross section of power-distributing buses to be reduced.

Distributing the power supply in this way means that heat lost through regulator inefficiency is spread around the cabinet. This is a great advantage relative to having one large central regulator, but it does mean that valuable card space is lost to accommodate the individual regulators. There has been little innovation in the design of such regulators over the past few years. Almost all the inefficiency in modern regulators is still caused by the voltage drop of a Schottky diode – evidence that current products are making the most of traditional switching circuitry.

A typical 5V, 30A regulator will have an efficiency of 83%. At full output, it would dissipate just over 23W. Clearly, such a regulator needs some form of heat sink on top of it, increasing the amount of valuable inter-board space needed for the card, its regulator and the regulator's heat sink.

While 5V regulators have been the norm, and alternatives to Schottky diodes have been impracticable, designers have had to tolerate regulators that need additional heat-sinking. But now that supplies lower than 5V are becoming common, the dissipation problem is compounded.

Efficiency of a traditional 3.3V Schottky-diode-based regulator drops to 79% at 30A – an equivalent 1.5V product is only 64% efficient. This fall in efficiency is mainly due to the fact that the diode’s voltage drop is becoming a greater proportion of the output voltage.

So when everything else is shrinking, the regulator assembly is actually increasing in size.

So efficient they don’t need a heat sink

Now, a new player in the DC-to-DC converter market, SynQor, has developed a range of products that need no heat sinking. Being more efficient, these regulators output more power for a given volume. And needing no potting compound or heat sink, they are significantly lighter. Eliminating the heat sink also removes the unreliability of the thermal interface between the traditional converter and its heat sink.

The company has replaced the traditional Schottky diodes with synchronous rectifiers, which has made a significant impact on efficiency. In addition, planar transformers are being used, offering benefits in both weight and board height. Windings of these transformers are actually PCB tracks, and their ferrite ‘core’ passes through the PCB, wrapping around heavy copper tracks.

These are not the first designs to be based on synchronous rectification, but they are the first to incorporate a patented method of improving rectifier efficiency. The rectifiers in this case are MOSFETs. To achieve a low ‘on’ resistance, these FETs have to be large-area types. But large area is synonymous with large gate capacitance.

Normally, driving a high gate capacitance at a few hundred kilohertz would waste considerable power, but SynQor is using a patented method of re-using the gate driving energy.

Resulting efficiency improvements are good at 5V, rising from 83% for a typical conventional converter, to 89% for the new products. But at 1.5V and 3.3V, the efficiency is 89% against 62% for a conventional converter. Work this out in watts at 30A and you will get an idea of what a difference the efficiency gain makes.

For more information, see www.synqor.com

See for yourself...

An evaluation kit for these new converters comprising:

- One regulator of any of the available voltages
- An evaluation board
- An evaluation procedure manual
- Carrying case

is available to Electronics World readers at a special 17.5% introductory discount price of £125. Simply mention Electronics World and this advertisement when ordering. Call SynQor on 01753 860276 or fax 01753 840332 for further ordering details and see www.synqor.com/synqor/synqor.nsf/EvaluationKitsMain for more information on the kit.

Voltages available are 2, 2.5, 3.3, 5, 12 and 15V in the 30A series and 1.5, 2, 2.5 and 3.3 in the 40A series. The 12-page manual and evaluation board allow you to thoroughly check out the performance of the module and to compare it against what you are currently using.

The kit is also the basis of an educational tool for anyone wanting to find out more about the characteristics of DC-to-DC converter modules.
Letters to the editor

Letters to "Electronics World" Quadrant House, The Quadrant, Sutton, Surrey, SM2 SAS

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TID: RIP?
Over the last thirty years there has been a continuing debate as to what might affect the sound quality of transistor power amplifiers.

In the early seventies, the argument was fired up by Lohstroh and Ota's transient modulation distortion (TMD) theory but over the last few years this appears to have been slowly falling out of favour.

Self has argued strongly for the Miller capacitor as a means to solve amplifier stability and distortion problems. On the face of it, this seems to be a useful way forward. However, this Miller capacitor causes slew-rate overloading when the input signal exceeds the slew-rate limit.

I thought it useful to determine this limit so that it need not be exceeded. The calculations I have made contain a surprise that does indeed link the amount of feedback to the maximum acceptable input rate of change of voltage as I will now explain.

Consider a typical transistor stage in the diagram on the right. The input differential pair operates at a nominal current of $i_i$ and the current source supplying them is $i_m$. The voltage-amplifier stage, or VAS as Self calls it, shares any current between the base current, $i_b$, and the Miller capacitor current $i_m$. The Miller current is proportional to the collector voltage $V_C$.

$$i_m = i_b + i_m$$

where,

$$i_m = \frac{dV_C}{dt}$$

This Miller-capacitor current would have appeared as a voltage across the emitter resistors of the input transistors, which are usually used to linearize the input stage to reduce distortion (see Self, op. cit.). In order to determine the maximum drive to this capacitor to prevent the input stage from hard switching, and thus cause a high level of distortion, it is necessary to consider what the limit might be.

