SUBSCRIBER TERMINAL INTERFACE REQUIREMENTS

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It is a privilege to serve with Dr. Powers and other members of the Frequency Allocation Subcommittee of the IEEE Coordinating Committee for Cable Communications Systems. I believe that the work of this group will prove to be significant in the development of needed frequency allocation standards for the cable television industry. During the course of our committee work, it became clear that performance characteristics of domestic television receivers are a major factor that must be carefully considered in establishing recommendations for frequency allocation plans. Time will not permit detailed consideration of all performance parameters that affect satisfactory operation of domestic color and monochrome receivers on Cable TV systems. I have selected four major topics for review in this paper:

(1) Rejection Ratios for Unwanted Adjacent Channels Carriers

(2) Local Oscillator Stability

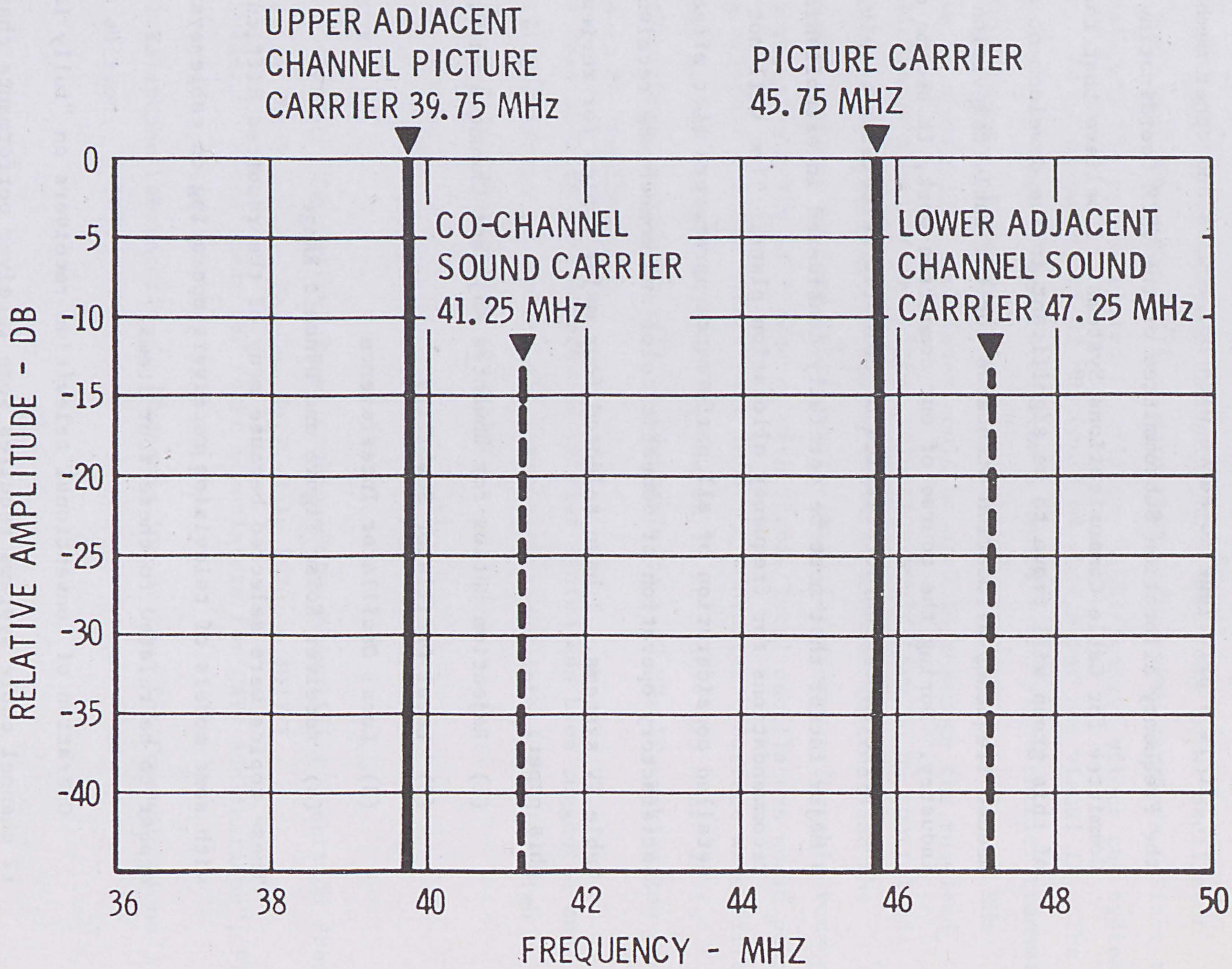
(3) Local Oscillator Interference

(4) Receiver Noise Figure and Dynamic Range

These topics were selected because many of the reported difficulties with some models of television receivers operating on cable systems appear to be related to these four items.

