ANALYSIS OF IBOC DAR SYSTEM PROPOSALS

Introduction

A wealth of information has been learned over the past three years through the laboratory testing of the In-Band-On-Channel (IBOC) Digital Radio Systems. These IBOC systems transmit the digital signal in the upper and lower first adjacent channels and are intended to conform with the FCC Power Spectral Density (PSD) mask. The all industry sponsored laboratory tests were performed on three IBOC systems, USADR FM-1, AT&T Amati DSB, and AT&T/Amati LSB. The laboratory tests revealed major digital transmission impairment problems and incompatibilities with the FM analog service for all three systems. The two proposals reviewed in this paper address many of the problems identified in laboratory tests. The first proposal, a paper describing an improved version of the USADR FM-1 system, was presented at the ITU meeting in Spain, and the second proposal was presented at the National SBE Convention last fall (Westinghouse proposal). Significant details of both systems were presented in these papers. Both proposals are variations of the sideband IBOC systems tested in the DAR laboratory. Both proposals take into account system problems revealed in the industry sponsored DAR laboratory tests. Because the new proposal used the same basic in-band-on-channel transmission technique as the systems tested in the DAR laboratory, the laboratory test data can be used to predict the new systems performance.

I System Descriptions

Diversity Sideband IBOC Proposal (Westinghouse)

The complete digital signal is duplicated for each digital sideband. The system will operate on the alternate sideband when interference is present. To reduce digital interference to the analog host or adjacent channel analog signals, the digital power is reduced 6 to 10 dB below the level used for the tested FM-1 system. The two independent digital modulated channels (sidebands) start at a frequency ±100 kHz removed from the channel center frequency and extend to ±200 kHz from the channel center frequency. Stereo audio source coding rate of 96 kbps, and a channel coding rate of 192 kbps is used. A system of time diversity and switch to time delayed analog FM is intended to reduce the effect of in-motion multipath. Because the two signals are not transmitted at the same time, short multipath events effecting the digital signal will be hidden by the switch to the analog FM stereo. The probability of both channels being effected by multipath at the same time is low. It is clear that for this system to operate, the same program must be transmitted on the analog and digital channels. This is a new feature. Figure 1 is a plot of FM-1 with the new system overlaid.

Diversity Sideband IBOC Proposal (USADR ITU paper)

As with the Westinghouse proposal the complete digital signal is duplicated in each sideband. The system will operate on the alternate sideband when 1st and/or 2nd adjacent interference is present. To reduce digital interference to host FM, the two independently modulated digital signals start at ±129 kHz and extend ±200 kHz from the FM channel center frequency. This avoids the 114 kHz interference band described in the compatibility section (II) of this paper. To further reduce interference to the adjacent analog channels, the power of the independent sidebands will be determined by a compromise between digital coverage and adjacent channel interference. Figure 2 is a plot of AT&T/Amati System with the proposed system overlaid.

USADR FM-1 (Lab Tested)

The composite DAR/FM signal in this IBOC system is intended to conform to the FCC PSD masks. The FM-1 stereo audio source coding rates vary from a minimum of 128 kbps to a maximum of 256 kbps on a frame-by-frame basis. The FM-1 IBOC system uses 48 spread spectrum data subchannels. The data rate for each channel is 8 kbps, for a total of 384 kbps. The symbol duration is 125 microseconds. For this system 48 subchannels are used. In addition, a 49th subchannel is transmitted as a training signal for multipath equalization.

The IBOC digital signal is located in a 100 kHz wide sideband that runs from 120 kHz to 220 kHz above and below the FM channel center frequency for a total composite channel bandwidth (3 dB) of 440 kHz. The digital signal average power was set at 15 dB below the host FM for the laboratory tests. Figure 3 is a spectrum analyzer plot of this system's composite baseband signals.

AT&T/Amati/Lucent Technologies (DSB)

The composite DAR/FM signal in the AT&T/Amati IBOC System is intended to conform to the FCC PSD masks. Digital audio coding is provided by the AT&T Perceptual Audio Coder (PAC) which provides a 160 kbps digital signal for a stereo audio channel. The IBOC signal uses discrete multitone or COFDM modulation. The subcarrier spacing is 4 kHz. The symbol duration is 250 microseconds with 32 subcarriers using differential 4-phase modulation.

The digital signal is located in a 73.5 kHz wide sideband that runs from 126.5 kHz to 200 kHz above and below the FM channel center frequency. The total composite bandwidth is 400 kHz. The signal average power was set at 15 dB below the host FM. Figure 4 is a spectrum analyzer plot of the AT&T/Amati signal.

AT&T/Amati/Lucent Technologies (LSB)

The second IBOC system proposed by AT&T/Amati was a single sideband IBOC system. By placing the complete digital signal on one sideband, this system is intended to work in situations where 1st adjacent channel interference is present on the alternate sideband. The equipment that was delivered to the DAR laboratory for testing was capable of operating in three modes, Double SideBand (DSB), Lower Sideband (LSB), or Upper Sideband (USB). The system was tested in the DSB and LSB modes. In Lower SideBand (LSB) mode the digital signal is transmitted in a single 73.5 kHz wide sideband that runs from 126.5 kHz to 200 kHz below the FM channel center frequency. The total composite bandwidth is 300 kHz. The signal average power was set at 24 dB below the host FM. The IBOC signal uses discrete multitone or COFDM modulation. In the LSB or USB modes, 18 subcarriers with 8-phase modulation is used. Digital audio coding is provided by the AT&T Perceptual Audio Coder (PAC) which operates at 128 kbps for the stereo audio digital channel. Figure 5 is a spectrum analyzer plot of the AT&T/Amati signal.

II. Compatibility for Proposed System

D -> Host Analog

Several different forms of decoding circuits have been used for decoding FM stereo. In practice the PLL stereo decoder has become the norm. Because the PLL stereo decoder uses square wave switching, this circuit will demodulate baseband signals which are at the odd harmonics of 38 kHz (3 X 114 kHz and 5 X 190 kHz). These frequencies are in the band used for the transmission of IBOC digital signals. Without special receiver circuitry (114 kHz LP filters or Walsh function PLL decoder), the stereo decoders will detect the IBOC digital signal as noise. To further understand this phenomena, a special receiver test was conducted at the DAR laboratory without the need of a DAR signal. The tests were designed to determine which receivers were sensitive to the digital signal at 114 kHz, and compare those results with the results of the IBOC tests. For the first part of the tests a CW subcarrier was added to the FM signal at 113 kHz with 10% injection, and the receiver audio output noise measured. The subcarrier was offset from the odd harmonics of 1 kHz, so that receivers sensitive to these frequencies would produce a beat 1 kHz tone. Auto receivers #1 and #5 showed little change in S/N with either the 113 kHz tests or the IBOC signals. These receivers employed the Walsh function decoders. Receivers #2, #3, and #4 did not employ Wash function decoders or 114 kHz baseband filters and exhibited a large increase in audio noise with the 113 kHz subcarrier and the IBOC systems. The results of these laboratory tests are shown in Table 1.

Table 1.	IBOC DAR -> Host FM RMS Noise Signal Level -47 dBm				
Receiver	Type Radio	S/N FM Only Reference	S/N 114 kHz Test	S/N AT&T/Amati DSB	S/N USADR FM-1
1. Delco 161924463	Auto	60.0 dB	No Change	60.7 dB	60.3 dB
2. Denon TU-280RD	Hi-Fi High End	68.0 dB	34.0 dB	50.0 dB	44.9 dB
3. Panasonic RX-PS430	Stereo Portable	67.5 dB	33.6 dB	44.2 dB	42.0 dB
4. Pioneer SX-201	HI-Fi	66.0 dB	33.1 dB	40.0 dB	39.2 dB
5. Ford F4XF-19B132-CB	Auto	65.0 dB	No Change	64.0 dB	62.7 dB

Additional IBOC to Host Lab Tests

The first additional test was designed to compare the receiver sensitivity to interference at 114 kHz, to the sensitivity at 190 kHz. The test was the Denon TU-380 (RBDS) home Hi-Fi receiver. This tests were conducted in two modes and at two frequencies: the first using a single subcarrier at 113 kHz and 189 kHz and the second using a single transmitter separated from the main carrier by -113 kHz and -189 kHz. The results of this test revealed that this radio's sensitivity to this interference at the two frequencies is within 2 dB or less, depending on the transmission mode.

