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Washington, D.C. 20590

Performance Test Results Of Automatic Direction Finder Receiver Interference Susceptibility

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December 1981

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16. Abstract

The intent of this effort was to measure the interference susceptibility of present-day ADF equipment and to determine if RTCA and ICAO documents dealing with this subject are still representative.

The results of these tests show that the equipment tested meet the specifications of DO-142 Category A.

Recent works had indicated that the interference susceptibility characteristics of ADF receivers may be dependent primarily on the absolute level of the undesired signal, and secondarily on the ratio of the desired to the undesired signal. The data presented in this report, however, demonstrated that the interference characteristics of the aircraft ADF system are a function of the ratio of the desired to the undesired signal levels present at the antenna, and are not correlated to the absolute undesired signal levels.

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ADF, NDB, interference susceptibility, navigation aid, powerline carrier (PLC)

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LENGTH

To / From	Cm	m	Km	in	ft	s mi	n mi
Cm	1	0.01	$1x10^{-5}$	0.3937	0.0328	$6.21x10^{-6}$	$5.39x10^{-6}$
m	100	1	0.001	39.37	3.281	0.0006	0.0005
Km	100,000	1000	1	39370	3281	0.6214	0.5395
in	2.540	0.0254	$2.54x10^{-5}$	1	0.0833	$1.58x10^{-5}$	$1.37x10^{-5}$
ft	30.48	0.3048	$3.05x10^{-4}$	12	1	$1.89x10^{-4}$	$1.64x10^{-4}$
S mi	160,900	1609	1.609	63360	5280	1	0.8688
n mi	185,200	1852	1.852	72930	6076	1.151	1

AREA

To / From	Cm^2	M^2	Km^2	in^2	ft^2	$S\ mi^2$	$n\ mi^2$
Cm^2	1	0.0001	$1x10^{-10}$	0.1550	0.0011	$3.86x10^{-11}$	$5.11x10^{-11}$
m^2	10,000	1	$1x10^{-6}$	1550	10.76	$3.86x10^{-7}$	$5.11x10^{-7}$
Km^2	$1x10^{10}$	$1x10^{6}$	1	$1.55x10^{9}$	$1.08x10^{7}$	0.3861	0.2914
in^2	6.452	0.0006	$6.45x10^{-10}$	1	0.0069	$2.49x10^{-10}$	$1.88x10^{-10}$
ft^2	929.0	0.0929	$9.29x10^{-8}$	144	1	$3.59x10^{-8}$	$2.71x10^{-8}$
$S\ mi^2$	$2.59x10^{10}$	$2.59x10^{6}$	2.590	$4.01x10^{9}$	$2.79x10^{7}$	1	0.7548
$n\ mi^2$	$3.43x10^{10}$	$3.43x10^{6}$	3.432	$5.31x10^{9}$	$3.70x10^{7}$	1.325	1

VOLUME

To / From	Cm^3	Liter	m^3	in^3	ft^3	yd^3	fl oz	fl pt	fl qt	gal
Cm^2	1	0.001	$1x10^{-6}$	0.0610	$3.53x10^{-5}$	$1.31x10^{-6}$	0.0338	0.0021	0.0010	0.0002
liter	1000	1	0.001	61.02	0.0353	0.0013	33.81	2.113	1.057	0.2642
m^2	$1x10^{6}$	1000	1	61,000	35.31	1.308	33,800	2113	1057	264.2
in^3	16.39	0.0163	$1.64x10^{-5}$	1	0,0006	$2.14x10^{-5}$	0.5541	0.0346	2113	0.0043
ft^3	28,300	28.32	0.0283	1728	1	0.0370	957.5	59.84	0.0173	7.481
yd^3	765,000	764.5	0.7646	46700	27	1	25900	1616	807.9	202.0
fl oz	29.57	0.2957	$2.96x10^{-5}$	1.805	0.0010	$3.87x10^{-5}$	1	0.0625	0.0312	0.0078
fl pt	473.2	0.4732	0.0005	28.88	0.0167	0.0006	16	1	0.5000	0.1250
fl qt	948.4	0.9463	0.0009	57.75	0.0334	0.0012	32	2	1	0.2500
gal	3785	3.785	0.0038	231.0	0.1337	0.0050	128	8	4	1

MASS

To / From	g	Kg	oz	lb	ton
g	1	0.001	0.0353	0.0022	$1.10x10^{-6}$
Kg	1000	1	35.27	2.205	0.0011
oz	28.35	0.0283	1	0.0625	$3.12x10^{-5}$
lb	453.6	0.4536	16	1	0.0005
ton	907,000	907.2	32,000	2000	1

TEMPERATURE

$^{o}F = 9/5\ (^{o}C - 32)$

$^{o}C = 5/9\ (^{o}F) + 32$

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SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT BRANCH

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Chapter 1 : Introduction

The purpose of this project was to determine as closely as possible the interference characteristics of typical ADF systems on the market today. The resulting data is to be used by the Federal Aviation Administration (FAA) to revise the criteria for adjacent channel and cochannel Non-Directional Beacon (NDB) frequency assignment.

The scope of the tests performed for this project include verification of the manufacturers' specifications for the ADF systems and measurement of the interference susceptibility of the systems.

This report examines previous work in the area of ADF interference susceptibility testing, evaluates the problems created by prior errors and the newer generation of ADF systems, and describes an effort to acquire interference susceptibility data from modern receivers. The results are analyzed in the final chapters, and recommendations are made based on these results.

Chapter 2 : Previous Work

The most relevant work done to date on the subject of ADF receiver interference susceptibility testing is described in two reports by William A. Kissick [1,2]. The first deals with ADF receiver susceptibility to interference from Power Line Carrier systems, and the second is a test plan for determining ADF receiver interference susceptibility. Both reports have their drawbacks, which are dealt with in chapter four. This chapter provides a summary of the relevant areas of the Power Line Carrier interference report and the test plan.

Power Line Carrier (PLC) systems are used by the power company to facilitate internal communications, remotely control switches, and to perform other related functions. A PLC system consists of transmitters and receivers coupled to power transmission lines by matching networks. Because of the physical characteristics of the transmission lines, a fairly low-leakage transmission path is formed. The frequency band most commonly used for PLC transmissions covers the range of 30 to 300 kHz, although frequencies as high as about 500 kHz are occasionally used. The injected power levels being considered range from a fraction of a watt to several hundred watts. Most currently used systems are limited, however, to a few tens of watts of injected signal.

The possibility of interference to the ADF system by direct radiation of the PLC is obvious. Investigations of several plane crashes in both Europe and the United States have listed PLC interference as a possible cause of the crash. The PLC interference report lists a set of suggested criteria for the siting and frequency assignment of Non-Directional Beacon (NDB) transmitters so as to reduce the probability of this type of interference.

The PLC interference report also lists a set of ADF interference susceptibility test data taken in a laboratory situation with the transmitter and antenna systems simulated. Due to errors in the laboratory test configuration which are described in chapter four of this report, the receiver susceptibility data in the PLC interference report is not reliable. The test configuration in the PLC interference report is very similar to the one in the test plan of reference two.

The interference susceptibility test plan is a document describing a complete procedure for an analysis of the susceptibility of ADF receivers to interference in the presence of desired and undesired signals. Included are three test configurations and appropriate sets of varied test conditions to determine the performance of the receiver in terms of indicated bearing error for most possible combinations of desired and undesired signals. Also included are suggestions for the display of the measured data and a set of forms for recording the data in the laboratory.

The "antenna simulator" boxes referred to in this report are devices which simulate the loop and sense signals from the ADF system antennas. They are calibrated in such a manner that an input signal of one micro-Volt at the input port will produce the same voltages at the input ports of the receiver as the normal ADF antennas would when a field of one micro-Volt per meter was present. This allows the simulated transmission and reception of the desired and undesired signals in the laboratory without the necessity of radiating actual signals. This is a tremendous advantage when one considers the alternative: build an RF cage with a set of radiating elements and a section of airplane fuselage inside to simulate the transmission in free space. The problem, however, is that ADF antennas vary considerably, and that no single simulator can correctly simulate them all. This will be given further consideration in chapter four.

The first configuration (Figure 2.1) simulates the arrival of the desired and undesired signals from directions

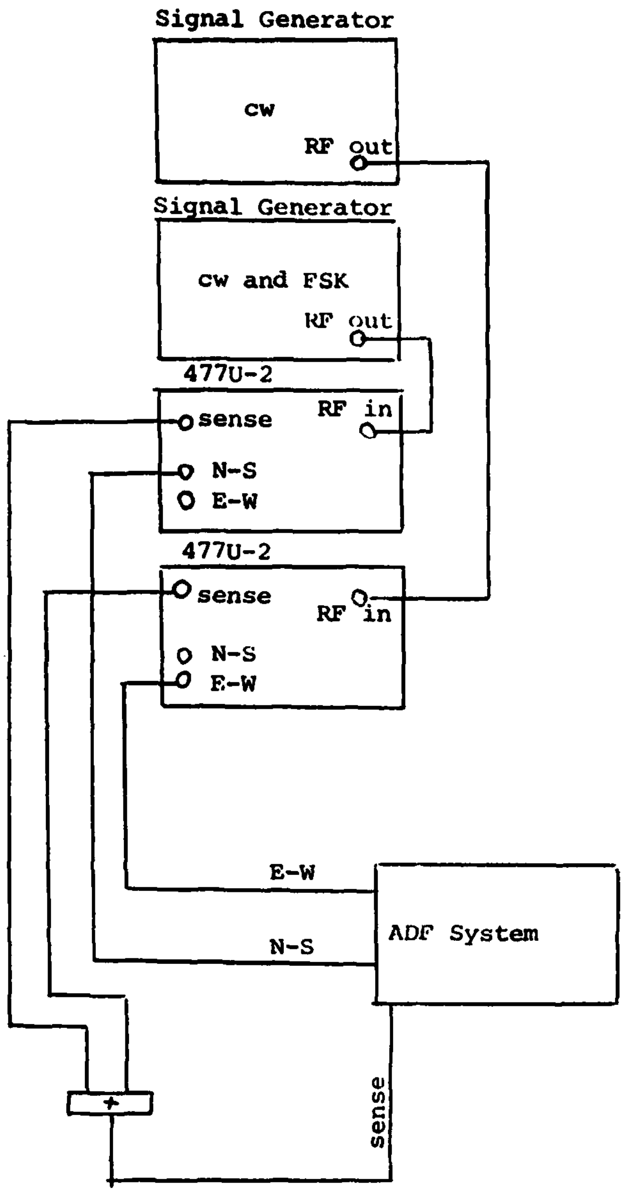


Figure 2.1 Test set-up for simulating the arrival of the desired and undesired signals from two directions differing by 90 degrees.

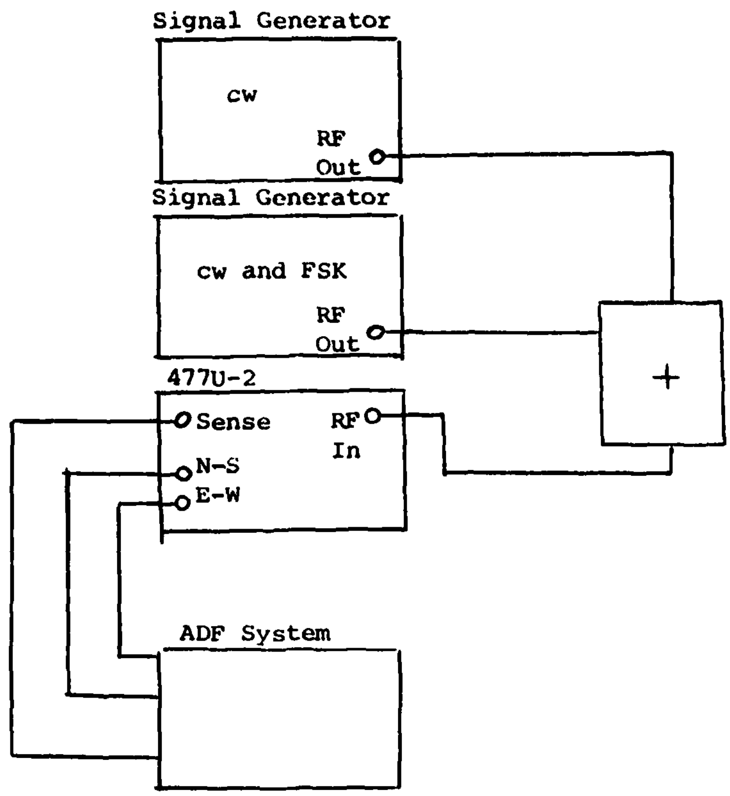


Figure 2.2 Test set up for simulating the arrival of the desired and undesired signals from the same direction.

differing by 90 degrees. This provides a "worst case" situation to the receiver in terms of bearing error since the signals are arriving in space quadrature. Thus, the bearing needle can be expected to point at the desired station, the undesired station, or somewhere in between. The desired signal is fed into the receiver through the EAST-WEST loop and the undesired signal is entered through the NORTH-SOUTH loop. The simulated sense components are summed and fed into the sense input terminals of the receiver.

The second configuration (Figure 2.2) simulates the arrival of the desired and undesired signal from the same direction. This condition may not be likely to cause bearing error but may cause problems with the pilot's ability to identify the beacon because of heterodynes or capture effect.

The third configuration (Figure 2.3) simulates the arrival of the desired signal from differing directions. This allows such phenomenon as re-radiation from standing structures and geographical features (mulipath) to be investigated.

Note that <u>only the first configuration was used</u> in the performance of this contract.

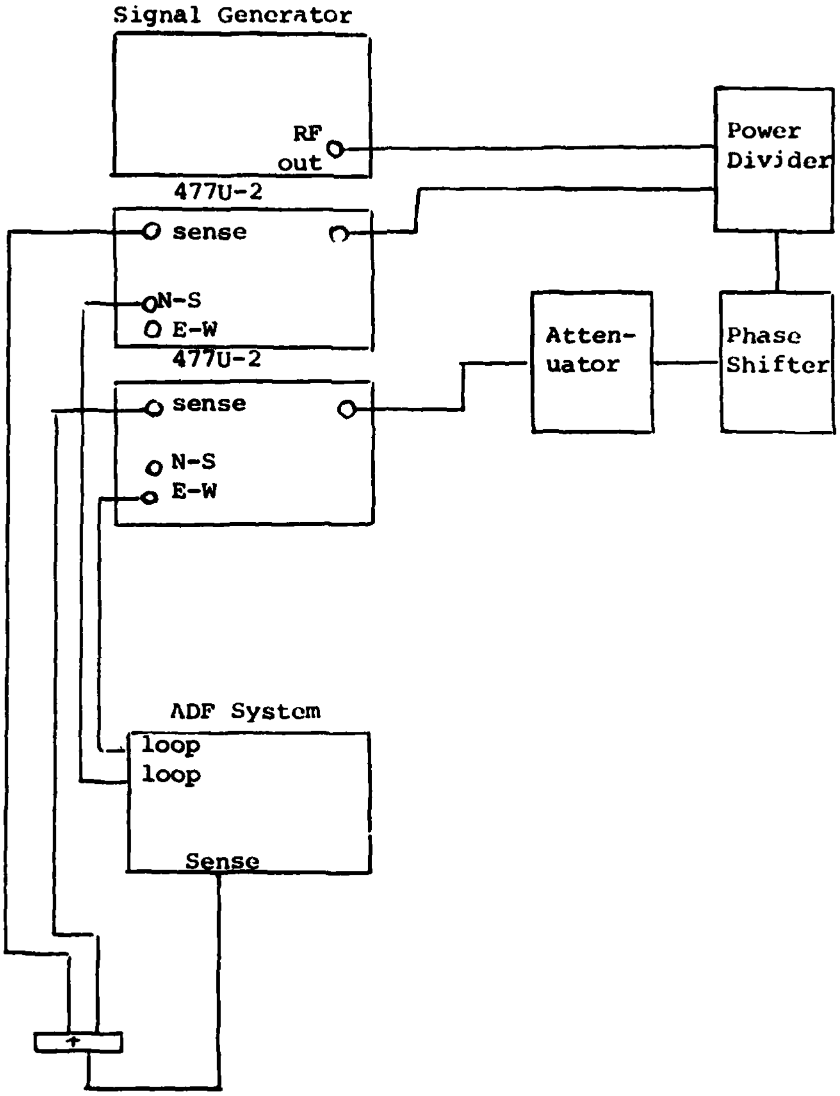


Figure 2.3 Test set-up for simulating the arrival of the desired signal from different directions.

Configuration 1

Desired and Undesired Signals from Different Directions

Measurement # ______________ **Date** ____________ **People** ______________

Notes ____

U-Level	Bearing Error	U-Level	Bearing Error	U-Level	Bearing Error	U-Level	Bearing Error	U-Level	Bearing Error	U-Level	Bearing Error

Figure 2.4 Data recording form for the configuration of Figure 2.1

Configuration 2

Desired and Undesired Signals From the Same Direction

Measurement # ____________ Date ____________ People ____________

Notes ____

Δf = ______		Δf = ______		Δf = ______		Δf = ______		Δf = ______		Δf = ______	
U-Level	Bearing Error	U-Level	Bearing Error	U-Level	Bearing Error	U-Level	Bearing Error	U-Level	Bearing Error	U-Level	Bearing Error

Figure 2.5 Data recording form for the configuration of Figure 2.2

Configuration 3

Desired Signal From Two Directions

Measurement # ____________ Date ____________ People ____________

Notes ____

U-Level	Bearing Error	U-Level	Bearing Error	U-Level	Bearing Error	U-Level	Bearing Error	U-Level	Bearing Error	U-Level	Bearing Error

Figure 2.6 Data recording form for the configuration of Figure 2.3

The plan also includes a set of forms for recording the data from each configuration. These sheets are then to be included in a log book of measured data. Figures 2.4, 2.5, and 2.6 are samples of these data sheets. Note that data is recorded with respect to only three variables: the difference in frequency, the undesired signal level, and the bearing error. All other variables are held constant for that particular set of measurements.

Chapter 3 : Description of Necessary Receiver Tests

There are two parts to be considered in the receiver testing. These are: Verification of the ability of the receiver to perform according to the manufacturer's specifications, and determination of its susceptibility to interference. This is only logical since a receiver which will not perform according to its listed specifications will not give representative data when it is tested for interference. This chapter provides a brief description of the tests involved in each part, and an idea of what they mean.

There are four types of tests which must be done in order to verify that the receiver is performing according to the manufacturer's specifications. These are: Selectivity, Sensitivity, Image Rejection, and ADF Bearing Error.

Selectivity is a measure of the receiver's ability to reject undesired signals. A receiver is said to have good selectivity when the received bandwidth is just sufficient to pass the desired signal frequency and its modulation sidebands. A receiver is said to have poor selectivity when the received bandwidth is so wide as to allow adjacent channel signals and noise to be received along with the desired signal. The selectivity of the ADF receiver is the major determining characteristic of its susceptibility to interference.

