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NATIONAL RADIO SYSTEMS COMMITTEE

NRSC-R32
A Review of the FM-IF Taboo in Contemporary FM Broadcast Receivers in Laboratory Tests
August 10, 1986

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FOREWORD

NRSC-R32, A Review of the FM-IF Taboo in Contemporary FM Broadcast Receivers in Laboratory Tests, documents an investigation into the susceptibility of contemporary (circa 1986) receivers to the FM IF interference mechanism. Thirteen FM receivers were tested in the NAB Science & Technology Electronic Laboratory. The NRSC Chairman at the time of the submission of NRSC-R32 was Charles Morgan.

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A REVIEW OF THE FM-IF TABOO IN CONTEMPORARY FM BROADCAST RECEIVERS IN LABORATORY TESTS

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August 10, 1986

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A Review of the FM IF Taboo
In Contemporary FM Broadcast
Receivers in Laboratory Tests

I. EXECUTIVE SUMMARY

The Federal Communications Commission, in a Notice of Proposed Rulemaking (MM Docket No.86-144), proposed to relax the protection ratios governing the spacing of FM broadcast stations separated in frequency by 10.6 and 10.8 MHz in the same market area. The Commission based their proposal mainly on the lack of evidence of widespread interference indicating the current protection ratio is overly conservative. On the other hand the Commission invited new test measurements and updated information about the extent of intermodulation interference with the Comments on this issue.

This report deals only with the latter factor, an investigation into the susceptibility of contemporary receivers to the FM IF interference mechanism. Tests of 13 FM broadcast receivers were conducted in the NAB Department of Science and Technology Electronic Laboratory.

IF interference can occur when two stations spaced 53 or 54 channels (10.6 or 10.8 MHz) apart in or near the same market combine at the input of an FM receiver to produce a signal which passes through the 10.7 MHz IF stages and is manifested as audible interference. Once above the threshold of perceptibility, the interfering signal becomes rapidly more objectionable due to the combination of the non-linear characteristics of the interference mechanism involved and the fact that the modulation from both interfering stations is heard on top of the desired station.

In the laboratory tests of FM receivers described in this report, it was found that an extremely wide range of interfering signal level will produce perceptible interference. It was determined that some receivers are virtually immune to IF interference while others are highly susceptible. In addition to audibly perceptible effects, IF interference can adversely affect the automatic tuning system on many electronically tuned radios. IF interference occurs over the entire FM band and once the threshold value has been reached the interference will cause a scanning receiver to stop at every channel instead of actual stations. IF interference can also be produced by a combination of an FM station and the aural carrier of a channel 6 TV station.

Because of the wide range of receiver performance, the number of receivers currently in operation by the public and the fact that lower cost receivers appears to be more susceptible to IF interference, there is ample evidence from these tests that the IF taboo exists and that rules to control such station configurations that contribute to its occurance must be maintained.

Further tests are warranted, however because of the wide range of receiver models and the lack of information regarding the subjective effects of this form of interference.

II. INTRODUCTION

Testing a variety of contemporary FM receivers represents a significant challenge due to the wide range of performance characteristics, antenna configurations and receiver controls. For example, many automobile receivers have local/distance switches, a 90 ohm coaxial input, electronic tuning and sophisticated circuits to minimize low signal noise during stereo reception. Small table model or portable receivers often have 300 ohm antenna inputs, monopole antennas and simpler tuning and audio processing circuitry.. High performance stereo sound equipment may combine a variety of these features.

In order to test a wide variety of receivers, a standard test bed was developed to provide the same signal to each receiver under essentially the same conditions. Modest antenna matching was provided by using a 300 ohm balun for receivers with 300 ohm inputs and monopole antennas and a 75 ohm feed was provided to those receivers with coaxial antenna inputs. While not a perfect match in all cases, the procedure provided a means for easily duplicating the process and represented a reasonably accurate means for supplying the appropriate signal level to the receiver input. All stereo capable receivers were operated in the stereo mode to simulate typical receiving conditions. The tests were conducted in a screen room which, for some extra-sensitive receivers, proved necessary to eliminate extraneous signals.

There is little available material on the subject of IF interference in FM receivers. In 1965, the FCC conducted a series of tests on 8 typical FM radios of which several were tube type.[1] In general the FCC test results showed a rapidly declining U/D ratio with increasing signals level. For example, a representative receiver showed a decline from 45 dB U/D at a signal level of 33 dBu to 21 dB U/D at a signal level of 73 dBu. The signal levels used in the FCC test were substantially lower than those used in the NAB test series. Assuming the decline in U/D continues, the same receiver would probably exhibit no more than 10 dB U/D at level of 90 dBu.

Several of the FCC tested receivers exhibited great immunity to the IF interference mechanism indicating as great a range in receiver performance as was found in the NAB test series. From all outward appearances however, there is little difference in range between the receivers tested in 1965 by the FCC and those tested in 1986 by the NAB.

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[1]FCC Laboratory Project #2223-10 "Intermodulation Problems of IF Spaced Stations in FM Broadcast Reception" January 12, 1965.

III. TEST EQUIPMENT SET-UP

An objective two-signal method of measurement was employed for this test series.[2] The test arrangement called for three signal sources to be used: one for the desired signal and the other two for the undesired combination providing the 10.6 or 10.8 MHz intermodulation source. The several sources were combined and controlled to provide the range of desired levels and undesired levels required to test the FM receivers. The output of the test bed was fed to a spectrum analyzer and the FM test receiver. A block diagram of the test set-up and a list of the equipment used for the receiver tests are shown in Figures 1 and 2.

The modulation source for the desired signal consisted of an audio oscillator to produce a 400 Hz tone used to set the maximum deviation of the RF generator and provide a reference level on the audio test equipment connected to the output of FM test receivers. A stereo generator was used to provide a 19 kHz signal to activate the stereo circuits in the receivers. It was also found that the internal 19 kHz signal source of the Boonton RF generator could also provide essentially the same results. During the test no other modulation was present.

The modulation sources for the undesired signals (generators #2 & #3) were noise signals tailored to simulate the spectrum occupancy of heavily modulated FM stations. The noise was modified by emphasizing low frequencies and rolling off high frequencies in order to produce the spectrum occupancy as shown in figure 3a. Two separate sources were used. For comparison, an FM station is shown in figure 3b. The spectrum analyzer accumulated the signal for 5 seconds for each photograph.

In order to measure the audio signal-to-noise a standard noise meter with ANSI-A weighting was employed. However, because the 19 kHz pilot signal was not suppressed in the receivers, additional attenuation was provided by using a graphic equalizer. The resulting filtering combined with the ANSI-A weighting is shown in figure 3c. Finally, the quality of the received signal was monitored using a high quality amplifier and speaker in order to detect inconsistencies or abnormalities in the testing process.