The TU-380 receiver was selected because it was the PLL receiver least sensitive to the IBOC digital noise during the DAR laboratory tests (Table 1.).

The second additional test was designed to further investigate this interference. If the above tests are accurate, it would follow that the frequency band between the two sensitive frequencies, less 15 kHz for (L-R) audio modulation, should be free of PLL stereo decoder interference. This frequency band is centered at 152 kHz with a bandwidth of no more than 46 kHz. This test used the Denon TU-360 receiver and a separate CW transmitter operating at a frequency -152 kHz below the FM channel center frequency. The CW signal did not effect the receiver S/N ratio. FM Modulation with +/- 20 kHz deviation was then applied to the transmitter. This resulted in an RMS S/N of 61 dB on the TU-360 receiver, 23 dB better than the tests with the CW signals at 113 kHz and 114 kHz. See Appendix 1 for test details.

The DAR tests have shown that receivers with un-filtered PLL stereo decoders have two 30 kHz wide bands of frequencies (centered at 114 kHz and 190 kHz) that are sensitive to interference. This test revealed that these bands are nearly equal in sensitivity to interference.

Figure 4 shows a plot of the AT&T/Amati IBOC signal, and Figure 3 the FM-1 systems. The digital PSD for both systems is shown. The 114 kHz and 190 kHz PLL receiver sensitive bands are noted on the upper sidebands. The AT&T/Amati plot (Figure 4.) shows that at 114 kHz the digital signal is down by 23 dB, and at 190 kHz the digital signal is at full amplitude. It can also be seen on the FM-1 plot (Figure 3) that the 114 kHz digital signal is 10 dB down, and the 190 kHz is at full amplitude. The results of the digital -> host analog test (Table 1.) show that even if the system avoided the 114 kHz band, the system had similar noise increase. It can be concluded that for the Amati/AT&T System the 190 kHz frequency band was the major contributor to the noise floor increase.

Diversity Sideband to Host Analog (Westinghouse Proposal)

This proposal substantially changes the frequency spread and power level of the digital sideband signal's. The power is reduced by 6 to 10 dB below the FM-1 levels. The digital signals frequency would be transmitted in two bands 100 kHz wide and run from 100 kHz to 200 kHz above and below the channel center frequency. It can be seen from the results of the above test that many of the compatibility advantages of the proposed digital power reduction may be offset by the transmission of a full amplitude digital signal at 114 kHz.

Diversity Sideband to Host Analog (ITU Proposal)

To avoid noise this proposal avoids the 114 kHz band by starting the digital signal at 129 kHz and running it up to 200 kHz above and below the carrier. This avoids the 114 kHz band but transmits a full level signal at 119 kHz. The compatibility tests show that the receivers are also sensitive to the 190 kHz band and avoiding only the 114 kHz band will not solve the IBOC digital -> to host analog compatibility problem.

III. Adjacent Channel Performance

First Adjacent A -> D (Westinghouse Proposal)

The major interferer for the sideband IBOC digital signal is the first adjacent analog. The FCC protects the FM station with a D/U of 6 dB (desired 6dB above undesired). This system proposes to set the digital signal power 21 to 25 db below the FM. The FM-1 and AT&T/Amati DSB laboratory tests were conducted at power level 6 to 10 dB higher than the proposed power. For comparison the A -> D first adjacent of 23 dB D/U at TOA will be used. This was the best first adjacent measured in the laboratory (AT&T/Amati DSB). To reduce the power will increase the D/U to a range of 29 to 33 dB without multipath. These D/U ratios exceed the FCC figures by 23 to 27 dB.

Second Adjacent D -> D (Westinghouse Proposal)

Because the sideband IBOC systems occupy a 400 kHz composite channel, the second adjacent FM station D/U criteria is in reality a digital first adjacent problem. This means that the IBOC systems will have to exist in an established FM second adjacent environment with D/Us of up to -40 dB. Both IBOC proposals have eliminated the FM-1 overlap by moving the digital signal within the outer edge of the first adjacent channel (200 kHz). In the laboratory tests the AT&T/Amati System had the best second adjacent performance without multipath, -17.5 dB at TOA, and -21 dB at POF. With multipath the system's susceptibility to second adjacent interference will be significantly increased.

D -> Adjacent Channel FM (Westinghouse Proposal)

The 6 to 10 dB reduction in the digital sideband power will reduce the interference to the first and second adjacent channels. The change in interference is receiver dependent. The calculated changes in interference to the first adjacent channel for each receiver are shown in Table 2.

The AT&T/Amati System is used for the adjacent channel calculations because its interference into the adjacent channel is similar in the Westinghouse proposal. The calculated changes in interference to the second adjacent channel for each receiver are shown in Table 3.

Table 2. First Adjacent (Westinghouse Proposal)
Digital -> Analog

Receiver	AT&T/Amati more sensitive to interference in D/U (reference) (Ref/System)	Calculated Westinghouse -21 dB SB power (Ref/System)	Calculated Westinghouse -25 dB SB power (Ref/System)
Delco	15 dB Non-Linear	9 dB	3 dB
Denon	10 dB Linear	4 dB	0 dB
Panasonic	2 dB Linear	0 dB	0 dB
Pioneer	4 dB Linear	0 dB	0 dB
Ford	26 dB No Test	20 dB	16 dB

Table 3. Second Adjacent (Westinghouse Proposal)
Digital -> Analog

	AT&T/Amati more sensitive to interference in D/U (reference) (Ref/System)	Calculated Westinghouse -21 dB SB power (Ref/System)	Calculated Westinghouse -25 dB power (Ref/System)
Delco	0 dB Linear	0 dB	0 dB
Denon	10 dB Slight NL	4 dB	0 dB
Panasonic	15 dB Linear	9 dB	5 dB
Pioneer	12 dB Linear	6 dB	2 dB
Ford	15 dB No Test	9 dB	5 dB

IV. Composite Digital Signal Performance

Westinghouse Proposal

With the bandwidth of the signal limited to 100 kHz and the reduction of the digital signal power by 6 to 10 dB, the coverage area, immunity to multipath, and the immunity to analog interference will be reduced. With the diversity proposal the complete stereo program signal is transmitted on three separate channels; lower digital sideband, upper digital sideband, and analog. Assuming the loss of one of the digital channels, the receiver will switch to the other digital channel. If both sidebands are interfered with, the receiver will switch to the FM analog channel. To cover the effects of switching from digital to analog, the quality of the FM analog channel will have to match the digital.

The audio processing for the FM analog audio channels will be significantly different than the ideal for digital. FM analog processing is designed to cover problems caused by pre-emphasis, noise, and system limited dynamic range. These problems will not be found in the digital channel. The use of the switch to analog to cover multipath problems or interference to the digital channel may be complicated by the different sound quality of the two transmission mediums. Compromises in processing the analog FM and digital channels to match the sound may prove to be the only solution. This would mean that the new digital service will sound just like the FM analog service.

V. FM Signal Levels and the Impact on the Proposed IBOC Systems

Introduction

To understand the environment the IBOC systems will have to operate in, measurements were made at several locations of FM broadcast signal levels throughout the 88-108 Mhz FM band. These measurements are to help determine existing spectrum occupancy with particular attention to signal ratios with varied signal adjacencies.

Methods

Measurements were made from a parked automobile with a 1/4 wave vertical antenna mounted on the roof (four feet above road). The FM receiver seek tuning mode was used for station selection. In the seek mode the receiver stopped for signals as low as -76 dBm at the receiver input. At this signal level the test receiver was in full blend (no stereo). Only the data from listenable signals was used (CCIR impairment level of 3, slightly annoying). Five representative graphs show the results of measurements at the five sites (Graph 2 through 6) selected from a field of 38 chosen to illustrate potential adjacent channel interference to IBOC digital reception in congested areas.

Discussion

The performance of IBOC DAB systems depends on the specific protection ratios for the first and second adjacent channels, as measured at the input terminals of the DAR receiver. Because FM band analog transmitting power levels are set by regulatory limits, analysis of band-wide signal level measurements at fixed locations will show the anticipated performance for DAB systems with adjacent channel interference.

