SIGNAL LEAKAGE AND INTERFERENCE WITH OVER-THE-AIR RADIO SERVICES

Robert S. Powers

Cable Television Bureau
Federal Communications Commission

ABSTRACT

A prime advantage of coaxial cables for telecommunications purposes is that signals carried on such cables will not, in principal, interfere with signals carried over-the-air or on other cables. Thus, the same frequency spectrum may be used many times without the necessity of spectrum coordination. This advantage exists, of course, only to the extent that the space inside cables is in fact electromagnetically separated from free space. To the extent that cable systems do "leak" signals, other measures have to be taken to assure non-interference with over-the-air radio services, particularly those radio services related to safety of life and property.

This paper will address how leaks can occur, what fields can be produced, circumstances under which interference can occur, and how interference can be prevented.

NOTE: Statements in this paper are those of the author alone, and do not necessarily represent the position of the Federal Communications Commission.

A prime advantage of coaxial cables for telecommunications purposes is that signals carried on such cables will not, in principle, interfere with signals carried over-the-air or on other cables. Thus, the same frequency spectrum may be used many times without the necessity of spectrum coordination. This advantage exists, of course, only to the extent that the space inside cables is in fact electromagnetically separated from free space. The extent that cable systems do "leak" signals, other measures have to be taken to assure non-interference with over-the-air radio services, particularly those radio services related to safety of life and property.

It is recognized that there are many factors which should motivate a cable operator to minimize ingress and egress of signals. Among these are loss of signals (particularly pay signals) to non-subscribers, interference to TV and FM radio reception by non-subscribers, ingress of Citizen's Band and other signals or man-made noise which can degrade service to cable subscribers, and physical leakage of water, which can produce additional service calls and perhaps shorten equipment life. But this paper will concentrate on signal leakage as it relates to potential interference with air traffic control radio services. We will examine some possible types of leakage sources, mechanisms by which leakage signals could cause some degree of harmful interference, and some possible techniques for preventing such harmful interference.

History

In February, 1971, the Office of Telecommunications Policy (OTP) addressed a letter to the (Acting) Chief Engineer of the Federal Communications Commission (FCC) expressing concern about possible interference to air traffic control communications during periods of "CATV equipment malfunction." OTP suggested that cable television systems be forbidden to use certain frequency bands. In its Cable Television Report and Order (Ref. 1) the Commission declined to adopt the suggested frequency restrictions, noting that the possibility of interference seemed remote in comparison to other known sources of interference, and recognizing the public benefit to full use of the spectrum within the cable.

The 1972 Cable Television Report and Order (Ref. 1) did adopt restrictions on the allowable signal leakage from cable systems. These restrictions, adopted with some modification from Part 15 of the FCC Rules, are more stringent by some 14 decibels than similar restrictions on radiation from television and FM radio receivers and far more stringent than limits imposed on television broadcast facilities radiating in the air traffic control frequency bands. As we will discuss below, however, the criteria for evaluating interference potential from cable systems may not be the same as those for television and FM receivers or transmitters.

Since 1969, a subcommittee of the Coordinating Committee on Cable Communications Systems, of the Institute of Electrical and Electronics Engineers (IEEE) had been addressing the problems of optimum frequency channelling plans within cable television systems. The Subcommittee recognized that potential interference to over-the-air services could limit the flexibility of frequency channelling plans for cable systems. Thus, a request was forwarded to the Office of Telecommunications, U.S. Department of Commerce (OT), that some specific investigations relating to air traffic control systems should be undertaken. OTP also recognized the need for detailed studies, and made a similar request to the Office of Telecommunications. Studies were undertaken by OT, funded in part by the Federal Aviation Administration (FAA), including the cooperation of personnel of FAA, NCTA, and the IEEE group. Results of these studies were published in 1974 and 1975 as a series of OT Reports (Refs. 2, 3, and 4). These reports give assessments of the susceptibility of certain aircraft navigation receivers to interference from simulated CATV signals, characterize the radiation patterns of a length of aerial cable under several fault conditions, and present results of flight tests which characterize the performance of one type of air navigation receiver under conditions simulating interference from CATV signal leakage.

In April, 1976, interference to an aircraft voice communications system due to CATV signal leakage occurred in Harrisburg, Pennsylvania. The FAA began using the frequency 118.25 MHz for ground/air communications at the Harrisburg airport. This frequency was also being used for pilot carriers by the Harrisburg cable television system. Shortly after initiating use of the frequency for communications, pilots began reporting that an interfering signal was causing communications receivers to "break squelch" (open the quieting circuit of the receiver). Although pilots experienced an undesired audio tone in many locations in the Harrisburg vicinity, the transmitter on the ground was sufficiently powerful to override the interfering signal when the transmitter was on. No significant degradation of actual desired signals seems to have occurred. The interference was investigated by field staffs of the FAA and FCC, with the full cooperation of the cable system operator. It was determined that several factors were involved in the interference.

