TUNER CHARACTERISTICS OF CABLE-READY RECEIVERS

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ABSTRACT

Congress has directed the FCC to define the characteristics a television receiver must have if it is to be marketed as "Cable-Ready" This paper describes the joint filing of the receiver and cable industries, along with the author comments, on those characteristics required in order that directly attached receivers A) not interfere with the operation of the cable system and, B) assure viewers of a reasonable degree of performance.

INTRODUCTION

The Cable Act of 1992 included two provisions specifically aimed at solving the technical interface problems between cable systems and consumer electronics equipment. The first directed the Commission to find solutions to such problems as independent tuning access for VCRs and TVs, while the second directed them to define the characteristics which receivers would have to meet in order to be marketed as suitable for direct connection to cable systems.

In its resultant Notice of Proposed Rulemaking, the FCC proposed both short-term and long-term solutions. By the time this is printed, the Commission is scheduled to have considered the extensive comments on those proposals and issued final rules.

The short-term proposals call for cable operators using converters to provide various modifications which will allow customer's receivers to access more than one channel simultaneously. The most common solution is expected to be some sort of bypass switch which will allow the converter to be bypassed for all non-scrambled channels.

The long-term proposals call for the provision, on receivers, of a Decoder Interface connector which will allow descrambling to happen *after* the receiver's tuner. Separate decoder modules on TVs and VCRs would allow completely independent selection of channels for viewing and recording, as well as timed, multi-channel recording of any combination of scrambled and clear programs.

Both short-term and long-term solutions will increase the likelihood that consumers' receivers (both TVs and VCRs will be directly connected to the broadband cable drop. Thus, defining receiver performance has become a critical issue for compatibility.

In actuality, negotiations between the television manufacturers, cable manufacturers and cable operators to define desirable receiver characteristics has been ongoing since the early 1980s, under the auspices of the NCTA/EIA Joint Engineering Committee ("JEC"). In fact an early draft of an interface specification (numbered IS-23) was actually circulated for ballot in 1985.

Under the pressure of the immediate rulemaking and Congressional deadline, the old draft was exhumed and compromise agreements made on nearly all the open issues, so that a joint filing of the industries was made to the Commission suggesting mandatory performance standards. The negotiators attempted to strike a balance between assuring good reception for cable subscribers and increasing the receiver cost so much that few would be manufactured or sold to consumers.

This paper will discuss the various important reception parameters and the logic that lead to the joint filing, as well as the continuing work on the more comprehensive voluntary "son of IS-23" specification which addresses parameters not included in the rulemaking as well as parameters on operation of cable systems. A summary of the parameters, the FCC's proposal, and the JEC recommendation are found in Table I at the end of the paper. Readers are cautioned that this summary does not include all the subtleties and details of the final submission..

For convenience, the parameters are divided between those that can degrade the operation of the cable network (and the reception of neighboring subscribers) and those which primarily affect the reception of the subscriber using the equipment.

CHARACTERISTICS WHICH AFFECT OTHER USERS AND EQUIPMENT

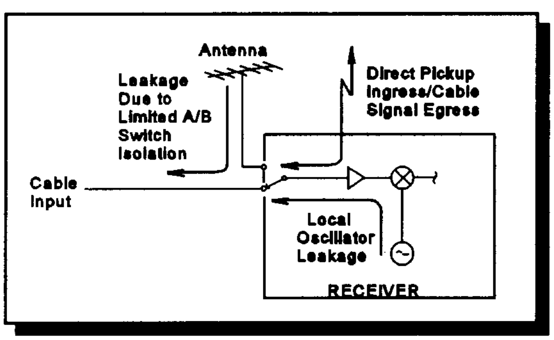

Figure 1: Receiver Antenna Terminal Egress/Ingress Mechanisms

When a receiver is connected to a cable system, it has the potential to affect other equipment connected to the system, as well as users of the electromagnetic spectrum. Those effects can be classified generally as conducted interference, excessive loss and egress.