Analysis

The following procedure is used for analyzing the performance of the proposed IBOC systems using the signal level RF measurements. The adjacent channel D/Us for the AT&T/Amati System are used for this analysis. Of the IBOC systems tested, this system was the least susceptible to adjacent channel interference and had the best IBOC measured performance characteristics.

Laboratory Test Results

1) first adjacent channel -- Without multipath the analog-to-digital laboratory tests measured a 23 dB D/U at TOA. Using the least aggressive multipath scenarios, the TOA D/U averaged 30 dB. With the proponents 6 dB power reduction, the first adjacent D/U is 36 dB for analysis.

2) second adjacent channel -- Without multipath the digital-to-digital laboratory

tests measured a -17.5 dB D/U at the TOA. With multipath factor added a -10 dB D/U is used for the analysis.

Table 4 shows the location of each test site, the number of FM stations listenable at each site, number of stations received with D/U that are out of FCC specifications, predicted number of digital signals received without interference, predicted number of digital signals received with one digital sideband, and number of receivers with interference on both digital sidebands (analog only). The letters in the table indicate receiver mode.

Receiver modes
A. Two digital and analog without interference
B. One digital and analog without interference
C. Analog only

Table 4. Number of stations

Site State	#FM stations received	Stations received with D/U outside FCC	Mode A Predicted number of stations received both sidbands & analog	Mode B Predicted Stations received in only one digital sidebands & analog	Mode C Predicted Stations with both sidebands interfered with (analog only)
1 VA	31	1	22	5	4
7 VA	35	4	23	8	4
10 MD	38	2	24	9	5
16 MD	47	14	23	17	7
10 NJ	47	25	13	25	9

VI Conclusions

Table 5 Conclusions

IMPAIRMENT	Westinghouse Proposal	UDADR ITU Proposal
Digital -> Host Analog Reference section II, page 3	Some improvement, but will not eliminate noise. Noise may not decrease linearly with digital power reductions.	Little change, system waveform is similar to AT&T/Amati waveform. Sideband power may be independently varied for coverage or interference.
Digital -> 1st Adj Analog Reference page 6 & Table 2	All interference reduced by 6 or 10 dB. First adj interference 9 dB worse than reference analog on Delco auto receiver. First adj interference 20 dB worse than reference analog on Ford auto receiver. Little to no interference on home receivers.	Little change, system waveform is similar to AT&T/Amati waveform. Interference should be similar to the AT&T/Amati interference listed in Table 2. Most adj channel interference should be found on narrowband auto receivers.
Digital -> 2nd Adj Analog Reference page 7 & Table 3	Improvement dependent on power reduction.	Little change, similar to AT&T/Amati. Four of the five receivers tested had 2nd adj interference from AT&T/Amati.
Analog -> 1st Adj Digital (Digital -> Digital 1st Adj similar problem) Reference page 5, section III	First adj analog is major interferer. Will force receiver diversity to operate. Sideband will require 29 to 33 dB D/U protection. FCC protection is 6 dB.	If power is reduced to protect adj station or improve compatibility, system will become more sensitive to first adj analog or first adj IBOC interference.
Analog -> 2nd Adj Digital Ref EIA DAR Lab Test Report	With a reduction in power, 2nd adj analog channel will become a problem for the desired digital signal.	Is a minor problem. If power is reduced second adj interference may be a problem.
Multipath Reference page 7, section IV	The diversity system is intended to switch to time delayed analog audio to hide the effects of in motion multipath. System will not operate when vehicle is not in motion. Matching the analog to digital audio quality will be a problem.	Not detailed in paper. If delayed analog audio is used, system will have same problems as the Westinghouse Proposal.
Diversity activation with interference Reference page 8 & 9, section V & Table 4	Table 4 shows five test sites where 198 stations were listenable. Interference should activate the diversity system for 93 of these stations. Tests were conducted in heavily populated areas.	If power is not reduced, system will be a little less sensitive to adj channel interference than with the Westinghouse proposal.