Sensitivity is a measure of the signal level which must be provided to the receiver terminals in order for it to function properly. If a receiver lacks sufficient sensitivity it may not be able to receive the beacon signals, particularly at the limits of the coverage area.

Image Rejection is a measure of the ability of the receiver to reject signals on its "image" frequencies. An image frequency is that frequency (in a superheterodyne receiver) which is displaced from the local oscillator by an amount equal to the first intermediate frequency in the direction opposite to that of the desired signal. For instance, if the first IF of the receiver is, say 455 kHz, and the desired signal is at 255 kHz, then the local oscillator must run at 200 kHz. This would mean that the image frequency corresponding to 255 kHz in this receiver would fall at 655 kHz. This image frequency is in the AM broadcast band, which means that if the receiver has very poor image rejection, and the aircraft it is installed in were to fly in the vicinity of a broadcast station operating in the vicinity of 655 kHz, then it is very likely that interference would result.

Bearing error is the error induced in the ADF pointer needle by the receiver. The receiver is tested for Bearing Error by providing signals to the receiver input terminals with the proper amplitude and phase relationships to simulate a given bearing and recording the difference between the simulated and the indicated bearing. Obviously this is a very important factor in ADF receiver performance. The maximum allowable bearing error is three degrees [5].

There are two major things to be considered in determining the interference susceptibility of an ADF receiver. These are: the bearing error, and the signal + noise/noise ratio (or, the signal to signal ratio). Given receivers which are performing properly, this information taken under various test conditions will produce a data base from which typical receiver performance can be determined. These measurements are usually taken with both the desired and the undesired signal present, differing in angles of arrival by 90 degrees. This provides a "worst case" situation to the receiver [5].

After verifying that the receiver performs according to specs, we can proceed to evaluate its susceptability to interference from undesired signals. The bearing error test is a measurement which determines the error induced in the

ADF bearing needle by the undesired signal. This bearing error test is distinctly different from the one made in the performance verification in that the bearing error being measured here is that which is generated by the presence of the undesired signal, not just that generated by the inherant inaccuracies of the receiver hardware. By varying the proximity of the undesired to the desired signal in frequency, amplitude, and modulation type and recording the resulting error, the bearing error data base is formed.

The signal + noise/noise ratio test determines the ability of the pilot to recognize the NDB station identifier with the receiver in RECEIVE mode. If the pilot cannot pick the tone-modulated Morse code out of the heterodynes or other effects, he cannot be sure that the receiver is tracking the proper signal. If the signal+noise/noise ratio in the receiver audio drops below 6 dB (the minimum level considered usable), then an interference condition exists [3]. These measurements are taken along with the bearing error measurements and added to the data base for evaluation.

Chapter 4 : Problems Encountered

There were several problems encountered during the progress of this project. The problems can be broken down into two categories: problems with the design of the test plan, and problems with the receiver and test set-up hardware. The first part of this chapter deals with the former, and the second part deals with the latter.

There were two basic problems with the test plan itself: an error in the fundamental design which introduced nonlinearity into the circuit, and the fact that the test plan made no provision for taking into account the signal + noise ratio in the receiver audio in the presence of both the desired and the undesired signals. The first error would make any test data measured useless, and the second leaves out a very important performance parameter.

The introduction of the non-linearity was brought about by the improper use of the power combiner in the sense circuit (see figure 2.1). Since the sense circuit is generally a very high impedance and the power combiner is a reletively low impedance (usually 50 Ohms), an impedance mismatch occurs. This mismatch means that the signal level at the input terminals of the ADF receiver can not be accurately predicted. In order to correct this situation, the test set-up of figure 5.7 was devised. Note that now the power combiner is terminated in the proper 50 Ohm impedance, as are the signal generators that feed the system.

Without proper data regarding the signal + noise ratio in the audio, there would be no way of telling whether or not the pilot would be able to properly determine which beacon station he was homing on, as he may not be able to pick the station identifier out of the interference and noise. The data form of figure 4.1 was be used to record the signal + noise data. The proceedure for taking this data is described in the next chapter.

After the test set-up was wired and the first receiver in place, it was found that there were problems in the hardware of the set-up.

The first problem to surface was that RF leakage through the cases of the signal generators was being directly radiated to the input terminals of the receivers, causing totally erroneous readings. Several signal generators were tried before this problem was solved. The generators finally settled on were the HP-606B and the General Radio 1003.

The next problem encountered with the hardware was the

6 dB (S+N)/N

Receiver: Date:

Personnel:

Comments:

Measurement Number	Δf	U-Level for 6 dB (S+N)/N	S/N of Desired Signal Only	Remarks

Figure 4.1 Data recording form for signal to noise measurements in the presence of both the desired and undesired signal.

leakage of the interconnecting coaxial cables when excited by relatively high RF Voltages. This leakage caused the same general problems as the leakage through the cases of the signal generators. This problem was solved by the use of shorter runs of cables which must carry the high level RF and by using lower signal generator levels and lower attenuation settings.

Once these problems were solved, testing went along more or less smoothly for the older types of receivers which did not put any of their active circuitry in the antenna unit. However, more problems arose with the others. These problems were centered around a basic incompatibility with the Collins 477U-2 antenna simulators.

In the case of the receivers with electronics in the antenna assembly, separate loop and sense terminals are not usually available at the receiver. Instead, signals are modulated and in some cases multiplexed onto fewer cables before being fed to the receiver. This means that in order to use the Collins simulators and the capacitive voltage divider, the electronics must be removed from the antenna unit and excited separately. Doing this properly can be difficult however, as the removal of the electronics from the antenna unit (when possible) can change circuit calibration paramaters and take away needed shielding from the electronics unit. In addition, the electronics units are very closely matched to the antennas, making the circuit parameters critical. This can cause complications because of the necessity of interconnecting cables between the test set-up and the antenna electronics. Each manufacturer has its own method of dealing with this situation, and it was impractical and uneconomical to deal with each situation given the time and budgetary constraints of this project. An attempt was made, however, to work with the system antennas as units in a simulated H-field.

In order to synthesize the H-field (loop) portion of the ADF antenna system without the use of the Collins simulators, a small screen room was constructed. A diagram of the screen room is shown in Figure 4.2. In order to save space and time, the room was made physically small. The formulas used for determining the resistor values and the "room factor" were taken from DO-142. In this case, the room factor being used is 30.0, and the input impedance seen at the input terminals is on the order of several thousand Ohms. In order to allow both the desired and undesired signal to be present and to have the simulated signals in space quadrature, two crossed H-field transmitting antennas were placed in the room. The ADF antenna was then placed on

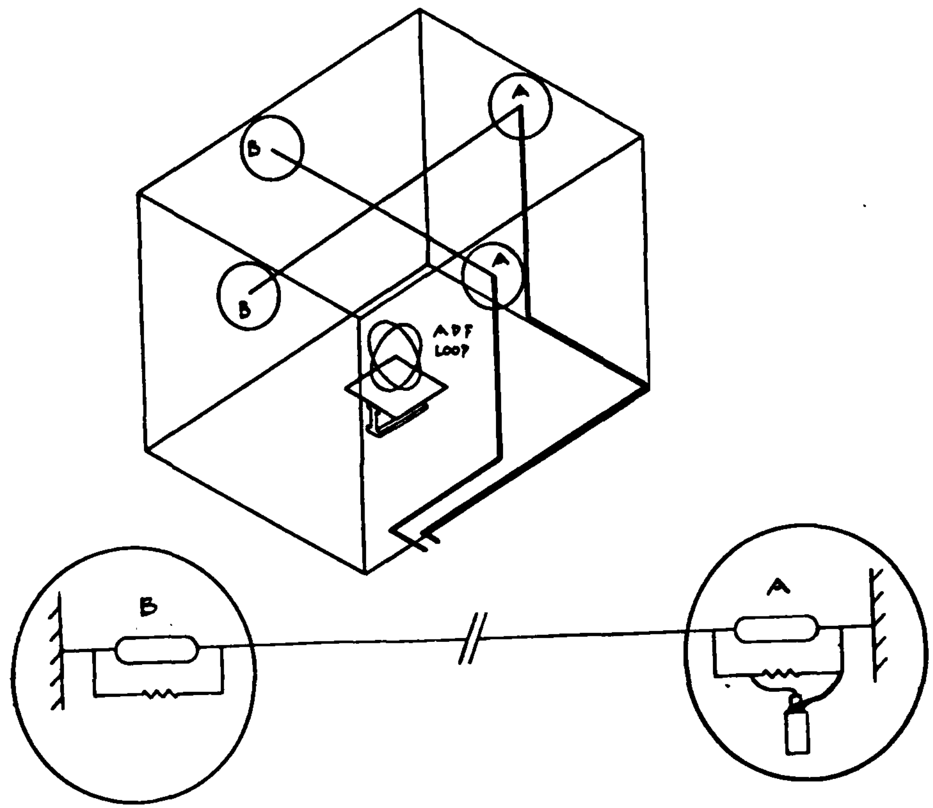


FIGURE 4.2 Diagram of the screen room.

a metal platform slightly raised above the bottom of the room to simulate its presence on the aircraft fuselage. The same capacitive voltage divider as was used with the Collins antenna simulator set-up is used to synthesize the E-field (sense) component.

The screen room worked fine for the older type of receivers already tested, which had small antenna assemblies. However, when the larger assembly of the Bendix ADF-2070 system was installed in the room it still did not work. Since the antenna assemby of the Bendix system was very large compared to the size of the room (the top of the antenna was touching the field simulator wires), this is most probably the reason for its failure to function properly. Also, there was much difficulty in trying to simulate the sense antenna signal properly. This situation was particularly difficult in the case of the Bendix ADF system. A telephone call to the company requesting the effective height and capacitance of the system sense antenna revealed that that particular company did not take the effective height and antenna capacitance into consederation in the design process, and therefore was unable to provide the needed data for the test set-up.

Some avionics manufacturers use a device called a "TIC

BOX" to make these tests. A TIC Box is a small, portable screen room which has had special elements added that allow it to simulate both E and H fields. The time and contract funds available did not justify the construction of such a device at Ohio University.

Unfortunately, the TIC Box method also seems to be the best suited to testing ADF systems which incorporate part of the receiver electronics in the antenna assembly. For example, the Collins ADF-60 system has only one RF feed cable to the antenna unit, and a few control lines carrying logical data. The sense and both loop signals are multiplexed onto this single RF cable.

It is obvious at this point that the provisions of DO-142 for receiver testing are obsolete, as they do not apply to the newer generation of ADF systems. Although each manufacturer has now developed a somewhat different approach to these types of tests, RTCA should updata their material on test set-ups when DO-142 is revised.

There was also some disagreement as to the proper way to make the signal + noise/noise measurements in the interference susceptiblity stage. The question was whether the measurements should be taken in RECEIVE mode or ADF mode. This necessitated the re-measurement of about 75% of the signal to noise data. All signal + noise/noise data in this report was taken in RECEIVE mode.

This chapter has summarized the problems encountered in the course of the project. The next chapter will describe the revised test set-ups and proceedures used to test the older types of receivers, namely the King KR-86 , the Cessna ADF-300 (two receivers), and the Collins 51Y-7.

Chapter 5 : Testing Procedures

After the problems in the test plan were accounted for and corrected, test set-ups for receiver performance verification and ADF interference susceptibility were devised. These set-ups and detailed instructions for their use for making the tests described in chapter three are the subject of this chapter. It should be emphasized, however, that these procedures work only for the older types of ADF receivers which do not incorporate electronic circuitry in their antennas. The problems which arose with these receivers were discussed in the previous chapter.

The test set-up for performance verification is shown in figure 5.1. It consists of three major parts: the signal source, the radio frequency field simulator, and the audio section.

The signal source is a Hewlett-Packard model 606-B signal generator with an HP-5245L frequency counter. This generator was chosen because of its low signal leakage. In order to properly test the receiver, the signal generator must be capable of providing both CW (Continuous Wave) and MCW (Modulated CW (30-85%)) signals. Additional resolution in output level without changing the output level vernier of the generator is provided by a set of HP click attenuators at the output of the generator. These attenuators provide 1

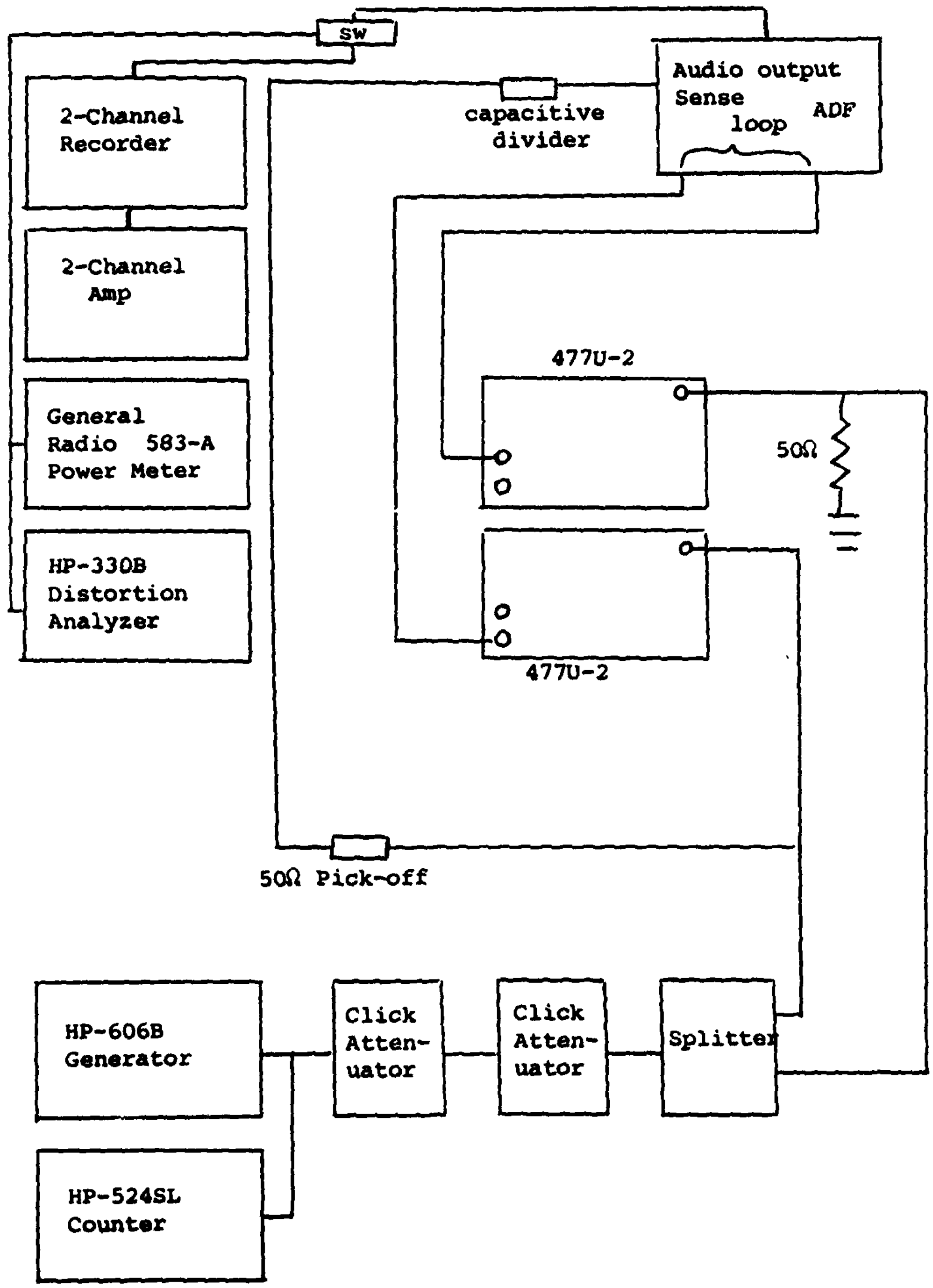


Figure 5.1 Test set-up for receiver performance verification.

dB steps in output level. The signal is split by a Werlatone power combiner (acting as a splitter) before being fed to the RF field simulator. It is recommended that the signal generator output level and modulation be checked for proper calibration before testing begins. It should also be noted that the use of the power combiner/splitter in the circuit causes a three dB reduction in the output level of the signal source. To correct for this error, the person taking the measurements should subtract three dB from the indicated signal level at the generator. For example, if the signal generator reads 0 dBm, the first click attenuator 10 dB, and the second click attenuator 0 dB, the corrected signal level would be -13 dBm.

The RF field simulator consists of two Collins 477U-2 antenna simulater boxes, a 50 Ohm pick-off termination, a 50 Ohm dummy load, and a capacitive voltage divider network. In order to make the simulators appear as a very high impedance the 51 Ohm resistors were removed from the input circuits of the 477U-2 simulators. This change is marked on the schematic of figure 5.2. The required 50 Ohm termination for the signal source is now supplied by the 50 Ohm pick-off and the 50 Ohm dummy load. The sample supplied by the pick-off is routed through the capacitive voltage divider network to supply the proper signal to the sense antenna input

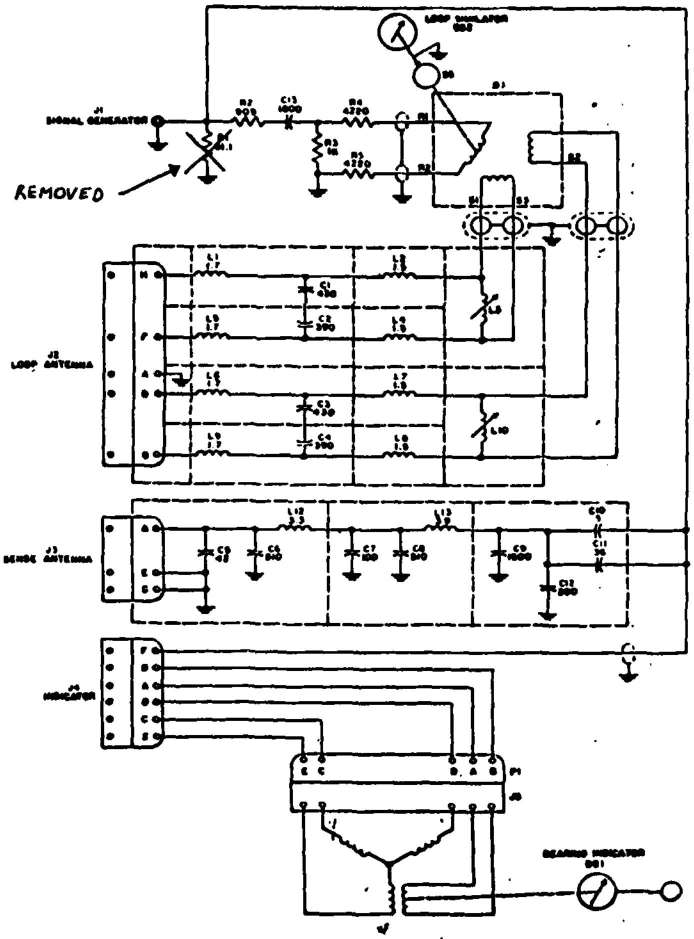


FIGURE 5.2 Schematic diagram of Collins 477U-2 Antenna simulator showing removed 51 Ohm resistor.

terminals of the receiver.