IV. TEST PROCEDURES

The signals from two RF generators (#2 & #3) were combined to produce the undesired signal combination. The separation in frequency was adjusted to be either 10.6 or 10.8 MHz depending upon which frequency produced the most interference in each receiver. At the beginning of each test series one of the generators was momentarily "de-tuned" to determine that no receiver interference mechanism other than IF was causing the interference. The

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[2]The test procedure was based on CCIR Report 796-1 "Determination of Radio-Frequency Protection Ratio For Frequency Modulation Sound Broadcasting."

frequencies of the two undesired signals were selected so as to provide receiver tuning range for the desired signals within, and on either side of, the undesired signals. Four frequencies were selected for the desired signal in order to test receiver performance at the low, middle and high end of the band. The chart in figure 4 shows the relationship between the desired (f_1, f^2, f3, f4) and undesired (t1, t2) signals.[3]

During each test sequence the two undesired signals were maintained at identical levels. It was noted that the interference remained essentially constant when simultaneously raising one undesired signal and lowering the other by an identical amount within a range of 10 dB or so, depending somewhat upon the amplitude of the stronger signal and the characteristics of the receiver.

Four signal levels were employed for the desired signal: 1) the level at which the receiver could be quieted to about 56 dB or maximum quieting whichever was greater was the first test. (Some less expensive receivers did not provide 56 dB signal to noise under any signal conditions.) The signal level for this test ranged from -75 dBm to -49 dBm. 2) -47 dBm corresponding to 70 dBu; 3) -37 dBm corresponding to 80 dBu; and 4) -27 dBm corresponding to 90 dBu.

To conduct each test series the desired signal generator and receiver were tuned to the same test frequency. The receivers were set (to the extent possible) to stereo, distant, volume slightly above normal, tone controls to mid-range and AFC on. The audio generator output was adjusted to produce 75 kHz p-p deviation at 400 Hz and the receiver output adjusted to produce a useful level on the signal-to-noise meter. The audio signal was replaced with a 19 kHz signal from the stereo signal generator (or from the Boonton RF generator internal audio oscillator) at a deviation of 6-7 kHz to activate the receiver stereo circuits. The RF level was adjusted to produce 56 dB S/N or the best S/N. At each of the four desired signal levels the undesired signal was increased until the signal-to-noise fell to 50 dB or 6 dB less than maximum (some low cost receivers would not produce 50 dB S/N) and the level of the undesired signal was recorded. A determination of whether to use 10.6 or 10.8 MHz as the difference between the two undesired carriers was made at this time as well by testing each and using the worst case. The reason for making this selection is that some receivers tend to be tuned to one side of the 10.7 MHz IF rather than on the center.

Because four different desired levels were involved it was necessary to make a decision with respect to what S/N would be acceptable. Although the

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[3]The frequencies chosen were selected to avoid conflicts with stray pickup of strong local FM stations.

IEEE test procedure[4] calls for a 50 dB stereo noise quieting, no value is specified for quality rating degradation produced by IF intermodulation. In order to maintain some element of consistency the 50 dB value was also used to establish the limit for acceptability at RF levels well above threshold. At higher RF levels the quieting may go as high as 70 dB. For this series of tests the level of undesired signal that degraded the audio to 50 dB (or 6 dB below maximum) was recorded. It should be noted that a change from 70 dB to 50 dB S/N would be quite noticeable in a quiet listening environment or on high performance equipment but such a change may be only slightly annoying in an automobile or other noisier environment.

A total of 16 measurements were made for each receiver (4 levels at 4 frequencies) in addition to determining the 56 dB S/N threshold levels. In some cases the level of the undesired signal required to produce the IF interference was above 0 dBm, which was the maximum signal that could be obtained in this particular test set-up. However, problem did not affect the determination of a median value for each test series.

V. TEST RESULTS

The results of the tests are shown graphically in figures 5-9. Figure 5 is a summary and shows 1) the relationship between the median and 90th percentile to the desired input signal level, and 2) the U/D ratio between undesired and desired signals for the test frequencies. From this chart it is apparent that the U/D ratio decreases as the desired signal increases. Note that at high levels the U/D ratio drops below zero on the 90th percentile receiver. The very wide spread between the median and 90th percentile illustrates the wide performance characteristics available in FM broadcast receivers.

An observation made while conducting the test is that some receivers, especially at relatively high signal levels, experienced rapid degradation of the desired signal with only a few dB increase in undesired signal level. Therefore, basing FM allocations on the median values may be misleading and could result in severe interference to those receivers with less immunity to IF interference. For this reason both median and 90th percentile receivers are shown in the composite graph in figure 5.

Figure 6 shows the spread of data for the threshold level test. The chart shows in U/D ratio derived from the individual receiver threshold levels which varied by about 20 dB. Note that the levels of undesired signal vary as much as 60 dB.

Figure 7 shows the spread of data for a desired signal of -47 dBm (shown on the graph as D) and the dark line. Absolute level (in dBm) is shown

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[4]ANSI/IEEE Standard 185-1975 "IEEE/IHF Standard Methods of Testing Frequency Modulation Broadcast Receivers."

on the left edge and U/D ratio is shown on the right. The numbers at the top of two columns indicate the number of data points that exceeded 0 dBm. Note that the U/D ratio spread exceeds 40 dB in a few cases.

Figure 8 shows the spread of data for a desired signal level of -37 dBm. Note that few data points fall below 0 dB U/D.

Figure 9 shows the spread of data for a desired signal level of -27 dBm. Note that nearly one-fourth of the data points fall below 0 dB U/D.

VI. EFFECT OF TV CHANNEL 6 AURAL CARRIER

During the test series two of the receivers were tested using a simulated television channel 6 aural carrier in addition to the other test signal combinations. For this test two interfering signals were generated. One signal, simulating a channel 6 aural carrier, was set to 87.75 MHz and modulated with the tailored noise source for a deviation of 25 kHz p.p. The other signal representing an FM station was set to 98.5 MHz. The difference in frequency is only 50 kHz away from the 10.7 MHz rather than the 100 kHz produced when both interfering signals are FM stations. This places the interfering signal closer to the receiver IF frequency and produces more interference. However, the channel 6 aural carrier is modulated to only 25 kHz p-p deviation which produces less interference. The result is that interference generated by the channel 6 aural carrier will be greater than FM/FM combinations on misaligned receivers or those with broadly tuned IF stages but will be less on more precisely aligned and tuned receivers.

The results of the channel 6 aural carrier test are shown in figure 10 in which the median value of the two receivers tested are plotted. One set of data points represents FM to FM interference and the other TV/6 to FM. There appears to be little difference between the two combinations in terms of interference potential.

A compilation of the raw data from all tests is shown in figure 11.

VII. RECEIVER TUNING EFFECTS

During the receiver tests it was noted that interference levels at U/D ratios that produce significant degradation also affect the ability of automatic scan radios to operate properly. One of the effects of the IF interference mechanism is to produce an apparent increasing noise level across the FM band. This appears to the receiver as an apparent signal which stops the automatic scan system in the receiver at each channel whether a station is present or not. As long as the two stations causing the IF intermodulation effect are present, and above the level which causes some interference, the receiver scan systems will not operate properly. Stations can still be received with more or less interference (depending upon their relative signal strength) but the receiver scan function will not perform properly.