Operation of conventional television receivers on "fully loaded" 12 channel cable systems requires some receiver performance characteristics that exceed the demands imposed by reception of a few non-adjacent over-the-air VHF channels. I cannot speak for the entire television receiver industry, but I do know that current production standards of

FIGURE 1 - **ADJACENT CHANNEL VIDEO AND SOUND CARRIERS**



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Magnavox television receivers embody the necessary design parameters and manufacturing controls to assure satisfactory television receiver operation on 12 channel cable systems. The design and manufacture of television receivers for satisfactory operation on 20 or more channels presents a set of new problems and new challenges.

Figure 1 illustrates the type of problem encountered by operation on contiguous, 6 MHz - spaced channels. The abscissa is shown in terms of TV intermediate frequencies. The adjacent channel picture and sound carriers are spaced only 1.5 MHz from the desired channel picture and sound carriers.

LOWER ADJACENT SOUND CARRIER

In Archer Taylor's report to the FCC for NCTA, "Performance Characteristics of Television Receivers Connected to Cable Television Systems," he suggested minimum threshold interference ratios between 35 and 40 db for suppression of lower adjacent channel sound carrier interference. Based upon a difference of 13 db between picture and sound carrier levels, and a difference of 3 db between adjacent channel video carriers, a selectivity ratio about 30 db would be required as a minimum to avoid interference from the lower adjacent sound carrier.

The 1950 tests referenced by Archer Taylor in the above report were probably conducted by observation of small screen monochrome receivers without aluminized picture tubes. We have conducted similar controlled interference tests, using large screen color TV receivers. We have verified the generally accepted minimum tolerable interference ratio of -57 db for coherent interference from signals in the vicinity of the video carrier. Thus, the adjacent channel sound carrier level at the second detector should not exceed 47 db:

57 db	interference ratio
-13 db	sound modulation level
+ 3 db	limit on adjacent channel signal level variance
-47 db	required rejection ratio for (47.25 MHz) adjacent channel sound carrier

The rejection of the unwanted 47.25 MHz sound carrier is usually provided by a trap in the intermediate frequency amplifier, since the unwanted sound carrier is only 1.5 Mz from the co-channel picture carrier. Typical adjacent channel sound carrier rejection ratios of 60 db are provided by current television receivers manufactured by Magnavox. Rejection ratios exceeding 50 db for lower adjacent sound carriers were indicated on the tests reported by Archer Taylor. Thus, properly adjusted 47.25 MHz traps should provide adequate rejection of the upper adjacent sound carrier, providing the tuner is properly adjusted.