The Capacitive voltage divider network is depicted in figure 5.3. In order to determine the proper values it is necessary to know the effective height (He) and the capacitance (Ca) of the ADF system sense antenna. The values for the capacitors can then be determined from the following formulas [3]:

$Cs + Cp = Ca$ (10% tolerance)

$Cs = HeCa$ (10% tolerance)

All capacitances are in pico-Farads.

The audio section consists of two switched subsections. The first is a General Radio 583-A output power meter and an HP 330B harmonic distortion analyzer. The second is a two-channel tape recorder, microphone and an amplifier for monitoring the audio output of the receiver. Note that the tape recorder is not used in the performance verification stage, but is left in the set-up in order to facilitate the switchover to the interference susceptability stage of the testing.

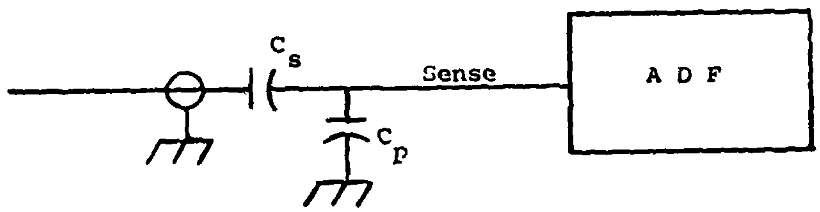


FIGURE 5.3 The Capacitive Voltage Divider network used to attenuate the sense antenna signals to the desired value.

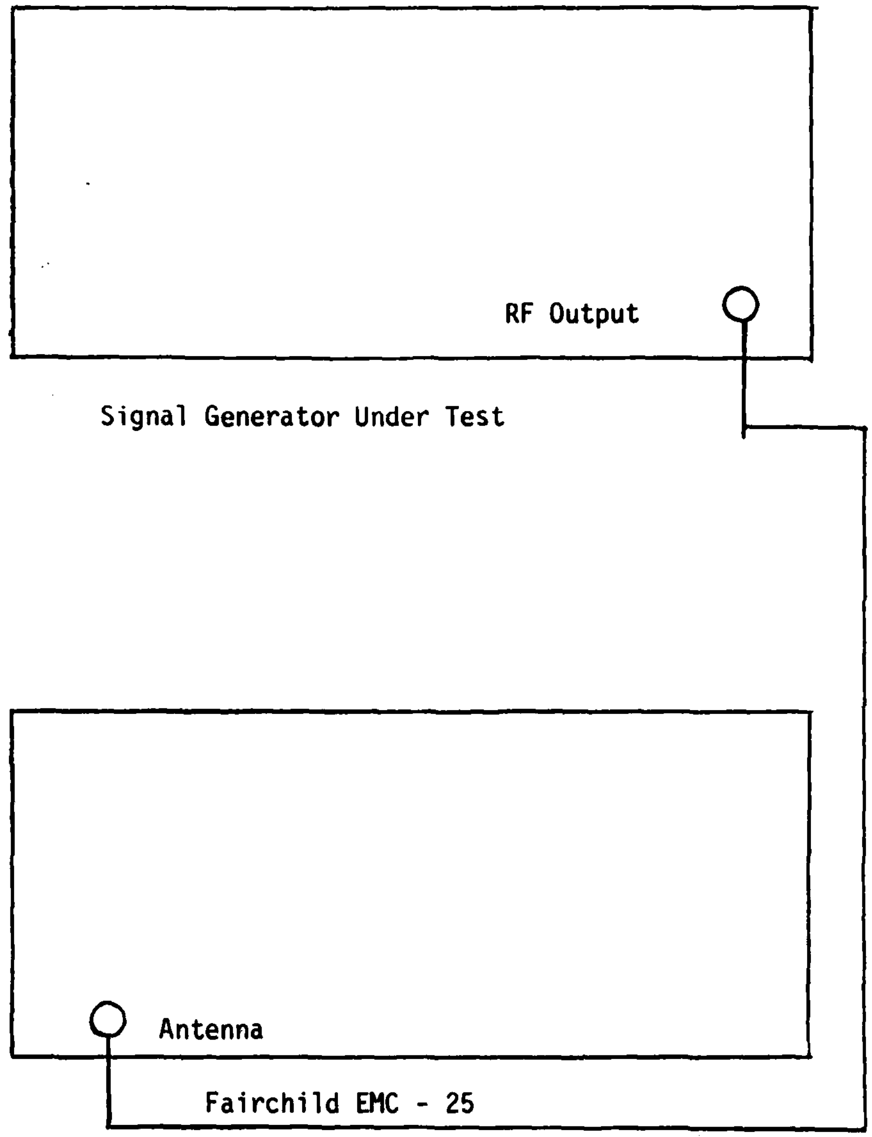


FIGURE 5.4 Set-up used to verify the calibration of the signal generator output meters.

The set-up of figure 5.4 should be used to check the calibration of the output of the signal source. The voltmeter should be a selective voltmeter such as the Fairchild EMC-25. The EMC-25 has an accuracy of 2 decibels throughout its range. Checks should be made approximately every 50 kHz in the range of 200 - 500 kHz.

The set-up of figure 5.5 should be used to verify the percentage of modulation (when MCW is used) since the modulation meter on the HP-606B is valid only for a full-scale reading on the output level meter. The technique used to measure the percentage AM modulation is the trapezoidal modulation waveform technique [4].

The trapezoidal waveform generated on the oscilloscope and the formula used to determine the percentage modulation are depicted in figure 5.6. Also shown are typical waveforms for amplitude modulation of less than 100%, 100%, and overmodulation (greater than 100%). The trapezoidal waveform is generated by the correspondance of the "peaks" and "valleys" of the modulation waveform with the peaks and valleys of the composite AM signal.

Before testing can proceed one must determine an audio signal level known as "reference output". Reference output

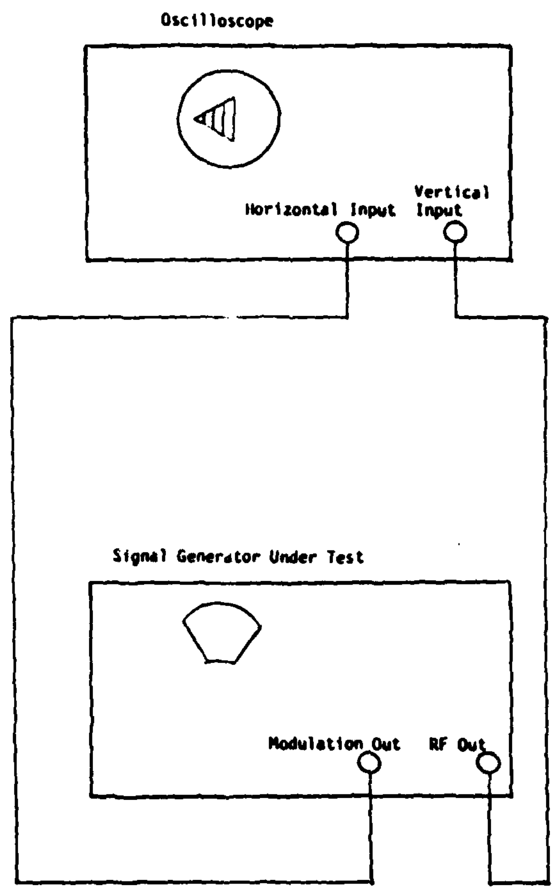


FIGURE 5.5 Set-up used to measure the percentage of AM modulation of the signal generator.

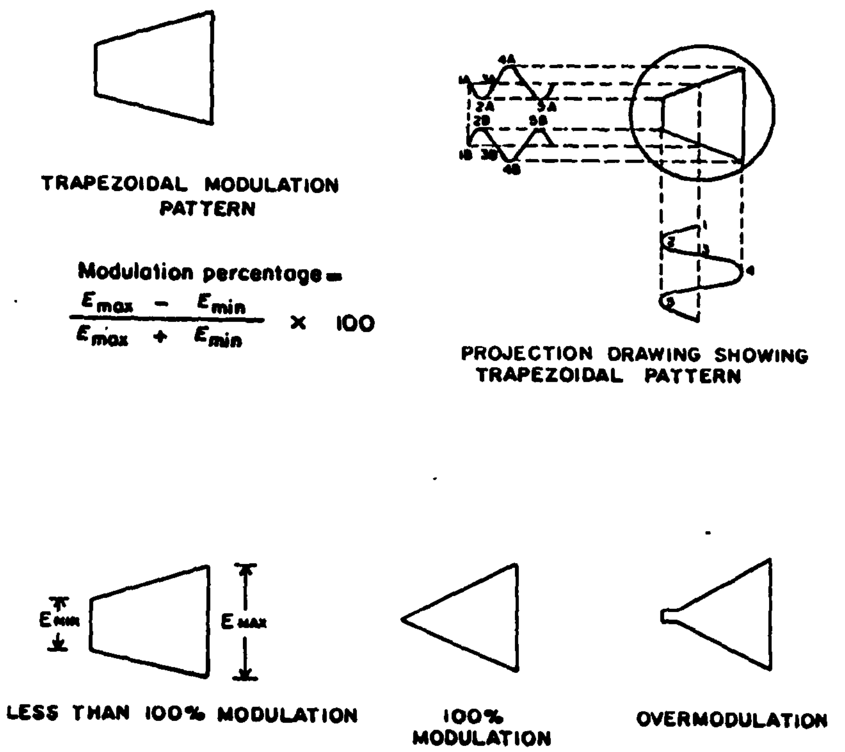


Figure 5.6 Representative trapezoidal modulation waveforms and their interpretation.

is defined (for a receiver without an RF gain control) as that audio output power produced by an input signal of 100 micro-Volts/meter with the same audio gain control setting as that which produces the maximum audio output power with no more than 25% distortion, when the RF input is .5 Volts/meter. The input signal for this test is to be modulated 30% at one kHz [5]. The proceedure for finding the reference output is as follows:

1) Set signal generator to a frequency in the middle of the frequency band in question (say 300 kHz).

2) Set signal source to .5 V (remember to add 3 dB, making the generator output meter read .707 V)

3) Set modulation to 30 %

4) Find maximum audio gain control setting which will still have a total harmonic distortion of less than 25%

5) Reduce signal source output to 100 micro-Volts (+3 dB = 140 micro Volts at generator output)

6) Read reference output level on output power meter

and record

The next performance test is the receiver sensitivity. The needed quantity is the level of signal necessary to achieve a 6 dB signal + noise/noise ratio in the audio output. Note: Some manufacturers have more stringent requirements. When these requirements exist the appropriate numbers should be substituted in place of the 6 dB figure used in this section. This test should be performed for both ADF and RECEIVE mode [5], and should be made for every 50 kHz increment of frequency in the band 200 - 500 kHz. The following procedure should be used:

1) Set signal source output to 0 dBm (signal generator to +3 dBm)

2) Set both antenna simulator resolvers to NORTH

3) Set modulation of signal source to 1 kHz, 30% AM and set frequency with to the receiver setting with the counter.

4) Set receiver audio output level to 20 % of reference output

5) Shut off modulation

6) If the drop in receiver audio output power is about 6 dB when performing step 5 then go to step 8.

7) Adjust signal level : Go to step 4

8) Record signal level. This is the sensitivity of the receiver in this mode at this frequency.

The next test to be made is the receiver selectivity test. This test is made only in RECEIVE mode and determines the receiver's ability to reject signals on frequencies other than the desired one. This test should be repeated every 50 kHz in the frequency band of interest. The following procedure should be used:

1) Select frequency, set signal source for 30% AM modulation at 1 kHz

2) Set signal level for 6 dB (S+N)/N using 20% of reference audio output.

3) Add n dB (n = 6,12,50,55,70,80 dB)

4) Tune generator below desired frequency until 20% of reference output is present in audio.

5) Record frequency

6) Tune generator above desired frequency unitil 20% of reference output is present in audio

7) Record frequency

8) The frequencies just recorded are the upper and lower n dB points of the receiver selectivity curve.

9) Go to step 3 until all values of n are exhausted

10) Go to step 1 for next frequency

The next test is for ADF bearing accuracy. This test measures the ability of the receiver to indicate the proper bearing with all other conditions being ideal. Obviously this test must be made in ADF mode. This test was repeated for signal levels of -70, -50, -10, and +7 dBm in order to get a good representation.

1) Set both simulator needles to 0 degrees

2) Record indicated bearing.

3) Rotate the resolvers on the simulators clockwise by 15 degrees [3].

4) Record indicated bearing.

5) If simulated bearing is not 0 degrees then go to step 3.

6) Finished

The last performance test to be done is the Image rejection test. This test should be performed in RECEIVE mode at 100 kHz increments. Proceedure:

1) Set signal generator frequency.

2) Set modulation to 30% at 1 kHz.

3) Set signal generator output level and audio gain control to produce 20% of reference output.

4) Record signal level

5) Set signal generator to image frequency

6) Increase signal level until 20% of reference output is present in receiver audio

7) Record difference in signal level between steps 4 and 6.

The number in step 7 is the image rejection in dB for the frequency of step 1.

The test configuration for the ADF interference susceptibility tests is shown in figure 5.7. The test set-up consists of four major parts: the desired signal source, the undesired signal source, the RF field simulator, and the audio chain.

The desired signal source consists of the HP 606-B signal generator, an audio signal generator, and a telegraph key. For most measurements the desired signal source provides either CW or MCW (85%) without the necessity of keying by using its internal 1 kHz modulation source. However, for determining the effects of interference on the

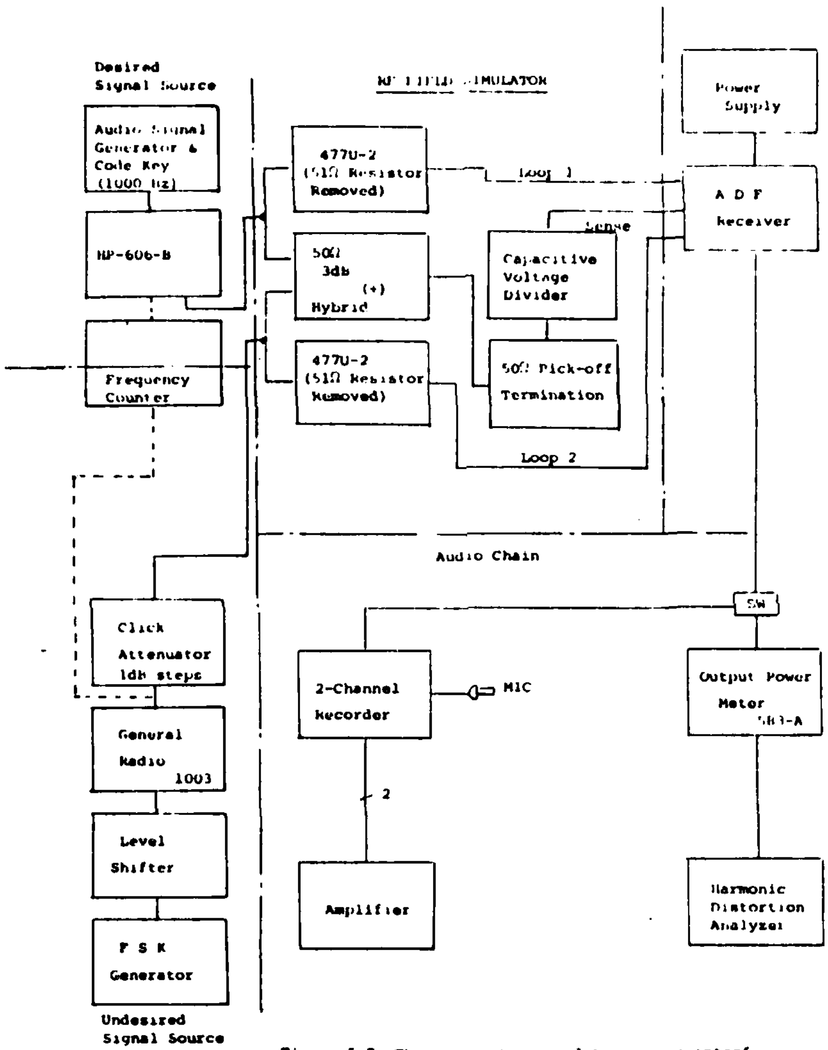


Figure 5.7 The test set-up used to measure interference susceptability.

pilot's ability to recognize the NDB station identifier, it is necessary to use the external keyed source to generate an artificial station ID. The desired signal source provides CW and MCW signals to the RF field simulator section. Its frequency can be checked by the HP 5245L counter.

The undesired signal source consists of a General Radio 1003 signal generator, a click (1dB steps) attenuator, and an FSK generator which was constructed for these tests (see chapter 6). FSK modulation is accomplished by feeding the output of the FSK generator through a level shifter into the external modulation inputs of the signal generator and using this signal to frequency modulate the generator. The data "transmitted" by the FSK source is part of a paragraph from a semiconductor data book. The undesired signal source provides CW and FSK signals to the field simulator. Its frequency can be checked with the HP counter.

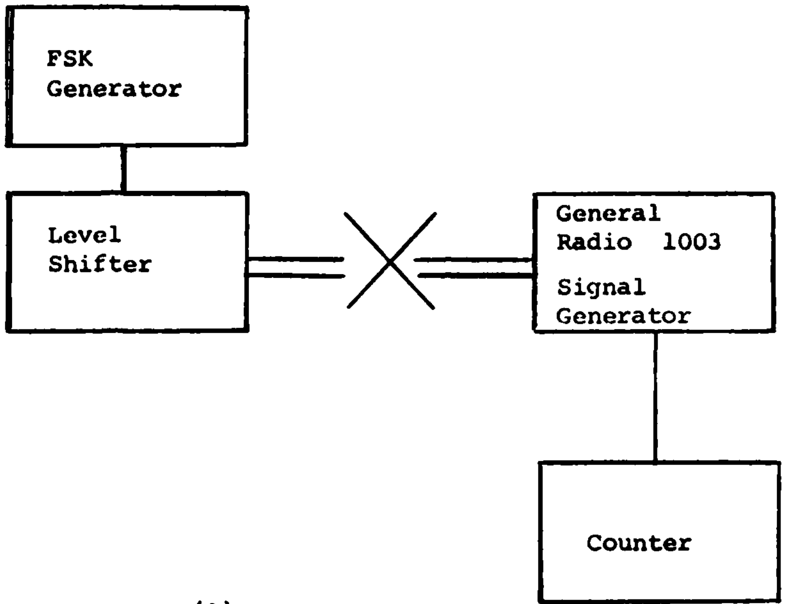
The RF field simultor section is somewhat different in configuration from the one used in the performance verification set-up but is very similar in function. This section consists of two Collins 477U-2 antenna simulators, a 50 Ohm power combiner (3dB Hybrid), a 50 Ohm pick-off termination, and the capacitive voltage divider network described earlier in this chapter. The 51 Ohm resistors have been removed from the input circuits of the simulators in order to make them appear as a very high impedance input. The power combiner reflects the 50 Ohm impedance of the pick-off termination back to its input ports in order to properly terminate the signal sources. The pick-off side of the termination sees the high impedance of the capacitive voltage divider network and the ADF receiver, so there is effectively no load on it.