VIII. SUMMARY AND CONCLUSIONS

It is apparent that many new FM broadcast receivers exhibit very high immunity to IF interference while others are quite susceptible especially at higher signal levels. Because of the non-linear effect of degradation, a few dB change in interference level can cause a substantial change in quality of the desired signal. Therefore, use of median values should be avoided when applying this information to allocation proceedings.

The presence of a channel 6 television station must also be taken into account when applying the FM-IF taboo.

There is a difference in degradation between a single interfereing station off-set in frequency from the desired station by 10.6 or 10.8 MHz and two stations apart from the desired station but separated in frequency by 10.6 or 10.8 MHz. The two interfering station combination creates more interference. (See footnote #1).

The wide range in performance suggests that the manufacturers of FM broadcast receivers could give more attention to the design of the RF and IF stages with the end result being less interference susceptibility, better performance and the elimination, or substantial reduction in influence of the FM-IF taboo.

The wide range in performance also requires that the allocation process take into account receivers which are less immune to interference so that an undue amount of interference is not created to large numbers of the listening public.

Finally, the receivers tested represented only a small protion of the range of receiver types, makes and quality levels. Further, more exhaustive testing may need to be conducted in order to better understand the potential for, and subjective effect of, FM IF interference.

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FM IF INTERFERENCE TEST
EQUIPMENT LIST

Boonton Model 102D (Gen #1)

Boonton Model 102B (Gen #2)

Boonton Model 103D (Gen #3)

Tektronix 7114 Spectrum Analyzer

Realistic Model 31-2009 Graphic Equalizer

Tru-spec Model DSU-2 RF Combiners

Macom Model BMT-12 RF Tap

CBS Technology Center Stereo FM Signal Generator

H-P Model 200CD Audio Generator

Tektronix Model AA-5001 Audio Analyzer

Digimax Model D-1200 Frequency Counter

KAY Model 449A RF Attenuator (0-70db, 1db steps)

