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CARRIER - INTERFERENCE RATIOS FOR FREQUENCY SHARING BETWEEN SATELLITE SYSTEMS TRANSMITTING FREQUENCY MODULATED AND DIGITAL TELEVISION SIGNALS

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ABSTRACT

As the data rates required for digitally encoded television are reduced, satellite systems employing the transmission of digitally encoded television will become attractive. It is likely that television transmitted in this format will be adjacent to or in the same frequency band as television transmissions in other modulation formats, so a knowledge of carrier to interference power ratios as a function of assessed picture quality will be required for frequency sharing between these different modulation formats. This paper presents the results of subjective and quantitative tests describing the results of interference to a particular digital television system from a frequency modulated (FM) television system, and for interference to an FM television system from a digital television system.

INTRODUCTION

As the achievable data rates for digitally encoded television are reduced, a point will be reached where the transmission of digitally encoded television through communications channels will become competitive (in terms of bandwidth and power required) with the transmission of analog television signals. In order to plan for these digital television systems, one element that will be needed is the interference protection ratio (the ratio of wanted to interfering signal power at the receiver input) as a function of assessed picture quality for digital television systems operating in the same or adjacent frequency bands as other television transmissions. For a variety of reasons, current television transmissions from satellites are frequency modulated. Hence, there will exist the possibility for interference between digital television systems and frequency modulated television systems in the near future.

This report presents the results of television interference protection ratio tests performed using a particular digital television system, the COMSAT Laboratories manufactured Digitally Implemented Communications Experiment (DICE). The results of subjective and quantitative tests are presented for interference to DICE from a frequency modulated television (FM TV) system, and for interference to an FM TV system from either DICE or from a digital data transmission system operating at half the data rate of DICE. Digital television systems of the future may use an encoding technique different from that employed in DICE, and are likely to operate at data rates different from that of DICE, so the measured protection ratios for DICE are only an estimate of the protection ratios that future systems will require.

The design of current television systems is based on interference protection ratios required by these systems when subjected to interference from other analog television signals (summarized in Ref. 1). In reconciling the test results obtained by several organizations using varying test conditions, a need for a set of standardized test conditions and measurement procedures became apparent. The Consultive Committee on International Radio (CCIR) established such a set of test conditions and measurement procedures (Refs. 2 and 3). Where practical and applicable, they have been followed. All measurements were made using system M,525 line television standards.

APPARATUS

The COMSAT Laboratories manufactured DICE equipment was produced for a joint experiment by COMSAT and NASA-Lewis Research Center to demonstrate the transmission flexibility and efficiency which can be obtained using digital techniques to transmit television, voice and data. The transmit section of DICE accepts NTSC (National Television Standards Committee) type of video, samples it and encodes it into a 43 megabit per second (Mb/s) data stream. This signal is then modulated for transmission using differential quadriphase shift keyed (D-QPSK) modulation. The transmit section also accepts data and up to 60 voice channels, encodes this information and multiplexes it with the encoded television signal. The receive section of DICE is comprised of a coherent QPSK demodulator, and a decoder which reconstructs the video, voice and data. The modulated D-QPSK signal is band limited by a 3-pole, low-ripple Chebyshev transmit filter with a 1 dB bandwidth of 45 megahertz (MHz). The signal into the receive section of DICE is band limited by a 5-pole equalized, elliptical filter having a 3 dB bandwidth of 33 MHz.

The encoding method used in DICE is a form of predictive differential coding. The encoder sends a unique word (a 16 bit data sequence which

is recognizable by the decoder) at the beginning of each video line. It calculates an estimate of each video sample based on the preceding video samples, finds the difference between this estimate and the actual video sample, and transmits this difference in four bits. In the receive section, the reception of a unique word initializes the decoding process and the decoder reconstructs the line of video based on its prediction (which is a function of previously received values) and the received four bit differences. This method takes advantage of the fact that there are usually few sharp transitions on a line of video and accepts a small amount of distortion at these transitions in order to significantly reduce the data rate.

A disadvantage of this technique is that when an error occurs in the transmission of a four bit difference, not only is the particular sample being reconstructed in error, but all subsequent picture elements on that line of video are in error since they are based on incorrect past values. Assuming the errors to be random in nature, the results will be a streak of random intensity, beginning at a random point on the line and continuing completely across that line. The reception of unique word, which initializes the decoding process, is required for future samples to be correctly reconstructed.

