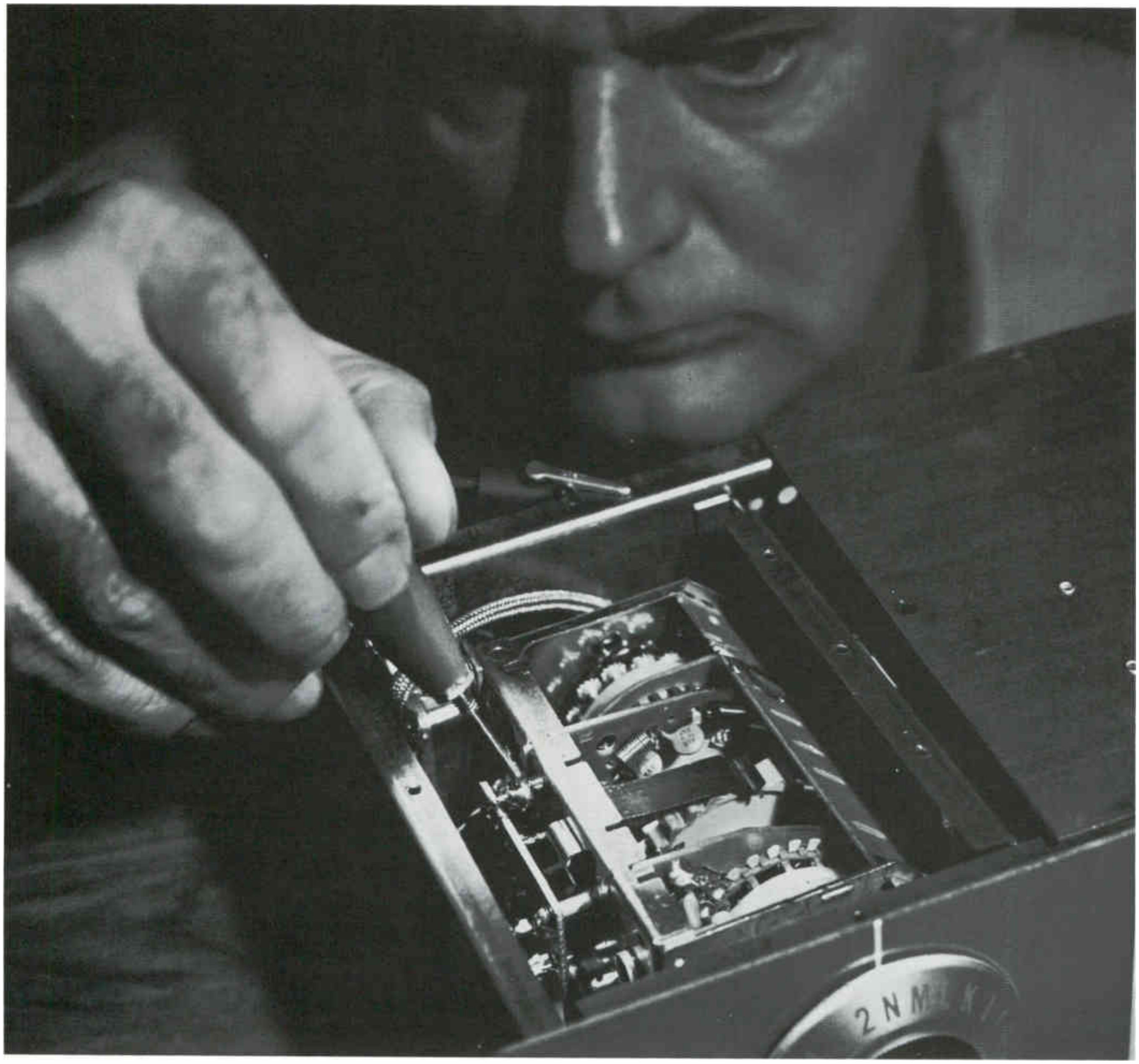
Mar./April '72 vol. 8/ no. 2

# CABLECASTING

## Cable TV Engineering

SCTE The official journal of the
SOCIETY OF CABLE TELEVISION ENGINEERS

Fisheye View of CATV Technical School (Theta-Com)



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## Contents

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# SOCIETY OF CABLE TELEVISION ENGINEERS

## NORTHWEST CHAPTER

The Northwest Chapter of the Society of Cable Television Engineers held a meeting on March 5th at the Thunderbird Motel in Portland, Oregon. Principle topics of the meeting were the C.E.T. test given by the State of Oregon.

Before lunch, Stan Bennett of Bennett Associates, gave a talk and slide presentation on Microwave Theory and Practice. CARS band equipment was displayed and Mr. Bennett gave information on the design of microwave systems. After lunch, Dick Harnicak of Tektronix spoke on spectrum analyzers and the basic difference between the scope and the spectrum analyzer.

The next meeting of the chapter will be held on June 4th, two weeks ahead of the Oregon Cable Communications Assn. annual meeting. For more information on the Northwest Chapter contact Bill Elkins, president (Liberty Television, Inc., 2225 Coburg Rd., Eugene, Ore.; 343-3301) or Don Hostetler, secretary (Corvallis TV Cable Co., Box T, Corvallis, Ore.).

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## CENTRAL ATLANTIC CHAPTER

The Central Atlantic Chapter of the SCTE held a meeting on February 26th at the Holiday Inn in Jersey City, N.J. In attendance were thirty-seven members and two guests. At this meeting, a specially engraved wall plaque was presented to past chapter president Earl Quam for his efforts in getting the chapter organized and his continuing contributions to its well being.

There were two technical presentations at this meeting. Delmer Ports, Director of Engineering of the NCTA, gave a presentation on the proposed FCC CATV standards. He also informed the membership that the SCTE will chair three workshop sessions at the NCTA convention in Chicago.

Bob McCall and Fred Site from Tektronix gave a visual presentation on VITS test signals in conjunction with a rack of test equipment made up for the purpose.

For more information on the Central Atlantic Chapter contact the Secretary, Gerald Goldman at TelePrompTer Corp., 50 W. 44th St., N.Y. 10036.