The audio chain consists of a General Radio 583-A output power meter, an HP-330B harmonic distortion analyzer, a two channel tape recorder, and an amplifier for monitoring both channels. The output power meter and the harmonic distortion analyzer are used in the susceptibility measurement phase to monitor the signal + noise/noise ratio in the receiver. At all other times the receiver output is switched through the 2-channel recorder and the audio amplifier. The second channel is used by the operator to comment on the measurement currently being recorded. The audio output of the ADF receiver is always terminated in its rated output impedance.

All measurements in the interferance susceptibility testing phase are recorded on the standard forms discussed earlier in this report.

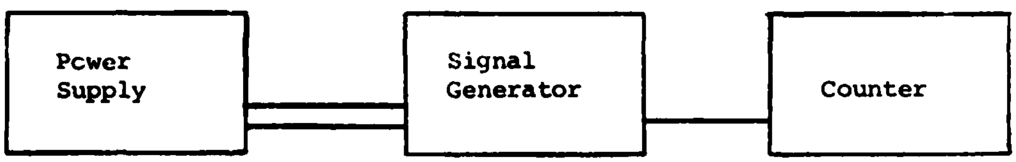
As mentioned earlier, both signal generators should be checked against a selective voltmeter to insure accuracy. In addition, when using FSK, the undesired signal source must be calibrated to produce the proper 200 Hz shift at the frequency in question. Figures 5.8-A and B show the set-up for calibrating the FSK generator and level shifter.

First, the output of the level shifter should be removed from the input of the signal generator as shown in Figure 5.8-A. The frequency of the generator should then be set with the counter to the desired frequency. Next, the minus power supply should be hooked up to the generator inputs as shown in Figure 5.8-B and the voltage adjusted so as to produce a 100 Hz shift. The oscilloscope should then be set for DC input and this level marked on the screen with a felt-tip pen (this type is easy to wipe off later). Next, the power supply leads should be reversed and the same proceedure followed. The level shifter can now be hooked up again, and the power supply removed. The scope should be left in the circuit henceforth for later calibration. With the FSK generator turned on, the FSK generator output and the two power supplies for the level shifter should be adjusted so that the 0-1 binary levels at the input to the



(A)

(B)



Figures 5.8A and B Calibration of the system when generating FSK signals.

MEASUREMENT NUMBER	DESIRED SIGNAL FREQUENCY (kHz)	DESIRED SIGNAL LEVEL (μV/m)	DESIRED SIGNAL MODULATION TYPE	UNDESIRED SIGNAL MODULATION TYPE	UNDESIRED SIGNAL LEVEL (μV/m)	UNDESIRED SIGNAL FREQUENCY (kHz)
1	200	40	CW	CW	VARIED DURING MEASUREMENT	VARIED DURING MEASUREMENT
2	200	500	CW	CW		
3	200	500	MCW	CW		
4	200	1,000	CW	CW		
5	200	1,000	CW	FSK		
6	400	30	CW	CW		
7	400	500	CW	CW		
8	400	500	CW	FSK		
9	400	1,000	CW	CW		
10	400	100,000	CW	CW		

Table 5.1 The Values of the Parameters for each Measurement Associated with Configuration 1.

signal generator fall on the marks previously made on the oscilloscope face. Note that these levels are frequency dependent and must be re-measured for each desired frequency. With the level-shifter power supplies on and the FSK generator OFF, the desired frequency can now be set with the counter. Turning the FSK generator ON will cause the generation of 200 Hz shift FSK modulation.

Now that the set-up is calibrated, the interference susceptibility measurements can be made. There are two measurements to be made in this stage: ADF bearing error, and signal + noise/noise in the audio. Note that now the antenna simulators are set in space quadrature so that the undesired signal will try to "pull" the needle away from the desired bearing.

For a listing of all the test conditions refer to Table 5.1. This table lists all the settings of desired signal level, frequency, and modulation type that should be used in order to obtain a good data set. This table was taken from the test plan [2]. For each of these 10 settings, it is necessary to vary both the difference in frequency between the desired and undesired signals, and the level of the undesired signal. The results of these variations will be a set of data points which should be recorded on the standard forms depicted in earlier chapters of this report. The values of delta-f (frequency difference between the desired and undesired signals) for the set of measurements were chosen to be plus and minus .25, 1, 3, 6, and 12 kHz. The following proceedure should be used to measure the bearing error and signal + noise/noise data.

1) Set desired signal source with a frequency counter, set output level to desired level for the particular measurement. The frequency should match the receiver dial frequency. Remember to compensate for the three dB loss in the power combiner

2) Set the undesired signal frequency to the first value of delta-f.

3) Vary the level of the undesired signal level in such a manner as to obtain enough data points to fit a smooth curve with respect to bearing error and undesired signal level. Most important, determine the three degree bearing error point.

4) Record the values measured in step 3 on the form provided (see figure 2.4).

5) For this value of delta-f, find the undesired signal level which degrades the signal + noise/noise ratio in the receiver audio in RECEIVE mode to 6 dB.

6) Record the number measured in step 5 on the form provided (see Figure 4.1).

7) Repeat steps two through six for all the given values of delta f for the measurement being done.

8) Repeat steps one through seven for all the entries in table 5.1.

This chapter has provided a description of how the measurements that were possible were performed. Again it should be noted that these proceedures only worked for the older types of receivers. The next chapter provides a full description of the FSK generator and its interface to the General Radio 1003 signal generator.

Chapter 6: The FSK Generation Scheme

One of the required tests involves the use of FSK (Frequency Shift Keying) modulation of the undesired signal. Since there was no provision built into the General Radio 1003 for FSK modulataion, and no convenient source of data to be "transmitted", it was decided to design and build a unit which would simulate the transmission of FSK signals. This chapter describes the design and construction of the FSK simulator and its interface to the General Radio 1003 signal generator.

Since neither the test plan or the PLC radiation report [1] specify the type of data to be "transmitted" via FSK, standard TELETYPE signals were chosen. This means that the data to be transmitted must be BAUDCT encoded and adjusted to one of the standard speeds. The standard speed of 75 baud is specified in the PLC report, and 30 baud in the measurement plan. Since 75 baud is standard and 30 is not , it was assumed that the 30 baud specification was a typograpical error and 75 baud was used.

Two other features were desired in the design. These were: variable output (0-5 Volts) and the ability to single-step through the transmitted data character by character. The completed design is depicted schematicly in figure 6.1.

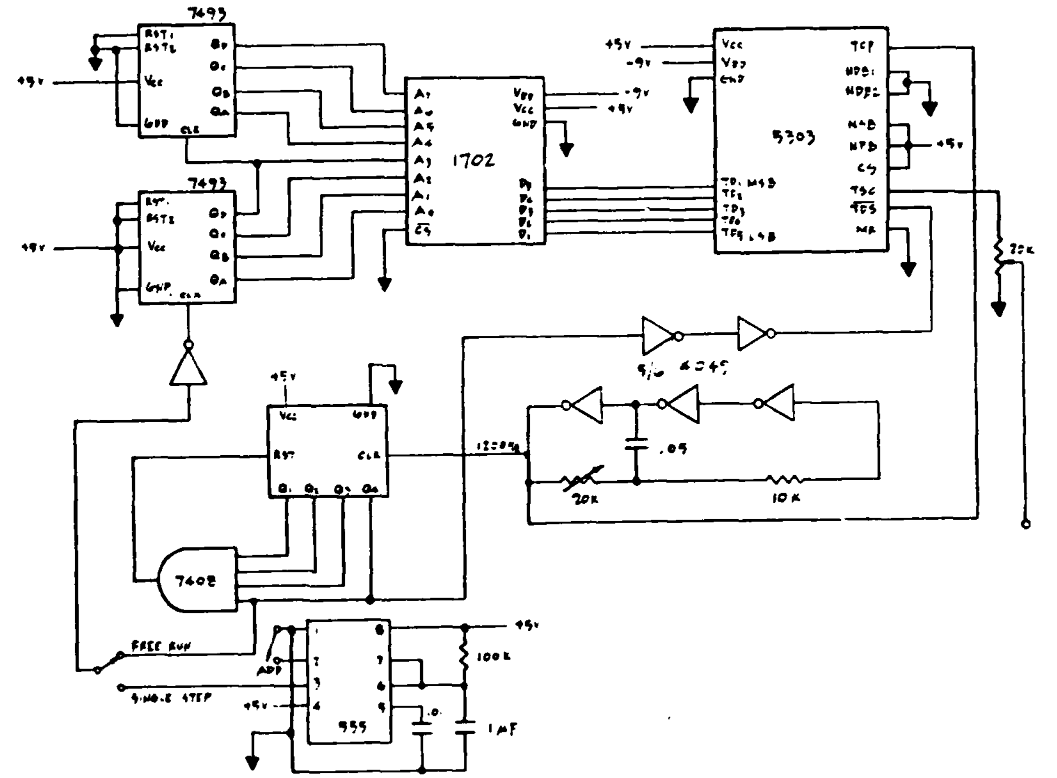


FIGURE 6.1 Schematic diagram of the FSK generator

The message to be transmitted (part of a paragraph from a data book) is contained in the 1702-A EPROM, which is addressed sequentially by the chained set of 7493 binary up-down counters set for count-up. Since BAUDOT is a 5 level code, only bit positions D1-D5 of the EPROM are used. These pins are connected to the data inputs of the MM5303 UART. The UART adds a start bit, 1.5 stop bits (BAUDOT convention) , and does a parallel to serial conversion. The data output pin of the UART is then connected to a potentiometer , and the output taken from the center wiper so that the output level can be controlled. The remainder of the PSK simulator provides timing signals to the UART and counters, and provides switched control from the front panel.

To achieve the 75 baud transmission rate, the UART must have a timing signal at 16 X 75, or 1200 Hz. This signal is generated by the three inverter oscillator circuit. The 4024 counter and 7408 AND gate provide a divide by 16 counter to provide a data strobe for the UART and an advance signal to the binary up-down counters. The two inverters in the active-low Tds pin of the UART provide a delay to synchronize the data-latch with the output of the 1702 EPROM. The 555 timer chip is simply wired as a one-shot circuit to allow single stepping of the 1702's data.

The FSK generator requires two power supplies, one at +5 Volts, and one at -9 Volts.

The 0-5 Volt output of the FSK generator is not sufficient to properly modulate the General Radio 1003 signal generator in FM mode to provide the desired 200 Hz frequency shift. To remedy this situation the level shifter of figure 6.2 was devised. This circuit is simply a CA4050 acting as a level shifter. To adjust the 1-0 threshold voltages, one need only adjust the plus or minus power supplies in conjunction with adjusting the output level of the FSK generator.

The level shifter requires two variable power supplies, one each at plus and minus 10 Volts.

To FM modulate the General Radio 1003 signal generator with the square wave output of the level shifter, the level shifter needs to be coupled into the 1003 via a socket on the rear panel. The modulation selector is then rotated to "EXT AC". When the level shifter is properly calibrated (see chapter 5), and the FSK generator powered on, the output of the signal generator is a 200 Hz shift FSK signal.

This chapter has provided a description of the FSK

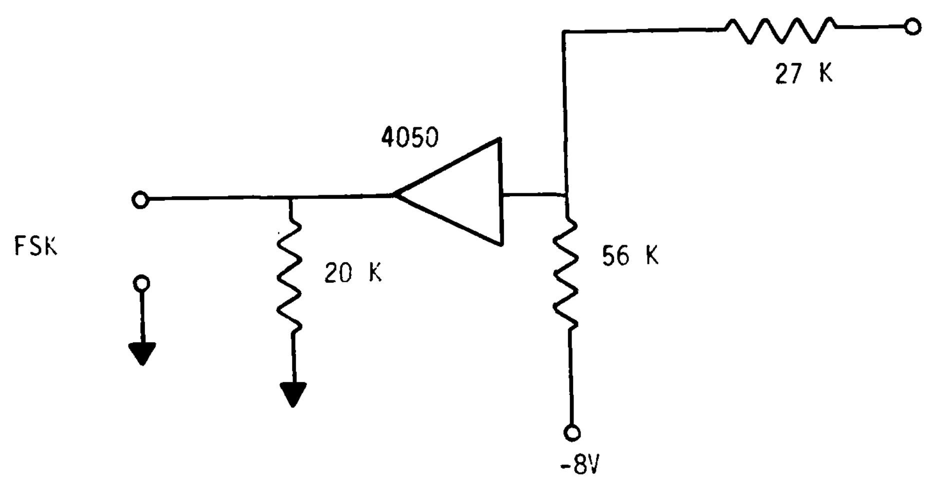


FIGURE 6.2 Schematic diagram of the level shifter circuit

generation technique. The next chapter will discuss the results obtained when the measurements of chapter three were made using the techniques of chapter five, incorporating (among other things) the FSK techniques discussed in this chapter.

Chapter 7 : Test Results and Comparison with Published Data

This chapter is a summary of the results of the performance verification tests and the ADF interference susceptibility tests. The receivers' compliance with the manufacturers' specifications is discussed, and then the inteferance susceptibility data is analyzed for correlation with the undesired and desired signal levels versus the difference in frequency between the two. The interference susceptibility data is then compared to the existing RTCA specifications (DO-137 and DO-142) and to the data reported by Kissick [1,2].

Generally speaking, the receivers which could be tested had little trouble meeting their manufacturer's specifications.

Figures 7.1 through 7.4 represent the three degree bearing error points for the King KR-86, the two Cessna ADF-300, and the Collins 51Y-7 ADF receivers plotted with respect to the desired to undesired (D/U) signal ratio and the difference in frequency (Delta f) between the desired and undesired signals. The three degree bearing error points define the boundaries of an area inside which harmful interference will occur. As can be seen from the figures, the shape of the curve is simply the selectivity curve of the receiver. Also plotted on the figures are the

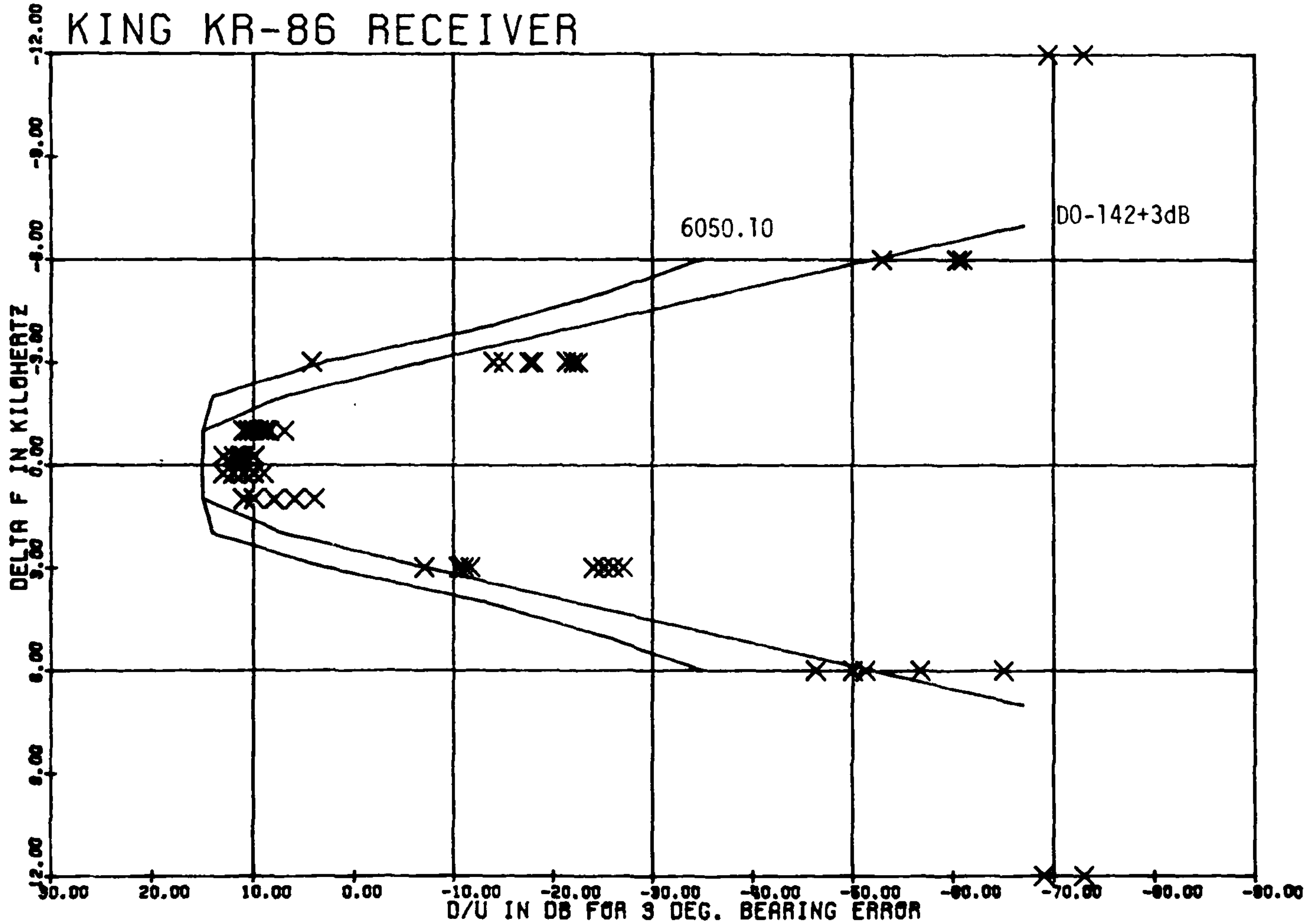


Figure 7.1 Three degree bearing error points versus D/U and delta-f for King KR-86 receiver