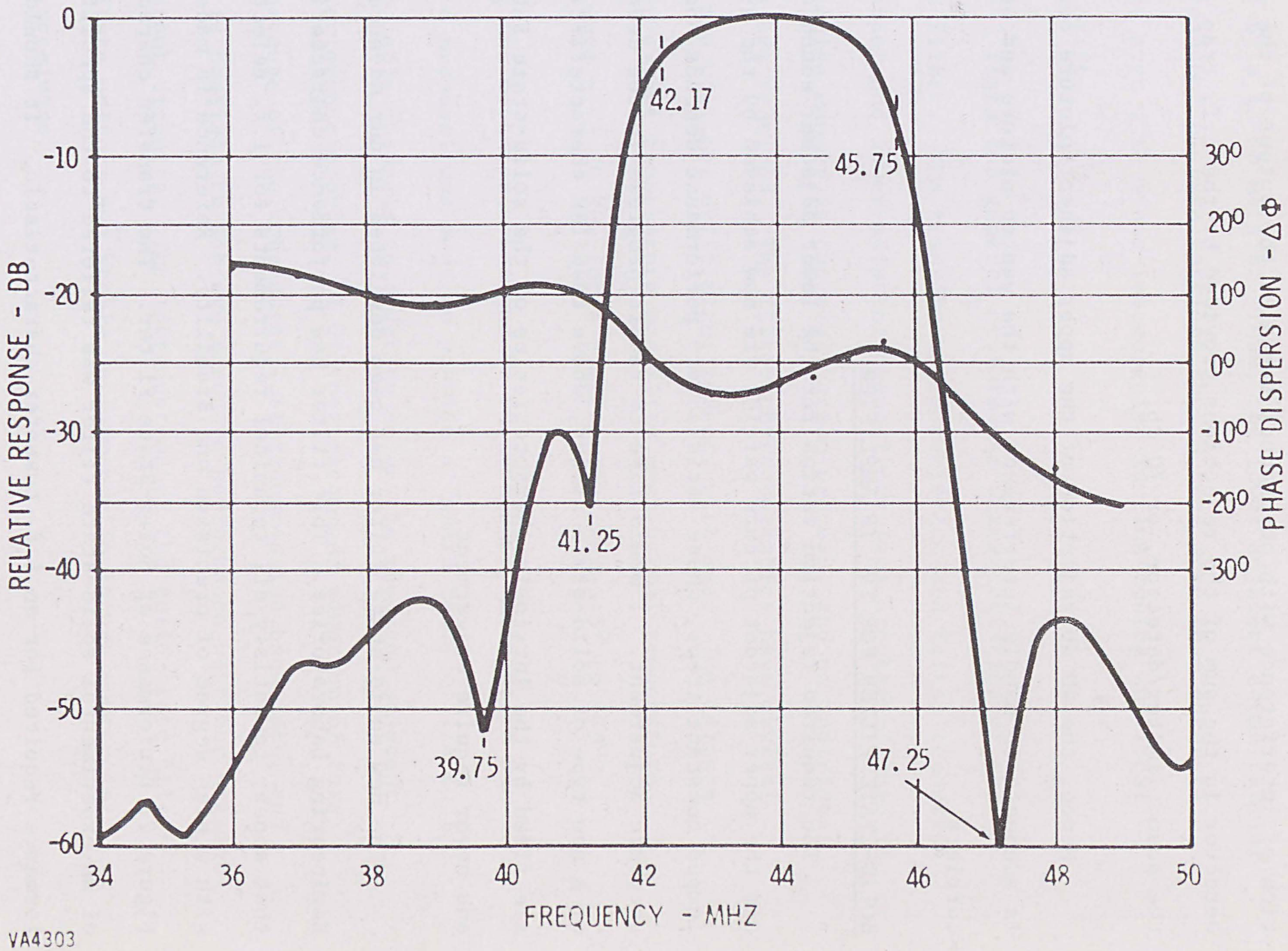
UPPER ADJACENT CHANNEL PICTURE CARRIER

Now, let us consider the effects of interference from the upper adjacent channel picture carrier. In order to avoid visible interference from the upper adjacent channel picture carrier, 40 db rejection of the unwanted adjacent picture carrier is required. The required rejection of the unwanted 39.75 MHz picture carrier is normally provided by a trap in an IF amplifier.

The effect of the upper adjacent 39.75 MHz carrier on the co-channel

FIGURE 2 -

PERFORMANCE OF TV SOLID-STATE FILTER



sound carrier is reduced by 30 db rejection of AM interference provided by the FM limiter and sound detector. Thus, the total effective rejection of interference with co-channel sound at the output of the FM detector is the sum of the rejections provided by the i.f. trap and the sound limiter/detector, or 70 db.

Hence, the 40 db rejection of the upper adjacent picture carrier is adequate to handle interference with the wanted picture and sound carriers.

SOLID-STATE FILTER FOR TV IF AMPLIFIER

The required rejection ratios for the lower adjacent sound carrier and the upper adjacent picture carrier are now achieved by the use of lumped constant traps, whose satisfactory performance depends upon accurate adjustment. I would like to report progress in the development of a new type of solid-state filter, whose transfer characteristics are fixed by the intrinsic characteristics of the solid-state substrate, and never require adjustment.

The new solid-state filter has been developed in our Advanced Engineering Laboratories. This filter has performance characteristics that appear to satisfy all technical requirements for i.f. selectivity with a high degree of precision and stability. Reference is made to Figure 2, Performance of Solid-State Filter. The transfer characteristic of an experimental solid-state filter was tailored to the specific performance required for an i.f. transfer characteristic. It should be noted that the minimum 40 db rejection of the upper adjacent channel

39.75 MHz picture carrier is exceeded by a 12 db margin. Rejection of the lower adjacent channel sound carrier exceeds the calculated 47 db requirement by a 13 db margin. Thus, the lower adjacent sound carrier and upper adjacent picture carriers should have more than adequate suppression, even with minor inaccuracies in fine tuning and local oscillator drift.

Figure 3 lists the general performance characteristics of the solid-state filter. The transfer characteristics and filter rejection nodes for upper and lower adjacent channel carriers are established in a highly precise manner in the replication process, and no individual adjustments are required. The filter characteristics have crystal stability, and will not drift significantly with age. The filters also have excellent temperature stability over normal temperature operating range - $\pm$ 20 KHz for a temperature range -5^{o} to +75^{o}C.

During the technical sessions of the Frequency Allocation Subcommittee, a proposal was made to provide a "guard band" of 1/4 to 1/2 MHz between cable channels in order to solve the reported adjacent channel interference problem. I did not recommend adoption of this proposal, because of the consequent lost transmission bandwidth, and because it is possible to achieve adequate performance with our present lumped-constant circuits. The introduction of the solid-state filter will facilitate uniform and stable performance in future commercial television receivers.