Conducted Interference

Conducted interference occurs when signals within a TV receiver or VCR are conducted "out" the device's input terminals and onto the cable system. Figure 1 shows the mechanisms by which signals can be transmitted out of a receiver's antenna terminals:

- Signals may be generated within the receiver and inadequately isolated from the input terminals. The most common is the first local oscillator, but other mechanisms are possible.
- Inadequate shielding may cause strong external signals to be picked up and transmitted back out the antenna terminals.
- When receivers include A/B RF input selection switches, inadequate isolation in those switches will cause cable signals to be transmitted out the antenna terminals, or signals from the antenna can be conducted back onto the cable system, thereby disrupting viewing of downstream subscribers.

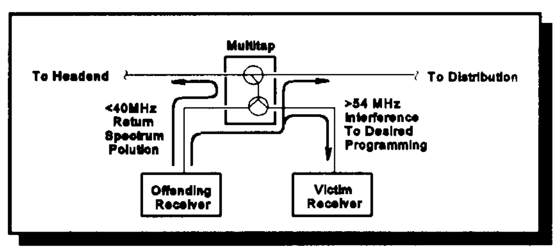

Figure 2: Interference Paths into Network and Other Receivers

These signals can affect the cable network in two ways (Figure 2). Signals which are in the sub-low band (5-30 or 5-42 MHz) will be directly transmitted towards the headend in any fully enabled two-way cable system. The combined effect of many such receivers may reduce the usability of the upstream spectrum or cause operators to have to install high-pass filters at every offending receiver.

Signals which are in the forward spectrum of the system will appear at the input terminals of other receivers, attenuated by the isolation between ports of multi-taps. They have the potential to directly interfere with programs being watched by others.

The first step to setting an appropriate specification for antenna terminal egress in the forward spectrum is to determine how much signal can be tolerated at neighboring receivers. The FCC requires cable operators to deliver at least 0 dBmV at receiver antenna terminals. The industry-accepted standard for "just perceptible" interference from discrete interfering carriers is 55 dB below the desired signal[1]. Thus, interfering signals should be less than -55 dBmV at neighboring terminals.

Cable operators are required to maintain 18 dB of isolation between adjacent tap ports, which would suggest that conducted emissions should be limited to -37 dBmV to guarantee no visible interference. The FCC proposed this level in its Notice of Proposed Rulemaking ("NPRM") for all sources of antenna-conducted egress.

Local Oscillator Leakage. Unfortunately, it is very difficult to provide the degree of isolation in receivers that will reduce antenna-conducted LO leakage to the FCC proposed level. There are, however, several factors that suggest that the worst-case situation will seldom happen in practice:

- There is a relatively low probability (about 2% for an 80 channel system) that receivers connected to ports of the same tap will be on and tuned exactly seven channels apart, which is where the interference occurs within single conversion tuners using a standard 45 MHz IF.
- Taps generally provide greater than the minimum 18 dB isolation and subscribers are further isolated by drop cable losses, which increase with frequency.
- In order to meet the specification on essentially all of their production, receiver manufacturers will have to provide higher isolation *on average*.

Given all these factors, the negotiators settled on an attainable recommendation of -26 dBmV from 54 through 300 MHz, declining to -20 dBmV up to 450 MHz and to -15 dBmV maximum and -20 dBmV average from 450 through 1002 MHz.

Clearly, these values are not sufficient to prevent all interference, but were deemed all that were practical with single conversion tuners.

Not dealt with in the specification to date, but still to be resolved are signals falling in the sub-low band from 5-40 MHz. These will interfere with upstream communications and, combined with those from other subscribers may considerably increase the "crud" in the return path.