FIGURE 1

TEST BED FOR

FM-IF INTERFERENCE TESTS

Prepared for FCC Docket 86-144

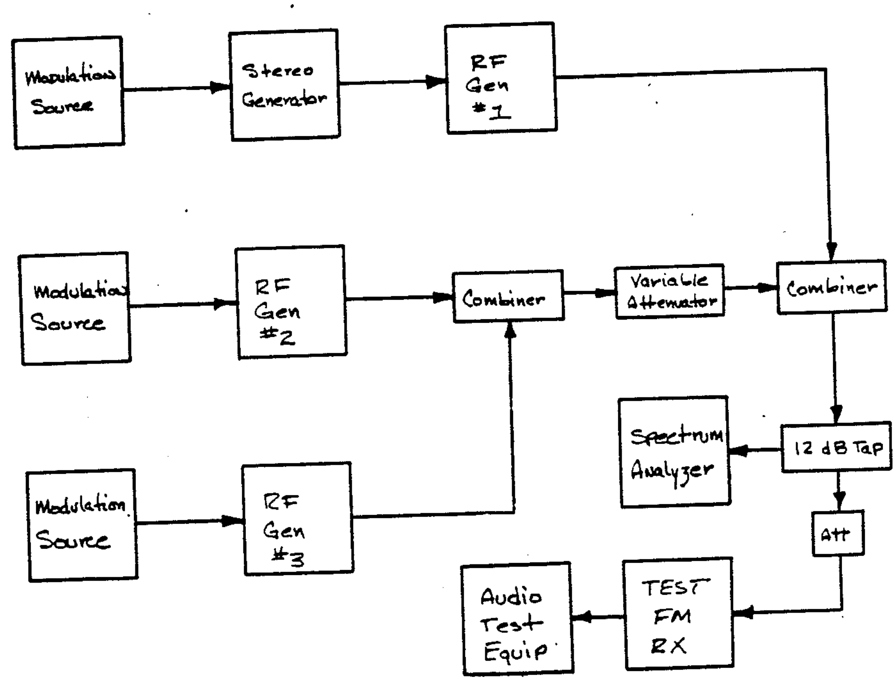

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FIGURE 2

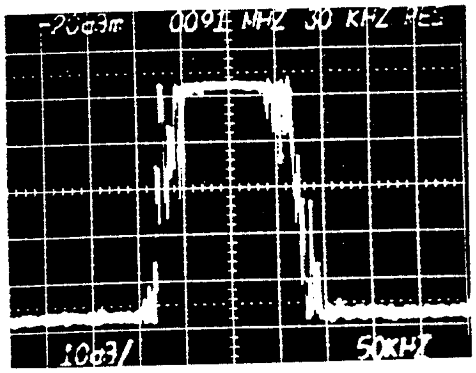


Figure 3a

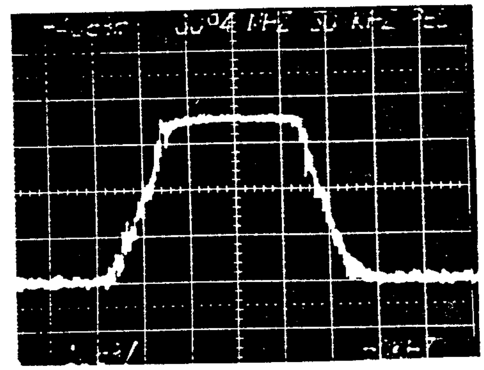


Figure 3b

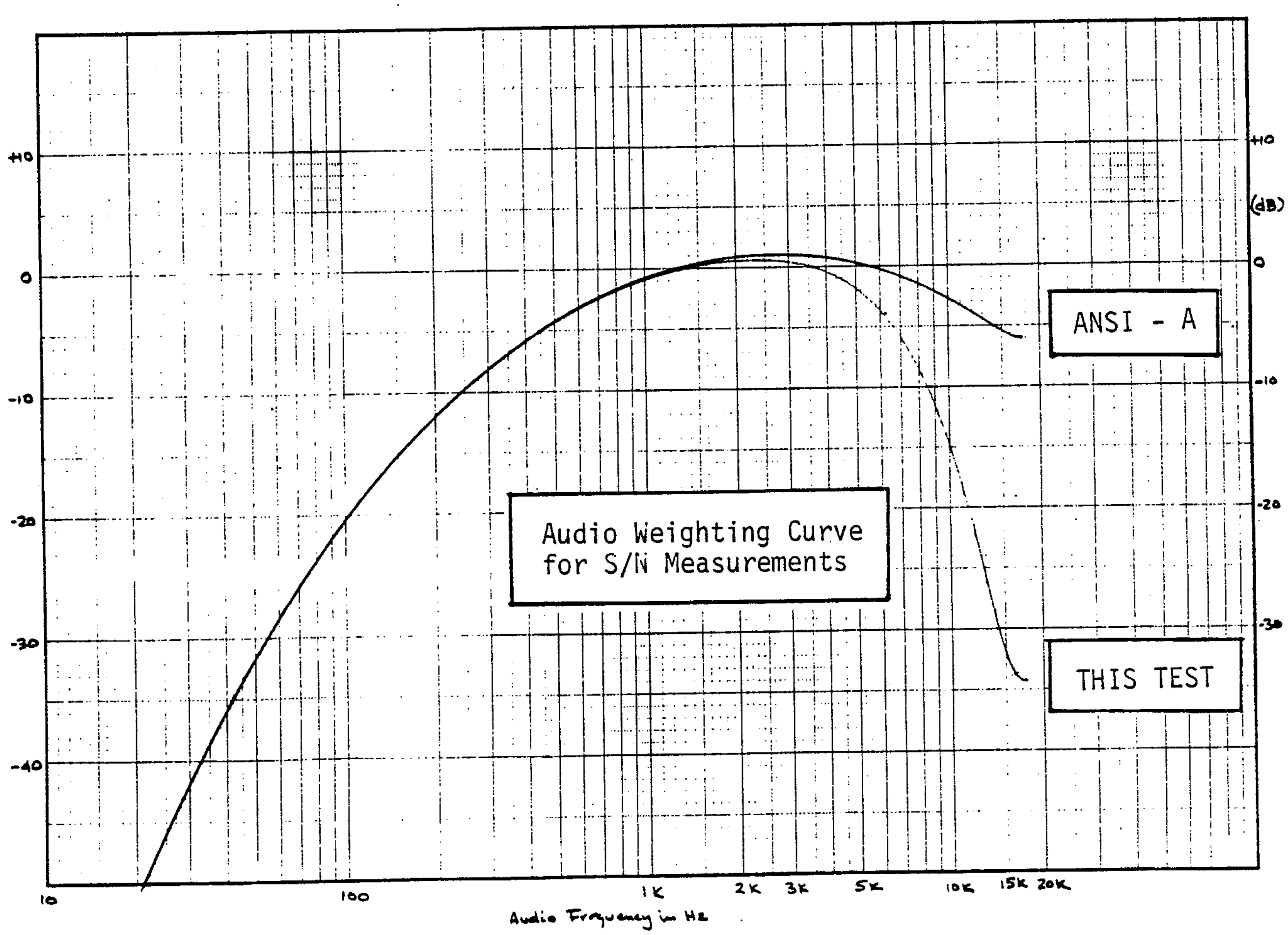


Figure 3c

Figure 4

Test Frequencies to Produce FM-IF

t_1 = 92.1; t_2 = 102.7 or 102.9 MHz

$t_1 - t_2$ = 10.6 or 10.8 MHz

Received (Desired) Frequencies

f_1 = 89.7 MHz

f_2 = 95.9 MHz

f_3 = 101.5 MHz

f_4 = 105.5 MHz

Received (Desired) Signal Levels

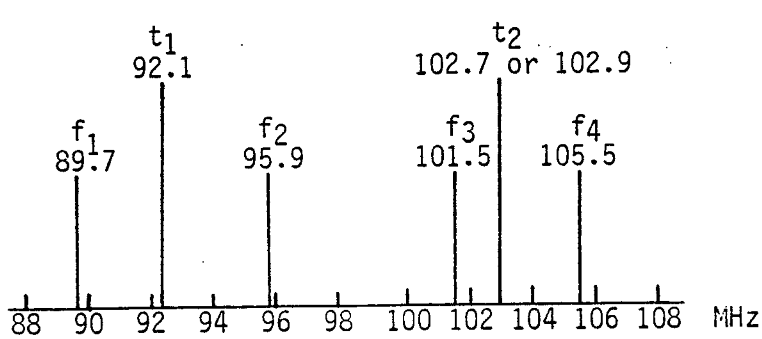
D_T = Threshold to produce 50 or 56 dB s/n (weighted)*

D_2 = -47 dbm at antenna terminals (70 dBu)

D_3 = -37 dBm at antenna terminals (80 dBu)

D_4 = -27 dBm at antenna terminals (90 dBu)