FIGURE 3 -

PERFORMANCE FEATURES OF SOLID-STATE FILTERS

1. FREQUENCY RANGE - 10 MHz TO 1 GHz

2. PHASE LINEARITY - $< 5^{\circ}$ DEVIATION THROUGHOUT FILTER PASSBAND

3. DYNAMIC RANGE - >90 dB

4. NUMBER OF ADJUSTMENTS - ZERO

5. MISALIGNMENT DUE TO SHOCK, VIBRATION, AND AGING - $< \pm 400$ Hz AT 40 MHz (CRYSTAL STABILITY)

6. TEMPERATURE STABILITY - $< \pm 20$ kHz OVER -5° TO $+75^{\circ}$C RANGE (40 MHz CENTER FREQUENCY)

7. BW OF NOTCHES (TRAP FILTER) - >50 kHz (6-dB POINTS)

8. DEPTH OF NOTCHES (TRAP FILTER) - >50 dB OVER 50 kHz BW

9. INTERFACING - COMPATIBLE WITH IC'S AND TRANSISTORS

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APPLICATION TO COLOR TELEVISION RECEIVERS

The same design and process techniques that were used to develop the solid-state filter are also applicable to automatic frequency control circuits. Figure 4 is a block diagram of the radio-frequency and intermediate frequency amplifier sections of an experimental television receiver. In this design, the automatic frequency control circuit is controlled by the solid-state circuit elements fabricated on the same substrate as the solid-state trap filter. In this configuration, any minor thermal drifts in the local oscillator frequency and trap null points due to substrate characteristics will track, and rejection of unwanted carriers will be maintained.

LOCAL OSCILLATOR STABILITY

Now, let us consider the stability of the local oscillator. The magnitude of local oscillator drift depends upon a number of factors, including:

Magnitude of thermal rise of tuner environment

Shift in electrical characteristics of passive circuit tuning elements as a function of ambient temperatures

Type of active devices used in oscillator circuit, and their susceptibility to thermal rise

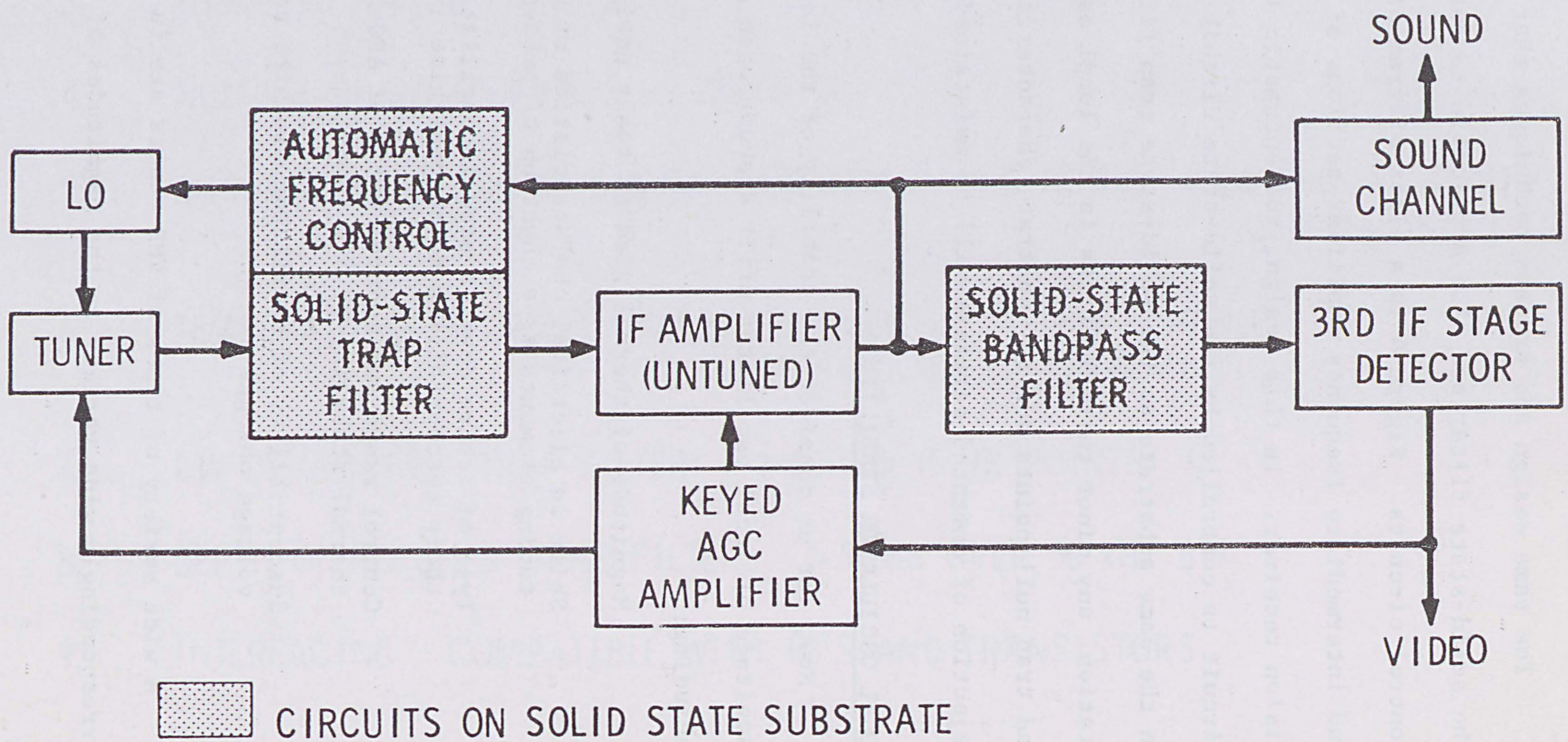
Control range and control ratio of AFC circuits, and thermal stability of AFC circuits