Test Setup - FM TV Interfering with DICE

The test setup used for measuring protection ratios for the case of an FM TV signal interfering with DICE is shown in Fig. 1.

The sources of video baseband signals for both DICE and the interfering FM TV transmitter were video tape recorders. At times, digital data from a data generator was used in place of the video baseband signal to DICE. In this mode of operation, data from the data generator bypassed the encoder in the DICE transmit section and, after modulation, transmission and detection by the receive section of DICE, the resultant channel bit error rate could be measured. The center frequency of the D-QPSK signal was 70 MHz.

The interfering FM TV signal was generated by modulating a 2.25 GHz FM transmitter and then translating this signal to approximately 70 MHz through use of a mixer and a frequency adjustable local oscillator. The interfering FM signal could then be centered at 70 MHz or offset in frequency by up to 30 MHz. Before detection, a noise voltage was added to approximate the noise encountered on typical communications channels. Line synchronization was established between the wanted and interfering baseband signals so that the sync bars of the interfering signals were transmitted during the picture portion of the wanted signal.

Test Setup - DICE Interfering with FM TV

The test setup used for measuring protection ratios for the case of DICE interfering with an FM TV system is shown in Fig. 2.

The DICE transmit section is either input video from a video tape recorder or a random data sequence from a data generator. After modulation, the resultant D-QPSK signal was translated to approximately 2.25 GHz using a mixer and a frequency adjustable local oscillator. After detection of the signal composed of the wanted and interfering signals, the resultant video signal was displayed on a video monitor and on a waveform monitor.

Tests were made using this setup with DICE operating in its normal mode (a baseband television signal is encoded to a 43 Mb/s data stream and transmitted) and with DICE operating as a digital data transmission system (a random data sequence at 22 Mb/s is modulated and transmitted). When operating at 22 Mb/s, an additional transmit filter was employed to reduce the bandwidth of the transmitted signal to approximately 24 MHz. When operating with DICE TV interfering with FM TV, line synchronization was established between the wanted and interfering baseband signals so that the sync bars of the interfering signal were concurrent with the picture portion of the wanted signal.

TEST PROCEDURES

FM TV Interfering with DICE

As described in Ref. 2, the recommended procedure for measuring protection ratios is to have a minimum of 10 to 20 viewers judge the perceptibility of any interference in terms of the five level impairment scale given in Ref. 3. The desired result is the interference protection ratio which yields a mean subjective grade of 4.5. A grade of 4.5 is midway between grade 5, "imperceptible" interference and grade 4, "perceptible, but not annoying" interference.

A problem arises when evaluating the protection ratios required by DICE in this manner. As a result of the additive noise used to simulate the noise encountered on communications channels and any FM TV interference present, DICE transmissions will have a certain channel bit error rate. The incorrect detection of a particular bit will not only cause the picture element which is described by that bit to be in error, but will cause all subsequent picture elements on that video line to be in error since they are based on an erroneous past value. Visually, the result is a streak of random intensity and color, beginning at the point the random error occurred and continuing completely across the monitor. This is usually easily perceptible. The error rate determines the frequency at which this streaking occurs. A bit error rate of 10^{-6} (approximately 43 bit incorrectly detected per sec) will cause about 21 streaks across the screen per second (D-QPSK modulation results in errors occuring in pairs). Subjectively, this results in severely annoying interference. Reducing the error

rate to 10^{-8} (approximately 0.4 bits incorrectly decoded per second) reduces the frequency at which the impairment occurs. The mean time between streaks is now about five seconds, but the streaks, when they occur, are still usually perceptible. Reducing the error rate further causes the mean time between errors to increase, but if one is willing to evaluate the picture for a long enough period of time, a perceptible impairment to the picture will occur. Thus, in evaluating the effect of FM TV interference to DICE, one is concerned with the frequency at which this perceptible impairment will occur and not with judging whether any perceptible interference is present or not.