Conducted DPU Ingress. Conducted DPU ingress occurs when signals from nearby TV and FM broadcast, land mobile radio and paging stations are picked up with the TV receivers, VCRs or FM tuners and are conducted out the devices' input terminals and onto the cable system. Using the same logic as above, the negotiators felt that -26 dBmV would be a sufficiently low level to make conducted DPU an unlikely source of viewing complaints at neighbors' receivers. Given that the probability factor is not relevant here, however (the interfering signals will always be present for all strong channels, regardless of where the receiver is tuned and regardless of whether it is turned on or off), that level is not allowed to relax at higher frequencies. That is especially important since some of the strongest external fields are due to UHF transmitters operating up to 800 MHz.

The most contentious issue has been the external field strength in which to immerse the receiver when measuring the conducted ingress level. A study done by Joe Stern, under CableLabs sponsorship, predicts that 40.8% of television households will experience field strengths of 100 mV/m or greater on at least one television broadcast channel. A similar study done on behalf of the EIA by Jules Cohen predicts that 46.2% of households will experience 100 mV/m. Above that field strength, the studies diverge, with Stern predicting that 6% will experience field strengths of 1 Volt/m, while Cohen predicts 8.4% will experience 300 mV/m, but less than 1% will experience 1V/m. Both studies predict that the probability of UHF interference exceeds that of VHF interference at the highest field strengths which is unfortunate from the standpoint of visual impairment as UHF stations are offset from cable channels in the same frequency ranges resulting in beat patterns which are subjectively more apparent than frequency coherent interference. Neither study included interference from non-television-broadcast sources such as paging transmitters.

There are, however, mitigating factors. For one thing, the test procedure currently under review by the JEC (developed by C.T. Jones under CableLabs sponsorship) measures susceptibility at all receiver orientations relative to the external field. Testing of 35 representative television receivers (plus a number of VCRs and converters) done by Jones suggests that susceptibility is strongly dependent on this orientation. Given that actual receivers may be oriented randomly with respect to external fields, the average susceptibility in homes will usually be less than the tested maximum. Secondly, neither study attempted to predict the attenuation effects of buildings and other structures on the signal strength received by receivers inside dwellings relative to that measured in relatively "free space" outside. While in some cases, the field strengths may actually be higher due to reflected signals constructively combining or due to receivers being located far above ground level (as in a high-rise apartment situation), on average it can be expected that there will be some attenuation affects.

Given all these factors, the JEC adopted a standard of 100 mV/m external field, measured at the orientation of greatest sensitivity using the C.T. Jones approach.

<u>A/B Switch Isolation</u>. This is the amplitude of a signal connected at one input terminal of a switch as measured at the other input terminal. It was felt that few external antennas would produce a field strength at the receivers in excess of +20 dBmV. Given a requirement to keep signals at adjacent receivers below -55 dBmV and a probable subscriber-to-subscriber isolation of about 29 dB, the isolation of antenna selector switches must be maintained at 46 dB or greater. As discussed below, however, this is inadequate to protect reception on the receiver incorporating the switch, so a higher value was chosen.

Radiated Interference

<u>Radiation from Receiver</u>. There has been a disparity between the Part 15 regulations, applying to receivers, and Part 76 regulations, applying to cable systems, with respect to radiated interference. The old Part 15 regulations applied only to signal sources originating <u>within</u> receivers, were higher in absolute levels than Part 76, and did not apply to *re*-radiation of antenna-applied signals. By contrast, the Part 76 regulations apply to cable systems, *including all connected equipment*, and limit leakage to a much lower level.

In its NPRM, the FCC proposed to apply Part 15 limits to re-radiation of antenna-connected cable signals of up to +25 dBmV. The JEC proposed, instead, to apply the Part 76 limits, but at more realistic signal levels of +15 dBmV. They felt that this was a more rational approach.

Radiation from Customer's Antenna. A second source of potential radiation occurs if cable signals are coupled into the customer's antenna due to inadequate isolation in the receiver's antenna selector switch. This issue has been before the Commission previously, and an isolation requirement of 80 dB to 215 MHz and 60 dB to 550 MHz was written into the Part 15 rules. The JEC suggested that the isolation limit between 550 MHz and 800 MHz be 55 dB.