First of all, the cable system was found to have multiple leakage sources producing fields large compared to those permitted under the FCC's cable television technical standards. A second factor that increased the effectiveness of the interfering signals was that the cable system happened to be using four independent pilot carrier generators in four different portions of the cable system. Although the pilot carrier frequencies were nominally identical, they actually differed by amounts corresponding to audio frequencies. Thus, in addition to opening the squelch on the aircraft receivers the interfering signals beat against each other to produce unpleasant and potentially distracting whistles whenever the ground transmitter was not activated. There was some indication (although no quantitative data were obtained) that at low altitudes the interference effect increased with altitude. This suggested a cumulative effect of large numbers of leaks, radiating signals nearly identical in frequency from an "antenna" consisting of large parts of the cable plant. It would have been necessary to perform extensive testing to adequately characterize both the leakage patterns on the ground and the effects in the air and to fully explain the effects of multiple leaks. This was not done, but it is hoped that future field work can be performed to fully clarify the effects of multiple leaks.

Recognizing its dual responsibilities in promoting the application of communications technologies for the public benefit and at the same time preventing the occurrence of unacceptable harmful interference to radio services, the FCC released in November, 1976, a Notice of Proposed Rule Making, which addressed the broad question of cable interference to air traffic control systems in the context of frequency channelling plans for cable television systems (Ref. 5).

In the remainder of this paper we will address four questions:

- How can leakage occur in cable television systems?
- What magnitudes of electromagnetic fields can be produced from cable leaks?
- Under what circumstances can such leakage fields cause interference to Air Traffic Control (ATC) systems?
- What can be done to prevent such interference?

We shall see that there are indeed circumstances in which harmful interference can occur. We shall also find that there are techniques which look promising for controlling such interference, although not all of the answers are yet known.

How Can Leaks Occur?

We all know that leaks can and do occur at many places within a cable system, from the head end to the subscriber terminal. Let us go through a system from one end to the other end at least crudely assess the likelihood and potential seriousness of various possible leakage sources.

To begin with the receiving antenna, it is clear that local oscillator signals could appear on the antenna, just as they can in the case of an ordinary television receiver. Whether such signals appear or not is determined by the type and arrangement of head end signal processing equipment. Even should they exist, however, these signals are not likely to be a problem. Local oscillator radiation, within the limits established under Part 15 of the FCC Rules, has not been judged a serious enough threat to the Air Traffic Control (ATC) system to warrant further restrictions.

The headend itself is unlikely to produce any leakage signal problem, since equipment is generally adequately shielded and is in a controlled environment. There may now exist some headends which radiate excessively. But the solution is obvious and not expensive.

Trunk and distribution cables, however, can provide an opportunity for signal leakage from outside plant. Trunk and distribution cables are generally of the semi-rigid type, of course, with solid outer conductors. Thus, a nominally non-radiating system is provided. But, as every cable operator can recite, there are numerous causes for leakage in these cables. These include connectors improperly installed or loosened due to thermal expansion and contraction, improperly sealed housings, cracks or splits in the cable itself due to fatigue, partial or complete ruptures due to vandalism or accidents. We note here two significant differences between trunk and distribution cables; (1) trunk cables carry signals at levels typically 10 to 15 decibels lower than those typically carried on distribution cables, and (2) trunk cables have fewer taps, splices, and other connections to provide ingress/egress opportunities. Connectors are of special interest here. Many cable operators are already quite familiar with the fact that older types of cable connectors tended to leak signals after a time, particularly after being tightened a few times. The connectors simply deformed the aluminum sheath of the cable until the sheath no longer offered a firm grip for the connector. Some modern connectors are much more resistant to signal leakage, for reasons to be discussed briefly later. Here we will only note that in a recent test FCC's Field Operations Bureau was unable to locate any leaks in a 100 kilometer section of the trunk and distribution lines of a recently constructed cable system.

Subscriber drops can provide significant leakage signals, even though the signal levels are lower in drop cables than in distribution lines. The drop cables themselves are generally braided, double braided, or covered with foil and braid rather than solid outer conductors. Older types of taps -- pressure taps -- have a history of signal leakage. Finally, the subscriber himself, or his reception equipment, can often find ways to radiate cable signals into free space. It is instructive to note that the same cable system which our Field Operations Bureau found to be non-radiating in the trunk and distribution cables provided nine sources of radiation (beyond the present FCC standards) in subscriber drops.