Two factors influencing the error rate are the energy contrast ratio (energy per bit to noise spectral density power ratio - E_b/N_o) and the wanted to interfering signal power ratio. A lower limit to the energy contrast ratio for a digital link is that which produces the highest acceptable error rate in the absence of any other interference. With DICE, an energy contrast ratio of 14.4 dB results in an error rate of approximately 10^{-8} (Fig. 3). Subjectively, this was felt to be the highest error rate for which perceptible, but not annoying, interference to the picture occurred. Increasing the energy contrast ratio to 15.1 dB reduces the error rate to approximately 10^{-9}. At this error rate, infrequent impairments to the picture occurred (the mean time between errors is approximately 50 sec). At this operating condition, the interference protection ratio which increased the error rate to that judge to cause perceptible, but not annoying, interference was measured. In addition, similar tests were performed to determine the protection ratios required when operating with energy contrast ratios of 18.1 dB and approximately 40 dB.

In addition to the subjective tests described, test were performed using a data generator and an error detector to determine, quantitatively, the lowest wanted to interfering signal power ratio which resultsed in a bit error rate of less than 2×10^{-8}.

DICE Interfering with FM TV

As contrast with analog TV interfering with FM TV, where additive noise and an analog TV interference manifest themselves in different ways in the received picture, the effect of DICE interfering with an FM TV system was similar to that of additive noise. Thus, the received picture and the baseband signal resulting from DICE interferening with FM TV appear very much like a signal corrupted only by noise. Since there are established measurement procedures for describing a signal corrupted by noise, it was felt advantageous to describe the effect of DICE interfering with FM TV in terms of the apparent baseband signal to noise power ratio, rather than judge the picture in terms of the five point impairment scale dealing with the perceptibility of the interference.

Thus, the tests performed give the wanted to interfering signal power ratio which yielded certain apparent baseband signal to noise power ratios. The procedure for making these measurements was to establish an FM TV link which had, in the absence of any interference, a signal to noise power ratio (unweighted) of 50 dB. The signal to noise power ratio (unweighted) is defined as:

Signal to noise power ratio (dB)

$$= 20 \log \frac{\text{peak to peak signal amplitude}}{\text{RMS noise}}$$

An interfering signal from DICE was then added so as to produce apparent signal to noise power ratios of 45, 40 and 35 dB. For these measurements, the signal was acutally corrupted by both the random noise encountered in the link, and, to a greater extent, the noisclike interference from DICE.

For all measurements, the FM TV system was operated with a peak to peak deviation of 12 MHz. The FM TV transmitter was operated with preemphasis as described in CCIR Recomendation 405.

MEASUREMENT ACCURACY

In addition to the inaccuracies inherent in subjective tests, certain errors will occur as a result of measurement inaccuracies. These are summarized in table I.

RESULTS AND DISCUSSION

FM TV Interfering with DICE

Using the test procedures and appratus described, the interference protection ratios required to yield pictures judge to have perceptible, but not annoying, interference were determined as a function of frequency offset and energy contrast ratio. Additionally, the lowest wanted to interfering signal power ratio which resulted in an error rate of less than 2×10^{-8} were determined.

Fig. 4 describes the required protection ratio and Fig. 5 describes the minimum wanted to interfering signal power ratio required to yield a channel bit error rate of less than 2×10^{-8} when operating with an energy contrast ratio of 15.1 dB.

Figs. 6 and 7 describe results when operating with an energy contrast ratio of 18.1 dB. Fig. 6 shows the subjectively determined protection ratios and Fig. 7 gives the minimum wanted to interfering signal power ratio required to maintain a channel bit error rate of less than 2×10^{-8}.

Fig. 8 describes the subjectively determined protection ratios and Fig. 9 describes the mini-

mum wanted to interfering signal power ratio required to yield a channel bit error rate of less than 2×10^{-8} when operating with an energy contrast ratio of approximately 40 dB.

Of major interest in these results are the peak protection ratios required to achieve perceptible, but not annoying, interference. These are summarized in table II. Also of interest are the peak wanted to interfering signal power ratios required to yield a channel bit error rate of less than 2×10^{-8}. These are summarized in table III.

The greatest protection ratios and wanted to interferings signal power ratios are generally required when the center frequencies of the wanted and interfering signals are offset by approximately 15 MHz. This is particularly apparent when operating with high energy contrast ratios. It is believed that the DICE equipment is susceptible to interference at these offsets due to interaction between the interfering signal and the clock recovery section of DICE. Different results might be obtained using other digital systems.

As shown in the results, a small increase in the energy contrast ratio (from 15.1 to 18.1 dB) can result in a much larger reduction in the required protection ratio (8 to 10 dB). Increasing the energy contrast ratio significantly above 18.1 dB, however, allows only a 1 to 2 dB reduction in the protection ratios required.