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# INTER-CHANNEL INTERFERENCE AND THE CABLE-FREQUENCY ALLOCATION PROBLEM

By John E. Ward

MIG Electronic Systems Laboratory

The CATV industry, in its effort to break out of the traditional pattern of 12 channels (or less) per cable, has only recently begun to make use of channel frequencies that are different from the standard VHF-TV channels for which all TV receivers are designed. The initial move in this direction was to take advantage of 66 MHz of unused bandwidth that was already being carried in all cable systems—that between the upper edge of the FM band (108 MHz) and the lower edge of Channel 7 (174 MHz). By general industry acceptance (but not specific standardization), a "mid-band" has been defined from 120-74 MHz, divided into 9 channels designated A through H (the 108-120 MHz region is apparently avoided because of possible interference effects of cable leakage on aeronautical radio and navigation services, although these services actually extend to 136 MHz). Use of these mid-band frequencies, which requires a special channel converter device at each subscriber TV location, permits 21-channel capacity (12 VHF plus 9 mid-band), and a few cable systems now offer such service.

Once started on this tack, it was natural to define a "superband" starting at 216-MHz (the upper edge of Channel 13), with the upper limit of this essentially open-ended. Many of the newer cable systems are engineered to carry frequencies up to 240 MHz, permitting four super-band channels (I through L) and 25-channel total capacity (with appropriate converters). With 300-MHz cable technology now becoming available, the super-band can be extended to provide nine additional channels M through U, or a total of 35 channels per cable (with mid-band as presently defined). Similarly, a "sub-band" has been defined in the region below 50 MHz, with the general consensus that this band will be used for upstream channels (signals moving from the subscribers toward the head end.) Some proposals are for four upstream channels between 6 and 30 MHz, but no general agreement has been reached as yet on channel assignments or usage, and the first upstream experiments are barely under way.

Unfortunately, adding these extra channels on a cable can and does raise problems of inter-channel interference that do not arise with use of only VHF Channels 2 through 13 (either broadcast or on the cable), largely because the frequencies for these VHF channels were chosen by the FCC partly on the basis of avoiding such problems. The intent of this discourse is not to say that these inter-channel interference problems are unsurmountable in augmented-channel cable systems, but to clearly define them, explain how they come about, and point out the precautions that must be taken in the design of subscriber equipment (converters or special cable receivers) and in the final agreement on cable-channel frequencies.

Since most of the interference questions revolve around the basic U.S. 6-MHz television channel standard and the carrier frequencies assigned within it, this subject is taken up first.

### The 6-MHz Television Channel

The origins of the 6-MHz channel bandwidth standard for U.S. TV are rather interesting. In the early 1930's, the first experimental television systems used the same double-sideband amplitude modulation technique that is still used in AM radio. The highest picture frequency component then transmitted was 2.5 MHz, and the picture signal thus required a 5-MHz channel, with the picture carrier in the center. To provide space for the sound signal, an extra 1-MHz was tacked onto the high side of this picture channel to create a total 6-MHz channel, with the FM sound carrier 0.25 MHz below the upper band edge (as it is now).

In the late 1930's, vestigal-sideband modulation techniques were perfected which permitted an increase in picture component frequencies (and thus in picture resolution) without increasing the 6-MHz channel bandwidth. With the change to vestigal-sideband modulation, all but 0.75 MHz of the lower picture sideband was eliminated and it became possible to move the picture carrier down to 1.25 MHz above the lower band edge (as it is now) and use modulation frequencies up to 4 MHz in the upper sideband. This of course obsoleted all existing receivers, but only a handful had yet been produced (television broadcasting was still largely experimental). Although these revised standards in 1939-40 were for monochrome transmission at only 441 lines per frame, the 6-MHz channel and the sound and picture carrier assignments within it have survived both the later increase to a 525-line standard in the 1940's (again obsoleting prior receivers) and the addition of compatible color transmission in 1953.

In regard to color, the majority technical opinion up to the late 1940's and early 1950's was that either a wider channel (perhaps 12 MHz) or a slower picture frame rate would have to be adopted in order to transmit each picture frame as three separate, field-sequential red, blue, and green images, as was then thought to be required for reconstruction of a color picture at the television receiver. Indeed, the quite controversial color television standard initially adopted by the FCC in September, 1950, was a field-sequential "color-wheel" system with scanning standards quite different from those in use for monochrome receivers then in the hands of the public. The subsequent intensive industry/government effort which found that it was possible to develop and standardize by December, 1953, a new method of color transmission that fitted the 6-MHz bandwidth and was compatible with the existing monochrome standards was a major engineering feat and finally got color TV off the ground. This dot-sequential system retains the standard monochrome picture modulation as a brightness signal (for either monochrome or color sets), and inserts a third carrier at 3.5795 MHz above the picture carrier to carry all color-related information needed by color receivers, but which can be ignored by monochrome receivers. The only change made in the previous monochrome standards was a 30-50 percent reduction in amplitude of the sound signal relative to the picture signals so as to reduce the possibility of any interference of the sound signal with the color carrier (the sound carrier and the new color carrier are only separated by 0.93 MHz in frequency). The final transmission standard which is in use today is shown in Fig. 1.

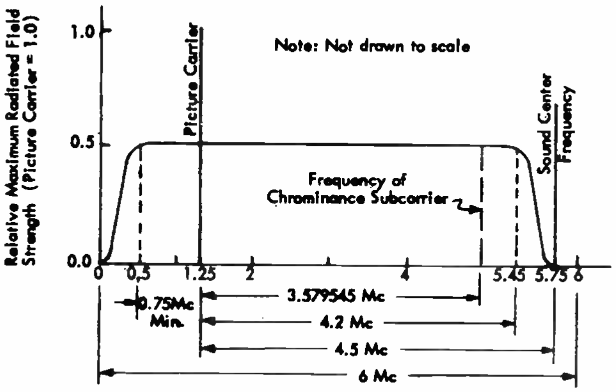

Fig. 1 The NTSC Color Television Channel

The gist of the above is that in the period 1937-1953, three major modifications were made in U. S. television transmission techniques to raise picture quality and add color, and by improved know-how and clever engineering, each of these modifications was accomplished without changing the basic 6-MHz channel bandwidth that had been chosen in the early 1930's for quite different transmission techniques. That is not to say, however, that all aspects of the present U.S. television standards are necessarily what one would now choose if it were ever possible to make a change. Three-quarters of the countries in the world have opted for better picture resolution by adopting higher line counts (625 or 819 lines), higher picture frequencies (5 or 6 MHz) and wider channels (7 or 8 Mhz), although the one-quarter of the countries using U.S. standards account for over half the world's TV sets (132 million out of the total 254 million.)