With a likely maximum cable input signal level of +20 dBmV and an isolation of 55 dB, the signal applied to the customer's antenna lead will not exceed -35 dBmV. With typical feedline losses and consumer antenna gains, this should not result in leakage in excess of Part 76 limits of 15 μV/m at 30 meters.

Excessive Signal Loss in VCRs and Converters with Bypass Functions

The majority of homes have a VCR connected in series with at least one television receiver. Since cable systems may deliver minimum signal strengths of 0 dBmV on at least one channel, the reception on a TV receiver connected to a VCR output is materially affected by the loss of the VCR. Similarly, under the new regulations, many converters will have bypass filters or switches of some sort designed to deliver clear signals directly to following receivers. As with VCRs, the loss of the bypass mechanism is important to assuring noise-free reception.

In the simplest configuration, VCRs incorporate a two-way splitter at the RF input and a switch at the output for selecting between its internal modulator and the bypassed input signal. VCRs have up to 10 dB or more of insertion loss, but in the ideal case, VCR through loss should not exceed 4-5 dB. However, it was felt that the specification should allow slightly more loss than the expected ideal to take into account manufacturing variances. Finally, both splitters and switches have increasing loss with frequency.

While recognizing the concerns of manufacturers, cable operators wished to make the specification sufficiently tight that a manufacturer could not use an unequal ratio splitter (to favor its own tuner) or a resistive splitter. They compromised on 6 dB to 550 MHz and 8 dB to 1 GHz. It will be incumbent upon CE manufacturers with high loss VCRs to insure the tuner has sufficiently a low noise figure to provide noise-free reception with low input levels!

CHARACTERISTICS WHICH DEGRADE THE USER'S OWN RECEPTION

Although some receiver characteristics can degrade the reception of other subscribers, others affect primarily its own performance in a cable environment. That environment is more benign than over-air reception in some respects (such as relatively uniform signal levels) and more challenging in others (such as tuner overload and use of adjacent channels). The specifications which follow are designed to assure that a cable-ready receiver will offer reasonable reception when connected to a cable system.

Adjacent Channel Rejection

In assigning off-air channels, the FCC has carefully avoided having broadcasters in one area operating on channels which are on adjacent frequency bands[2]. Thus, receivers intended for purely broadcast reception do not typically have to deal with lower or upper adjacent signals. Cable operators use the full spectrum of available channels, but control levels of adjacent channels within 3 dB and lower aural levels to 10-17 dB below the associated visual carrier.

In the worst case, therefore, adjacent visual carriers could be 3 dB higher than the desired visual carrier and adjacent aural carriers as high as 7 dB below the desired visual carrier. In order to prevent visible interference, neither of those conditions should result in products falling within the tuned channel and having amplitudes greater than -55 dBc.

In considering this, the JEC determined that the dominant problem was the lower adjacent aural carrier and so simplified the specification to that single parameter. It further deemed it unlikely that operators would run aural carriers as high as -10 dBc and that, if they do, that it would be uncommon for the 3 dB channel difference and -10 dBc aural levels to occur simultaneously. For that reason, the final recommendation to the Commission was that a lower adjacent aural carrier 10 dB below the tuned channel's visual carrier would not cause in-channel products of greater than -55 dBc.

Tuner Distortion Products

One of the most fundamental differences in the signal environment of over-air reception and cable reception is in the overall RF spectrum presented to the tuner. When connected to an antenna, a receiver typically has to deal with far fewer signals, but of widely varying amplitude. Thus, off-air tuners are characterized by the use of low-noise preamplifiers and wide AGC ranges.

When a receiver is connected to a cable system, the minimum signal levels are much higher and the total dynamic range is generally much less, but the total RF power is significant because all or nearly all channels are simultaneously used. Furthermore, the total power is increasing as cable systems are built to wider and wider bandwidths. The result is often visible second and third order beat generation in the preamplifier and mixer stages.