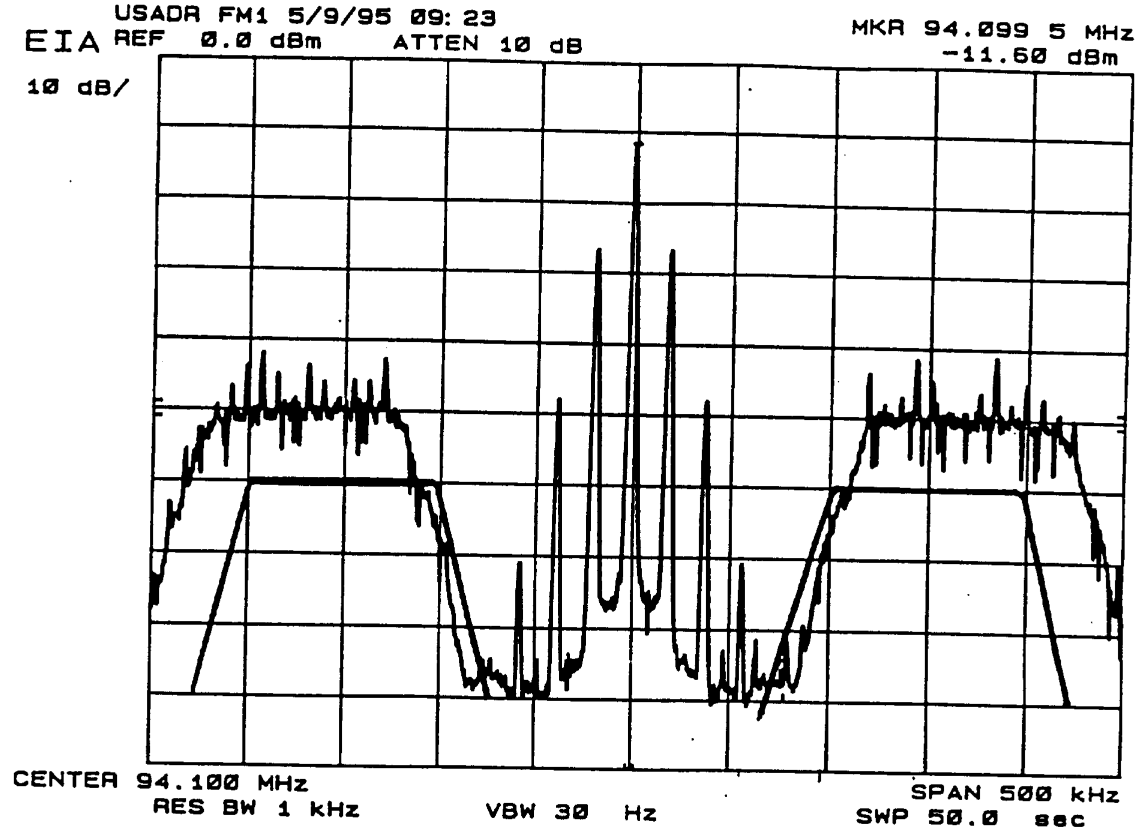


Figure 1 FM-1 with Westinghouse Proposal Overlaid

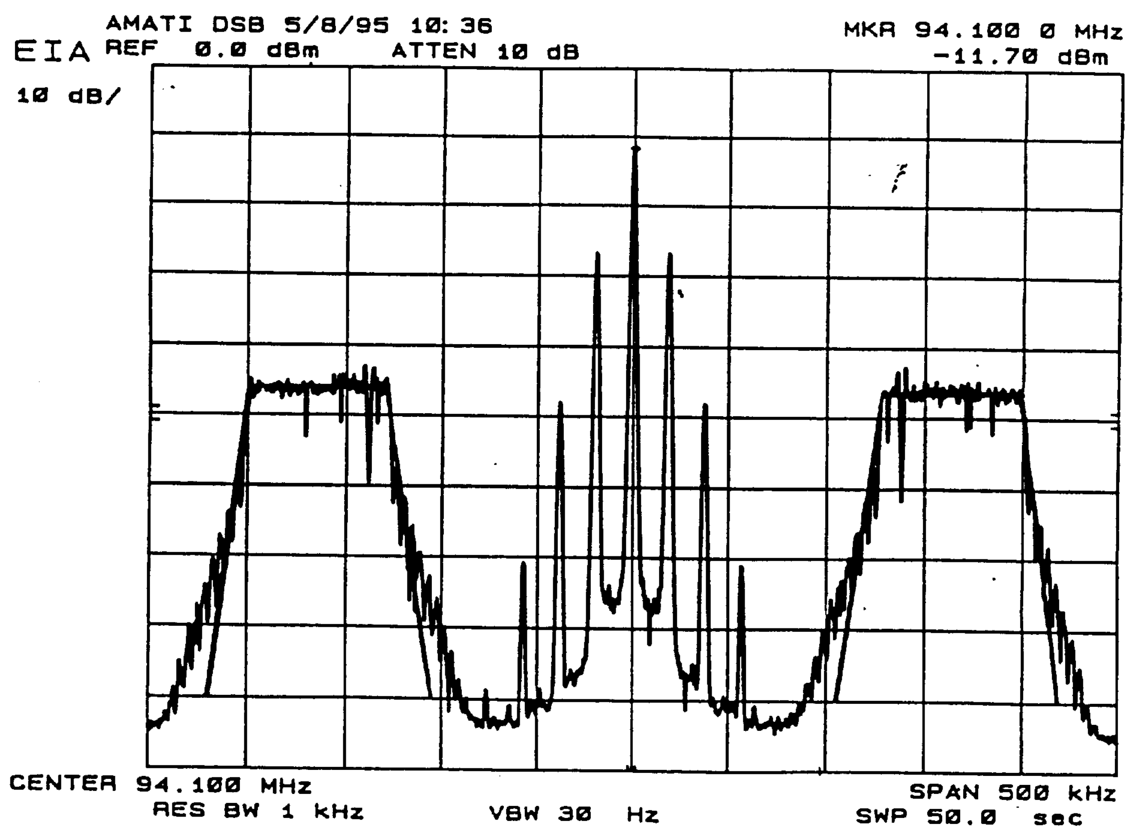


Figure 2 AT&T/Amati with USADR ITU Proposal Overlaid

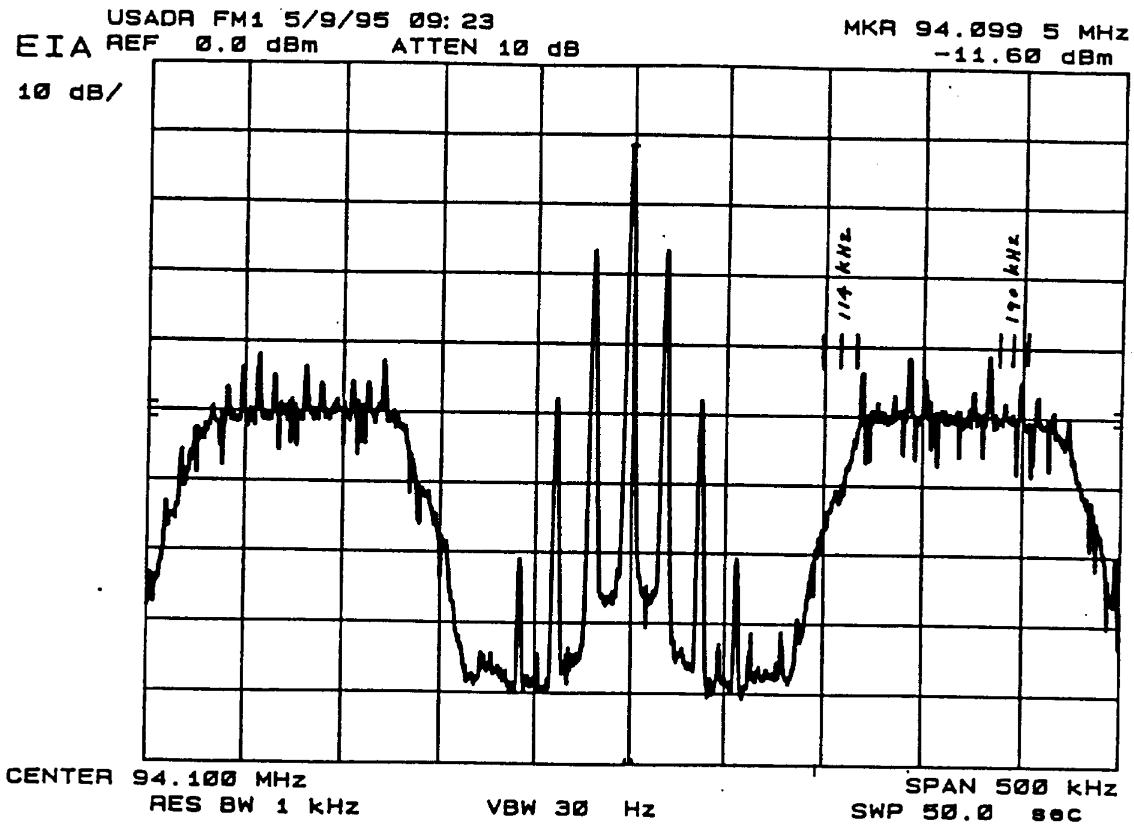


Figure 3 USADR FM-1 System

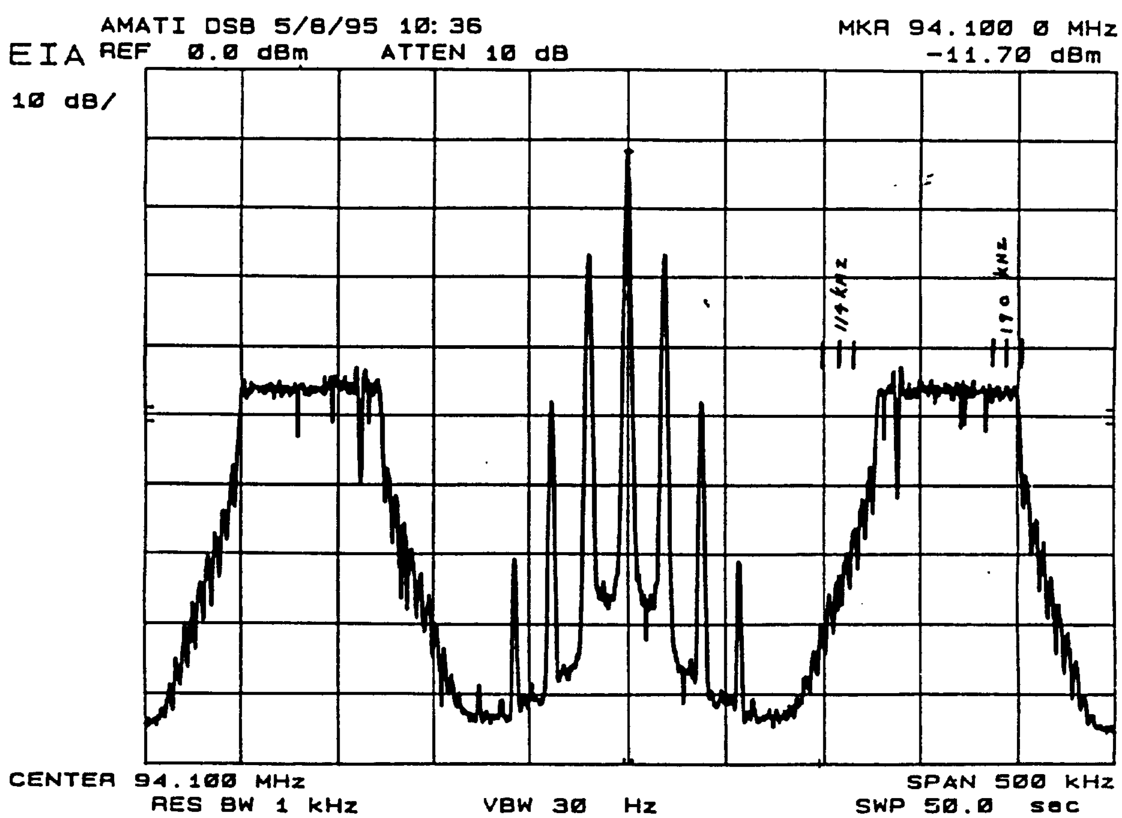


Figure 4 AT&T/Lucent/Amati DSB System

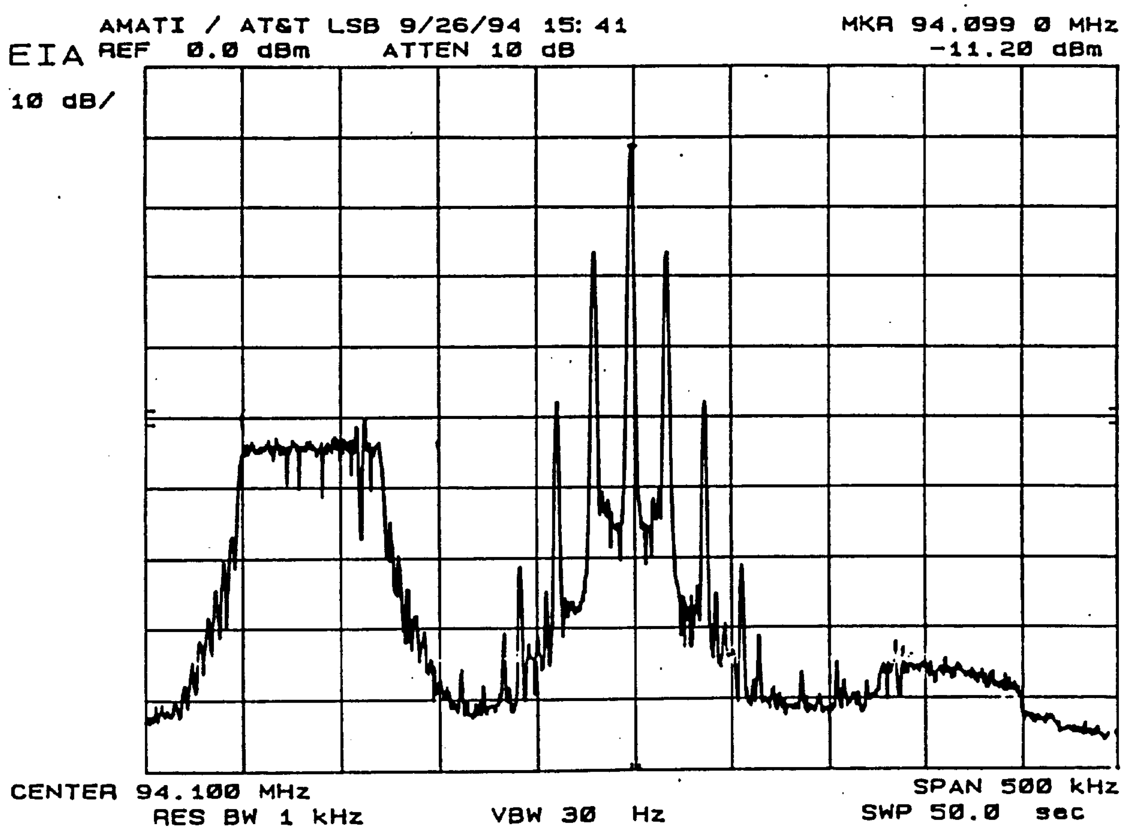
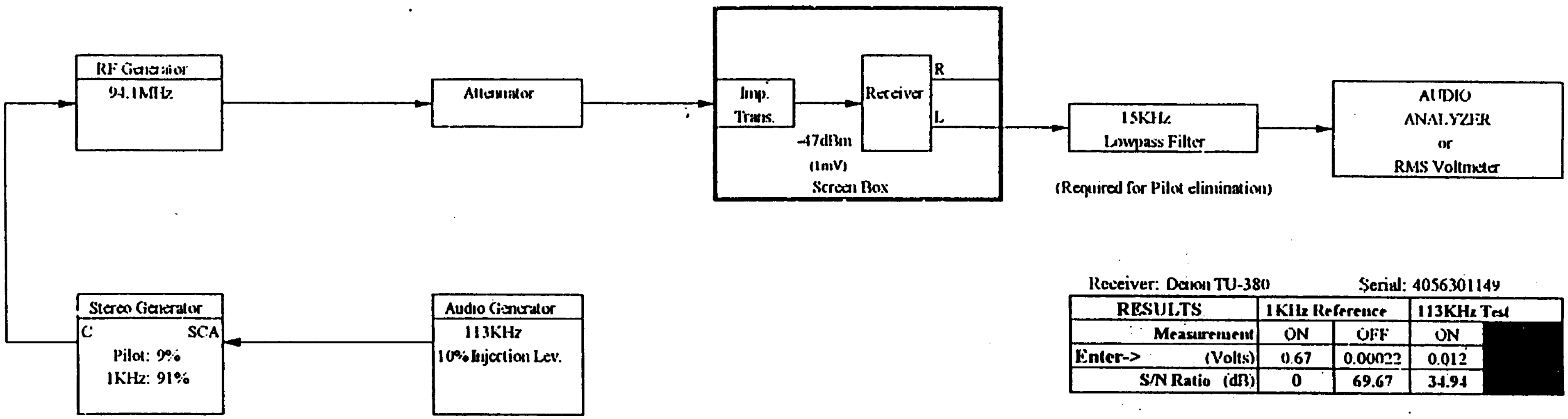


FIGURE 5 AT&T/LUCENT/AMATI LSB SYSTEM

APPENDIX 1

WALSH FUNCTION TEST

EIA Digital Audio Radio Test Laboratory



Receiver: Denon TU-380 Serial: 4056301149

RESULTS	1KHz Reference		113KHz Test	
Measurement	ON	OFF	ON	
Enter-> (Volts)	0.67	0.00022	0.012	
S/N Ratio (dB)	0	69.67	34.94	

Date: Sept. 28/95 Engineer: RMc