* or maximum s/n achievable



Relationship of Various Test Frequencies

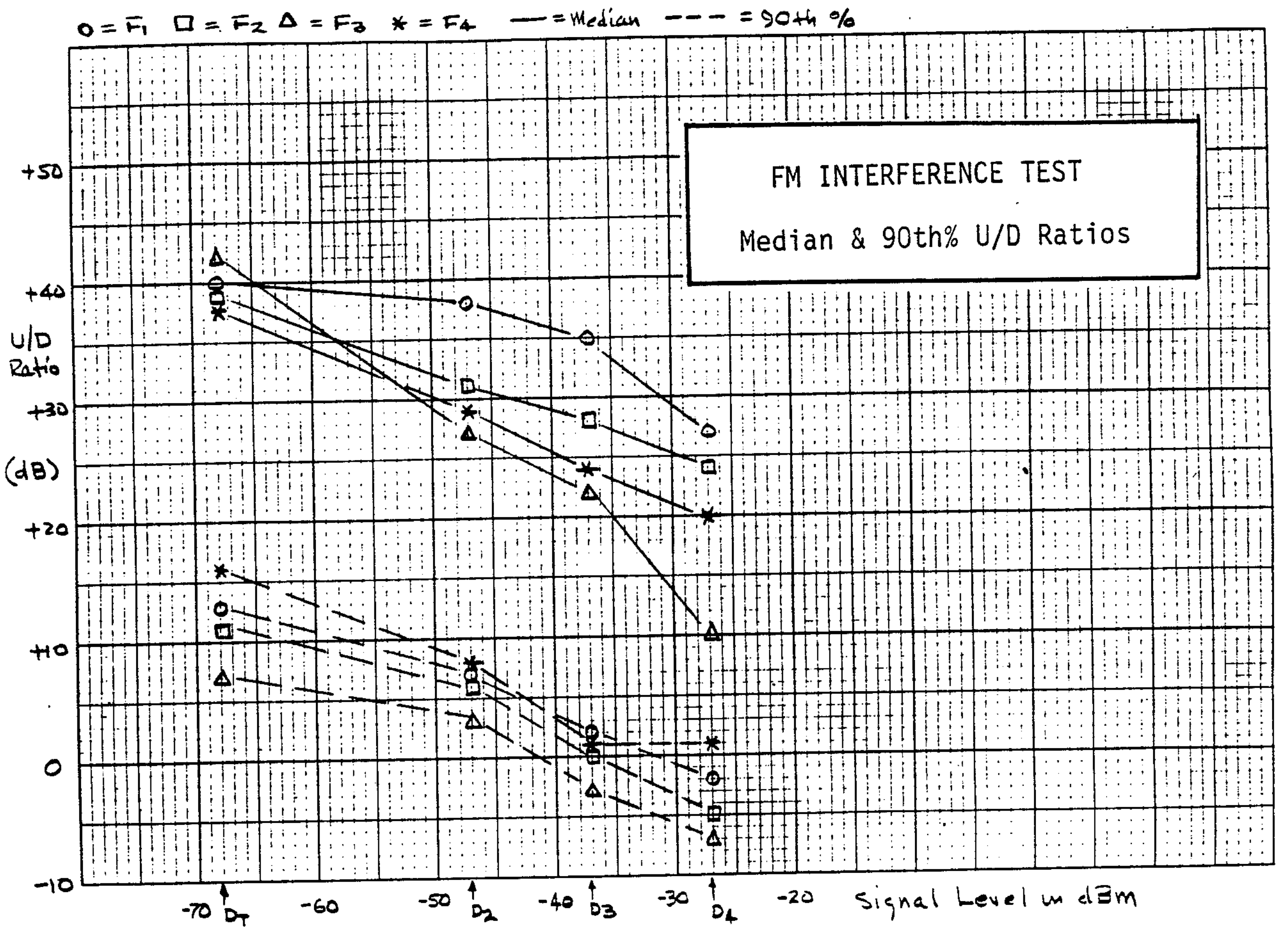
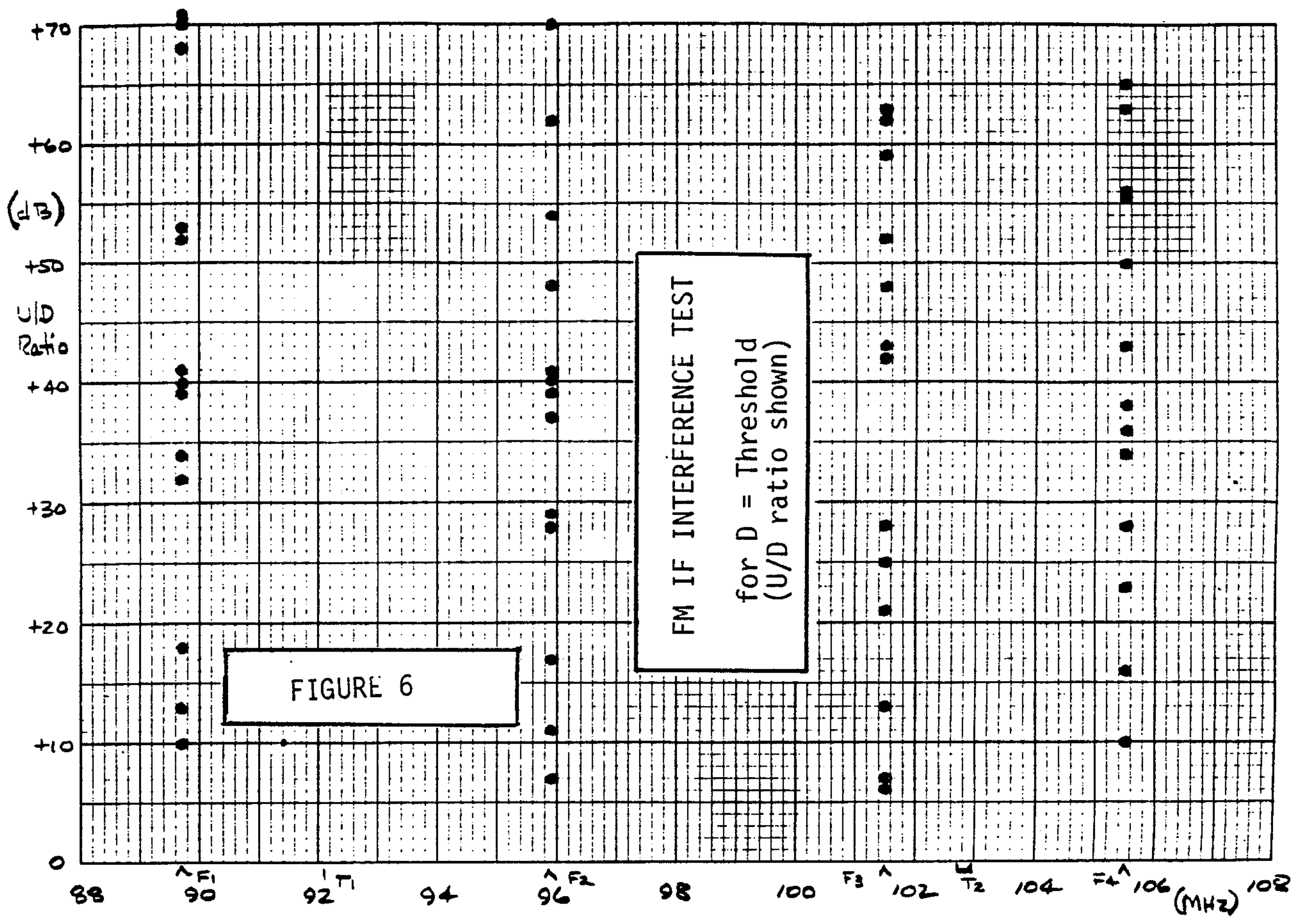

o = F1 □ = F2 Δ = F3 * = F4 —— = Median - - - = 90th %
FM INTERFERENCE TEST
Median & 90th% U/D Ratios
U/D Ratio (dB)
+50
+40
+30
+20
+10
0
-10
-70
D_T
-60
-50
D2
-40
D3
-30
D4
-20
Signal Level in dBm

FIGURE 5


FM IF INTERFERENCE TEST
for D = Threshold
(U/D ratio shown)
FIGURE 6
U/D Ratio (dB)
+70
+60
+50
+40
+30
+20
+10
0
88
90
92
94
96
98
100
102
104
106
108
(MHz)
F1
T1
F2
F3
T2
F4