DICE Interfering with FM TV

Using the test procedures and apparatus described, the wanted to interfering signal power ratios required to achieve certain apparent baseband signal to noise power ratios in an FM TV system subjected to interference from to DICE were determined. The FM TV link had, in the absence of any interference, a signal to noise power ratio (unweighted) of 50 dB.

Fig. 10 describes the wanted to interfering signal power ratios required to achieve apparent signal to noise power ratios of 45, 40 and 35 dB. The interfering signal from DICE was a television signal encoded to 43 Mb/s and modulated using D-QPSK modulation. In all measurements, the FM TV link was operated with a peak to peak frequency deviation of 12 MHz. The FM receiver had a 6 pole, low ripple Chebyshev receive filter with a 3 dB bandwidth of 21 MHz. Fig. 11 describes the results when the interfering signal from DICE was a 22 Mb/s random data sequence modulated using D-QPSK modulation.

The peak wanted to interfering signal power ratios are required when the wanted and the interfering signals have approximately the same center frequency. These are summarized in table IV. The results show a direct relationship between the wanted to interfering signal power ratio and the apparent baseband signal to noise power ratio.

REFERENCES

1. "Broadcasting-Satellite Service (Sound and Television), Measured Interference Protection ratios for Planning Television Broadcasting Systems," Conclusions of the Interim Meetings of Study Groups 10 (Broadcasting Service (Sound)) and 11 (Broadcasting Service (Television)), Geneva, 3-18 May 1976, International Telecommunications Union (Geneva), CCIR Rep. 634, pp. 118-158, Rev. 1976.

2. "Standardized Set of Test Conditions and Measurement Procedures for the Subjective and Objective Determination of Protection Ratios," CCIR Document 11/301-E, International Telecommunication Union (Geneva), July 20, 1976.

3. "Method for the Subjective Assessment of the Quality of Television Pictures," in Proc. 13th Plenary Assembly, Vol. 11, International Telecommunications Union (Geneva), Recommendation 500, pp. 65-68, 1975.

TABLE I. - ERRORS IN MEASURED PARAMETERS

Measured parameter	Maximum error
Frequency offsets	0.25 MHz
Wanted-to-interfering signal power ratio - FM TV on DICE	.6 dB
Wanted-to-interfering signal power ratio - DICE on FM TV	2.2 dB
Signal-to-unweighted noise ratio	2 dB

TABLE II. - PEAK PROTECTION RATIOS REQUIRED FOR PRECEPTIBLE, BUT NOT ANNOYING, INTERFERENCE FOR FM TV ON DICE

E_b/N_o = 15.1 dB	E_b/N_o = 18.1 dB	E_b/N_o = 40 dB
Protection ratio, dB		
23.9	13.7	12.7

TABLE III. - PEAK WANTED-TO-INTERFERING SIGNAL POWER RATIOS FOR A CHANNEL BIT ERROR RATE OF LESS THAN 2×10^{-8} FOR FM TV ON DICE

E_b/N_o = 15.1 dB	E_b/N^o = 18.1 dB	E_b/N_o = 40 dB
Wanted to interfering signal power ratio, dB		
25.5 dB	14.5 dB	12.4 dB

TABLE IV. - CO-CHANNEL WANTED TO INTERFERING SIGNAL POWER RATIOS

REQUIRED TO ACHIEVE SPECIFIED BASEBAND SIGNAL TO NOISE

PLUS INTERFERENCE POWER RATIOS

Apparent baseband signal to noise power ratio	DICE data rate = 43 Mb/s	DICE data rate = 22 Mb/s
	Wanted to interfering signal power ratio, dB	
45	24	26
40	19	21
35	14	15

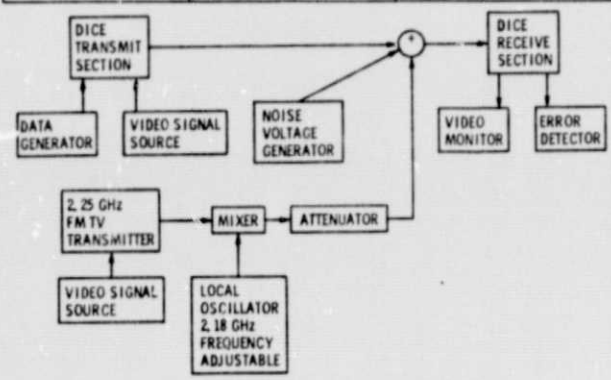

Figure 1. - Test setup - FM TV interfering with DICE.