Preliminary investigation of the causes indicated the following:

1. Six loose "F" connectors on customer drops.
2. One defective 75/300 ohm balun.
3. One radiating customer TV.
4. One customer had connected 300 ohm twin lead to CATV drop.
5. One high level amplifier in apartment house complex.
6. One set of rabbit ears connected to CATV drop.
7. One unknown cause inside house (subscriber not at home).

These add to more than nine because there was frequently more than one cause associated with a given leakage field. Field Operations Bureau measurements indicated some leakage fields in the range 50 to 350 microvolts per meter 10 feet from the cable, whereas the maximum field presently allowable under FCC Rules is 20 microvolts per meter, 10 feet from the cable. These fields were generated in subscriber locations, even though the signal levels in subscriber drops are typically 25 to 50 db lower than the maximum levels occurring in the cable distribution system (+40 to +50 dBmV in the distribution cables, 0 to +15 dBmV in the subscriber drop cables).

In concluding this section, it seems fair to say that with modern equipment, connectors, construction practices, and monitoring techniques it may well be practical for a conscientious cable operator to build trunk and distribution systems that are essentially leak-free, although the dynamics of appearance, detection, and elimination of leaks has yet to be established. It may also be possible to build and maintain those portions of the subscriber drop which are under the operator's control in a leak-free condition, although that has yet to be demonstrated in general practice. Probably the most worrisome points, in a modern system, are those under the subscriber's control -- the TV set, the receiving antenna which can become a transmitting antenna, and the twin-lead or other non-shielded cable which the subscriber may improperly connect to the cable in some fashion.

<u>What magnitude of electromagnetic fields can be produced from cable leaks?</u>

In the previous section we have cited evidence of fields of around 350 microvolts per meter from improperly installed subscriber drops and from improper subscriber actions or equipment. The Harrisburg case reviewed earlier in this paper has provided ample evidence of the ability of cable systems having multiple leakage sources to produce signals high enough to be detected by airborne voice communications receivers. Although no quantitative field measurements were made over Harrisburg, interference was experienced up to altitudes of at least two thousand meters. There are no firm estimates of the number and magnitude of leakage sources in the Harrisburg Cable system. However, the general experience of our Field Operations Bureau personnel in checking older systems for leakage, combined with the facts that the Harrisburg system serves about 35,000 subscribers with about 600 miles of aerial plant and about 95% of the subscriber taps being pressure taps, is roughly consistent with the observed interference.

More quantitative estimates of possible leakage fields are given by Harr and Juroshek (Ref. 3) and by Chwedchuk, Poirier, and Walker in a report from the Canadian Department of Communications (Ref. 6). Further details of the Canadian work are given in a report from the Department of Communications, Telecommunications Engineering Laboratory (Ref. 7).

Harr and Juroshek (Ref. 3) report results of measurement on five possible types of cable leaks. The five types of leaks and the maximum gain (compared to isotropic) observed for each are shown in Table 1.

In the cable section of Type 4, a part of the outer conductor over a two foot section was removed, leaving the center conductor intact but exposed. It was found that in all cases the damaged cable section served as a more or less effective feed point for the outer conductor and the messenger cable, which together constituted an unterminated long wire antenna. The radiation patterm observed show fairly narrow main lobes with 3 dB beamwidths about 10 degrees wide. The direction of the main lobes were generally at an elevation angle of 4.8 to 8 degrees, and at an azimuth of 0 to +12 degrees off of the cable center line. For the tests, the damaged cable sections were installed at the center of a 0.5 in cable suspended 16 ft. above the ground. There were four spans of cable, each 200 ft. in length.

The principal conclusion is that although the 3 dB width of the main beam is narrow (about 10 degrees) it is possible for some types of cable breaks (types 1 and 2) to radiate signals somewhat larger in the main beam direction than would be expected from a matched isotropic antenna. In practice, of course, we should recognize that breaks of Type 1 would be extremely rare in cable systems. Chwedchuk et al (Ref. 6) report that practical laboratory tensile breaks result in a maximum of 3 inches of exposed center conductor. Breaks of Type 2 are quite possible, however, We should also note that if breaks of Types 1, 2, or 3 appeared in trunk or distribution lines, the cable operator would expect to have subscriber complaints within a few minutes. The cable break would cause service to be cut off to downstream subscribers, either because the cable is completely severed or because the direct current circuit would be broken and downstream power supplies would cease to operate.

A closely related type of cable break is the so-called "wedding ring" crack. In this case the shield is broken circumferentially, but electrical connection is still complete at part of the circumference of the cable. Wait and Hill (Ref. 8) suggest that such a crack would be a somewhat less effective feed point than the circumferential slot studied by Harr and Juroshek. With such a cable break, subscriber complaints might not occur, since both RF and direct current connections would still exist.