### The VHF Channel Allocations

In the original allocation of transmission frequencies for television in 1937, the FCC adopted the standard 6-MHz channel width and set aside 19 television channels as shown in Table 1, although only the eight lowest were considered technically feasible within the radio art of the day. Three years later, an FCC revision reallocated the 44-50 MHz channel to FM broadcasting and added 60-66 MHz as a television channel (FM was to be later moved to 88-108 MHz). Although these 1940-vintage channels were allocated in pairs, separated mostly by 6- or 12-MHz frequency gaps assigned to other services (government, amateur, police, etc.), the basic pattern of the present VHF channel allocations was beginning to emerge, and six of the channel allocations (the present Channels 3, 4, 8, 9, 12, and 13) are still the same. It is also interesting to note that most of these 1937 frequency allocations that did not become part of the final post-war VHF-TV allocations are identical with presently accepted mid- and super-band (letter) channels for CATV (156-168 MHz, and those above 234 MHz).

The FCC again revised the frequency allocation charts in the mid-1940's to create the present lineup of VHF television Channels 2-13 (see Table 2), at the same time moving the FM broadcast band from 44-50 to 88-108 MHz. One of the factors in these final frequency shufflings was a desire to choose the television channel frequencies so as to avoid as much as possible four types of potential interference in home receivers

1937-1940 Television Channel Allocations

| MHz | Present VHF or Cable Channel | Notes |
|---|---|---|
| 44-50 | | Reassigned to FM June 1940 |
| 50-56 | | |
| (60-66) | 3 | Added in June, 1940 |
| 66-72 | 4 | |
| 78-84 | | 88-108 is present FM broadcast band |
| 84-90 | | |
| 94-102 | | |
| 102-108 | | |
| 156-162 | (G) | Present mid-band cable usage |
| 162-168 | (H) | |
| 180-186 | 8 | |
| 186-192 | 9 | |
| 204-210 | 12 | |
| 210-216 | 13 | |
| 234-240 | (M) | Present super-band cable usage |
| 240-246 | (N) | |
| 258-264 | (P) | |
| 264-270 | (Q) | |
| 282-288 | (T) | |
| 288-294 | (U) | |

Table 1

Present VHF Television Channel Allocations

| VHF Channel Number | Frequency Band | Picture Carrier | Receiver Local Oscillator | Receiver Image Band | Channel in Image Band (Beat freq.) |
|---|---|---|---|---|---|
| 2 | 54-60 | 55.25 | 101 | 148-142 | |
| 3 | 60-66 | 61.25 | 107 | 154-148 | |
| 4 | 66-72 | 67.25 | 113 | 160-154 | |
| 5 | 76-82 | 77.25 | 123 | 170-164 | |
| 6 | 82-88 | 83.25 | 129 | 176-170 | 7(-.5) |
| 7 | 174-180 | 175.25 | 221 | 268-262 | |
| 8 | 180-186 | 181.25 | 227 | 274-268 | |
| 9 | 186-192 | 187.25 | 233 | 280-274 | |
| 10 | 192-198 | 193.25 | 239 | 286-280 | |
| 11 | 198-204 | 199.25 | 245 | 292-286 | |
| 12 | 204-210 | 205.25 | 251 | 298-292 | |
| 13 | 210-216 | 211.25 | 257 | 304-298 | |

Note: All frequencies in MHz

Table 2

(other than adjacent-channel) that can be caused by particular relationships among channel transmission frequencies: interference from local oscillator radiation (leakage) by neighboring TV receivers, image interference, intermodulation interference, and IF beats. These interference effects were almost completely eliminated in the VHF allocations because of the way the channels are grouped into two isolated blocks of 6 and 7 channels each, separated by a large frequency band (86 MHz, equivalent to over 14 channels). Note that except for Channels 5 and 6, the VHF channel boundaries are all integer multiples of 6 MHz, the channel bandwidth (Channel 5 is offset from Channel 4 by an intervening 4-MHz band assigned to radio services). As will be explained later, a uniform integer-multiple pattern is highly desirable in multichannel systems, and the present FCC frequency assignments for Channels 5 and 6 represent a problem in broadband cable TV.

The inter-channel interference problems occur in both broadcast-TV and cable-TV and are all generated in or by television receivers as a result of the interaction of receiver design parameters and particular channel-frequency relationships. Their deleterious effect on received pictures can be eliminated or reduced (at least below levels discernible to the viewer) by some combination of proper receiver/converter design, proper choice of channel frequencies and transmission standards, and in broadcasting, by geographic isolation of troublesome station frequency assignments. There are two other interference problems that are peculiar to cable systems and have somewhat different impact on cable and receiver engineering and the choice of cable frequencies: co-channel interference with cable signals by broadcast TV signals, and possible interference of cable signals, should they escape from the cable, with other radio services. These are described below.

## Co-channel Interference by Broadcast Signals

In the early days of cable-TV, systems were usually installed where there were no strong local television stations, and programs were generally carried on the cable on the same channels on which they were broadcast. As cable expanded into areas nearer the stations, it was found that with such on-channel carriage, many subscribers were troubled by interference caused by dual reception of the same program: a direct, unwanted signal leaking into the cable or their receiver from the broadcast station, and the same signal as picked up by the cable system antenna, processed by the cable head-end, and transmitted through the cable. Because the cable signal travels a greater distance, at least part of which is through a slower medium (1.2 µsec per 1,000 feet in the cable as opposed to 1 µsec per 1,000 feet through the air), the interfering direct-pickup signal arrives first and creates various effects depending on its strength relative to the cable signal and the relative signal delays. Particular effects in received pictures are left-hand ghosts, vertical black sync bars, or random stripe patterns.

As a result of the on-channel carriage problem, it has been common cable practice to carry strong local stations on different "quiet" channels on the cable. This represents both an inconvenience for the subscribers (these stations are not found at their normal positions on the dial), and a wastage of channel capacity. In some metropolitan areas with many local stations, as many as five or six cable channels are unusable because of on-channel interference, leaving only six or seven channels in what should be a 12-channel cable. It was this problem that has prompted the installation of many dual-cable systems (with subscriber "A/B" selector switch) to increase capacity, but note that the same interference rules apply to both cables and some dual-cable systems can still offer only 12-14 channels.