The above set up will test for the presence of either a Walsh Function type stereo decoder or a decoder using a filter to reduce interference at and above 114KHz
The test injects 113KHz to heterodyne or "beat" with any 114KHz component. If the 114KHz component is present a 1KHz tone will result and thus degrade the S/N ratio.

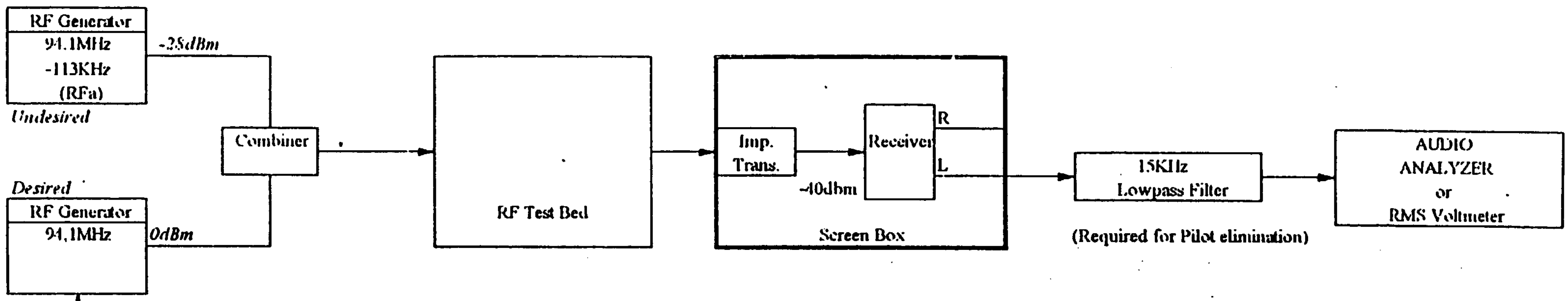
1) Using an audio analyzer or RMS voltmeter, measure the receiver output with a 1KHz @ 91% and 19KHz @ 9% modulation signal.
Enter the result (in volts) in the 1KHz Reference "ON" column. This will establish the 0dB stereo reference.

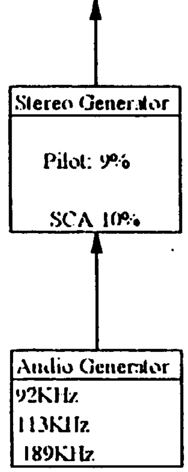
2) Turn off the 1KHz and record the measurement (in Volts) in the 1KHz Reference "OFF" column. The Stereo Signal to Noise Ratio will be calculated.