The Canadian work (Refs. 6 and 7) examined ten types of cable breaks ranging from flush cut open circuits and short circuits (no effective radiation) to yagi and dipole antennas connected directly to house drops. Fields were measured near the ground along the cable, and in the air at 1,000 ft elevations using a dipole suspended from a helicopter.

In the tests with the yagi and the dipole connected to house drops, the signal level at the drop was maintained at 16 dBmV, which is higher by 5 to 10 dB than is usually provided to subscribers in this country, although a higher level may occasionally occur. In the yagi and dipole subscriber drop tests, fields of around 18 dB relative to a microvolt per meter were observed at the 1,000 ft altitudes.

Other Canadian tests involved various lengths of exposed center conductors (like Harr and Juroshek's Type 1 and Type 3 breaks) and a ring incision in the shield, similar to Harr and

Table 1

Types of Cable Leaks

	Test Cable	Max Power Gain (dBi)
(1)	3 ft. (0.91 m) exposed center conductor	+5.0
(2)	3/8 in. (0.95 cm) circumferential slot	+3.0
(3)	3 in. (7.6 cm) exposed center conductor	-6.0
(4)	2 ft. (0.61 m) scrape in outer conductor	-15.0
(5)	1/4 in. (0.64 cm) random holes in outer conductor	-42.5

Juroshek's Type 2 break. These tests were done on distribution cable in an operating cable system with power levels of about 26 dBmV. The maximum levels generally occurring in U.S. cable systems are around 50 dBmV. If the Canadian results are corrected to correspond to a power level of 50 dBmV in the cable, they show field strengths of around 50 dBuV/m (dB relative to one microvolt per meter) at the 1,000 ft elevation.

Reference 6 also indicates that radiation from TV sets connected to rooftop antennas can reach levels of around 12 dBuV/m at the 1,000 ft elevation. Chwedchuk et al conclude that if allowance is made for the usual 6 dBmV level at house drops rather than the 16 dBmV level used in their tests, interference to aircraft receivers from a TV local oscillator can be about the same level as that due to a single cable house drop connected to a roof-top antenna. It has been pointed out, however, that there is a practical difference between the two cases. TV set radiation is somewhat random in frequency, and depends upon the channel to which the set is tuned. In the case of cable, however, radiation may occur from multiple leaks, and is present constantly at whatever frequencies the cable system is using. Furthermore, all leakage sources fed from the same headend will be on the same frequency. The practical significance of this difference depends upon how many subscribers' antennas might be improperly connected to the cable at any one time, and their location relative to each other and the aircraft.

Under what circumstances can such leakage fields cause interference to Air Traffic Control (ATC) systems?

This question must be addressed in two parts. The mechanisms for interference to Instrument Landing Systems (ILS) and VHF Omni-Range (VOR) systems are similar, but the nature of interference to voice communication systems is somewhat different. Both U.S. and Canadian studies conclude that ILS and VOR systems are most susceptible to interference only in a very narrow frequency range. But voice communications receivers are susceptible to interference over a wider bandwidth.

Our primary concern is the power radiated at the visual carrier frequency. Aural carriers are carried 13 to 17 dB lower, the color subcarrier is 30 dB down, the closest (and highest) 15 kHz sync pulse peak is 20 dB down, and the 60 Hz sync pulse peaks are 35 dB down (Ref. 2). These ratios change somewhat if average power rather than peak power at the visual carrier frequency is considered. But the susceptibility analysis can be done on the basis of a CW signal at the peak level.

Both VOR and ILS systems are most susceptible to interference at certain precise sideband frequencies. In the case of VOR these frequencies are 30 Hz and 9,960 Hz removed from the VOR carrier frequency. It has been suggested that VOR systems are also sensitive to interference at a frequency 19,920 Hz (twice 9,960) from the carrier as well, but quantitative data are not yet available. ILS systems are most susceptible to interference 90 Hz and 150 Hz removed from the carrier frequency. This is true both for the localizer systems operating in the band 108-112 MHz and the glide slope systems operating at 328.6 - 335.4 MHz. The OT study (Ref. 2) found that the carrier of the interfering TV signal and the VOR/ILS sideband frequency must be zero beat with each other to a precision of 2 or 3 Hz in order for maximum interference effect to occur Since neither the ATC systems nor cable television systems exhibit that order of stability, special stabilization techniques were necessary in order to observe and quantify the interference produced. The susceptibility results reported in Reference 2 are summarized here in Table 2. The ILS and VOR receivers under test exhibited unacceptable degradation in performance when both the frequency and the desired-to-undesired signal ratio criteria were met. A television test signal was used to produce

Table 2

Conditions for degraded ILS/VOR performance

System	Frequency difference (Hz) between system carrier and visual carrier of TV test signal (± 3 Hz)	Desired to undesired signal ratio (S/S') (dB)
ILS Localizer	0	4
	90	49
	150	24
ILS Glide Slope	0	21
	90	16
	150	21
VOR	0	9
	30	34
	9960	9

the interference. Power was measured with an average-reading power meter.