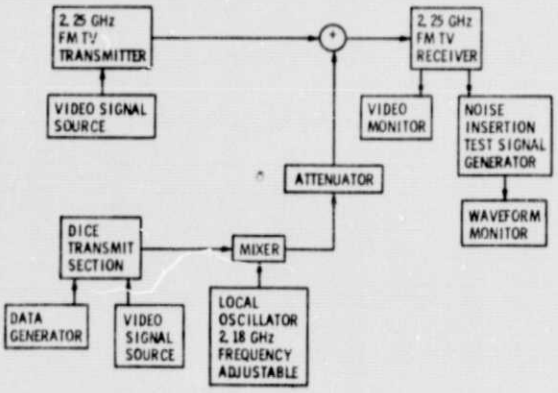

Figure 2. - Test setup - DICE interfering with FM TV.

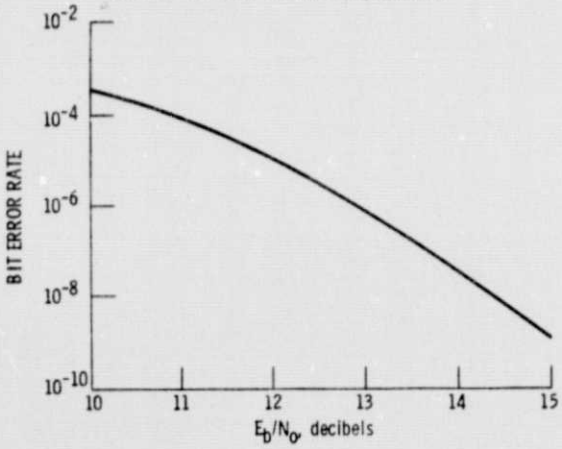

Figure 3. - Bit error rate versus energy contrast ratio for DICE (D-QPSK).

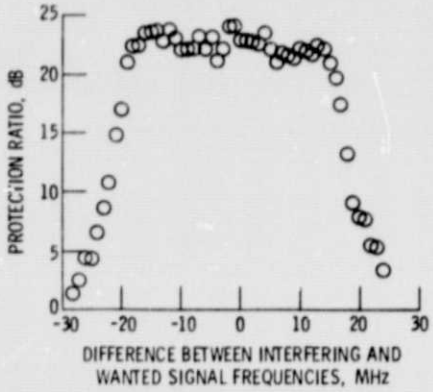

Figure 4. - Protection ratios required for perceptible, but not annoying, interference to DICE from an FM TV system, E_b/N_0 = 15.1 dB.

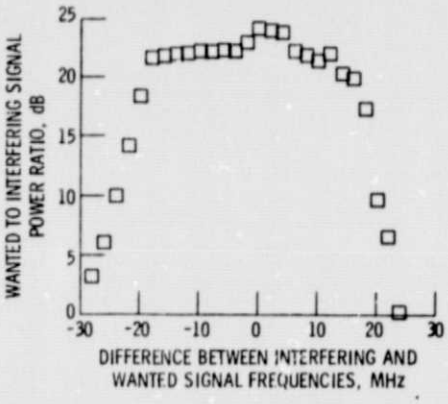

Figure 5. - Wanted to interfering signal power ratios to achieve a bit error rate of less than 2×10^{-8} for FM TV interfering on DICE, E_b/N_0 = 15.1 dB.

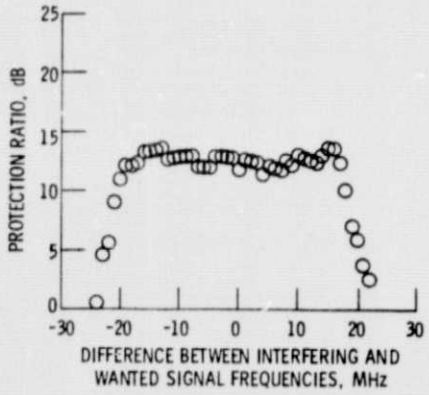

Figure 6. - Protection ratios required for perceptible, but not annoying, interference to DICE from an FM TV system, E_b/N_0 = 18.1 dB.