In order to reach a consensus, the JEC had first to deal with the fact that maximum signal strengths are not specified under the Part 76 rules except for a blanket "don't overload" statement. Additionally, the rules do not take into account non-video signals that may be present in the delivered cable spectrum and therefore impinge on the tuner. Examples are positive trap scrambling carriers, data carriers, FM carriers and digital audio signals.

As a result, although the current rulemaking does not involve reconsideration of the Part 76 rules, the voluntary IS-23 specification does contain limitations on maximum and average amplitudes of both video and non-video carriers delivered to receiver inputs. In general, individual carriers are limited to +20 dBmV and average carrier levels across the spectrum are limited to +15 dBmV.[3]

Given these restrictions on delivered cable signals, the test condition that was recommended for evaluating the distortion performance of receiver tuners was a continuous comb of CW carriers extending from 54 to 750 MHz at a uniform carrier level of +15 dBmV. Under these conditions, the JEC recommended that the tuner should generate no in-band products in excess of -51 dBc. Since this is a CW test, the expected performance under modulated signal conditions should be better by 6 dB for second order products and 12 dB for third order products.

DPU Ingress

Arguably the most contentious issue for the many years of these negotiations has been shielding performance. From operator's standpoint, this has certainly been the most frequent cause of complaints for systems located within the "Grade B" contour of TV broadcast stations or other radio transmitters, especially paging transmitters.

The results of the studies done by both industries to support their arguments are discussed above. The study by C.T. Jones of existing equipment not only showed susceptibility to be dependent on receiver orientation, but also established that few current production televisions or VCRs come close to acceptable performance when measured at the most sensitive channel and orientation.

The compromise agreed upon by the JEC negotiators was that, when measured at the most vulnerable of several channels spread across its tuning range and at its most vulnerable orientation with respect to the external field, a receiver will not experience DPU interference greater than 50 dB below a 0 dBmV input signal when immersed in a 100 mV/m external field (with some relaxation at the highest frequencies).[4]

Although this might appear to represent no improvement over the existing Canadian ingress standard (which also uses a 100 mV/m external field), there are important differences:

- The Canadian standard is measured only over 300 MHz
- The test condition for the Canadian evaluation uses a time and frequency coherent interfering signal so that the threshold of visibility (it is a subjective viewing test) is only about 40-45 dB desired to undesired ratio.
- There is no requirement in the Canadian test for testing at the most vulnerable orientation with respect to the external field.

Given these differences, the proposed new standard arguably represents at least a 15 dB improvement over the Canadian standard. Whether it is sufficient to eliminate the effects of DPU interference in urban cable systems remains to be seen.

Image Rejection

Single conversion television receivers using the common 41-47 MHz IF frequency also have a potential response to signals higher than the desired channel by twice the IF frequency, or approximately 90 MHz. In VHF off-air reception, this is not a problem because of spectrum assignments for the low and high band channels. In UHF, it can occur, but is statistically unlikely. By contrast, cable systems use the entire spectrum, so that virtually every potentially interfering image channel is present at the tuner input.

FCC regulations allow cable signal levels to vary by 10-17 dB across the spectrum, depending on the system total bandwidth. In the worst case, therefore, the image signal could be 17 dB higher than the desired carrier and 72 dB of image rejection would be required to insure a 55 dB (barely perceptible) image response. More realistically, though, the variation across 90 MHz is unlikely to be that great and, with newer fiber-to-the-neighborhood architectures, the variation is unlikely to exceed 5 dB.

Based on this, the JEC settled on a compromise of 60 dB image rejection up to 650 MHz, reducing to 50 dB through 900 MHz. The reduction at the high end reflects the feeling of the negotiators that frequencies above 750 MHz will most probably be used for digital signals whose amplitude will be reduced at least 5-10 dB relative to analog visual carrier levels. Certainly, this is a marginal performance specification, but reflects the difficulty in achieving higher image rejection in single conversion tuners without significantly greater cost and without affecting in-band frequency response. Should cable industry practice ultimately lead to full amplitude analog or digital carriers through 1,000 MHz, this specification will turn out to be inadequate.