3) Turn on the 113KHz tone (at 10% injection) and measure the receiver output. Record the result (in Volts) in the 113KHz Test "ON" column.
The new Signal to Noise ratio will be calculated. This figure will show whether or not the receiver is sensitive to interference from 99KHz to 129KHz.

Receivers with no filtering or Walsh type decoders will typically show a reduction in S/N ratio with the presence of 113KHz on the order of 20 to 30dB.
Receivers with filters or Walsh type decoders will show little (5dB) to no difference in S/N ratio.

EIA Digital Audio Radio Test Laboratory

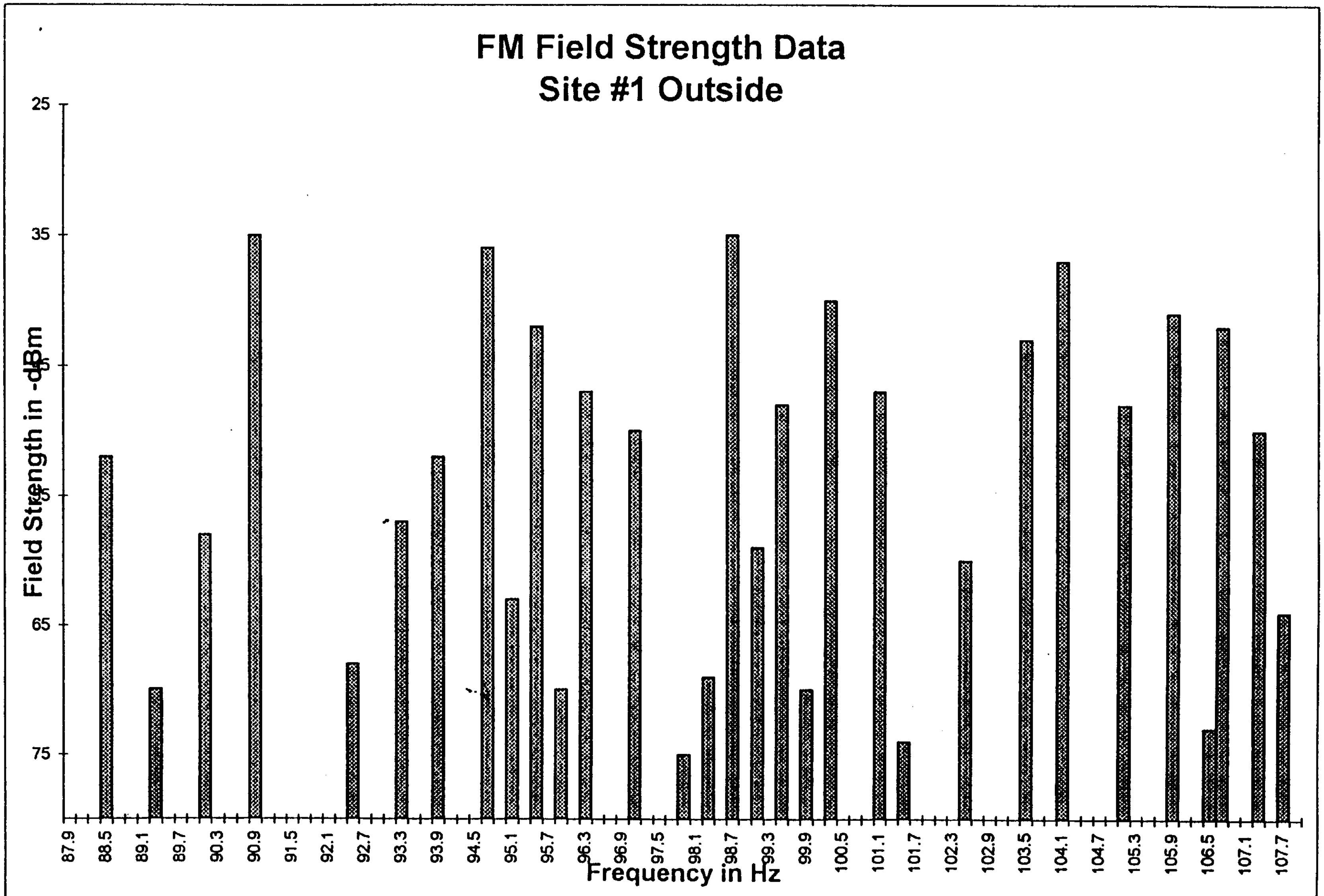




Date: 10/23/95 Engineer: RMc
Receiver: Denon TU-380 Serial: 4056301149

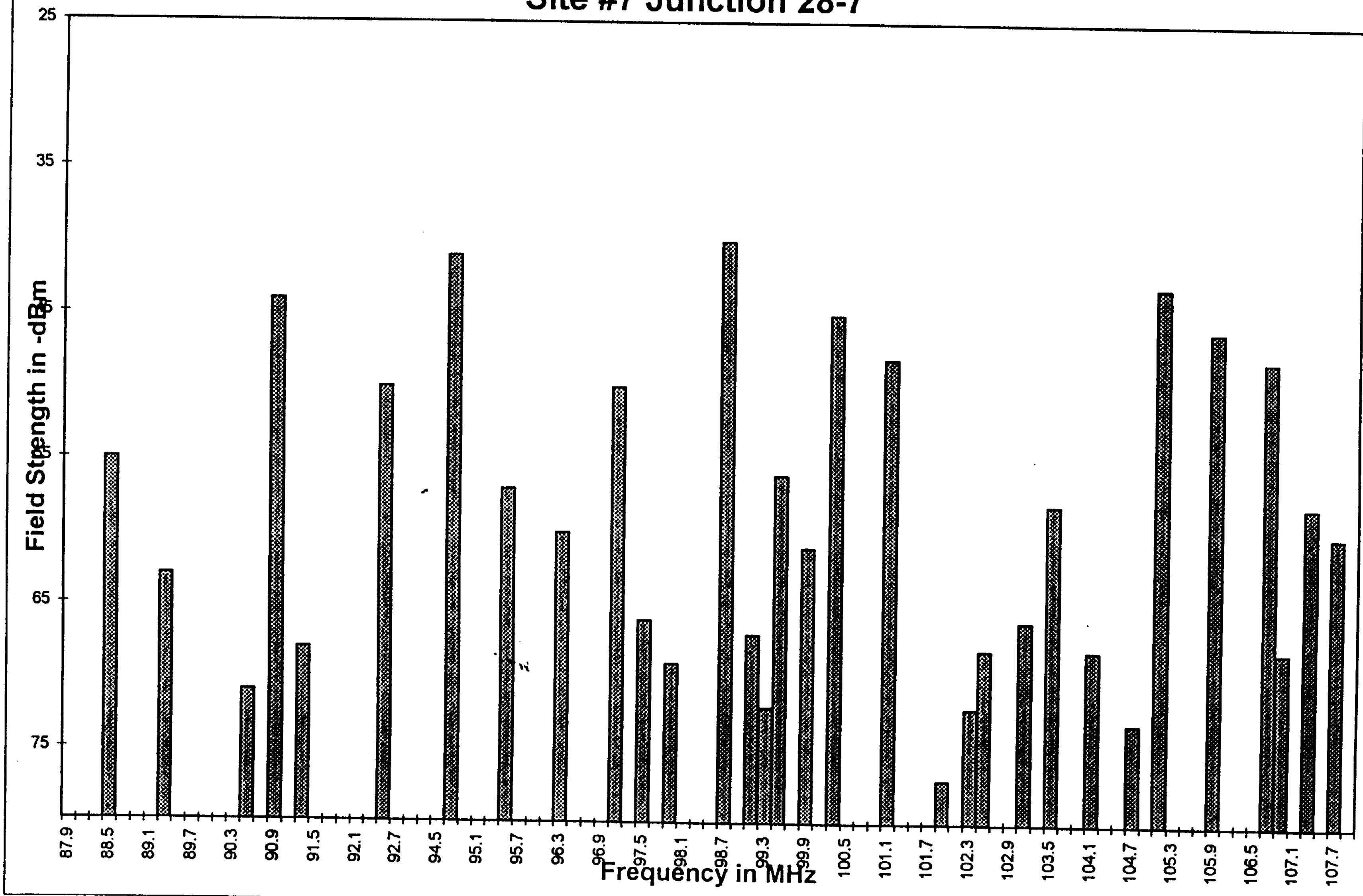
Signal	S/N Ratio (dB) RMS	Qpk/W	
Normal	69	61.5	
W/92KHz	65		
W/113KHz	38		
W/189KHz	40		
W/RFa	38		--- (94.1MHz @ -40dBm) + (94.1MHz - 113KHz @ -68dBm)
W/RFb	38		--- (94.1MHz @ -40dBm) + (94.1MHz - 189KHz @ -68dBm)
W/RFc	68	61	--- (94.1MHz @ -40dBm) + (94.1MHz - 152KHz @ -68dBm)
W/RFc	61	51.1	--- (94.1MHz @ -40dBm) + (94.1MHz - 152KHz @ -68dBm Modulated +/-20KHz)