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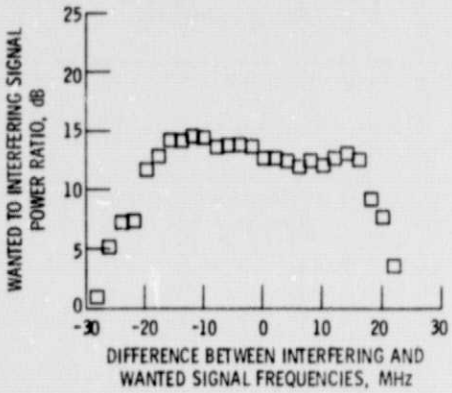

Figure 7. - Wanted to interfering signal power ratios to achieve a bit error rate of less than 2×10^{-8} for FM TV interference on DICE, $E_b/N_0 = 40$ dB.

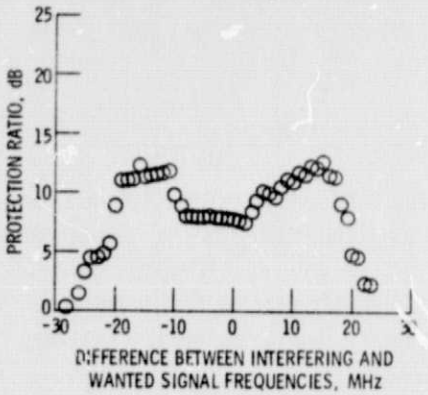

Figure 8. - Protection ratios required for perceptible, but not annoying, interference to DICE from an FM TV system, $E_b/N_0 = 40$ dB.

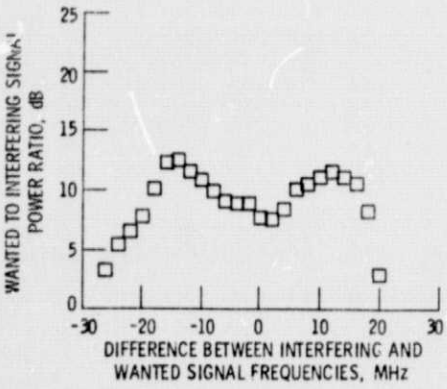

Figure 9. - Wanted to interfering signal power ratios to achieve a bit error rate of less than 2×10^{-8} for FM TV interfering on DICE, $E_b/N_0 = 40$ dB.

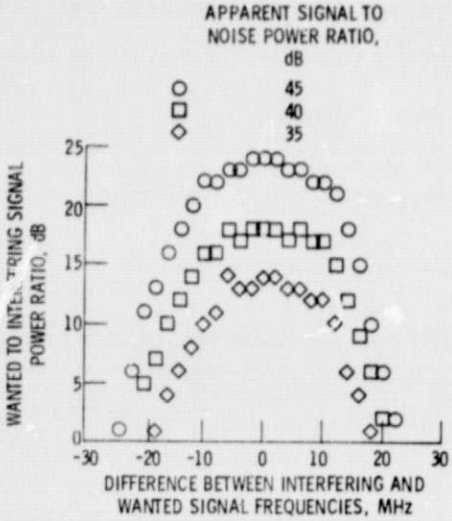

Figure 10. - Apparent FM TV signal to noise power ratio (unweighted) when subjected to interference from DICE operating at 43 Mbps.

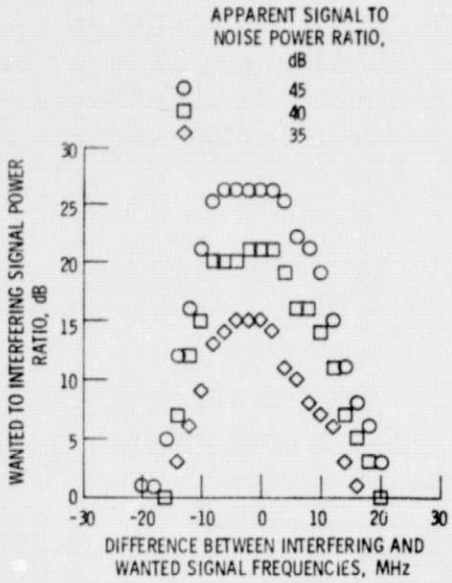

Figure 11. - Apparent FM TV signal to noise power ratio (unweighted) when subjected to interference from DICE operating at 22 Mbps.