Susceptibility of oscillator circuits to power supply voltage changes

A wide variety of types of VHF tuners are in current use, with a correspondingly wide variety in the magnitudes of local oscillator

FIGURE 4 -

BLOCK DIAGRAM OF TV RF AND IF SECTION
(SHOWING SOLID-STATE FILTERING ELEMENTS)



drift over several hours. The tests reported by Archer Taylor indicated local oscillator drifts from 65 KHz to 200 KHz in one hour. Industry sources have suggested that an acceptable high limit for long term thermal drift for current VHF tuners should be +100 KHz, -300 KHz, without AFC correction; frequency shifts due to line voltage changes would be ±100 KHz. The above values for thermal drift seem to be higher than our experience with current VHF tuners. The specified drift for a typical tuner is: For a 15°C thermal rise, the long-term local oscillator drift limit is 75 KHz, without AFC control. Using an AFC loop with a 10:1 control ratio, the total long-term thermal drift is less than ±10 KHz.

Changes in local oscillator frequency due to line voltage changes could be significantly reduced by the use of a voltage regulator for the VHF tuner.

On the basis of the information available, it appears that thermal drift of TV local oscillators can be controlled within tolerable limits, by proper application of known design techniques, considering the design parameters listed above.

The combination of precisely-controlled and stable filter nodes in the solid-state filter and AFC - controlled thermal drift of the local oscillator, the adjacent channel sound and picture carriers should produce no discernable adjacent channel interference.

LOCAL OSCILLATOR INTERFERENCE

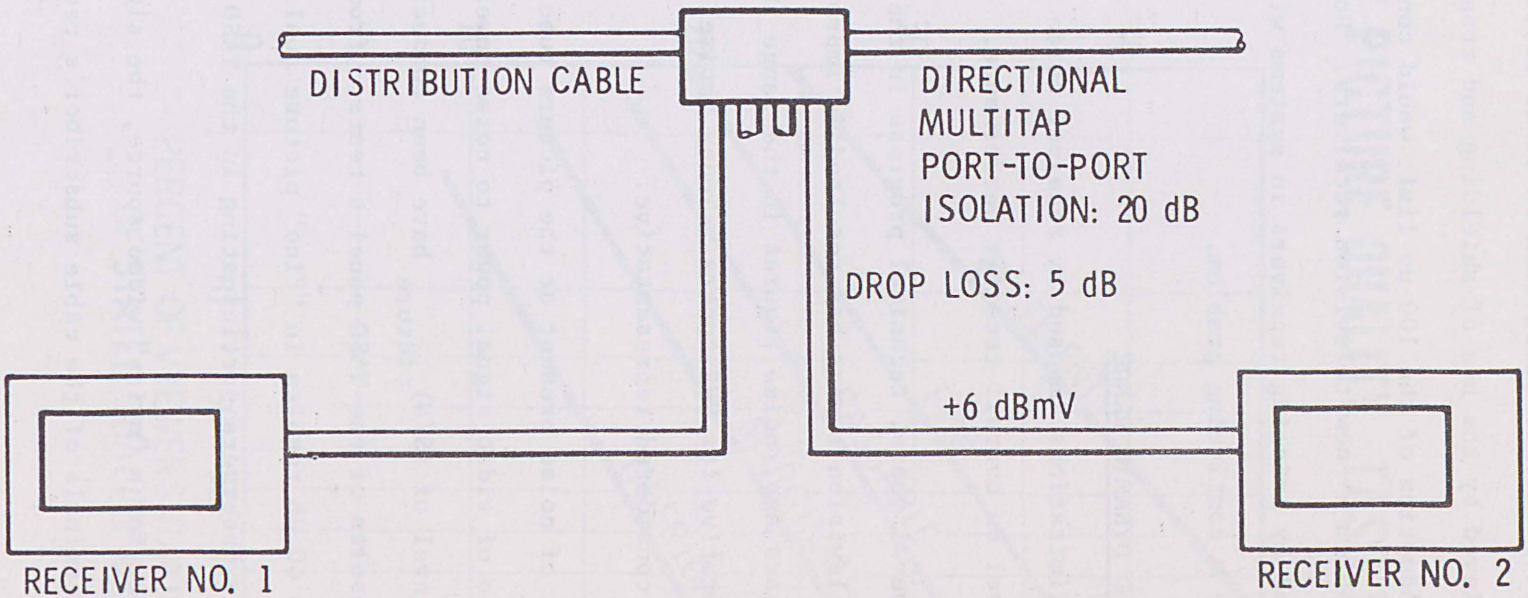
Let us consider the effects of local oscillator signals conducted to the cable.