The critical signal-to-interference ratios given in Table 2 are not sufficient to describe the degree of threat posed to operating ATC systems from operating cable systems. One needs to know the radiation patterns possible from leaking cables. The propagation path losses from the cable break to the aircraft and from the ATC transmitter to the aircraft must also be known in order to estimate desired-to-undesired signal ratios at the aircraft. Finally, we should know something about the expected number and geographical distribution of cable breaks in order to estimate any cumulative effects due to multiple breaks. Harr et al (Ref. 2) proceed to estimate, for a single break, the distance from the ATC transmitter at which cable leakage could cause unacceptable ATC system degradation, as a function of distance from the cable break. These estimates were based on assumed worst case cable leakage, including the assumption that the frequencies were superposed in the worst case fashion to a precision of 2 or 3 Hz.

In the later pair of reports already mentioned (Refs. 3, 4) Harr and Juroshek characterized a selected set of cable breaks and calculated the critical break-to-aircraft and VOR-to-aircraft distances the basis of actual flight tests. For the flight tests a ring-type cable break (Type 2, as described previously in this paper) was used to represent the broken cable. Figure 12 of Reference 4, reproduced here, shows the summary of their flight testing.

The OT reports did not address the susceptibility of ILS and VOR receivers to undesired signals at frequencies other than the most critical frequencies. The Canadian work, however (Ref. 6), indicates that for modulated interfering signals, VOR receivers may be about 29 dB less susceptible to "worst case" undesired signals other than those zero beat with the critical frequencies. At a frequency 20 kHz removed from the VOR carrier, the VOR receiver is indicated to be about 35 dB less susceptible than at 30 Hz from the VOR carrier. Worst case interference to ILS receivers occurs with unmodulated interfering signals. In that case, ILS receivers are indicated to be about 40 dB less sensitive to interference at non-critical frequencies than to interference at 90 or 150 Hz.

The interference susceptibility of communications receivers, designed to receive amplitude modulated voice transmission, is not such a sharp function of frequency, although Chwedchuk et al (Ref. 6) show that interference susceptibility may be down by about 30 dB at a frequency 25 kHz removed from the desired frequency, at least for the particular receiver they examined. One practical criterion by which to judge the degree of interference of unwanted cable TV signals is whether or not the cable signals are sufficiently strong to open the squelch on the aircraft receiver. The interference caused by the cable system at Harrisburg was of this sort. Radiating pilot generator signals opened the receiver squelch and caused whistles because of audio beats with other unwanted pilot carrier signals. Although communication with the ground control tower was not interrupted due to this interference, the unwanted cockpit noises could be a distraction to the pilot in some circumstances, and must be avoided.

Assume an aircraft 1,000 ft directly over a cable leak, with a receiving antenna of unity gain, a receiver input impedance of 50 ohms, and a squelch set for 5 microvolts. Assume a peak power level in the cable of 50 dBmV, which, for average picture conditions we may take as an average power level of about 45 dBmV (Ref. 2). Also assume that the cable leak is well matched to an isotropic antenna. Under these conditions the receiver would experience an average input potential of over 100 microvolts due to the cable leak. Obviously, such leaks would cause unacceptable interference.

Based on experience of FCC's Field Operations Bureau, as well as the result of some Canadian surveys of cable systems (Ref. 6), this author would suggest that it may be possible to reduce the probability of large leaks in the high-level portions of a well maintained cable plant of modern construction to very nearly zero. But this possibility has yet to be convincingly demonstrated with significant plant mileage over a significant time period. Many older systems do have large numbers of major leaks, although perhaps not radiating at such high levels as in this "worst case" example. Less well controlled are potential leakage sources in subscriber drops, particularly where the subscriber himself may connect twin-lead or even a roof-top antenna to the drop cable. However, the level of a single leak of this type will generally be much lower than the maximum possible leak in the high level distribution lines. The signal level in subscriber drops is generally at least 40 dB lower than the 50 dBmV level used in the above estimate.