Modulation of the undesired signal with 400Hz +/- 20KHz to create interference in the desired signal from 129KHz to 175KHz. Less modulation caused much less noise. More modulation caused much more noise indicating a fairly sharp knee and the presence of a "hole" between 129KHz and 175KHz

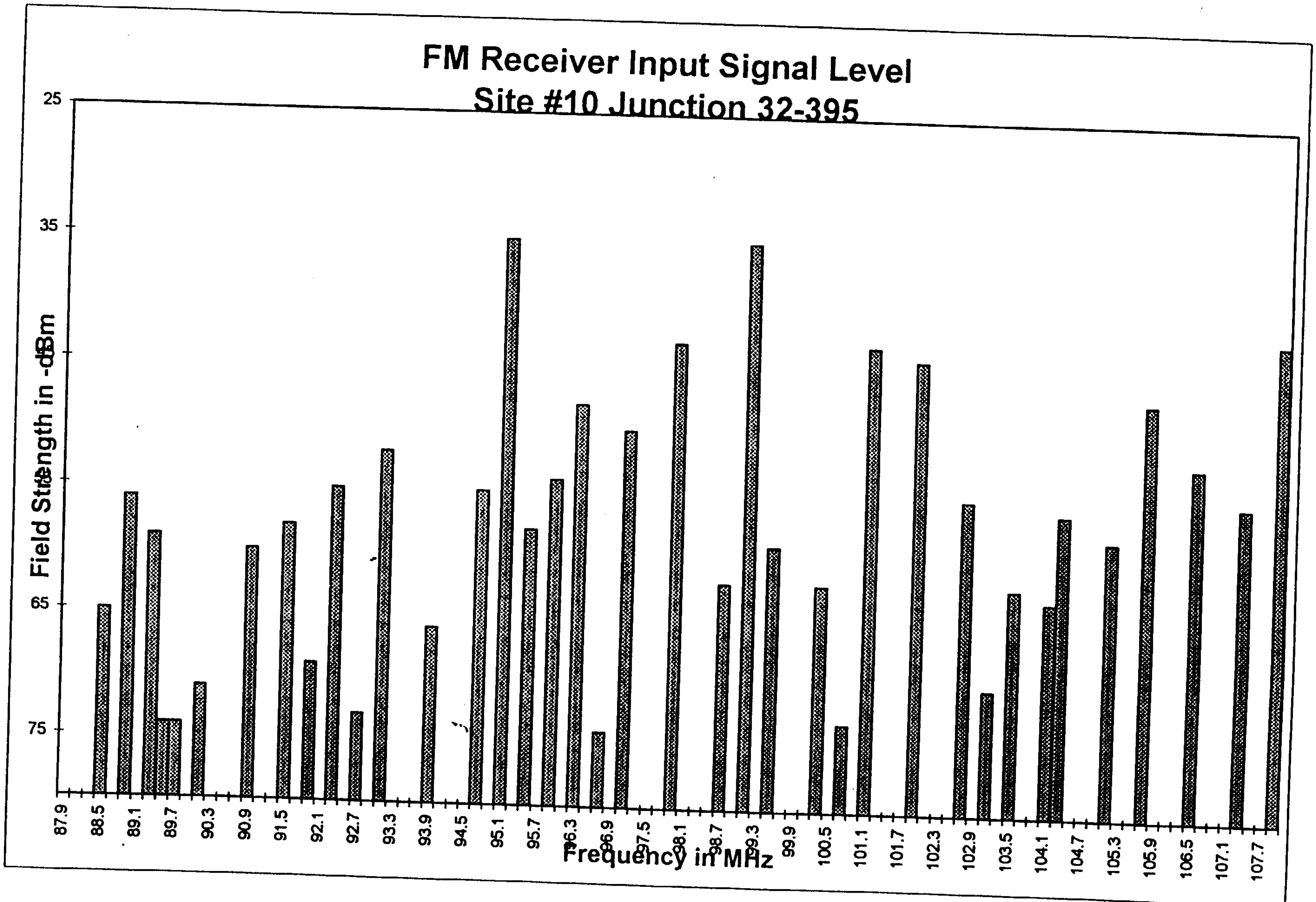

FM Field Strength Data
Site #1 Outside
Field Strength in -dBm
25
35
45
55
65
75
87.9
88.5
89.1
89.7
90.3
90.9
91.5
92.1
92.7
93.3
93.9
94.5
95.1
95.7
96.3
96.9
97.5
98.1
98.7
99.3
99.9
100.5
101.1
101.7
102.3
102.9
103.5
104.1
104.7
105.3
105.9
106.5
107.1
107.7
Frequency in Hz