A variable local oscillator in a television receiver is mixed with a received signal to generate the intermediate frequency. Since the mixer circuit is not electrically isolated from the cable, the local oscillator fundamental and harmonics can be readily conducted to adjacent subscribers. The standard 12 VHF channels were assigned in such a way that the local oscillator fundamental frequencies do not interfere with the VHF channels. However, the local oscillator signals and their harmonics can cause interference with mid and super band channels.

Figure 5 illustrates how the local oscillator signal from Receiver No. 1 is conducted to Receiver No. 2 via the subscriber drops and directional multitap. If the maximum allowable level of coherent interference is -57 db, and the cable TV signal level is +6 dbmv, the maximum allowable received local oscillator interference level at Receiver No. 2 is -51 dbmv. If 5 db cable drop loss is assumed for each subscriber, and the tap port-to-port isolation is 20 db, the maximum allowable L.O. signal level generated at the terminal of Receiver No. 1 is -21 dbmv, or 80 uv. This value is similar to the 100 uv limitation of local oscillator signal level requested in the NCTA petition to the FCC.

Measurements of local oscillator signal levels and harmonics at the 75 ohm terminals of current VHF tuners indicate that the 100 uv level limitation could be satisfied by some tuners, but not by others.

FIGURE 5 - **LOCAL OSCILLATOR INTERFERENCE LEVELS**



ALLOWABLE COHERENT INTERFERENCE:	-57 dB
CATV SIGNAL LEVEL AT RECEIVER:	+ 6 dBmV
MAXIMUM ALLOWABLE L.O. INTERFERENCE LEVEL	-51 dBmV
DROP LOSS BETWEEN RECEIVERS	10 dB
PORT-TO-PORT ISOLATION:	-20 dB
ALLOWABLE L.O. SIGNAL LEVEL	-21 dBmV, or 80 UV

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Based upon a design study conducted by a tuner manufacturer, it was determined that the proposed 100 uv limitation on local oscillator signal level can be achieved by the use of shielding and traps, at some additional cost. Adoption of the 100 uv limit would control only one part of the problem -- new television receivers. However, the interference produced by existing receivers in systems with more than 12 channels will be a continuing problem.

RECEIVER NOISE FIGURE AND DYNAMIC RANGE

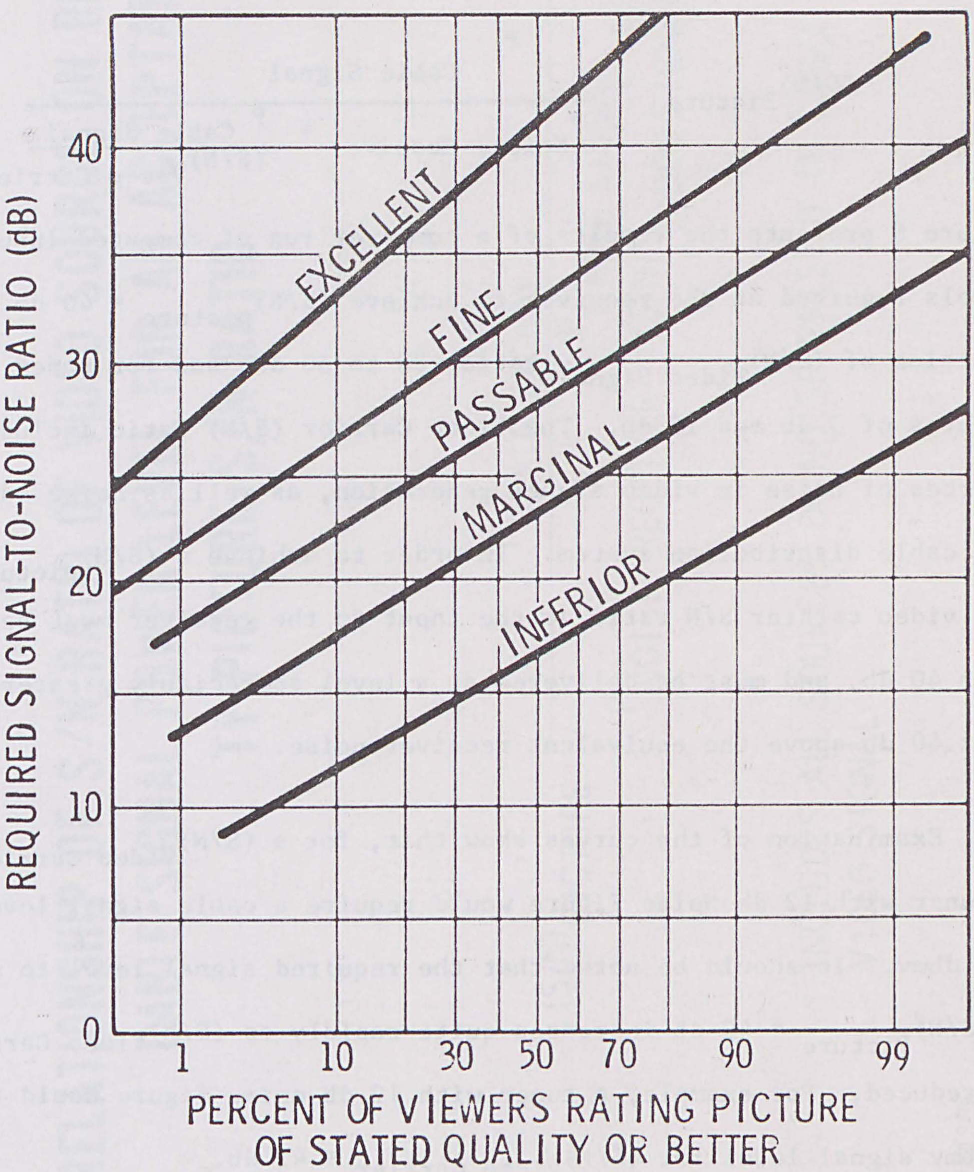
Let us now review limitations imposed by receiver noise level and cross modulation level on overall receiver performance.