The Canadian Department of Communications (Refs. 6, 7) examined the potential magnitude of radiation from subscriber drops by feeding a matched dipole and matched yagi antenna with a television signal of 16 dBmV level. As, mentioned previously, they suspended dipole 100 feet below a helicopter, 1000 feet above the radiating dipole or yagi. In both cases they observed fields of 18 dB relative to 1 microvolt per meter, at the 1000 ft height. At 100 MHz, assuming an isotropic receiving antenna, such a field would produce a signal level of 5.6 microvolts at the 50 ohm receiver input. This is about the level required to open the receiver squelch, depending on the squelch setting.

If one is to argue that leaks of the "worst case" variety described above can be prevented or controlled adequately to prevent interference due to single leaks, one still must address the question of multiple leaks. At this writing there is still some controversy over whether it is possible for a significant number of leaks to add "in phase", so that the effective received field due to leaks each producing field E at the aircraft is equal to nE, as compared to an effective received field of $n^{1/2}E$, as would be expected if the fields at the receiving antenna were random in phase. It has been suggested that very large numbers of tiny leaks could combine in phase to yield significant total fields at the aircraft. However, it would seem that if the usual statistics of large numbers is any guide in this case such accidental coherence of large number of small signals is quite unlikely, and becomes more unlikely the larger the number of small leakage sources. On should further note in this regard that the peak signal level in the composite television signal -- the synchronizing pulse -- is at least 13 dB higher than the next highest component of the composite television signal. Furthermore, it is of short duration. The sync pulses are about 5 microseconds in length, repeated at 63.5 microsecond intervals. The arrival time of a sync pulse from any one leakage source at the aircraft is determined by the delay time in the cable and the delay time in the propagation path. If the relative delay between signals arriving via two different paths is between 5 and 58.5 microseconds, the two sync pulses will not overlap at the aircraft, and therefore cannot combine "in phase". Both signals will still contribute to interference, of course, but only through their average powers, and there can be no "in-phase addition of the peak amplitudes."

Since a 5 microsecond delay corresponds to a path difference of about 5000 ft (in free space), it is easy to see that in a cable system with many miles of plant, spread over many square miles of the earth's surface, only about 10% of any large collection of leakage sources will be contributing sync pulses at the aircraft position at any given instant.

This discussion suggests why it might be that the only documented incidence of interference to air navigation systems by a cable television system involved pilot carriers and not television signals. The pilot carriers are, after all, CW signals. Thus, peak power is the same as average power, and whatever addition of signals takes place at the aircraft receiver will involve peak powers at all times. This suggests that pilot carriers should perhaps be maintained at levels considerably lower than peak levels of television signals, or perhaps should be excluded entirely from frequency bands where interference with over-the-air radio services is even remotely possible.

<u>What can be done to prevent cable interference to air navigation systems?</u>

Once again, we must recognize the difference between the instrumented air navigation systems (ILS and VOR) and the voice communications systems. The above discussions have perhaps suggested a few measures which might be taken, and those measures are not always the same for both the voice and the instrument systems. We will discuss here a few such possibilities. The list we will discuss does not purport to be a complete list of even the presently known possibilities. Still further suggestions may arise in the current proceeding before the FCC (Ref. 5) or as a result of future investigations.

Perhaps it is not necessary to say that the <u>sine qua non</u> of interference prevention is a far better job of leak prevention and monitoring than is now common in the cable television industry. It has been suggested that few, if any, existing cable television systems could dependably pass a thorough inspection against the FCC's existing signal leakage standards. This statement does not suggest, in this author's view, <u>either</u> that the industry has been entirely irresponsible in the past <u>or</u> that FCC's existing standards are too strict and should be relaxed. Until the last few years, the cable industry has lacked the tools to really do a dependable job of meeting FCC leakage standards.

One of the major cable plant problems has been due to the lack of cable connectors which could be installed leak-free and remain leak-free through years of buffeting by the weather. Older connectors were simply tightened down on the aluminum outer conductor of the cable. The aluminum eventually would flow under the pressure. If not re-tightened, the joint would then radiate. After repeated tightening it eventually became impossible to make an adequate seal between connector and cable. Now, however, connectors having built-in steel sleeves are available. These sleeves fit under the aluminum outer conductor. Thus, the relatively soft aluminum is supported both inside and outside, and cannot so readily flow to relieve the connector's pressure.

Another cable plant problem has been the taps for subscriber drops. The older pressure taps are reported to be unreliable, as to signal leakage. Modern multiport taps are better constructed in this regard.

Equally importance to the availability of leak free cable plant equipment is availability of effective tools and techniques for monitoring for signal leakage. Until very recently, the only available monitoring and measuring techniques were slow and clumsy, and required expensive equipment and a rather high degree of technical competence. Because most equipment used was wideband, manmade noise was often a limiting factor in the sensitivity of measurements. Now, however, there is available equipment which is relatively inexpensive, easy to use with little technical skill, can be used essentially continuously while traveling along the cable plant, sensitive, and quite narrow band. Such equipment is available at least for monitoring purposes, it not for quantitative measurements.