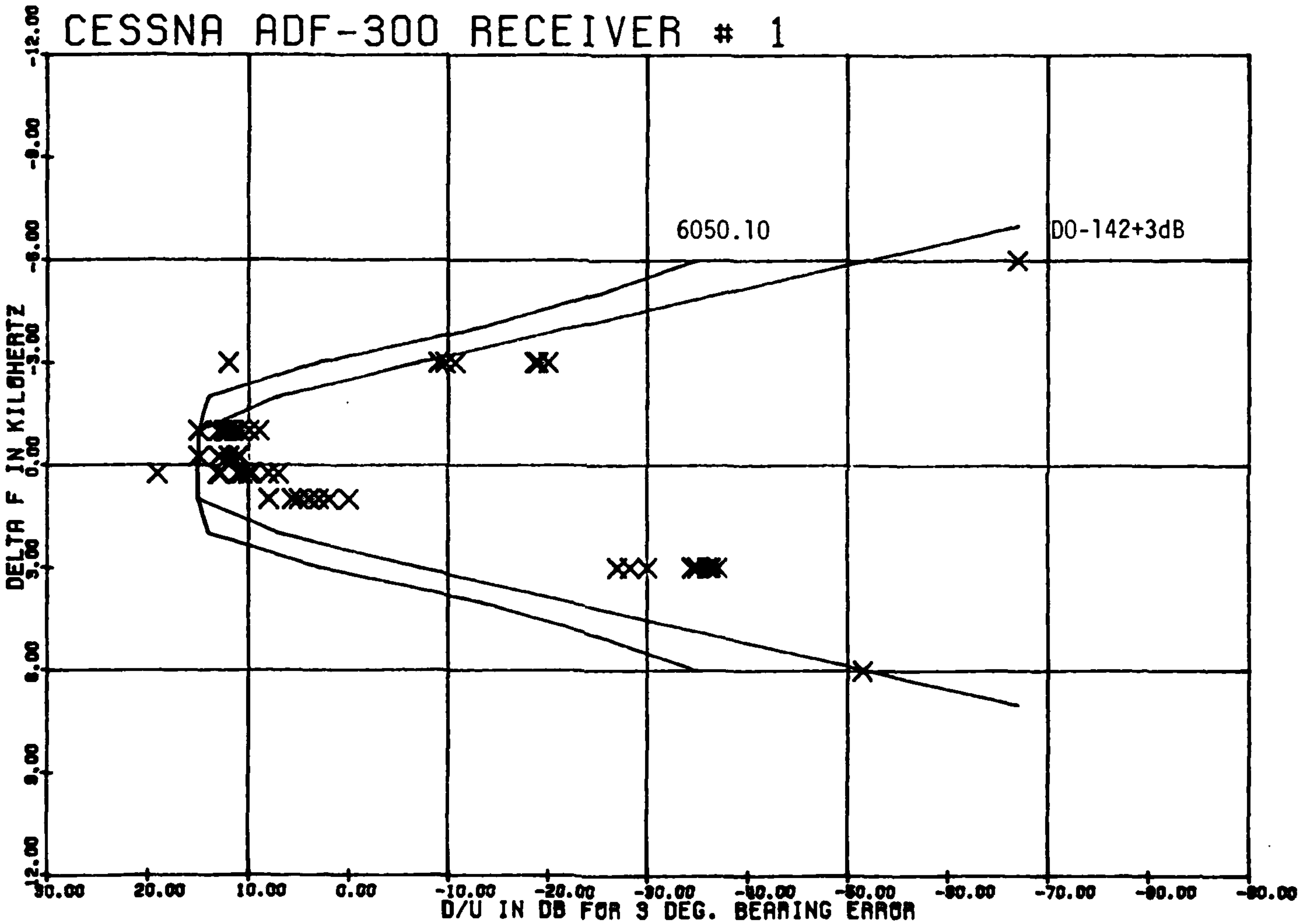


Figure 7.2 Three degree bearing error points versus D/U and delta-f for second Cessna ADF-300 receiver.

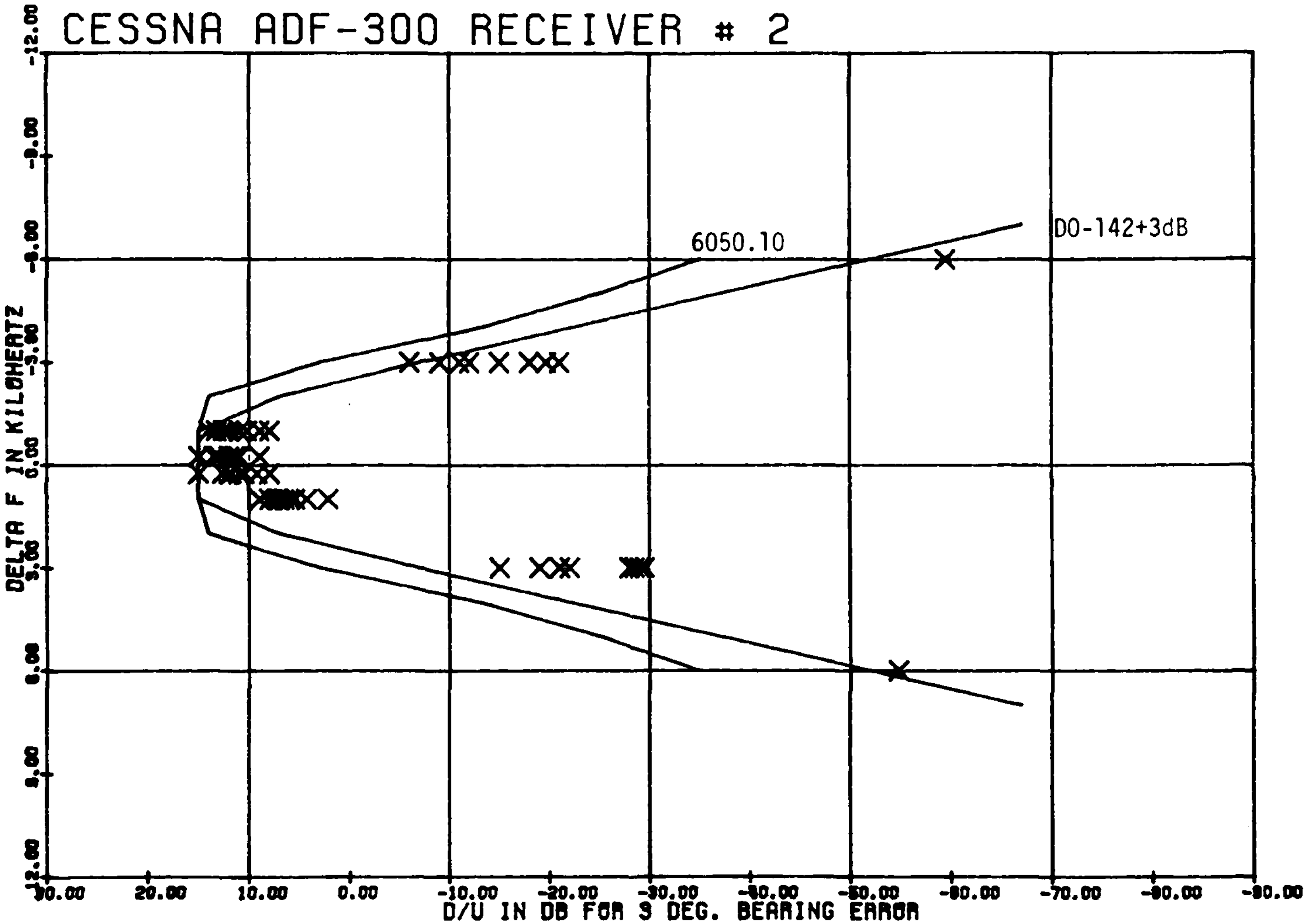


Figure 7.3 Three degree bearing error points versus D/U and delta-f for second Cessna ADF-300 receiver.

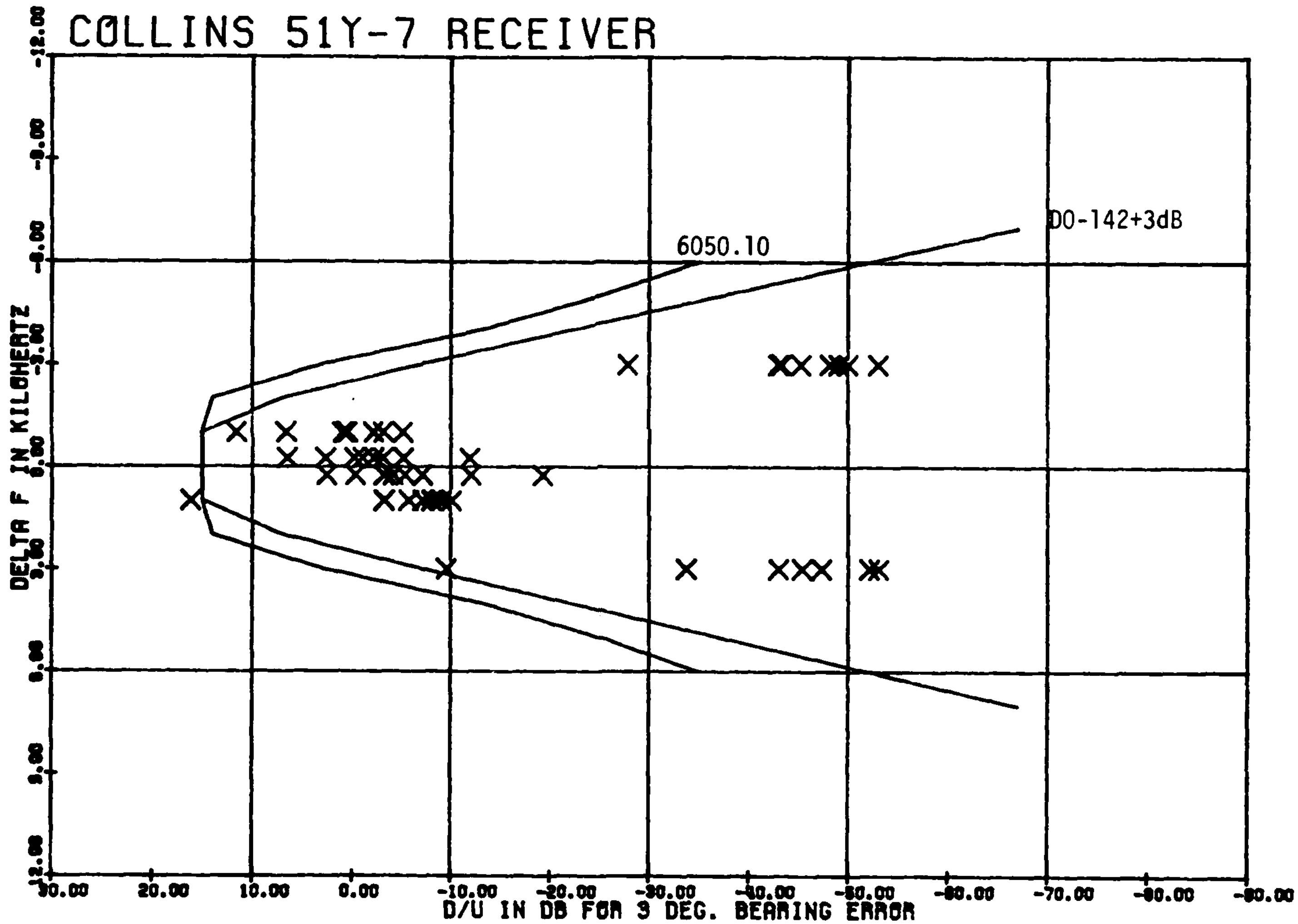


Figure 7.4 Three degree bearing error points versus D/U and delta-f for Collins 51Y-7 receiver.

selectivity curves specified in DO-142 catagory A (+3dB, to allow for a 3 dB NDB station monitor tolerance) and 6C50.10. As can be seen, the specifications of both were met by all the receivers tested.

Figures 7.5 through 7.8 are the same three degree bearing error points as were plotted in figures 7.1 through 7.4. However, this time they are plotted with respect to the absolute undesired level and delta-f. It should be obvious that there is no correlation between the absolute undesired level and the three degree bearing error points, as there is no distinct boundary. In other words, it is impossible when refering to this curve to determine when interference will occur.

Figures 7.9 through 7.12 are essentially the same as figures 7.1 through 7.4 except that now the quantity being plotted is the point where the signal + noise/noise ratio in the receiver audio drops below six dB. As can be seen from an examination of the figures, a distinct boundary curve is again formed by the points.

Figures 7.13 through 7.16 are also plots of the 6 dB signal + noise/noise breakover points, and as in figures 7.5 through 7.8 they are plotted with respect to the absolute

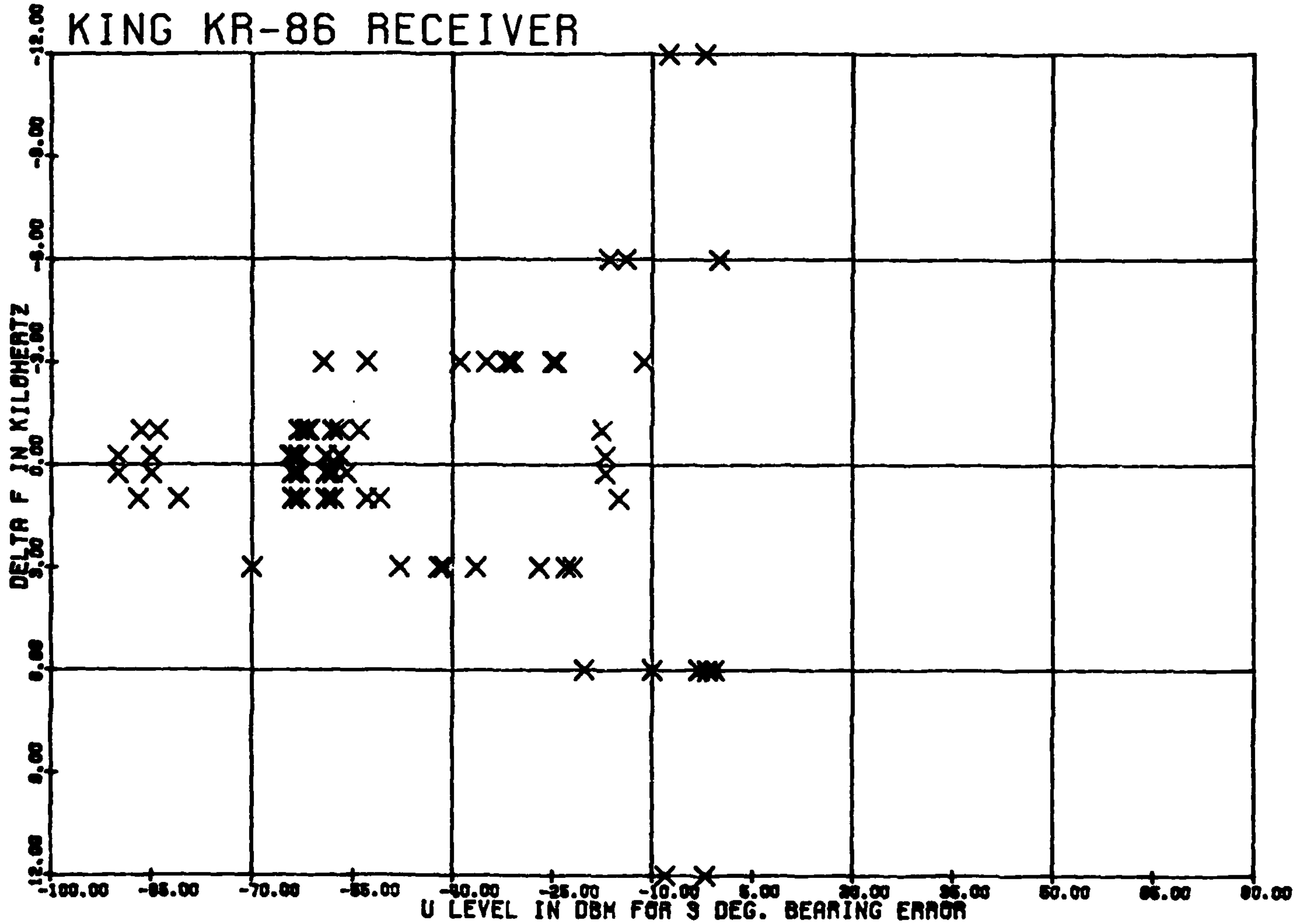


Figure 7.5 Three degree bearing error points versus absolute U-level for King KR-86.

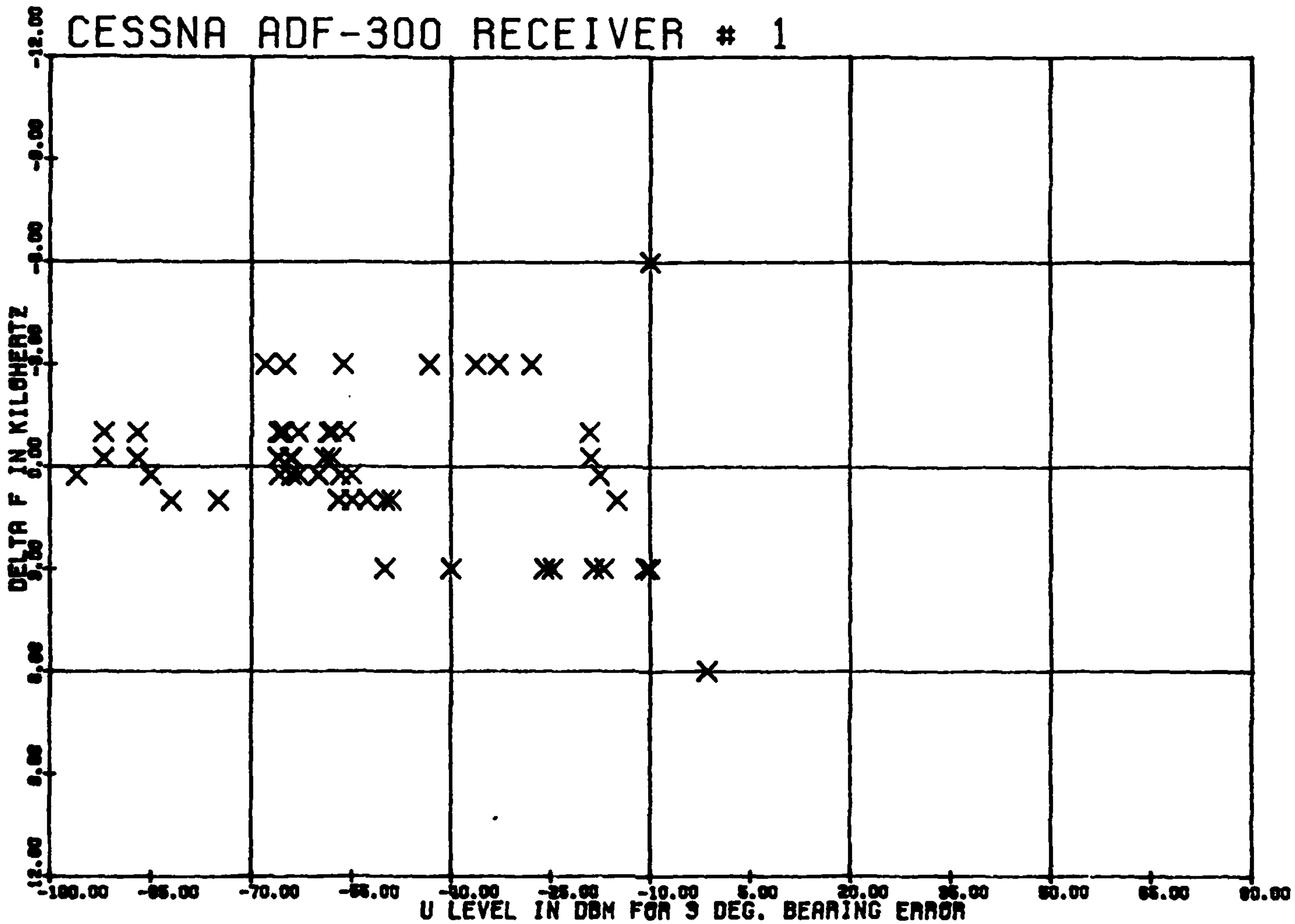


Figure 7.6 Three degree bearing error points versus absolute U-level for the first Cessna ADF-300 receiver.