Broadcast signals can leak into any part of the cable system (up to and including the final connection to the antenna terminals of a subscriber receiver), or directly into the receiver itself via pickup in its internal wiring or circuits (note that on-channel leakage is of little concern in broadcast reception). On-channel leakage pickup into the cable system is susceptible to correction in a large number of cases by careful engineering and installation; the methods for this have been described by Archer Taylor. *"However, in this same article, Mr. Taylor also states:

> Where cable subscribers are located less than about 10 miles from a local TV transmitting antenna, it is probable that nothing short of modification of the TV receiver will cure some cases of direct pickup. ........ In the final analysis, the best answer is the redesigning of TV receivers so that they are isolated (shielded) from ambient fields. Work on this is in progress. We stand a better chance of success when we have 20 million subscribers than we do with 3 1/2 million (1969).

These comments of course apply to cable systems in which receivers are directly connected to the cable, i.e., without use of subscriber (set-top) converters. It would probably take at least 10 years to turn over the present inventory of sets in use, even if only shielded sets were to be produced from now on.

When certain (but not all) types of converters are used, the receiver is left tuned to a "quiet" VHF channel, eliminating any co-channel problem in the receiver. However, the converter must then be designed with sufficient shielding to prevent co-channel interference effects within it, but this is relatively easy to do and the requirement is clear-cut, which it hasn't been for TV receivers.

### Cable Interference with Other Services

The signals carried in a cable system are at radio frequency and thus are quite capable of propagating in all directions through the air if not properly confined within the coaxial cable and shielded equipment boxes which form the system. Although the cable signal levels are quite low compared to those normally applied to the antenna of a transmitter, they can still create significant field intensities (and thus interference) up to a few thousand feet from the cable in the case of the worst possible type of shielding break—one that somehow acts as a perfectly efficient isotropic antenna and is located immediately following a cable amplifier where the signal levels are highest. Even without a major cable fault of this sort, cable systems can never be perfectly shielded and there will always be some radiation, even if it is only detectable within a few feet of the cable.

Radiation from a cable system carrying only the 12 standard VHF channels should of course cause interference only with television reception, and only in receivers located nearby. However when additional mid-and super-band frequencies are carried, cable radiation could possibly affect other radio services as follows:

Mid-Band

88-108 MHz — FM Broadcast (may actually be carried on the cable)
108-136 MHz — Aeronautical
136-144 MHz — Government, Space Research, Meteorological
144-148 MHz — Amateur
148-151 MHz — Radionavigation
151-174 MHz — Land-Mobile, Maritime, Government

Super-Band

216-225 MHz — Government, Amateur
225-329 MHz — Government

The FCC has long recognized the problem of cable radiation, and specifies in subpart D, Section 15.161 on "Radiation from a Community Antenna Television" of its Rules and Regulations:

Radiation from a community antenna television system shall be limited as follows:

| Frequencies (MHz) | Distance (feet) | Radiation Limits (micron v/m) | |
|---|---|---|---|
| | | General requirement | Sparsely inhabited areas[1] |
| Up to and including 54 | 100 | 12 | 15 |
| Over 54 up to and including 132 | 10 | 20 | 400 |
| Over 132 up to and including 216 | 10 | 50 | 1000 |
| Over 216 | 100 | 15 | 15 |

[1] For the purpose of this section, a sparsely inhabited area is that area within 1000 feet of a community antenna television system where television broadcast signals are, in fact, not being received directly from a television broadcast station.

Although not immediately apparent because of the fact the specified distances are not all equal, the protection in the band between 54 and 216 MHz is considerably higher than for frequencies above and below it. Note also that permissible levels are much higher in the TV bands (and midband) in areas remote

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*"On-Channel Carriage of Local TV Stations on CATV", Archer S. Taylor, IEEE Transactions on Broadcasting, Vol. BC-5, No. 4, Dec. 1969, pp. 102-104.

from TV stations where every TV receiver is expected to be on the cable and not using an antenna.

Now that substantial use is beginning to be made of mid- and super-band transmission on cable systems, the FCC and FAA among others have become concerned about potential interference dangers with the radio services that are listed above, particularly the aeronautical (ATC) services. One situation postulated is that an aircraft in taking off or making a landing approach may fly quite low over a CATV cable at the same time that it is a considerable distance from the ATC transmitter. If the cable were faulty and radiating at the ATC frequency, the resulting interference at the aircraft receiver might have critical consequences, even though the time exposure to it would be brief (of the order of 40 seconds maximum). One analysis to date concludes that this should not be a serious problem, but that certain safeguards should perhaps be established:

(1) adoption of upper signal level limits for CATV cables,

(2) installation of break-detection devices in all cable systems,

(3) placement of mid-band CATV carrier frequencies between ATC channels.

This subject is just coming under intensive study and discussion by the FCC, and FAA, the Offices of Telecommunications and Telecommunications Policy, the IEEE Cable Television Task Force Committee, and others, as part of the current debate on cable standards. The intent here is not to shed any light on the solution but only to point out that this question adds another dimension to the cable frequency allocation problem, and that the ultimate decisions, particularly in regard to item (3), may have a deleterious effect on the channel capacity of future systems.

### The Cable Channel Allocation Question

So long as cable systems simply carried television signals on the same channel frequencies assigned by the FCC for VHF broadcasting, only two interference effects represented any real problems for cable operators: adjacent-channel interference and on-channel pickup; the former handled by careful signal balancing and level-control, and the latter by idling the troublesome channels. However, as new cable channels began to be added in a few systems starting about 1968, other interference effects applied, initiating a debate which has just reached full intensity in the past few months. The following are indicative of the questions now under consideration.

### A Non-Contiguous Channel Scheme

In a paper presented at the 1970 NCTA National Convention, M.E. Jeffers (Jerrold Electronics Corp.) set forth the oscillator and image beat effects in the generally accepted mid-and super-band assignments (shown by the boxes in the last two columns of Table 3) and proposed a realignment of the mid- and super-band cable-channel assignments to eliminate these problems. His proposal for realignment was to alter the band limits for the mid- and super-bands and insert frequency offsets between these channels at appropriate points, with the objective of placing all oscillator and image beats at band-edge (between channels) where their interference effect would be minimal.