Clearly, contemporary plant equipment and contemporary measurement and monitoring techniques will be most useful in preventing signal leakage. Indeed, it may prove to be simply impossible for some older plant to utilize frequency bands in which the consequences of signal leakage could provide significant threat to life and property.

It is also clear that no monitoring system can ever be absolutely perfect. Signal leakage, to some degree, will inevitably occur. Only experience will show how reliable monitoring and repair systems can be, in practice, at keeping radiation levels low enough that no interference could occur.

Let us briefly examine additional techniques for preventing interference in the event signal leakage does occur.

The previous discussion of interference conditions and mechanisms for the ILS and VOR systems suggests a simple offset in frequency between the video carrier and those critical sideband frequencies at which ILS and VOR systems are found to be sensitive. If the video carrier frequency is removed by 25 kHz or more from the ILS and VOR carrier frequency, all of these critical sideband frequencies are avoided, including the frequency 19,920 Hz from the VOR carrier, the sensitivity of which has yet to be established. Under current operating conditions, this frequency offset generally exists already. ILS and VOR carriers presently exist only at 100 kHz intervals, from 108 to 118 MHz. The traditional carrier frequencies for the bands A-1 and A-2 are 109.25 and 115.25. These fall 50 kHz from the nearest possible ILS/VOR frequency. Frequency tolerances of 5 kHz or less are adequate to maintain sufficient frequency separation, reliably. This situation could change, of course, if an when the Federal Aviation Administration implements a plan to make VOR/ILS assignments at 50 kHz intervals. The same frequency offset principle would be valid, but cable frequencies would have to be modified in some instances, and frequency tolerances might also have to be tightened.

The situation in the voice communications case is not so simple. Frequency assignments in the communication bands are now made at 50 kHz and 25 kHz intervals in some cases, producing potential conflicts at the video carrier frequencies of the traditional cable channels, A, B, and C. These are 121.25, 127.25, and 133.25 MHz, respectively. Since the communications receivers are designed to receive AM voice signals, there is no set of critical frequencies which, if avoided by only a few hertz, decreases the interference susceptibility dramatically, as is the case with ILS and VOR systems. Thus, the choices seem to be four: (1) establish that cable systems can indeed be maintained adequately tight to avoid interference, (2) avoid the three frequencies 121.25, 127.25 and 133.25 (and perhaps the adjacent frequencies as well) for air navigation communication purposes until such time as it is established that cable systems can be maintained adequately leak-free, (3) avoid channels A, B, and C for cable TV use, or (4) for cable TV purposes, avoid frequencies which are used for air navigation purposes in the vicinity of the cable TV system.

The first option may be feasible in the very near future, at least for the trunk and distribution lines that are under control of the cable operator. In the case of subscriber-accessible portions of the plant, it is more doubtful that leakage can be prevented, even though levels are lower. In that case, however, if every subscriber were provided either with a set-top converter having output only in the VHF television band, or a trap was installed at the tap so the subscriber would have no access to midband frequencies, then at least it should be much less likely that even relatively low levels of interference would occur.

The second option may seem simple enough, in view of the superficiallly large number of frequencies available for ATC communications between 118 and 136 MHz. However, the air navigation system is sufficiently pressed for frequency spectrum that this approach would certainly not be welcomed by those responsible for that system. Furthermore, such an approach would tend to negate one of the primary advantages claimed for cable communications systems -- namely, that because the systems are "closed" over-the-air spectrum is conserved.

The third option has obvious disadvantages complementary to those of option 2. This option would require use of the so-called superband above channel 13 to provide even 19 channel CATV service. If it true that interference problems in the government bands between 225 and 400 MHz are similar to those discussed here in the midband, then avoiding A, B, and C completely would also imply avoidance of all but one of the superband channels, limiting cable to only 19 channels, including the 12 broadcast channel frequencies.

The fourth option would probably be viable in many locations, where no airports or en route transmitters are nearby. But the major problem is not in those locations. The problems are more likely to exist in and around metropolitan areas, where the demand for ATC services and multi-channel cable services co-exist. Even in those locations, frequencies used by ATC systems could be avoided on an ad hoc basis. But since the ATC systems must be free to modify frequency assignments at any time -- and this is done quite frequently -- the cable system would be subject to unplanned frequency changes at any time. In many cases this might be accomodated by small frequency changes not noticeable by subscribers. But when adjacent channels are used, the flexibility for changing the frequency of any one channel is limited. The alternative of modifying the cable system's channel carriage assignments on short notice because of changes in the ATC system is not likely to be welcomed by cable operators or subscribers.