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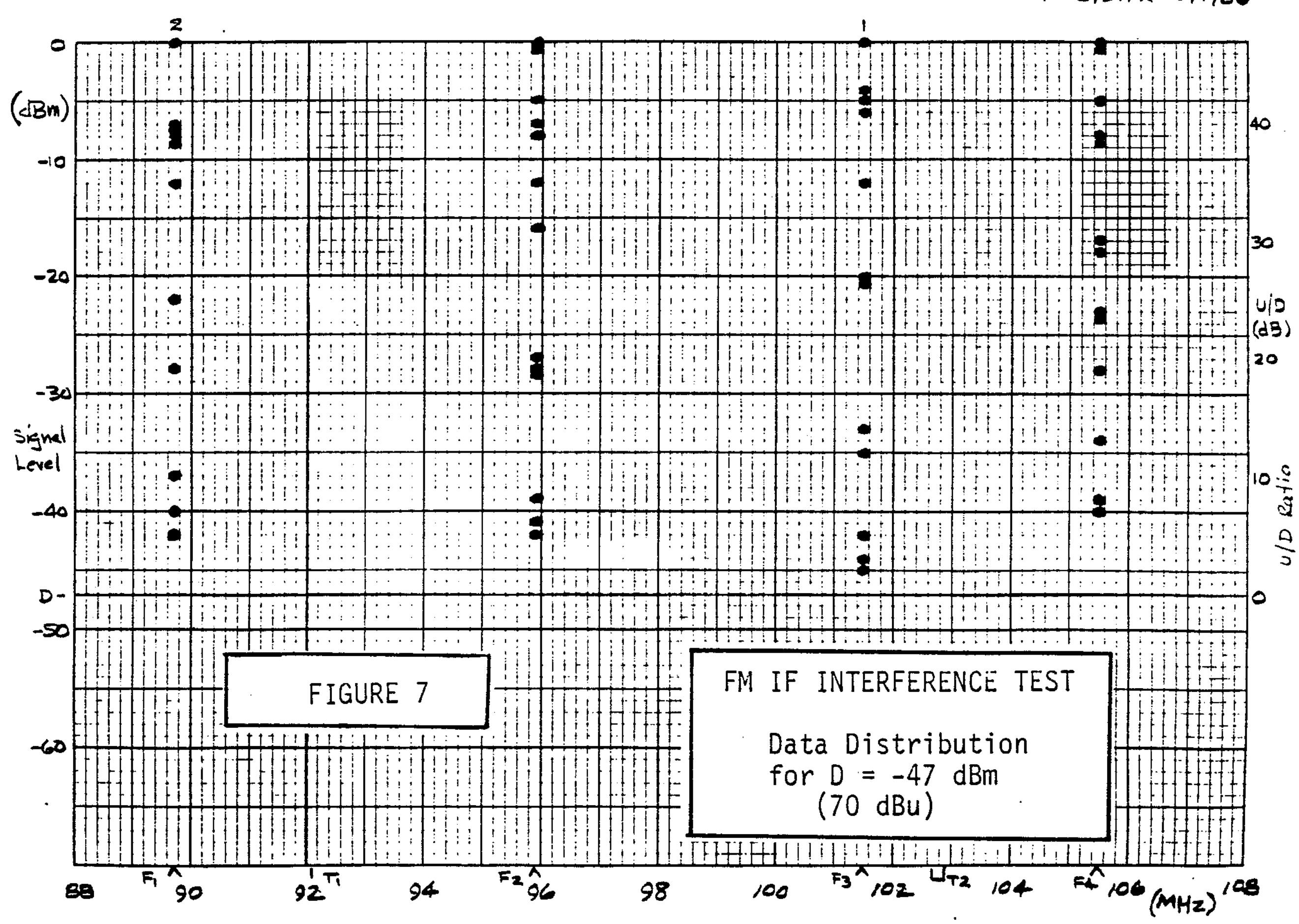
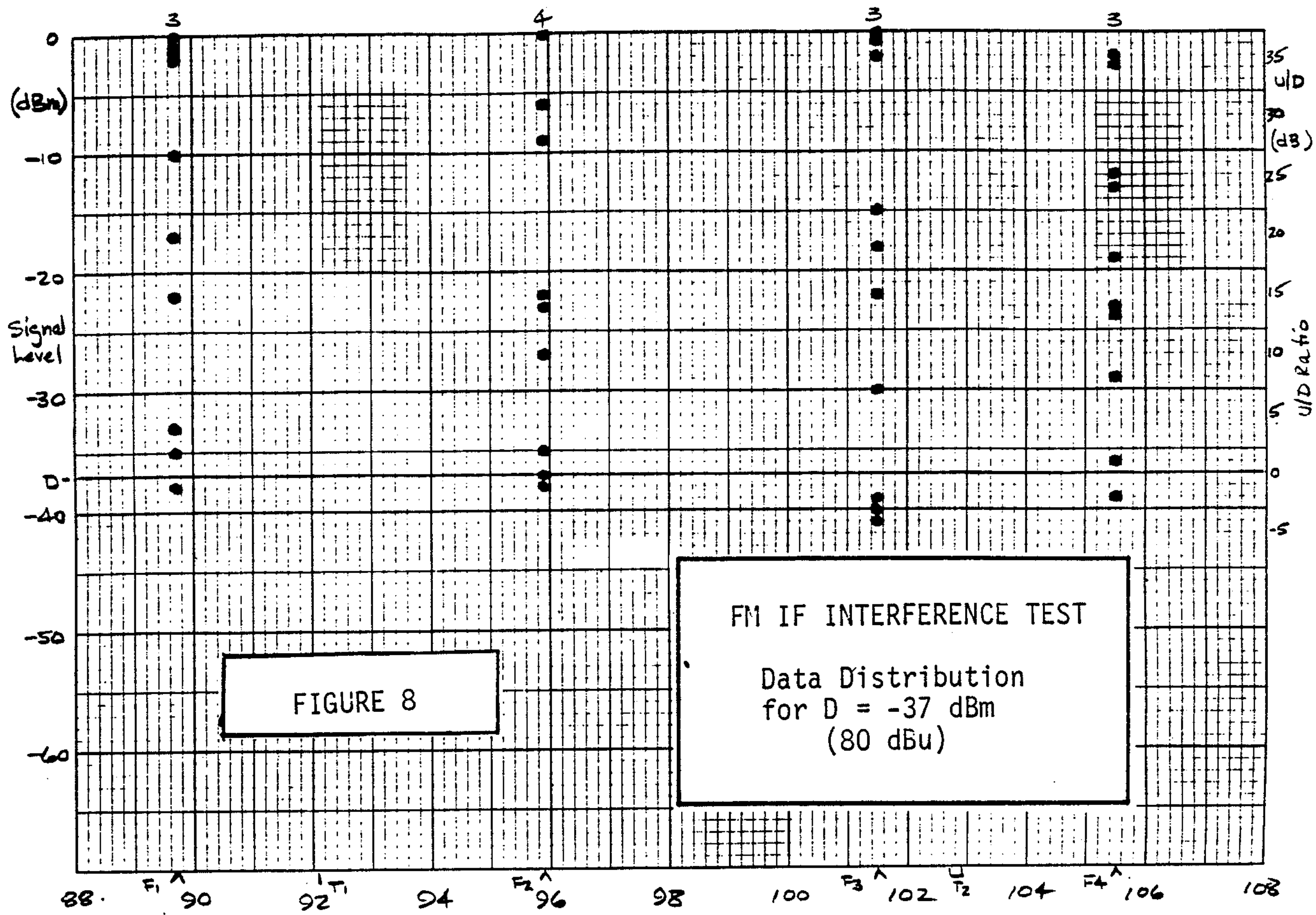


FIGURE 7
FM IF INTERFERENCE TEST
Data Distribution
for D = -47 dBm
(70 dBu)
Signal Level (dBm)
0
-10
-20
-30
-40
D-
-50
-60
U/D (dB)
40
30
20
10
0
U/D Ratio
2
1
88
90
92
94
96
98
100
102
104
106
108
(MHz)
F1
T1
F2
F3
T2
F4


FM IF INTERFERENCE TEST
Data Distribution for D = -37 dBm (80 dBu)
FIGURE 8
Signal Level (dBm)
U/D Ratio (dB)