Graph 1

FM Receiver Input Signal Level
Site #7 Junction 28-7

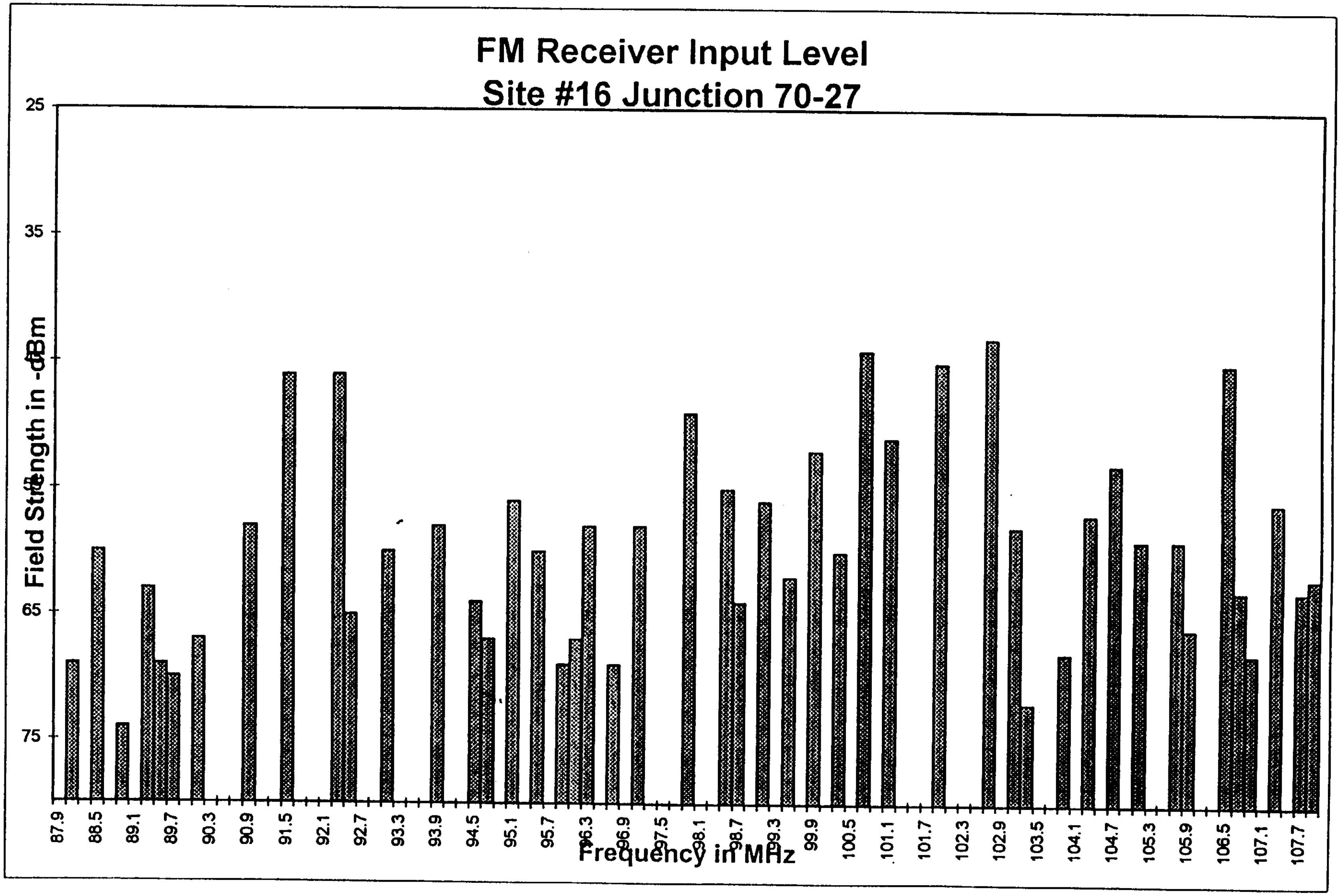


Graph 2

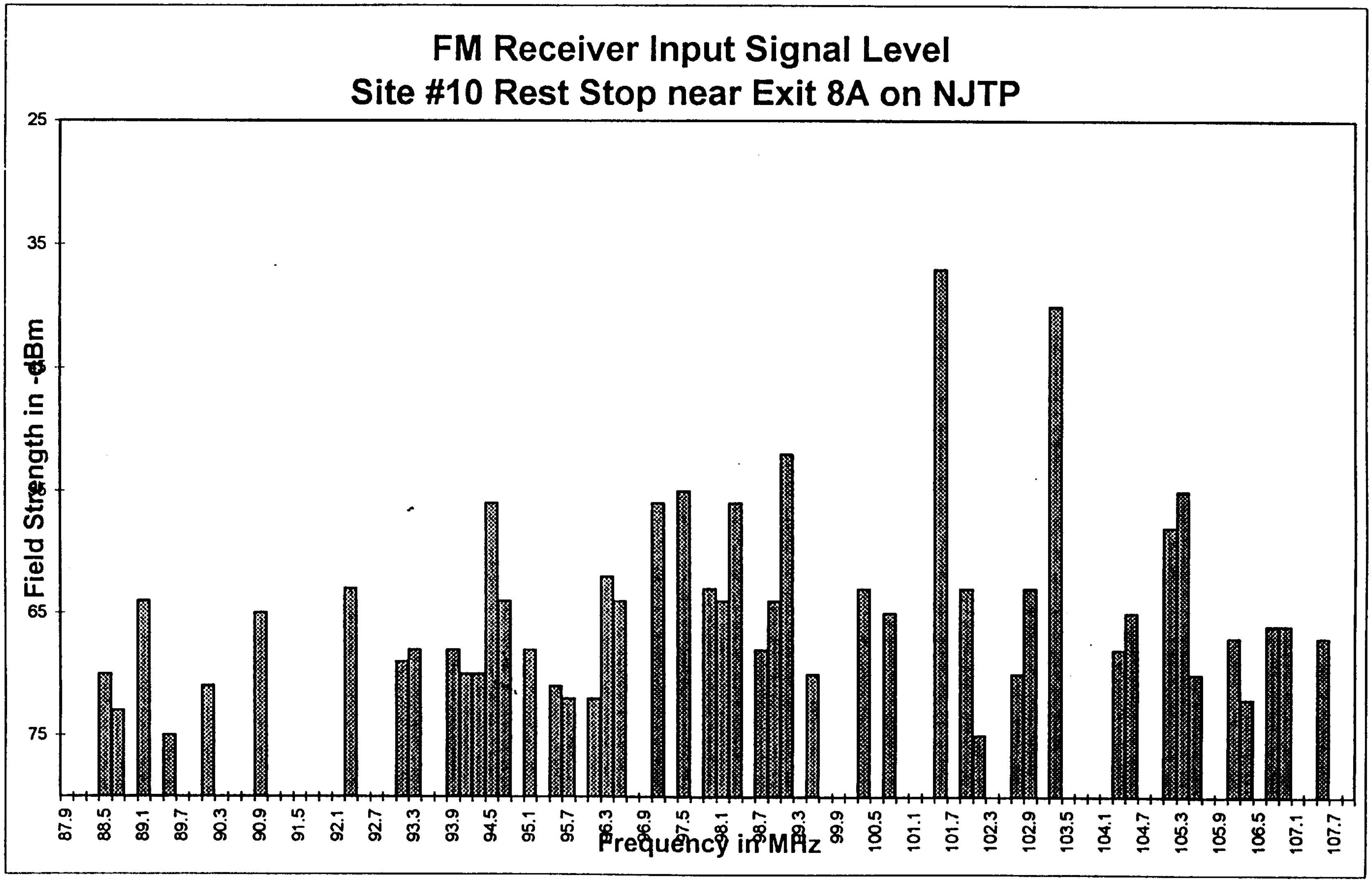


FM Receiver Input Signal Level
Site #10 Junction 32-395
Field Strength in -dBm
25
35
65
75
Frequency in MHz
87.9
88.5
89.1
89.7
90.3
90.9
91.5
92.1
92.7
93.3
93.9
94.5
95.1
95.7
96.3
96.9
97.5
98.1
98.7
99.3
99.9
100.5
101.1
101.7
102.3
102.9
103.5
104.1
104.7
105.3
105.9
106.5
107.1
107.7

Graph 3


FM Receiver Input Level
Site #16 Junction 70-27
25
35
65
75
Field Strength in -dBm
87.9
88.5
89.1
89.7
90.3
90.9
91.5
92.1
92.7
93.3
93.9
94.5
95.1
95.7
96.3
96.9
97.5
98.1
98.7
99.3
99.9
100.5
101.1
101.7
102.3
102.9
103.5
104.1
104.7
105.3
105.9
106.5
107.1
107.7
Frequency in MHz

Graph 4


FM Receiver Input Signal Level
Site #10 Rest Stop near Exit 8A on NJTP
Field Strength in -dBm
25
35
65
75
Frequency in MHz
87.9
88.5
89.1
89.7
90.3
90.9
91.5
92.1
92.7
93.3
93.9
94.5
95.1
95.7
99.9
100.5
101.1
101.7
102.3
102.9
103.5
104.1
104.7
105.3
105.9
106.5
107.1
107.7

Graph 5

APPENDIX 11

Analysis of USADR IBOC DAR System Modifications and Their Impact on Performance

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EXECUTIVE SUMMARY

USADR has proposed changes in their direct sequence spread spectrum IBOC system (FM-1) that claim to have solved problems in their original system. For this study, MDS developed a detailed computer model of the original FM-1 system and the modified system, using the best available information. From these computer simulations, we have determined that by decreasing "processing gain" (the relative amount of spectrum spreading of the digital signal), lowering injection level and increasing complexity, the bit error rate of the modified system went up and bandwidth went down. These changes have seriously impaired performance, however, and make the modified system much more susceptible to interference and multipath. Thus, in the modified system, there is much less chance the digital signal can be recovered successfully.

I. IBOC Report

A. Background

The USADR FM-1 DAB system uses Direct Sequence Spread Spectrum (DSSS) to transmit digital audio on specially shaped sidebands centered at approximately 180kHz on either side of the main channel analog modulation. There are fundamental concerns in operating a direct sequence system in so closely spaced in frequency to an analog FM system. At issue is interference - the IBOC signal can interfere with the analog FM signal or with other IBOC signals; likewise, the analog FM signal can interfere with the IBOC signal. In addition, the IBOC signal must contend with the issues that are systemic to operation in the FM band, such as multipath, co- and adjacent channel interference.

By their own admission, the original USADR FM-1 proposal exhibited some significant problems in these areas; these problems were listed as: [13]