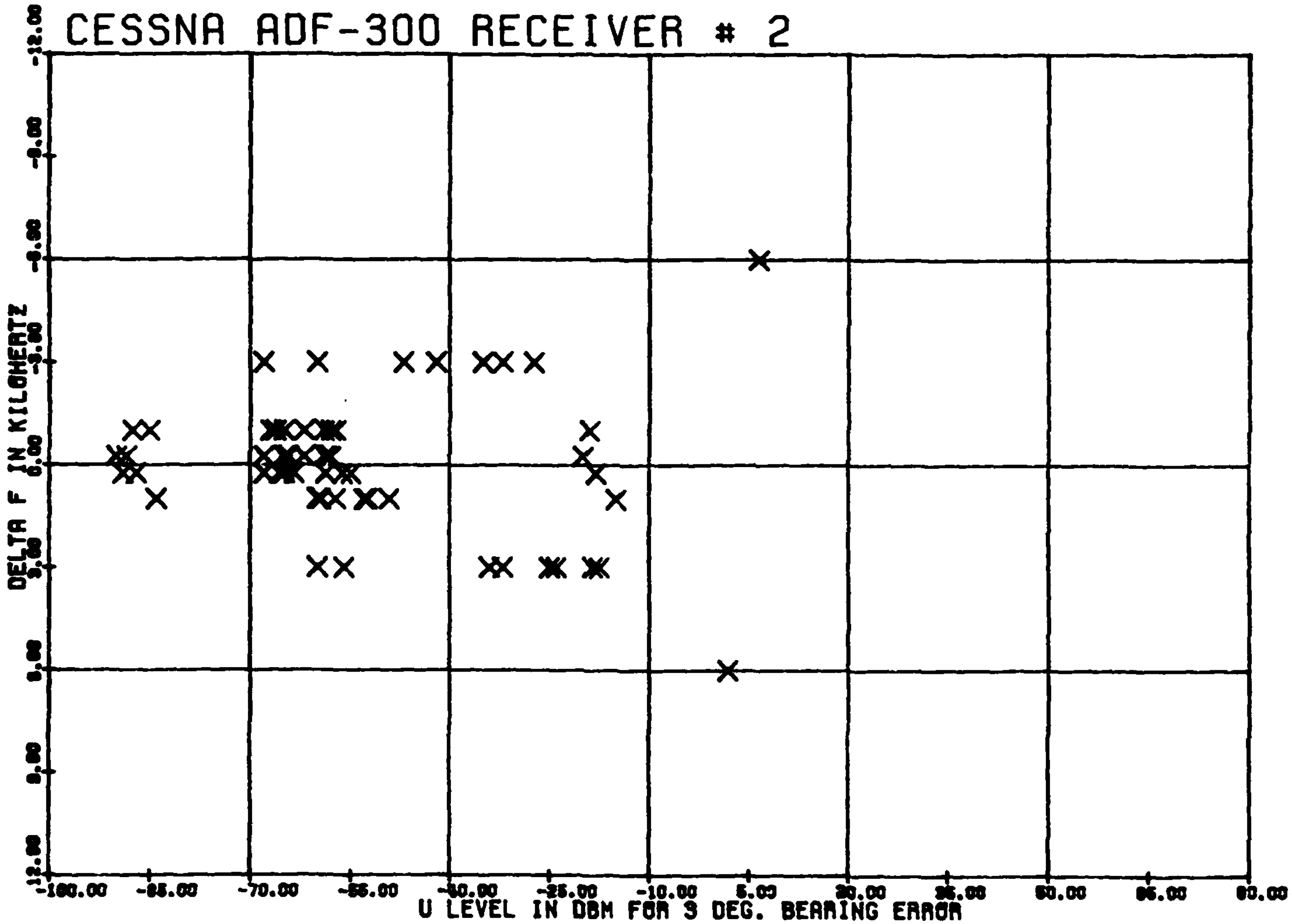


Figure 7.7 Three degree bearing error points versus absolute U-level for the second Cessna ADF-300 receiver.

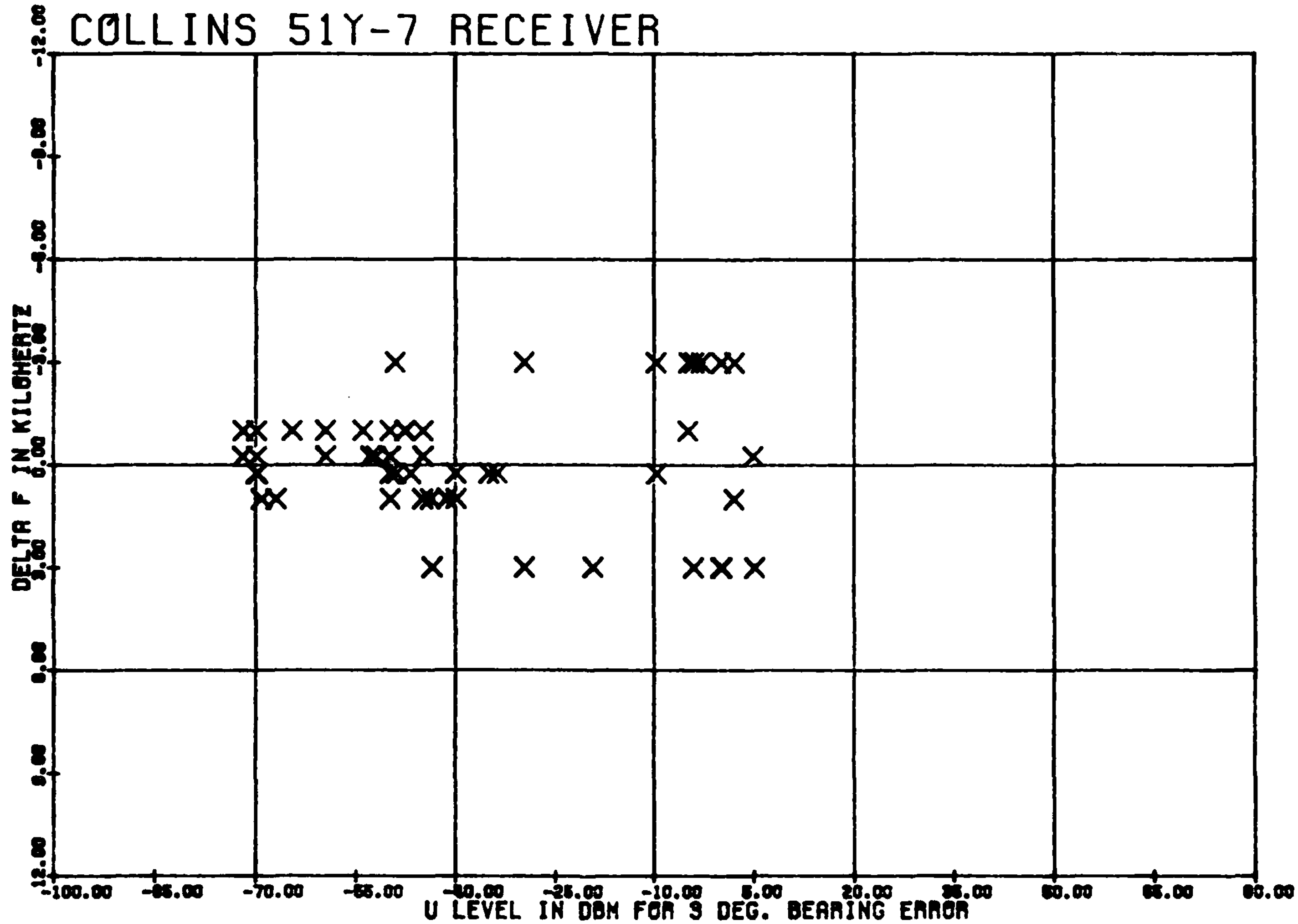


Figure 7.8 Three degree bearing error points versus absolute U-level for the Collins 51Y-7

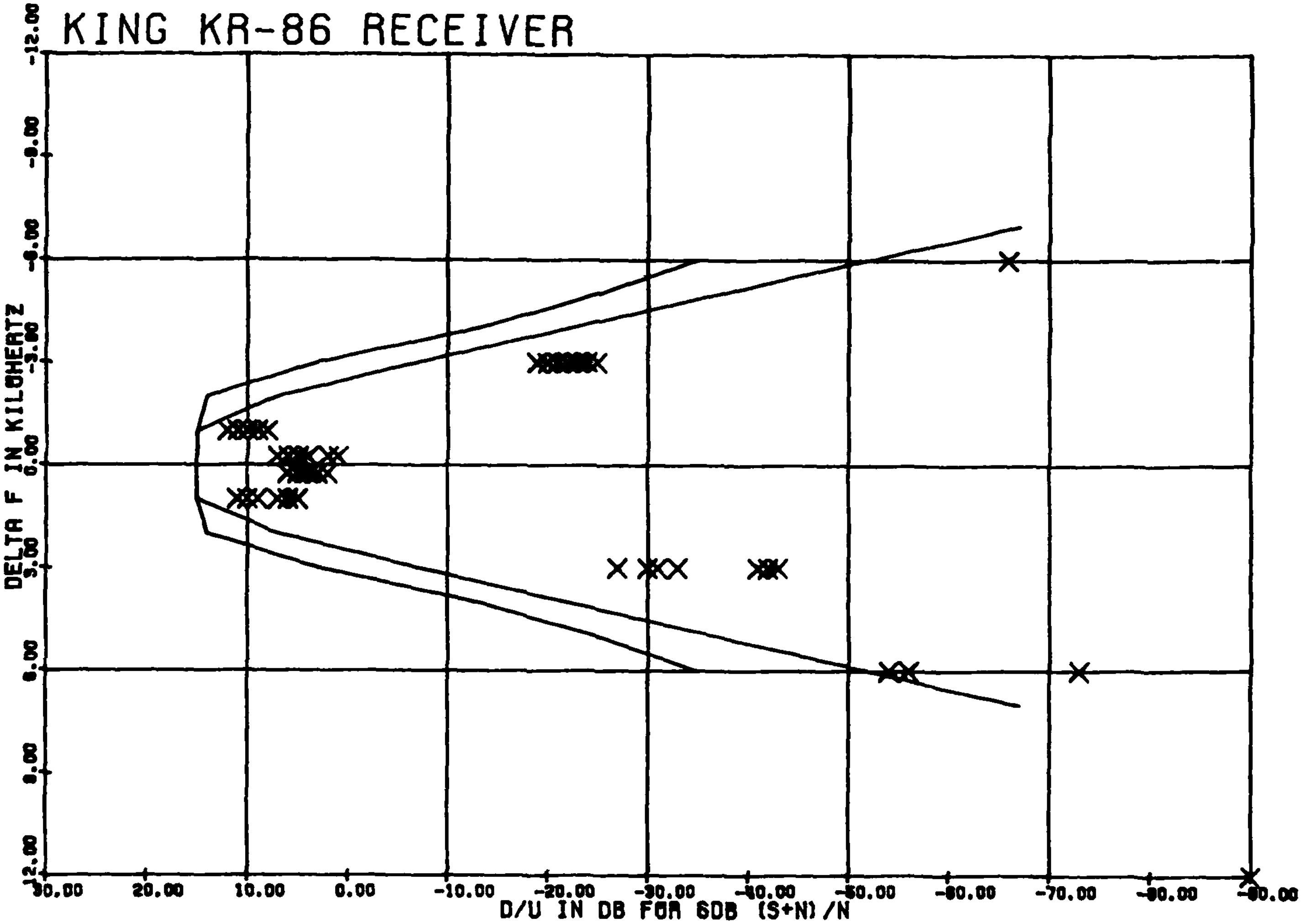


Figure 7.9 Six dB signal + noise/noise breakover points versus D/U for King KR-86 receiver.

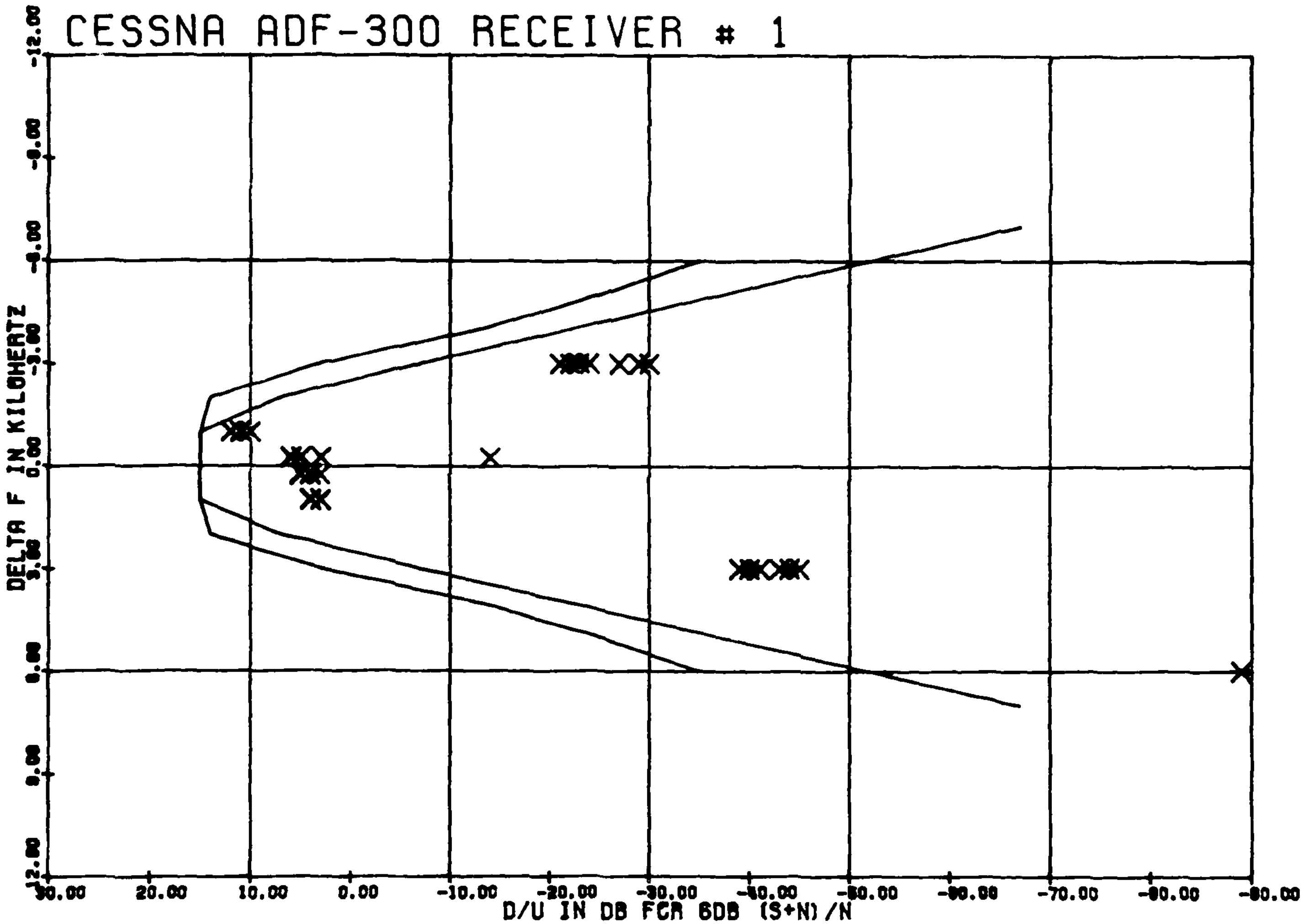


Figure 7.10 Six dB signal + noise/noise breakover points versus D/U for the first Cessna ADF-300 receiver.

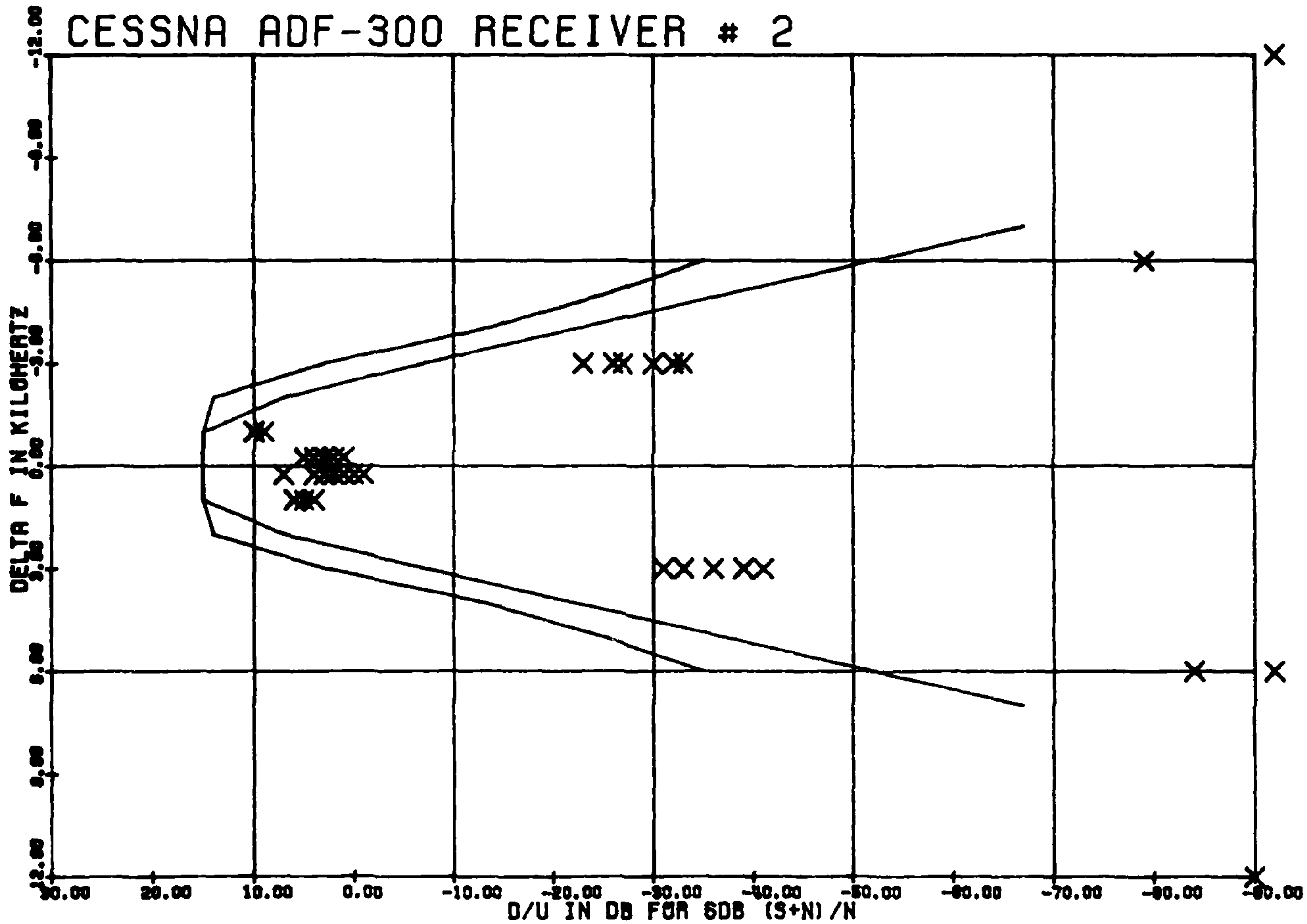


Figure 7.11 Six dB signal + noise/noise breakover points versus D/U for the second Cessna ADF-300 receiver.