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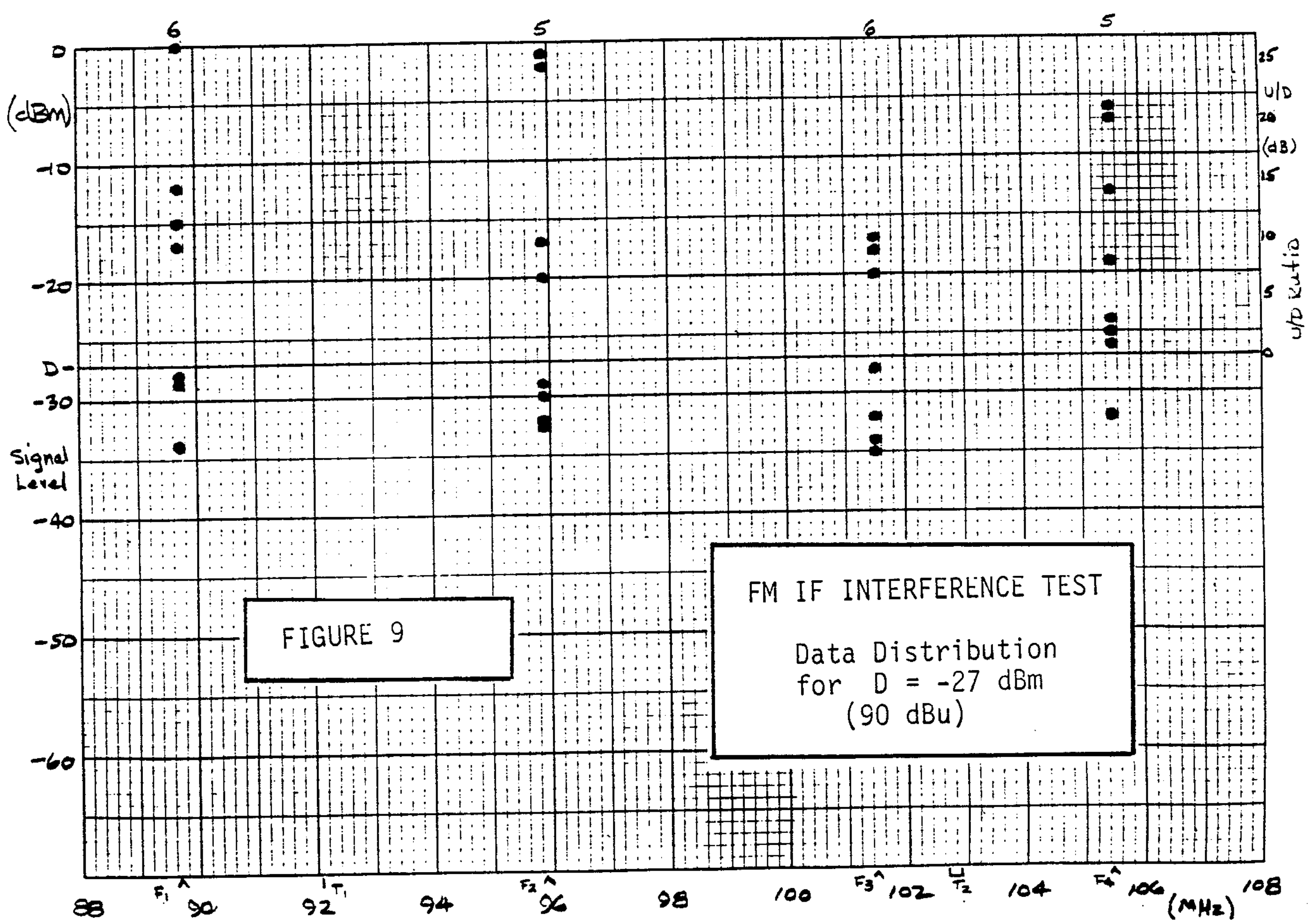
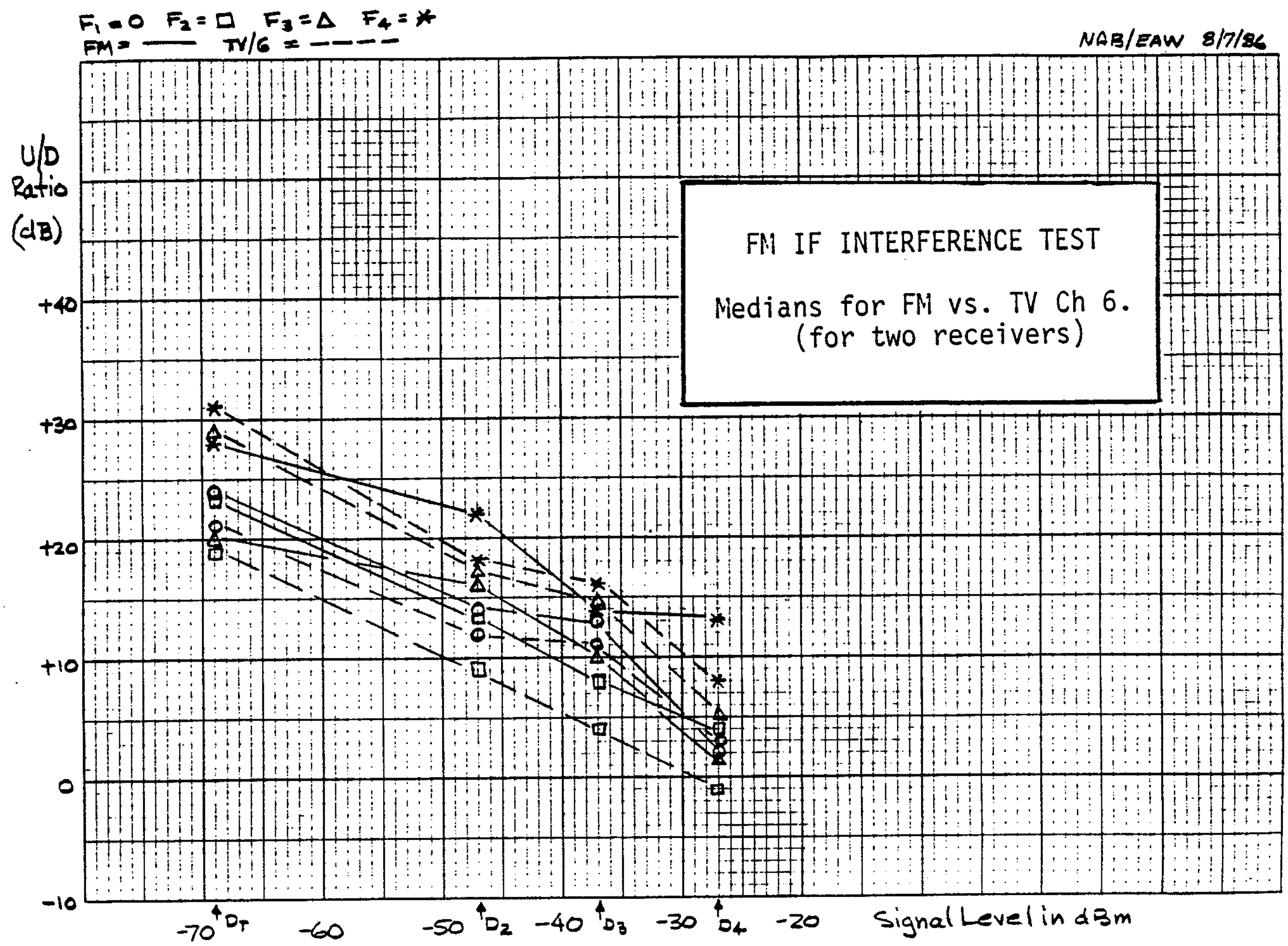