Present VHF, Mid-Band, and Super-Band Assignments

| Channel | | MHz | Video Carrier | Osc. Freq. | Image Freq. | Channel Affected by Osc. | Video Carrier on Image Frequency |
|---|---|---|---|---|---|---|---|
| 2 | | 54-60 | 55.25 | 101 | 146.75 | | E (1.5) |
| 3 | | 60-66 | 61.25 | 107 | 152.75 | | F (1.5) |
| 4 | | 66-72 | 67.25 | 113 | 158.75 | | G(1.5) |
| | | 10 | | | | | |
| 5 | | 76-82 | 77.25 | 123 | 168.75 | A (1.75) | - |
| 6 | | 82-88 | 83.25 | 129 | 174.75 | B (1.75) | 7 (-.5) |
| | | 32 | | | | | |
| A | MID-BAND | 120-126 | 121.25 | 167 | 212.75 | H (3.75) | 13 (1.5) |
| B | | 126-132 | 127.25 | 173 | 218.75 | I (3.75) | J (1.5) |
| C | | 132-138 | 133.25 | 179 | 224.75 | 7 (3.75) | K (1.5) |
| D | | 138-144 | 139.25 | 185 | 230.75 | 8 (3.75) | L (1.5) |
| E | | 144-150 | 145.25 | 191 | 236.75 | 9 (3.75) | M(1.5) |
| F | | 150-156 | 151.25 | 197 | 242.75 | 10 (3.75) | |
| G | | 156-162 | 157.25 | 203 | 248.75 | 11 (3.75) | |
| H | | 162-168 | 163.25 | 209 | 254.75 | 12 (3.75) | |
| I | | 168-174 | 169.25 | 215 | 260.75 | 13 (3.75) | |
| 7 | | 174-180 | 175.25 | 221 | 266.75 | J (3.75) | |
| 8 | | 180-186 | 181.25 | 227 | 272.75 | K (3.75) | |
| 9 | | 186-192 | 187.25 | 233 | 278.75 | L (3.75) | |
| 10 | | 192-198 | 193.25 | 239 | 284.75 | M (3.75) | |
| 11 | | 198-204 | 199.25 | 245 | 290.75 | ↑ | |
| 12 | | 204-210 | 205.25 | 251 | 296.75 | 3.75 MHz is a color beat | |
| 13 | | 210-216 | 211.25 | 257 | 302.75 | | |
| J | SUPER-BAND | 216-222 | 217.25 | 263 | 308.75 | | |
| K | | 222-228 | 223.25 | 269 | 314.75 | | |
| L | | 228-234 | 229.25 | 275 | 320.75 | | |
| M | | 234-240 | 235.25 | 281 | 326.75 | | |

Table 3

Since the new channel assignment charts in Mr. Jeffers' paper did not cover the entire 54-300 MHz cable spectrum, an overall chart based on his mid- and super-band assignments was prepared as shown in Table 4. This gave the total channel count (35), but also brought to light the fact that because of the complexity of the inter-channel relationships, it is almost impossible in such a frequency juggling exercise to avoid creating new problems while trying to correct other ones. For example, Mr. Jeffers was successful in placing all mid-band/low-VHF band and super-band/high-VHF-band image and oscillator beats at band edge, but in the process created three dead-beat images of super-band channels on mid-band channels and five undesirable ("positive") oscillator beats on high-VHF band channels by mid-band channels, as shown by the boxes in the last two columns of Table 4.

These findings were brought to Mr. Jeffers' attention, and he has agreed with them. However, he feels that these particular problems can be eliminated by proper converter design—either holding oscillator radiation and image rejection to very tight limits, or using a different, very high IF frequency in converters to completely eliminate oscillator and image beats. These measures would not help reduce intermodulation interference effects, which become

Suggested New Mid- and Super-Band Allocations by M.F.Jeffers

| Channel | | MHz | Video Carrier (6-MHz separations except as noted) | Osc. Freq. | Image Freq. | Channel Affected by Oscillator (Beat Freq.) | Video Carrier on Image Frequency (Beat Freq.) |
|---|---|---|---|---|---|---|---|
| 2 | | 54-60 | 55.25 | 101 | 146.75 | - | - |
| 3 | | 60-66 | 61.25 | 107 | 152.75 | - | - |
| 4 | | 66-73 | 67.25 | 113 | 158.75 | - | - |
| | | | 10 | | | | |
| 5 | | 76-82 | 77.25 | 123 | 168.75 | B(-1.25) | - |
| 6 | | 82-88 | 83.25 | 129 | 174.75 | C(-1.25) | 7(-.5) |
| | | | 35 | | | | |
| A | JEFFERS CHANNELS | 117-123 | 118.25 | 164 | 209.75 | H(- .75) | - |
| B | | 123-129 | 124.25 | 170 | 215.75 | - | - |
| C | | 129-135 | 130.25 | 176 | 221.75 | 7(+.75) | I(-.5) |
| D | | 135-141 | 136.25 | 182 | 227.75 | 8(+.75) | J(-.5) |
| | | | 6.5 | | | | |
| E | | 141.5-147.5 | 142.75 | 188.5 | 234.25 | 9(+1.25) | K(0) |
| F | | 147.5-153.5 | 148.75 | 194.5 | 240.25 | 10(+1.25) | L(0) |
| G | | 153.5-159.5 | 154.75 | 200.5 | 246.25 | 11(+1.25) | M(0) |
| | | | 10 | | | | |
| H | | 163.5-169.5 | 164.75 | 210.5 | 256.25 | 13(-.75) | O(-2) |
| | | | 10.5 | | | | |
| 7 | | 174-180 | 175.25 | 221 | 266.75 | I(-1.25) | P(-2) |
| 8 | | 180-186 | 181.25 | 227 | 272.75 | J(-1.25) | Q(-2) |
| 9 | | 186-192 | 187.25 | 233 | 278.75 | K(-1.25) | R(-2) |
| 10 | | 192-198 | 193.25 | 239 | 284.75 | L(-1.25) | S(-2) |
| 11 | | 198-204 | 199.25 | 245 | 290.75 | M(-1.25) | T(-2) |
| 12 | | 204-210 | 205.25 | 251 | 296.75 | N(-1.25) | U(-2) |
| 13 | | 210-216 | 211.25 | 257 | 302.75 | O(-1.25) | ▨ |
| | | | 11 | | | | |
| I | JEFFERS CHANNELS | 221-227 | 222.25 | 268 | 313.75 | P(-.75) | ▨ |
| J | | 227-233 | 228.25 | 274 | 319.75 | Q(-.75) | ▨ |
| K | | 233-239 | 234.25 | 280 | 325.75 | R(-.75) | ▨ |
| L | | 239-245 | 240.25 | 286 | 331.75 | S(-.75) | ▨ |
| M | | 245-251 | 246.25 | 292 | 337.75 | T(-.75) | ▨ |
| N | | 251-257 | 252.25 | 298 | 343.75 | U(-.75) | ▨ |
| O | | 257-263 | 258.25 | 304 | 349.75 | ▨ | ▨ |
| | | | 10.5 | | | | |
| P | | 267.5-273.5 | 268.75 | 314.5 | 360.25 | ▨ | ▨ |
| Q | | 273.5-279.5 | 274.75 | 320.5 | 366.25 | ▨ | ▨ |
| R | | 279.5-285.5 | 280.75 | 326.5 | 372.25 | ▨ | ▨ |
| S | | 285.5-291.5 | 286.75 | 332.5 | 378.25 | ▨ | ▨ |
| T | | 291.5-297.5 | 292.75 | 338.5 | 384.25 | ▨ | ▨ |
| U | | 297.5-303.5 | 298.75 | 344.5 | 390.25 | ▨ | ▨ |

35 channels

Table 4

exceedingly complex with such noncontiguous channel spacing.