Antenna Selector Switch Isolation

Just as inadequate A/B switch isolation can result one customer's antenna input signals being coupled into the network and affecting a neighbor's reception, it can also affect his own reception.

Given that cable signals may be as low as 0 dBmV and antenna input signals may be easily as high as +20 dBmV, an isolation of at least 75 dB would be required to suppress the antenna signals to 55 dB below the cable input.

The FCC has previously considered this issue and, as a result, existing Part 15 regulations require that antenna selector switches maintain 80 dB of isolation through the VHF broadcast band, and at least 60 dB through 550 MHz. They asked, in this NPRM, what the isolation should be between 550 MHz and 1,000 MHz.

The receiver manufacturer's problem is that these switches are typically either made with PIN diodes or reed switches and it is very difficult to achieve consistently high isolation at the high end of the band.

Fortunately, few customers currently use antenna selector switches for alternating between roof-top antennas and cable system inputs so a lack of isolation in current receivers has not been a frequent cause of customer complaints. When an interference situation does occur due to high external levels, a cable operator can put an attenuator in the antenna input and eliminate the problem by reducing the external level.

Based on the above, and that average receivers will have to considerably exceed the standard in order for all receivers to pass, the JEC agreed to drop the required isolation to 55 dB for frequencies in excess of 550 MHz. In the authors' opinion, this is a very marginal specification.

REFERENCES:

1. This was recently confirmed by a Bronwen Jones study dated October 12, 1993 and published in the CableLabs document, Customer Premises Equipment Performance and Compatibility Testing, Chapter 5, "Direct Pick-up Interference Subjective Tests".

2. Channels 4 and 5 are not actually adjacent, nor are 6 and 7.

3. In the special case of upstream signals, those limitations are unrealistic. It is not uncommon for set-tops to generate signals as high as +60 dBmV. Given the finite isolation of multi-taps, this could easily result in levels at neighboring receivers of nearly +40 dBmV. The draft IS-23 allows for this level up to 30 MHz. Still under dispute is the expansion of the return band from 30 MHz to 42 MHz.

4. Shielding is typically characterized by Relative Equivalent Length (REL) which is calculated as:

REL=ExternalField(dBmV)-InputSignalLevel((dBmV) +Carrier/InterferenceRatio (dB)

Using this definition, the proposed REL is 90.

TABLE I
SUMMARY OF RECEIVER REQUIREMENTS

Characteristic	FCC NPRM Proposal	JEC Proposal	Final FCC Rules
Local Oscillator & other Conducted Interference	54-1002MHz: -37 dBmV	54-300MHz: -26 dBmV 300-450MHz: -20 dBmV >450 MHz: -20 dBmV Average, -15 dBmV peak.	
Egress Conducted Interference	-37 dBmV	-26 dBmV @ 100mV/m field, 54-1002 MHz	
Antenna Selector Switch Isolation	54-216MHz: 80 dB 216-550MHz: 60 dB >550 MHz: no proposal	54-216MHz: 80 dB 216-550MHz: 60 dB 550-800MHz: 55 dB	
Re-radiation of Cable Signals	Part 15 limits @ +25 dBmV input	Part 76 limits @ +15 dBmV input	
Tuner Overload	Distortion products below -55 dBc, unspecified conditions	51 dB CTB & CSO with 110 CW input carriers +15 dBmV	
Adjacent Channel Susceptibility	"Just perceptible" with + 3 dB adjacent signals	-55 dBc with lower sound @ -10 dBc	
Image Rejection	No proposal	54-650MHz: 60 dB 650-1002 MHz: 50 dB	
DPU Interference	"Just perceptible" @ 100 mV/m	54-800MHz: 90 dB REL .8-1GHz: 80 dB REL	
VCR Loss	6 dB	54-550 MHz: 6 dB 550-1002 MHz: 8 dB	