During the past several years, technical progress in the design of input circuits for television tuners has resulted in improvements in noise figure. Ten years ago, noise figures in the range 10-12 db were considered representative for VHF tuners. Today, noise figures in the 5-6 db range are considered representative.

The tolerable level of noise present at the picture tube can be expressed as the db ratio of video signal power to noise power. Various tests of the tolerable level of $(S/N)_{picture}$ have been conducted. Figure 6 presents the results of the TASO panel 6 tests: from this figure, a $(S/N)_{picture}$ = 40 db results in "fine" picture quality for a large percentage of the observers participating in the TASO tests.

It can be shown that, for a "noisy" video source, the signal level delivered to the input terminals of the cable subscriber's receiver

FIGURE 6 - **TV PICTURE QUALITY, TASO PANEL 6 DATA**



must be higher than would be the case for a noise-free video source and a noise-free receiver. As shown in Figure 7, mathematically, the relationships between signal, power (P_{signal}), receiver noise power (P_N) receiver and the overall signal to noise ratio of a noisy video source $(S/N)_{Video\ Carrier}$ are:

$$(S/N)_{Picture} = \frac{P_{Cable\ Signal}}{P_{Noise,\ Receiver} + \frac{P_{Cable\ Signal}}{(S/N)_{Video\ Carrier}}}$$

Figure 8 presents the results of a computer run of computed input levels required at the receiver to achieve $(S/N)_{picture}$ = 40 db as a function of $(S/N)_{Video\ Signal}$ ratios 38 to 50 db, and for tuner noise figures of 5 db and 12 db. The Video Carrier (S/N) Ratio includes all sources of noise in video signal generation, as well as noise added by the cable distribution system. In order to achieve a $(S/N)_{picture}$ = 40 db, the video carrier S/N ratio at the input to the receiver must be greater than 40 db, and must be delivered at a level appreciably greater than just 40 db above the equivalent receiver noise.

Examination of the curves show that, for a $(S/N)_{Video\ Carrier}$ = 44 db, a tuner with 12 db Noise Figure would require a cable signal level of -12 dbmv. It should be noted that the required signal level to maintain a $(S/N)_{Picture}$ = 40 db increases quite rapidly as $(S/N)_{Video\ Carrier}$ is reduced. For example, a tuner with 12 db noise figure would require 0 dbmv signal level for $(S/N)_{Video\ Carrier}$ = 41 db.

FIGURE 7 - **RELATIONSHIP OF S/N RATIO OF VIDEO SOURCE ON REQUIRED CABLE SIGNAL POWER LEVEL FOR AN ACCEPTABLE TV PICTURE S/N RATIO**

$$(S/N)_{PICTURE} = \frac{P_{CABLE\ SIGNAL}}{P_{NOISE,\ RECEIVER} + \frac{P_{CABLE\ SIGNAL}}{(S/N)^{*}_{VIDEO\ SIGNAL}}}$$