FM IF INTERFERENCE TEST
Data Distribution for D = -27 dBm (90 dBu)
FIGURE 9
Signal Level (dBm)
U/D Ratio (dB)
(MHz)



F1 = O F2 = □ F3 = Δ F4 = *
FM = —— TV/6 = - - - -
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U/D Ratio (dB)
+40
+30
+20
+10
0
-10
-70 D1 -60 -50 D2 -40 D3 -30 D4 -20
Signal Level in dBm
FM IF INTERFERENCE TEST
Medians for FM vs. TV Ch 6.
(for two receivers)

FIGURE 10

FM-IF RECEIVER TEST DATA SHEET

(All levels shown in dBm)

#	F	THRESH	DT	D2(-47)	D3(-37)	D4(-27)	Notes
RX #1	**Portable - Monophonic**						
F1	89.7	-70	-22	-12	-10	-15	monopole antenna
F2	95.9	-75	-36	-27	-27	-30	max s/n 45dB
F3	101.5	-73	-25	-20	-18	-18	10.6 MHz offset
F4	105.5	-76	-26	-23	-23	-25	mech tuning
RX #2	**Hi Fi Tuner**						
F1	89.7	-66	-27	-7	0	> 0	75 ohm input
F2	95.9	-67	-30	-7	> 0	> 0	Tuner only - stereo
F3	101.5	-68	-25	-6	0	> 0	equal offset (10.6)
F4	105.5	-67	-31	-18	-13	-7	Elec tuning
RX #3	**Full AM-FM Receiver**						
F1	89.7	-68	-34	-22	-17	-12	300 ohm input
F2	95.9	-70	-42	-28	-23	-20	10.8 MHz offset
F3	101.5	-70	-49	-35	-30	-28	mech tuning
F4	105.5	-70	-42	-28	-23	-19	
RX #4	**Hi Fi Tuner**						
F1	89.7	-65	-48	-40	-35	-28	300 ohm input
F2	95.9	-67	-50	-39	-35	-29	10.8 MHz offset
F3	101.5	-67	-54	-42	-39	-34	Elect tuning
F4	105.5	-67	-44	-34	-29	-24	
RX #5	**Auto Radio**						
F1	89.5	-70	-38	-28	-22	-17	Top of Line with tape deck and AM stereo
F2	95.9	-69	-38	-28	-22	-17	
F3	101.5	-70	-42	-20	-15	-20	Elec tuning
F4	105.5	-69	-35	-23	-19	-13	
RX #6	**Auto Radio**						
F1	89.5	-66	-26*	-8	0	>0	* Same level as for adjacent channel intermodulation
F2	95.9	-66	-26*	-8	0	>0	
F3	101.5	-67	-25*	-12	>0	>0	equal offset (10.8)
F4	105.5	-68	-25*	-5	>0	>0	elec tuning
RX #7	**Portable - Stereo**						
F1	89.5	-49	-39	-37	-33	-28	Monopole antenna
F2	95.9	-51	-44	-42	-37	-32	stereo plus AM stereo
F3	101.5	-51	-45	-44	-41	-32	mech tuning
F4	105.5	-53	-43	-40	-39	-31	

FIGURE 11

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FM-IF RECEIVER TEST DATA SHEET
(All levels shown in dBm)

#	F	THRESH	DT	D2(-47)	D3(-37)	D4(-27)	Notes
RX #8	Full AM-FM Receiver						
F_1	89.7	-72	-27	-8	0	>0	300 ohm input
F_2	95.9	-70	-32	-16	-9	-1	10.6 MHz offset
F_3	101.5	-70	-45	-33	-22	-17	
F_4	105.5	-70	-32	-17	-12	-6	
Rx #9	Portable Stereo						
F_1	89.7	-57	-44	-42	-38	-34	"Boombox" small
F_2	95.9	-60	-49	-41	-37	-32	monopole antenna
F_3	101.5	-60	-53	-45	-40	-35	10.6 MHz offset
F_4	105.5	-61	-45	-39	-36	-32	
RX #10	Auto Radio						
F_1	89.7	-69	>0	>0	>0	>0	Regular model
F_2	95.9	-68	-14	-5	0	>0	Electuning
F_3	101.5	-68	-5	>0	>0	>0	
F_4	105.5	-68	-5	0	>0	>0	
Rx #11	Auto Radio						
F_1	89.7	-72	-4	>0	>0	>0	Delux Model
F_2	95.9	-72	-16	0	>0	>0	Elec tuning
F_3	101.5	-71	-9	0	>0	>0	
F_4	105.5	-71	-6	0	>0	>0	
Rx #12	Auto Radio						
F_1	89.5	-64	-12	-8	-2	0	Delux model
F_2	95.9	-66	-26	-12	-6	-2	Elect tuning
F_3	101.5	-67	-8	-5	-2	>0	
F_4	105.5	-66	-10	-8	-2	>0	
Rx #13	Auto Radio						
F_1	89.5	-73	-2	0	>0	>0	Includes AM Stereo
F_2	95.9	-73	-2	0	>0	>0	Elect Tuning
F_3	101.5	-73	-21	-5	0	>0	
F_4	105.5	-74	-18	-8	-2	>0	
Rx							
F_1	89.5						
F_2	95.9						
F_3	101.5						
F_4	105.5						

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FM-IF RECEIVER TEST DATA SHEET
(with Ch-6 Aural Carrier)

#	F	THRESH	DT	D2(-47)	D3(-37)	D4(-27)	Notes
RX #4		Hi Fi Tuner					
F1	89.7	-65	-52	-40	-35	-30	used for Ch-6 Test also
F2	95.9	-67	-56	-43	-38	-33	
F3	101.5	-67	-44	-34	-28	-23	
F4	105.5	-67	-39	-27	-22	-18	manual tuning
RX #5		Auto Radio					
F1	89.7	-70	-41	-31	-27	-21	Elec tuning used for Ch-6 Test also
F2	95.9	-69	-43	-33	-28	-23	
F3	101.5	-70	-35	-25	-19	-15	
F4	105.5	-69	-35	-23	-20	-13	
RX							
F1	89.7						
F2	95.9						
F3	101.5						
F4	105.5						
RX							
F1	89.7						
F2	95.9						
F3	101.5						
F4	105.5						
RX							
F1	89.5						
F2	95.9						
F3	101.5						
F4	105.5						
RX							
F1	89.5						
F2	95.9						
F3	101.5						
F4	105.5						
RX							
F1	89.5						
F2	95.9						
F3	101.5						
F4	105.5						

(All levels shown in dBm)

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NRSC Document Improvement Proposal

If in the review or use of this document a potential change appears needed for safety, health or technical reasons, please fill in the appropriate information below and email, mail or fax to:

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