Limited-slew criterion
I propose that the worst-case limit should be where the input transistors are able to respond to an input, and thus retain control of the amplifier. If the input pair currents are altered by up to half their DC levels, this would leave a current of a further 50% still available to them. But with such a change this would already be "large signal" and the distortion levels would be rising. However, it seems to be a reasonable starting point.

In this circumstance, $i_b$ might be 1.5$I_i$, while $I_i=0.5$I_i. Note that the emitter-base voltages are quite different, and are,

$$dV_{EBC} = (I_{I-EBC}(log(1.5) - log(0.5)))$$

where $V_{EBC}$ is the thermal voltage, 25mV at 20°C, and the logs are natural. (I prefer the programmer's "log" rather than the mathematician's "In".) $dV_{EBC}$ is 27.8mV here.

With rather low values, in my opinion, of 2kΩ emitter resistors, as Self originally suggested, there is an additional increase of 22mV where $\mu=1mA$. This gives a total margin between the bases of about 50mV. It would be 130mV for 100kΩ resistors.

When the output voltage is limited by the slew rate to,

$$\frac{dV_{OUT}}{dt} = \frac{V_{OUT}}{C_{LOAD}}$$

where the feedback point ($V_B$) the base of the second output transistor) rises at a rate of,

$$\frac{dV_{B}}{dt} = \frac{V_{B}}{C_{LOAD}}$$

At the time, although these things were being used in the USA, there was no product available in the UK, so I was unable to nominate a supplier or give a review. Now a firm called VAS in Newcastle-upon-Tyne is making a rather good design that has won an Innovation 99 award. I have tried it out and it seems fine. You have to adapt your technique to this, but it certainly relieves the aches and pains of continuous mousing.

Rod Cooper
Sutton Coldfield
West Midlands

There's a mouse on my knee
In the article "Mouse holes" in the May 1999 issue, I mentioned the use of a proprietary pad on the upper leg for working the mouse. Using it there reduces muscular strain.

At the time, although these things were being used in the USA, there was no product available in the UK, so I was unable to nominate a supplier or give a review. Now a firm called VAS in Newcastle-upon-Tyne is making a rather good design that has won an Innovation 99 award. I have tried it out and it seems fine. You have to adapt your technique somewhat, but it certainly relieves the aches and pains of continuous mousing.

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Fig. 1. Input stage of an audio amplifier in which current through each device of the input pair is $I_i$.
Early radar

In the very interesting history article on Blenheim in the March issue of Electronics World, the statement that the radio direction finding, later to be called radar, came from the later airborne aircraft, seems to be a bit off. At Boulton Paul, fighter pilots, from the earliest days there were ‘chain home low-flying’, or CHLF, radar, then ground-controlled, radar, or GCL, version.

The radar worked by flying worked at 2,000MHz on the transmitter valve anodes. The range was up to 20 miles, if the open feeder was kept below 1000 ohms, or when the feed was kept below 1001, but on occasions of temperature inversions, second-stage feedback was used with transistors with a rise of up to 400 ohms.

Domestic thermocouples?

Can someone tell me how thermocouples work? From time to time I change one domestic ones, but I don’t know how one wire of around 12V can do the work of opening and closing a gas valve?

I’m a member of a couple of professional installers of heating equipment. One said he didn’t know the other that it transmitted heat. Grahame

West Sussex

I'm not an expert on this, but the thermocouples you first used to control gas appliances, etc., are not thermocouple. I’ve always assumed they rely on expansion, or state change, or some material within their copper tubing. The only ones I’ve seen have been a number that activates an electrical push switch or deactivates a mechanical valve. Does anyone know how they work? Are thermocouples found in domestic appliances? Ed.

J.N. Ellis

Tavistock

Devon

Free PCB layout tool

A ‘ất’ version of the Eagle layout tool from Cadsoft is available off the web for free. It has the limitation that it can produce a maximum board size of 4in by 3in, double sided. I’ve successfully built a board for the ‘Five-chip logic analyser’ from EW February 1999 using the package.

I printed the layout for both sides on a laser printer and used blue ‘iron-on’ transfer material to make the board.

I succeeded first time and easily produced line thicknesses down to 0.1mm on a certain increase in distortion figure.

Now for the surprise. In equation 5, the amplifier feedback attenuation ratio was included. Otsa et al. (op. cit.) conjectured that a high level of feedback may increase transient intermodulation distortion. Equation 5 shows a simple but significant result - that for more feedback, where x is greater, corresponding to a lower gain, a smaller input signal can be tolerated.

Perhaps I was slow to appreciate this point before, because this is really just another way of saying that for more feedback, the bandwidth is greater! This would appear then to agree with Cherry’s comments about TAV.

The sound of a power amplifier might have been affected by high-speed preamplifiers, which would undoubtedly influence low swing-margin amplifiers. If a simple input filter is used, it might, with the power amplifier limit, have adversely affect the overall frequency response of the system. The simplest way out of this would be to use a faster amplifier. Another approach might be to use a two or three-order filter, to try to have more of the audio frequencies untouched before the cut-off point.

It is not a new idea to include a low-pass filter on the input of an amplifier to prevent low-slew-rate limiting, but I hope this has shown a method for determining the optimum.

Alternatively, large input resistors are the problem, admittedly with some other drawbacks. However, with either approach, we can lay the ghost of TFD to rest.

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