## A Contiguous Channel Scheme

Inter-channel interference effects have long been a factor in the analog frequency-multiplex systems utilized by the telephone company in its intercity trunk circuits, and methods have been developed to cope with them. One of these is the careful control of channel frequency ratios, including derivation of all carriers by suitable frequency multiplications from a common master oscillator.

Mr. I. Switzer (Maclean-Hunter Cable TV Limited) has presented a paper advocating use of such techniques in CATV systems.* Mr. Switzer has also corresponded with the author on the mid- and super-band frequency allocation question, advocating a contiguous set of channels at constant spacing to help overcome intermodulation effects. If such a plan were carried through completely, Channels 5 and 6 would have to be moved 4 MHz lower in frequency to fit into the plan. This would not be of any consequence in a system where all subscribers have converters or special cable receivers, but would if "dual-class" service is offered, as discussed later.

A contiguous-channel allocation scheme would yield a total of 41 CATV channels if the spectrum

*(Continued on page 14)*

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*"Phase Lock Applications in CATV Systems", I.Switzer, Presented at NCTA Annual Convention, Chicago, Illinois, June, 1970.

# Heterodyne TV Signal Processor

By Sulo Koskinen
Director, Engineering
Anaconda Electronics Ltd.

In the early days of cable television, the best means of receiving a station for cable distribution was through the use of a strip amplifier. Almost 20 years ago a California company called Ampli-Vision manufactured a seven-tube strip amplifier that was perhaps the best head end unit at the time. This amplifier had low noise cascade input and good AGC on video carrier.

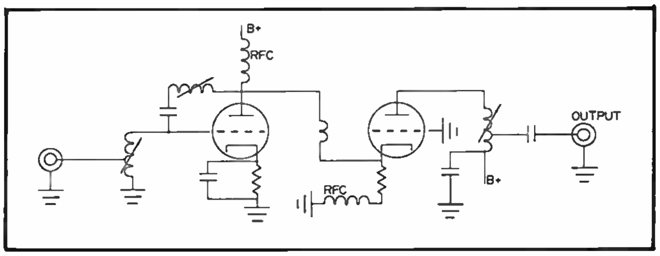
Despite the fact that the amplifier had 13 tuned circuits for selectivity, the adjacent channels had to be trapped externally. The worst problem, however, was the lack of AGC on sound, and it was common to see sound fading into noise and the next moment, spoil the picture with sound bars.

In the years that followed, more and better strip amplifiers were introduced by several manufacturers, but numerous efforts to harness the sound level were less than satisfactory. The first comprehensive solution for CATV signal processing problems was the Channel Commander I, which used the heterodyne principle.

### Heterodyne Receiver

The heterodyne principle is quite old and it was first used in radio receivers around 1930. The basic idea calls for converting any input signal into an IF frequency, usually lower than input frequency. Most of the processing for selectivity and signal stabilization can then be done on a fixed and lower frequency. In radio and TV receivers, the processed IF frequency is demodulated, but in the CATV signal processor the IF frequency is converted back to the input channel or some other channel as required.

Figure 1 Cascode amplifier; low noise tube circuit

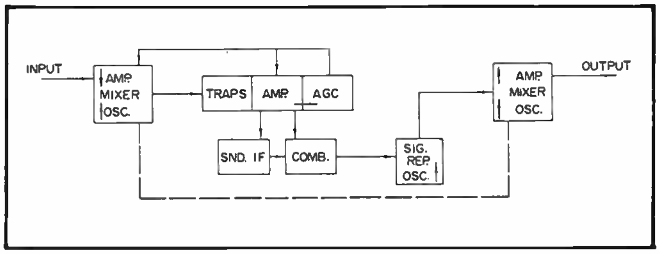


The input section of the Channel Commander was a modified version of a commercially available TV tuner, and many of the principles used in sound and video IF circuitry were previously proven in commercial TV receivers. However, a special requirement for wider IF bandwidth for the CATV processor required a much higher degree of precision. Automatic frequency control circuitry for a non-crystal-controlled input oscillator added to the complexity of the unit, and in the early years there were only a few CATV technicians who dared to tackle the re-alignment of a Commander. Even though the input match was extensively sacrificed for improved noise figure, the improvement over previous strip amplifier head ends on weak signals was fantastic when the unit was used with a mast mounted desnower preamplifier. For a long time, the cross modulation performance was better than any transistor effort.

The fact that Channel Commander relied on an AFC loop for stabilizing the input oscillator did not cause many problems as long as adjacent channels were not used and color receivers were not in general use. If and when the oscillator frequency drifted downwards, the carrier frequencies at the IF level shifted down also. This caused the sound IF to come out of the trap and the color carrier to fall into the slope of the sound trap. The result was instability in the sound level and severe color distortion or lack of color. Since the front panel meter was used for zero setting the AFC, it took only a slight misadjustment or drift in the discriminator tuning and the frequency was pulled on the wrong spot and kept there automatically.

Some time ago, when 12-channel cross modulation test sets where organized in some of the most ad-

Figure 2 shows a block diagram of a typical CATV heterodyne processing unit.



vanced labs, a heterodyne unit with AFC was used to receive a local air channel and the IF signal, after amplification, was fed into 12 output sections to obtain programs on twelve channels. The discriminator was off alignment and all twelve output channels were .25 MHz off the frequency — all the while the front panel meter was reading zero!

A few years after the introduction of Channel Commander, Benco Associates in Canada introduced their Benavac. In many respects it was similar to the Commander, but it used specially designed, crystal-controlled input circuitry and more advanced tubes in the RF amplifier for better noise figure while obtaining the input match.