* INCLUDES ALL SOURCES OF NOISE PRESENT IN CABLE VIDEO SIGNAL

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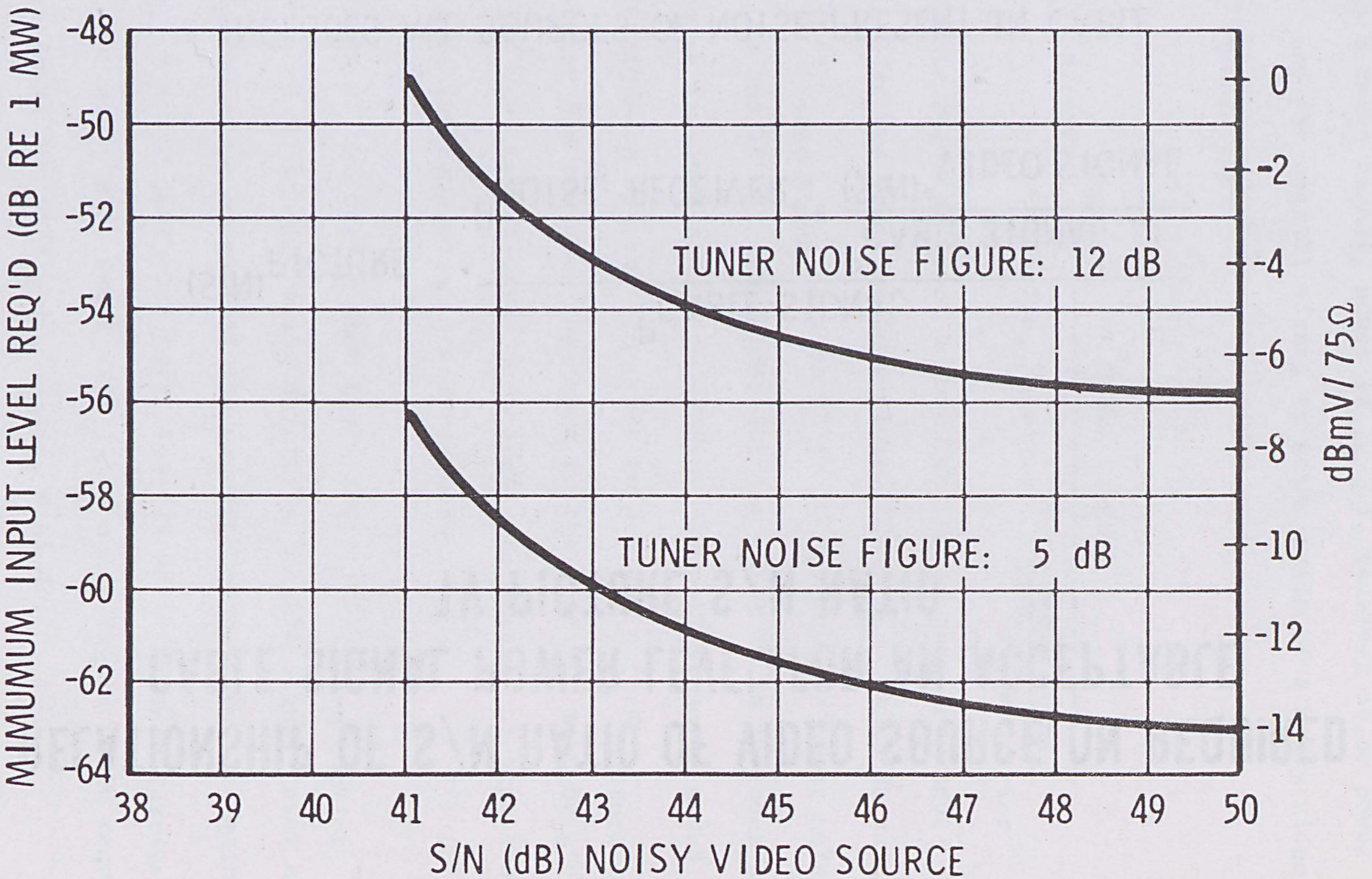
FIGURE 8 - **INPUT SIGNAL LEVEL REQUIRED FOR 40 DB PICTURE QUALITY vs. S/N RATIO, NOISY VIDEO SOURCE**



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Thus, the performance of modern television receivers does not appear to be receiver noise limited. The FCC requirement of 0 dbmv minimum signal level should provide adequate service to cable subscribers.

A series of tests was conducted to determine the performance of Magnavox teleivision receivers with respect to cross modulation at high signal levels. The tests utilized 26 cable channels operating at equal levels. Several types of tuners were evaluated; both vacuum tube and solid-state tuners were tested. Signal levels were varied from 0 dbmv to +20 dbmv in 2 db steps, and the resulting pictures were evaluated for evidence of cross modulation. Under these conditions, no observable cross modulation was detected at signal levels up to +20 dbmv. Since this signal level is well above normal signal levels delivered to cable subscribers, we concluded that the dynamic range of our current tuners is adequate for operation on 12 channel cable systems.

From the foregoing tests, we believe that no limitation in overall performance is imposed by receiver noise level for minimum level cable signals, nor by intermodulation distortion for high level cable signals.

CONCLUSION

In this paper, I have attempted to summarize progress that has been accomplished in solving some of the reported problems in operating television receivers on cable systems. I believe that further progress toward the goal of delivering the best possible service to television viewers, whether they be served by cable TV systems or by broadcast television, depends, to a high degree, upon industry-wide understanding of the problems involved, cooperation among concerned Government agencies, the CATV industry, and domestic television manufacturers. I believe that we are experiencing a good example of this type of understanding and cooperation in the work of the Frequency Allocation Subcommittee of the IEEE Coordinating Committee for Cable Communications Systems.