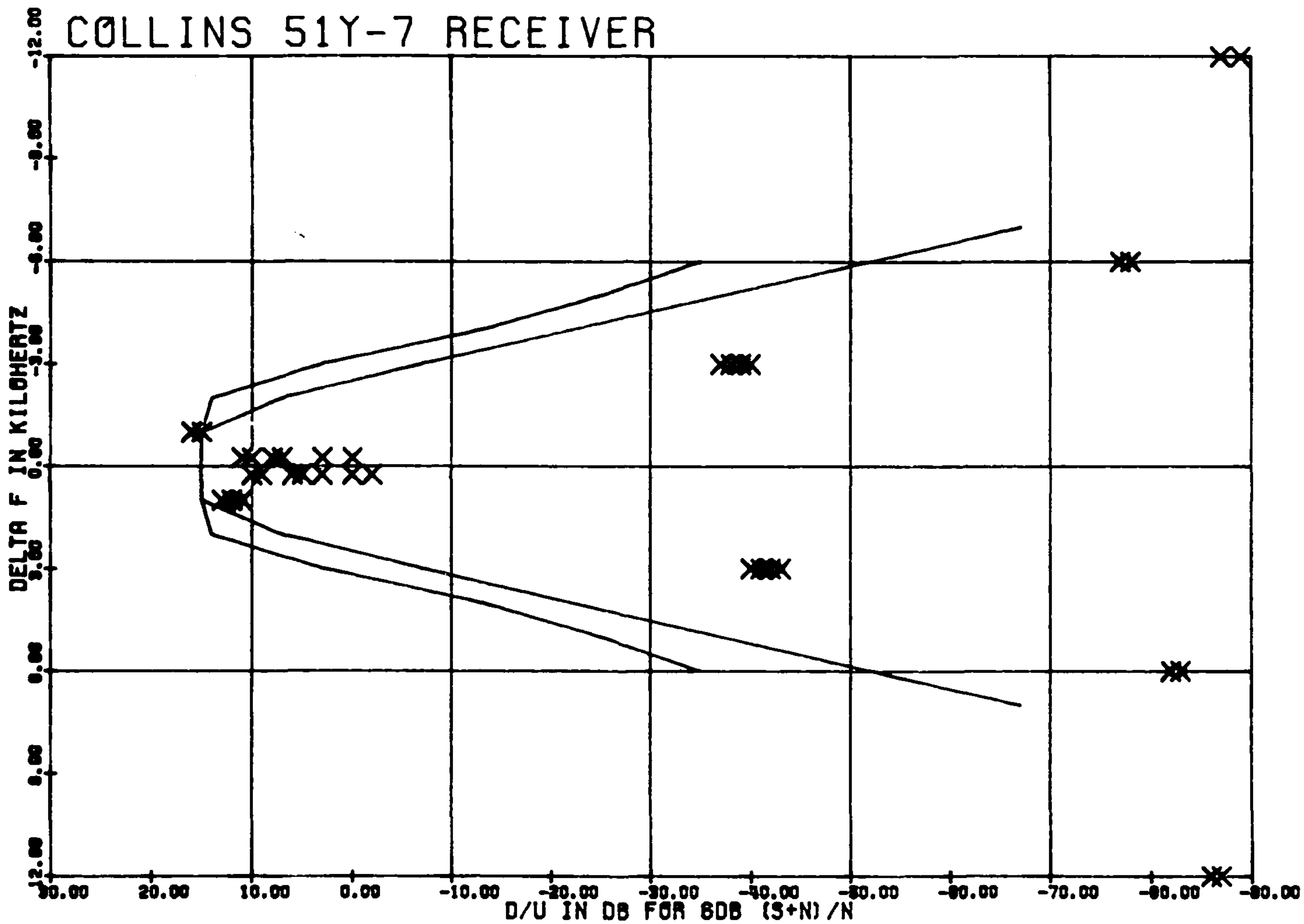


Figure 7.12 Six dB signal + noise/noise breakover points versus D/U for the Collins 51Y-7

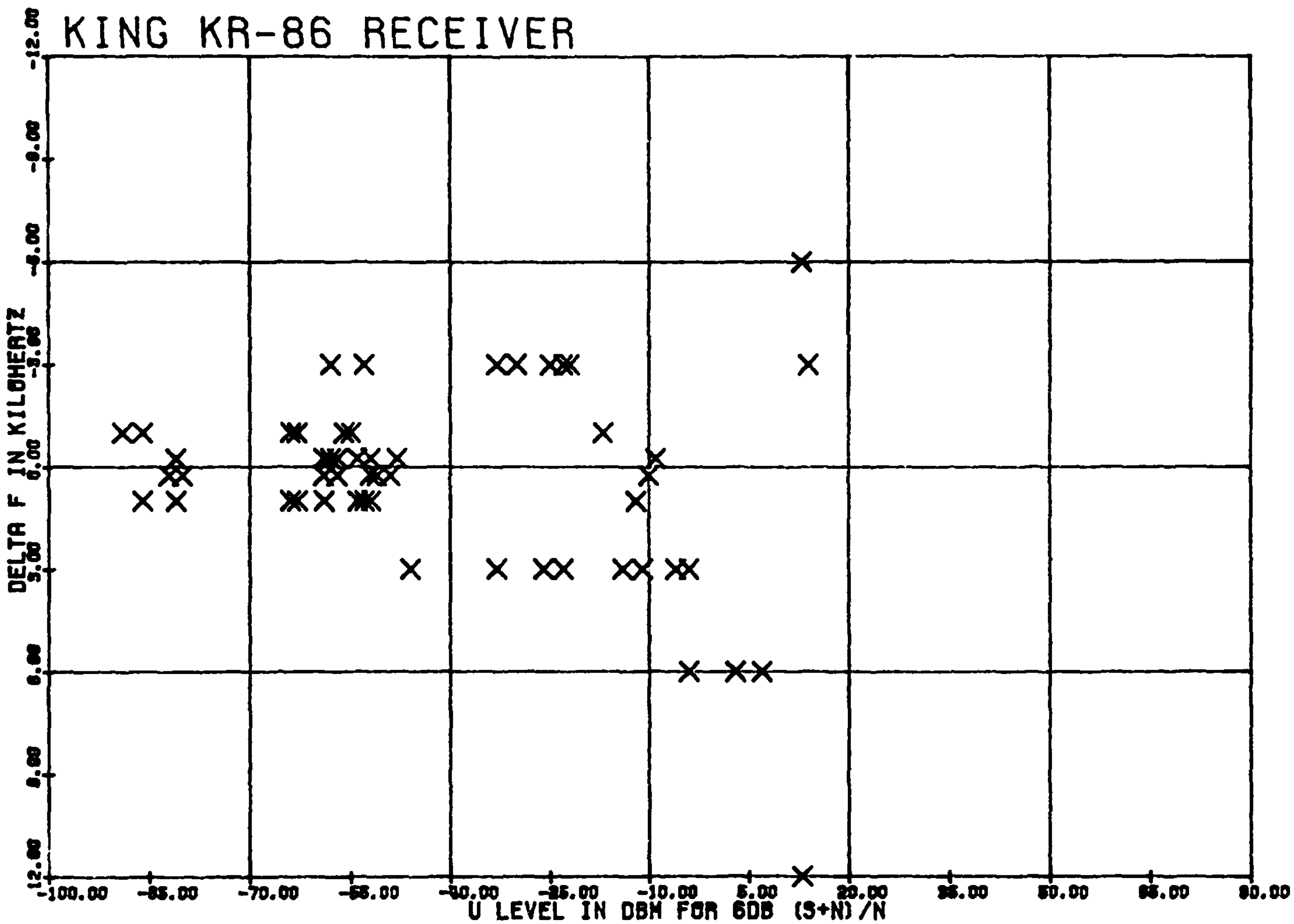


Figure 7.13 Six dB signal + noise/noise breakover points versus U for the King KR-86 receiver.

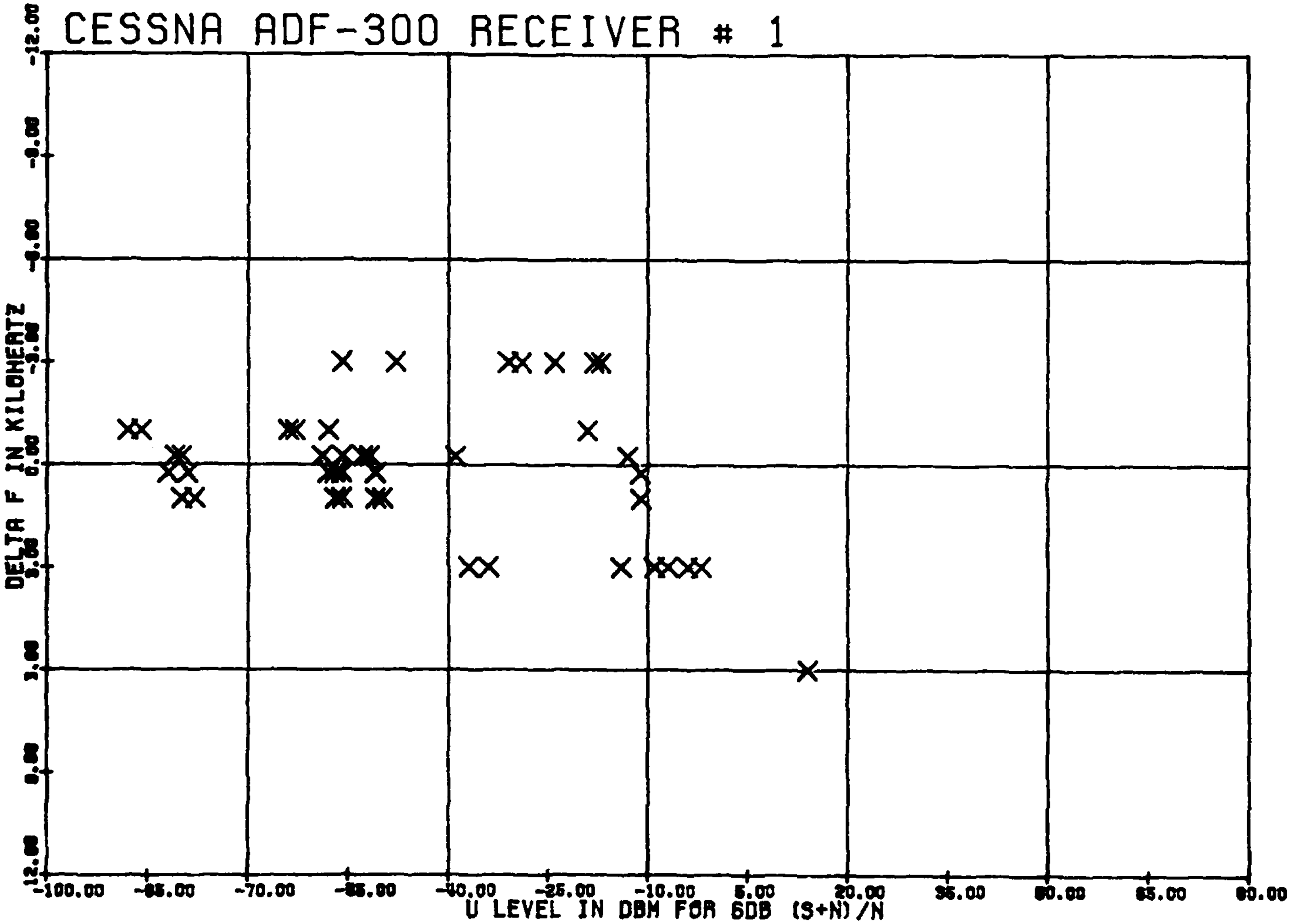


Figure 7.14 Six dB signal + noise/noise breakover points versus U for the first Cessna ADF-300 receiver.

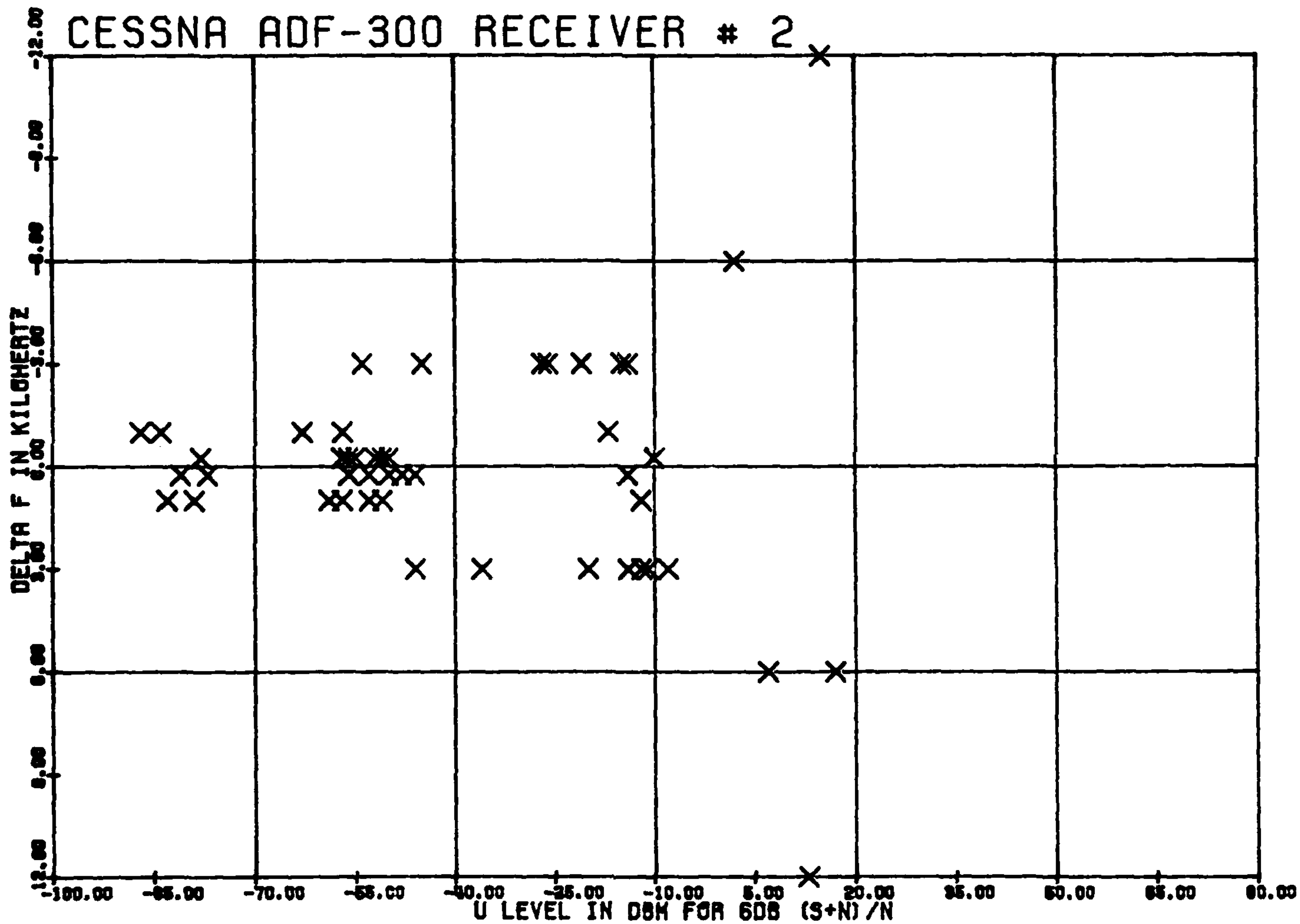


Figure 7.15 Six dB signal + noise/noise breakover points versus U for the second Cessna ADF-300 receiver.