While we all knew that these two heterodyne units performed very well when everything was in top shape, the aging of the tubes caused deterioration in the performance. Since the alignment was always effected to some extent when tubes were replaced, and there was a shortage of technicians capable of maintaining these complex units, the need for solid state heterodyne grew stronger everyday.

### Early Problems With Transistors

Although 25 years have elapsed since the transistor was invented, and 22 years have gone by since I built my experimental point contact transistors out of germanium diodes, the art of VHF and UHF transistors is not old. It took semiconductor labs a long time to get any gain out of transistors on these frequencies, and this with very fragile units and little repeatability. These transistors distorted very early and better noise figure could only be obtained with very low current and voltage. Overloading got worse as the noise figure improved.

All through the 1960's intense semiconductor research was carried out and advances were made on field effect transistors, invented earlier. It's theoretical advantages promised to eliminate one of the worst shortcomings of the so-called bipolar transistor, namely, ability to provide good noise figure without cross modulation.

### Field Effect Transistor (FET)

It may be instructive to briefly describe the FET and how it differs from the conventional bipolar transistor.

In Figure 3 we can see an NPN transistor, and on the left we have expanded it to two separate junctions: collector-base junction and base-emitter junction. When we have 2 diodes back-to-back, no current will flow from E to C. If we apply a forward bias of +.7 volts on B, the current will flow through B to E diode. On the right, we have pulled the common terminals (B) of two diodes very close together, but we still have the same two junctions back-to-back. When we apply forward bias on B terminal now, the current will again flow from E to B, but because of the very close proximity of these two junctions some of the electrons rush right through the common B area and in the reverse direction to terminal C. In any actual transistor, only a very small fraction of the emitter current flows to base, and most of the current flows to collector, but the magnitude of the collector current is controlled by the base current. Signal applied to the base along with the bias will control the collector current and thus amplify the signal.

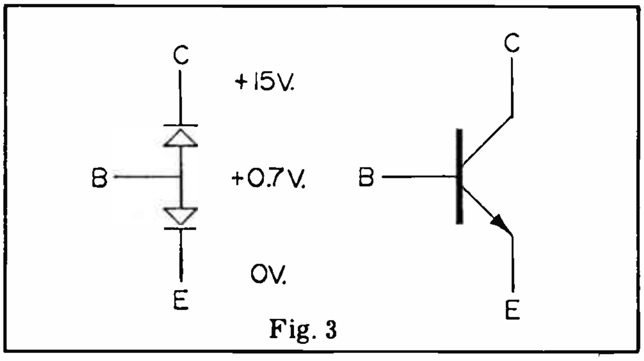


Fig. 3

BIPOLAR TRANSISTOR.

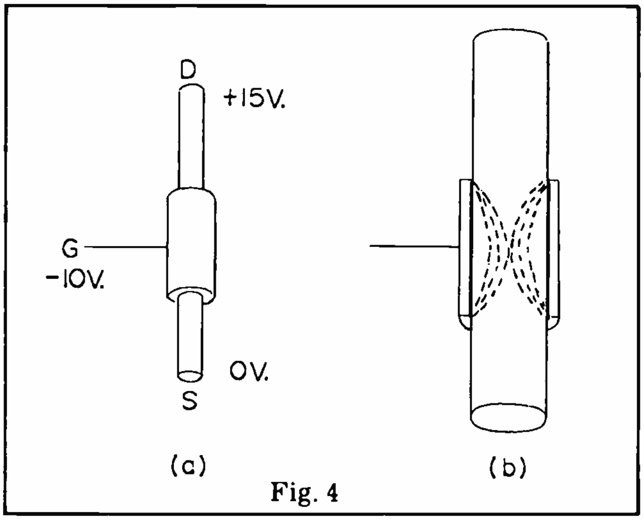


Fig. 4

FIELD EFFECT TRANSISTOR.

In the field effect transistor we are dealing with an altogether different mechanism. In Figure 4 (a) we have a silicon bar S-D. Wrapped around the middle of the bar is a cylinder insulated from the bar. The silicon bar is doped to have substantial conductivity and it actually behaves like a resistor from S to D and initially the electron current from S to D is limited by this resistance of the bar only. However, we can "choke" this current off, if we apply high enough negative voltage on the insulated cylinder. The electric field inside of the cylinder is illustrated in Figure 4 (b) and the effect of this electric field will control the width of the conducting current channel and thereby the current flow through the device. As no current, except the initial charging current, is needed for controlling the channel current there is only a negligible power needed for the control. Because the circuit S to D involves current as well as voltage, it is obvious that power gain is available from this device.

In an actual FET, the S terminal is called "source," D terminal is called "drain," and G terminal is called "gate." The gate may be a metal electrode, insulated by a very thin layer of metal oxide. This type of device is called MOSFET, metal oxide semiconductor field effect transistor. The gate may also be a reverse biased semiconductor junction. In this case the device is called JFET, junction field effect transistor.

Without going into FET structure any further I will outline the main operating characteristics. Many FET devices are specified to have maximum noise figure of 2 dB at 100 MHz, but can even get below 1 dB with some devices. This noise figure is obtainable with 15 volts and 5 mA biasing. The output current of an FET is proportional to the square of the gate voltage. This type of device will have very low third order distortion. Therefore, good FET amplifiers can usually stand 20 dB higher adjacent channel interference than a bipolar transistor amplifier for the same cross modulation.

Another problem created by third order distortion is so-called third order intermodulation, involving the creation of beats from two or more carriers. It turns out that FET's, because of their square law characteristics are the "good guys" again.

### Solid State CATV Heterodyne

I will now discuss some of the characteristics of solid state heterodyne processors.

Gain of the unit must be high enough to bring the minimum specified input level to the recommended output level. Excessive gain is usually harmful since the relatively close proximity of output networks and cables can radiate into the input cables and antenna coupling networks, causing instability when input and output are of the same channel. We keep overall gain between 75 and 80 dB.

Referring to Figure 2, we can consider the optimum gain distribution. In the input section, the noisiest element is the mixer stage. FET mixers operate best when the input signal to the mixer is from 0 dBmV to + 30 dBmV. For input signals of - 20 dBmV to + 10 dBmV, the preamplifier gain should be 20 dB. For higher input signals, the preamplifier gain must be turned down by AGC. We would aim to keep the average level to the mixer around + 30 dBmV. Since the adjacent channels are not present in the output mixer and sound level is usually down more than in the input, + 30 dBmV may be exceeded if necessary. The overall gain of the output section should be about 27 dB.