Finally, we should note that all the actions mentioned in this section have assumed that cable television systems will continue to operate more or less as they do today, using VHF frequencies on coaxial cables. Longer term solutions include, of course, use of optical fibers for television signal transmission. If optical transmission all the way to the subscriber's premises should ever prove practical, signal leakage problems would recede into dim memory. Another alternative is the use of UHF frequencies for delivery to subscribers, if not for trunking as well. Even if trunks and distribution lines were to remain at VHF, UHF delivery to the subscriber would prevent the possibility of the troublesome subscriber-caused signal leakage. With modern improved UHF tuners and continually improving solid state amplifiers, UHF distribution and delivery may not be nearly as "far-out" a suggestion as it seemed only a few years ago.

Conclusion

The author has attempted to give some overview of the technical problems and opportunities for preventing interference between cable TV systems and air navigation and safety systems. It is clear that some actions will have to be taken to prevent the recurrence of such interference. Hopefully, the restrictions which may be imposed will be at the same time effective and not unnecessarily burdensome for cable operators, although it seems possible that some older systems may be quite restricted in their use of air navigation and safety frequencies. We note that two major areas, of particular interest to the FCC, have not been addressed at all in this paper. Those are the problems of (1) determining whether an individual cable TV system is indeed technically prepared to maintain signal leakage at a sufficiently low level, and (2) how to monitor and enforce, or otherwise assure that whatever restrictions and rules are judged necessary are actually implemented by every cable TV system using navigation and safety frequencies.

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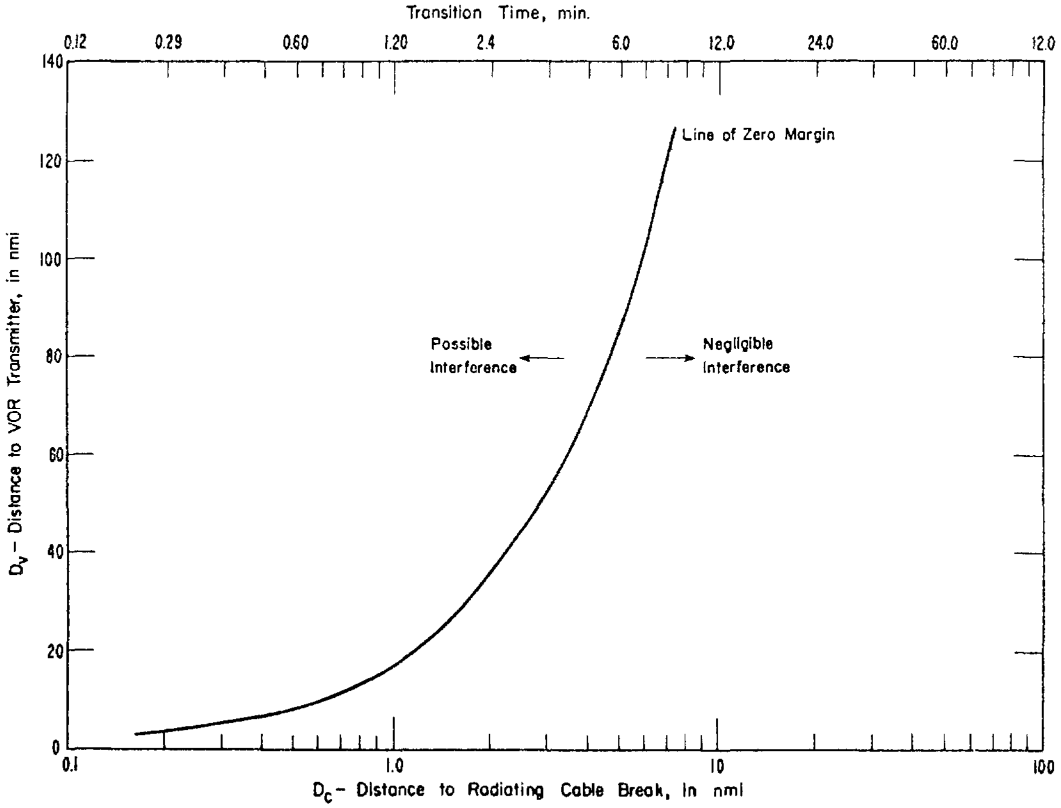

Figure 12. Expected performance of an operational VOR in similar interference tests. Transition time is the time required to fly a straight line distance of $2D_c$ assuming a ground speed of 185 km/hr (100 nmi/hour).

SOURCE: Juroshek and Harr (1975), OTR 75-75 (Ref. 4)