The IF amplifier must have sufficient gain to make up the balance of the overall gain as well as compensate for the video-sound combining loss and signal replacer loss. An IF amplifier gain of 40 dB, for example, will yield an overall gain figure of 75 to 80 dB.

Selectivity of the heterodyne unit should be like that of an ideal bandpass filter that allows only the desired channel to get through with minimum deterioration in the quality of the signals. It would seem that a filter like this could be built and inserted in the IF amplifier and all the rest of the heterodyne could be broadband. If we were dealing with ideally linear amplifying devices this could be done and manufacturing would be simple and economical. With practical solid state devices, however, distributed selectivity is required.

All practical transistors produce intermodulation products and these products are often classified as 2nd order, 3rd order, 4th order, 5th order, and so forth. Generally speaking the higher the order of the intermodulation product, the lower the amplitude. Usually the 2nd order and 3rd order products are most troublesome. Beats produced by 2nd order distortion on two carriers are far from a desired TV channel and are very easy to eliminate with a simple double-tuned circuit. In a two carrier system, the 3rd order beats may fall 4.5 MHz below picture carrier and 4.5 MHz above sound carrier. These are much more difficult to filter out. Fortunately FET's are very low in 3rd order distortion. However, successive 2nd order distortion can produce 3rd order beats. For example, a second harmonic produced in the first stage of the amplifier can form a second order beat with the fundamental in the next stage, resulting in a 3rd order product. For this reason it is important to remove 2nd order beats between the stages by means of distributed selectivity in heterodyne units.

Leveling action of the heterodyne unit should be effective enough to limit the output level change to less than 1 dB when the input signal changes 25 dB up or down from nominal value. This means an almost 50 dB change in the overall gain of the unit. Noise and overload considerations dictate that this amount of gain change must be distributed in three locations of the system. Automatic gain control in the input amplifier must be delayed until a very high input signal threatens to overload the input mixer. But if all the remaining AGC action was placed in the input stage of the IF amplifier, the high gain after this stage would impair the signal-to-noise ratio on high input signal levels. For this reason I believe it is preferable to design AGC into two stages of the IF amplifier.

The gain of a bipolar transistor can be reduced by reducing collector voltage and current. This type of control is called reverse AGC. With a large signal, however, the transistor is operated with small current and voltage, and overload occurs very easily. Another type of AGC requires a special type of transistor, the so-called forward gain control transistor. Here, the high frequency gain vanishes when the collector current is increased past an optimum point. As much as 60 dB of gain control can be obtained from a single stage at 45 MHz IF frequency. With high input signal, the collector current is high and signal handling capability is very good. Incidentally, field effect transistors can be used to get 10 dB of distortion-free AGC per stage by controlling the gate bias. However excessive gain reduction will lead to distortion.

### Problem Channels

Frequency conversion as used in CATV heterodyne units is based on strong 2nd order distortion. A new frequency, equal to f(osc.) — f(signal), is used out of the input converter as well as from the output converter. Once the IF frequency is chosen, one or more channels become difficult to process.

For example, let us consider channel 6 up conversion, when the video IF of 45.75 MHz and sound IF of 41.25 MHz are fed in the input. With an oscillator signal of 129 MHz, the 2nd order process will generate channel 6 video and sound carriers in the output. At the same time, however, the same process will generate 2 x 45.75 = 91.5 MHz, 2 x 41.25 = 82.50 MHz, and 45.75 + 41.25 = 87 MHz. The first beat is just outside of the band and difficult to filter out; the other two are in the band and are impossible to filter out. Fortunately all these products cancel out in a balanced converter.

More difficult problems take place with channel 6 in the input converter unless 3rd order distortion is kept very low. Possible beats are in the IF band, one near the color carrier, making a very annoying interference pattern on color programs. One solution used is to specify lower maximum input level for low band, and particularly channel 6 units. In addition, the best possible mixer transistor type must be found for the input converter. We've found that with optimized biasing and oscillator injection level, the JFET mixer provides 15 to 20 dB improvement over MOSFET mixers.

Heterodyne units have made a great job of improving signal processing for CATV, but they have brought up some new problems of their own. The conversion process will change the frequency of a desired signal the way we want, but at the same time often change an undesired signal the way we do not want. A sharp single-channel filter is not always the best answer for eliminating interfering signals. The fact that a strong signal in the input is far remote from the frequency of the desired signal does not always mean that it is not involved, nonlinearities can bring a remote signal into the band. On the other hand, a remote signal is easy to remove with stable, low-loss, inexpensive high pass and low pass filters.

Today some very high performance spectrum analyzers are available for CATV engineers. The best way to solve the beat problems is to study the output signal, study the input signal, and try to gain an understanding of how the problem is born. It is then often very easy to find the remedy.

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*(Continued from page* 10 *)*

between 54 and 300 MHz were completely filled. As has been discussed, some frequencies in this range may be unusable for CATV if it is determined that a serious interference hazard exists with other services, particularly with aeronautical radio-navigation aids in the 108-136 MHz band.

### Dual Service Class Considerations

One factor which additionally complicates the whole frequency allocation issue is the fact that many operators may desire or need to offer two classes of compatible service on the same cable: VHF-only at one price for subscribers with standard receivers and no converters and VHF plus cable channels at a higher price for subscribers using converters or special cable receivers. Thus a channel-utilization scheme which depends primarily upon the ability of converters or special cable receivers to eliminate interference effects might be unacceptable for such dual-class-service — those standard TV receivers that are directly connected to the cable might not be able to cope with interference beats resulting from the presence of non-VHF cable channels. Here an allocation scheme that provides additional protection to the VHF-TV channels may be required, such as the proposal by M.F. Jeffers. On the other hand, the optimum solution for broadband cable service may turn out to involve relocation of the present VHF Channels 5 and 6 downward by 4 MHz to fit into a contiguous channel allocation scheme, and a non-converter subscriber to such a system would be unable to receive Channels 5 and 6 and be "channel poor". Current discussions include the possibility that there may have to be several alternate cable-frequency allocation standards to fit different situations, but this would be unfortunate from the point of view of cost-effectiveness in equipment manufacture and interchangeability or portability of equipment from system to system. Eventual large-scale production of augmented-channel TV sets for cable use would seem to depend upon having a single nationwide standard, such as now exists for broadcast-TV.

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