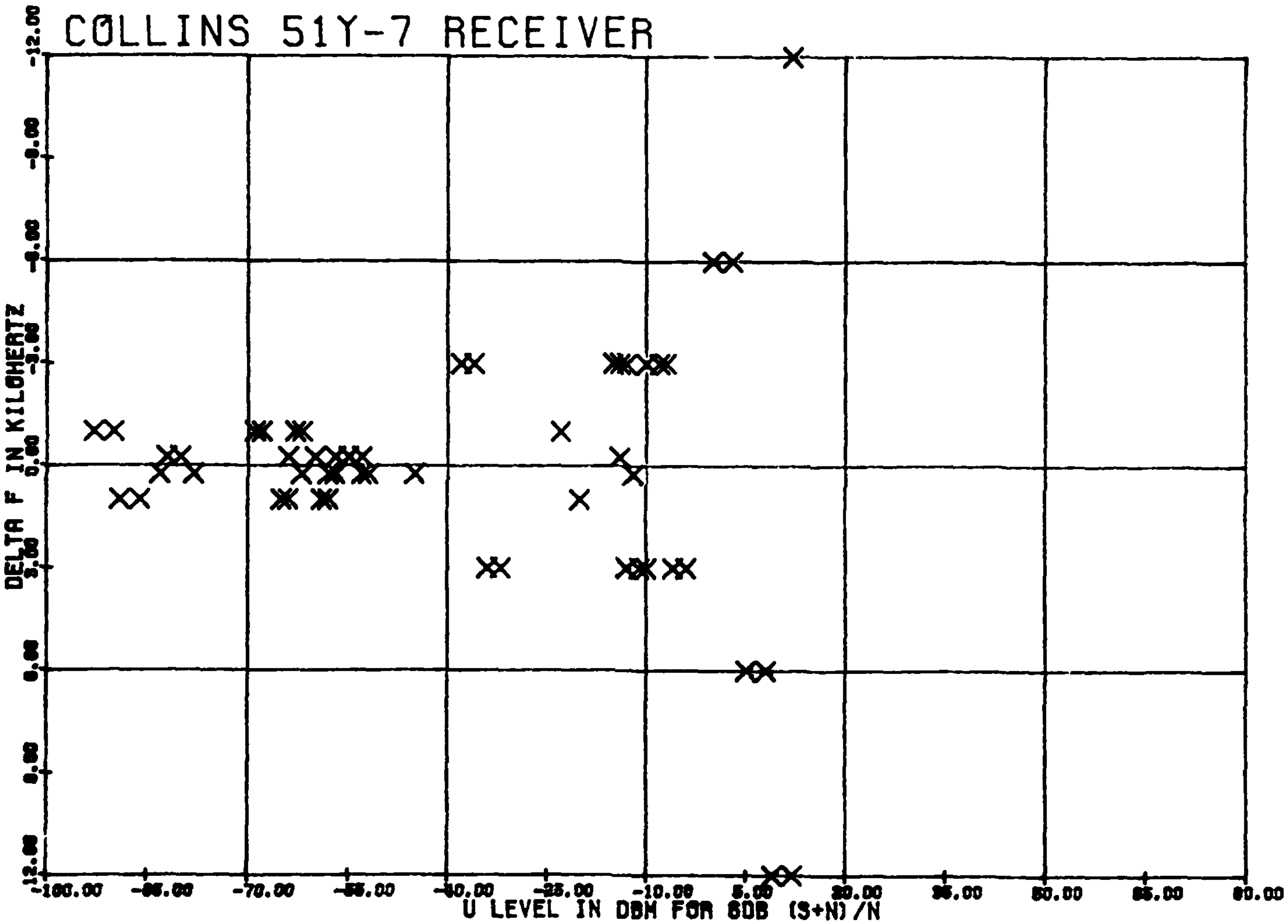


Figure 7.16 Six dB signal + noise/noise breakover points versus U for the Collins 51Y-7 receiver.

undesired signal level. As in the three degree bearing error plots, no correlation can be seen between the interference threshold and the absolute undesired signal level.

Figures 7.17 through 7.20 are plots of the three degree bearing error points with respect to the desired to undesired signal ratio and the absolute undesired signal level. An inspection of these figures shows that the trend is for the different symbols representing different values of delta-f to cluster around a narrow range of values for the D/U ratio while being very spread out over the range of absolute undesired level. This leads to the conclusion that the susceptability of the ADF system to interference from an undesired signal is primarily correlated to the ratio of the desired to the undesired signal levels.

Figures 7.21 through 7.24 are the same types of graphs as figures 7.17 through 7.20 except that now the 6 dB signal + noise/noise breakover points are being plotted. The same general conclusion can be drawn from these graphs as were drawn from the bearing error graphs of the previous paragraph.

Since it has been determined by simple graphical

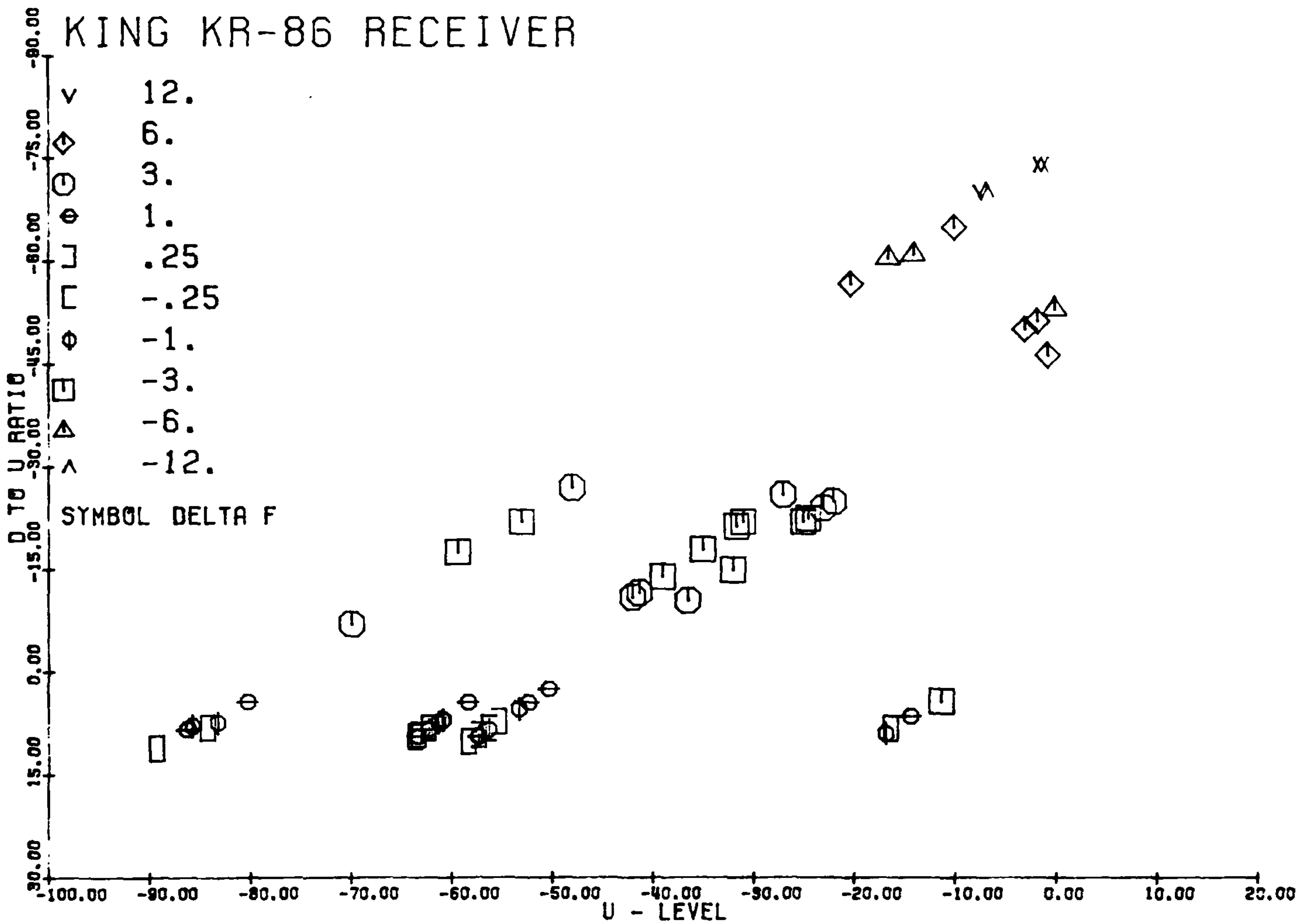


Figure 7.17 Three degree bearing error points with respect to U,D/U, and delta-f for the King KR-86 receiver.

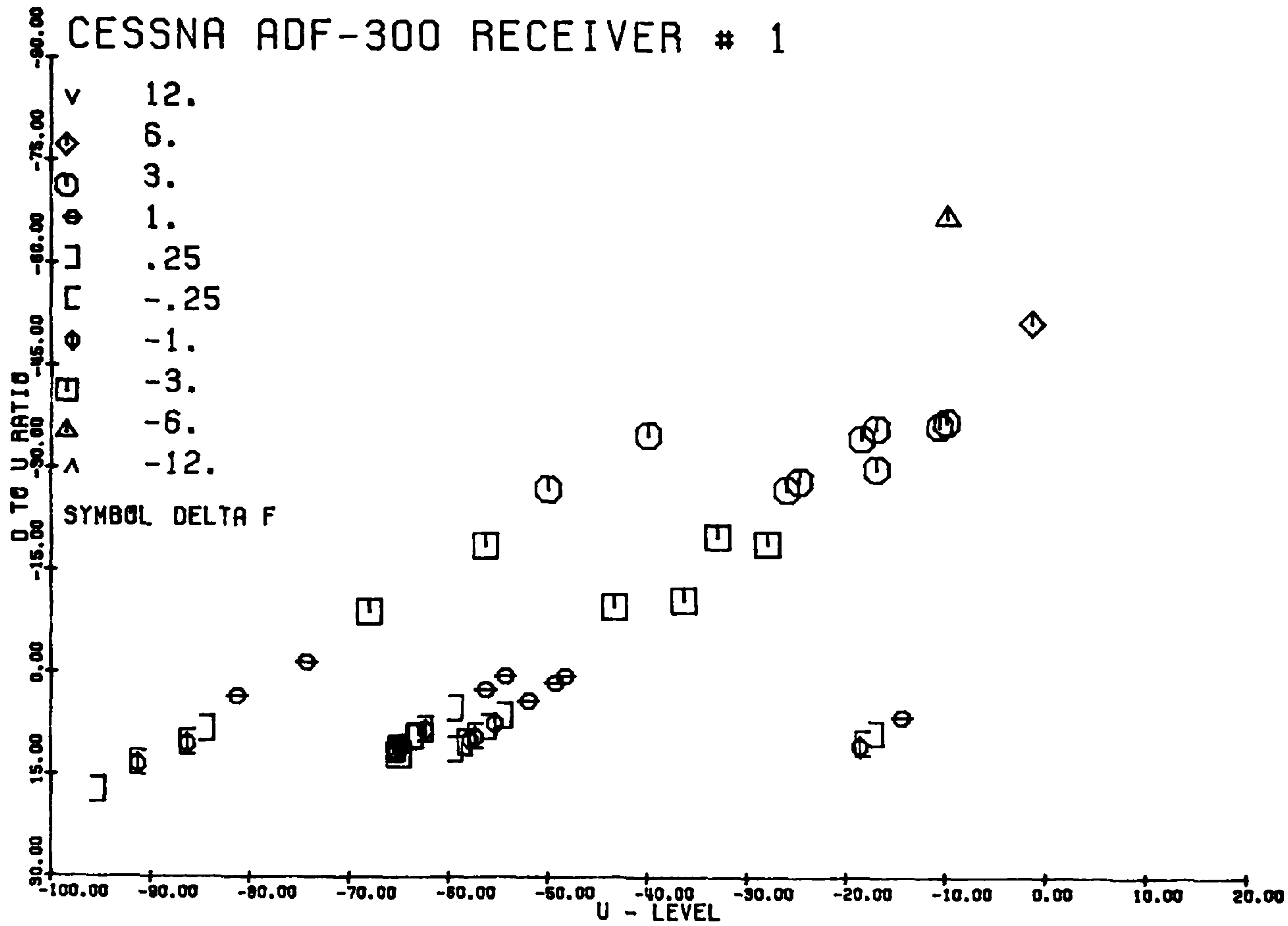


Figure 7.18 Three degree bearing error points with respect to U,D/U, and delta-f for the first Cessna ADF-300 receiver.

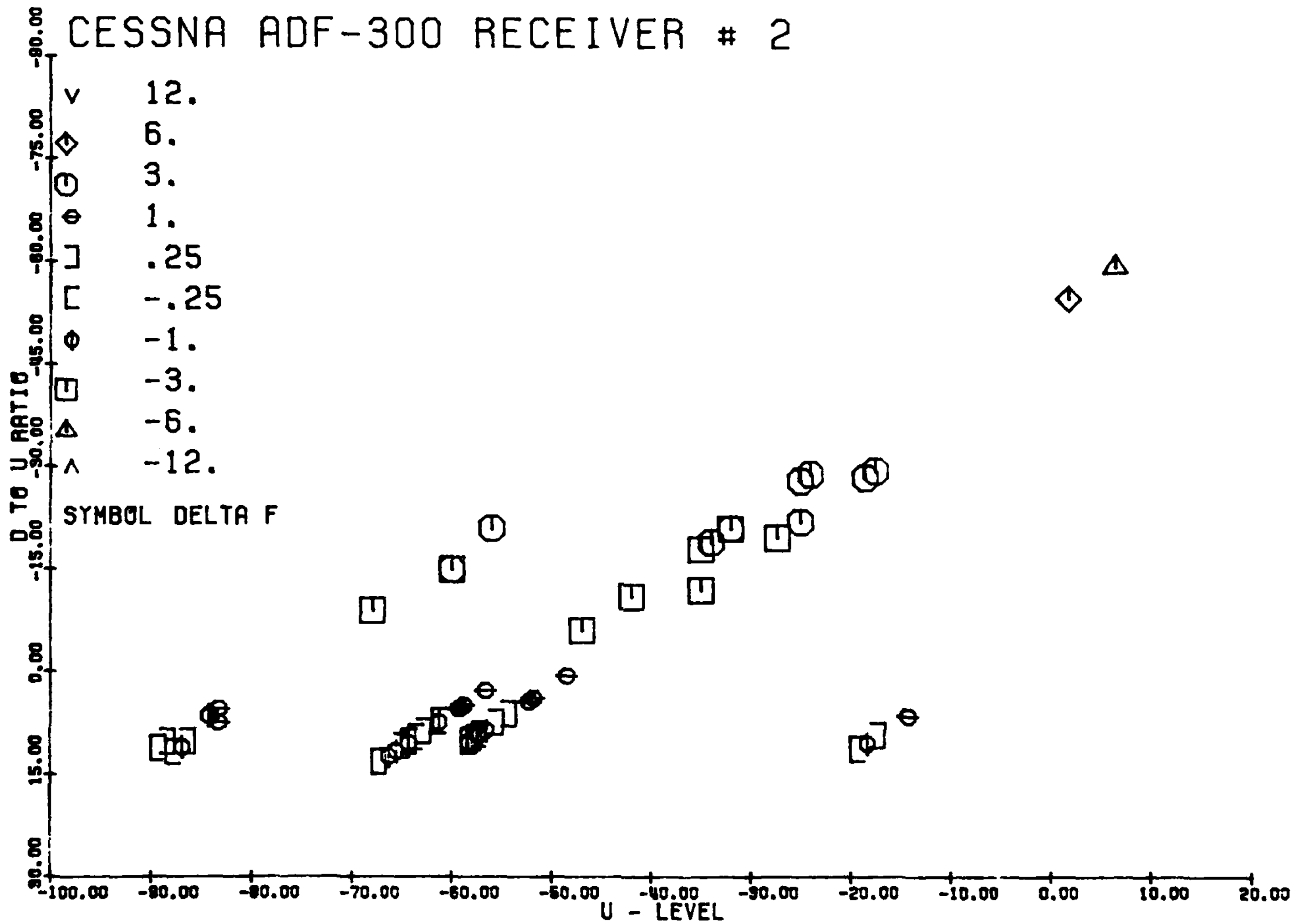


Figure 7.19 Three degree bearing error points with respect to U,D/U, and delta-f for the second Cessna ADF-300 receiver.

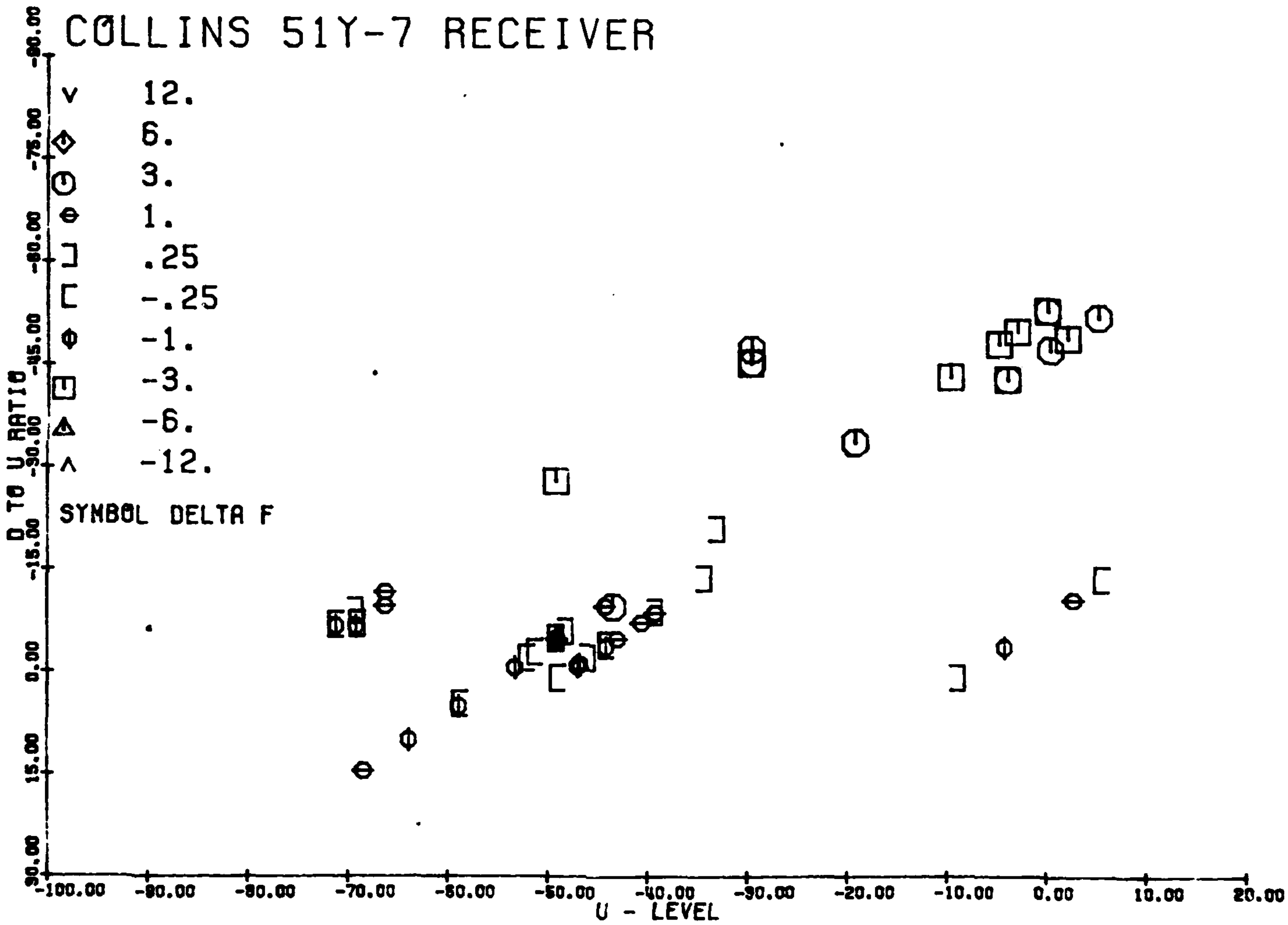


Figure 7.20 Three degree bearing error points with respect to U,D/U, and delta-f for the Collins 51Y-7 receiver.

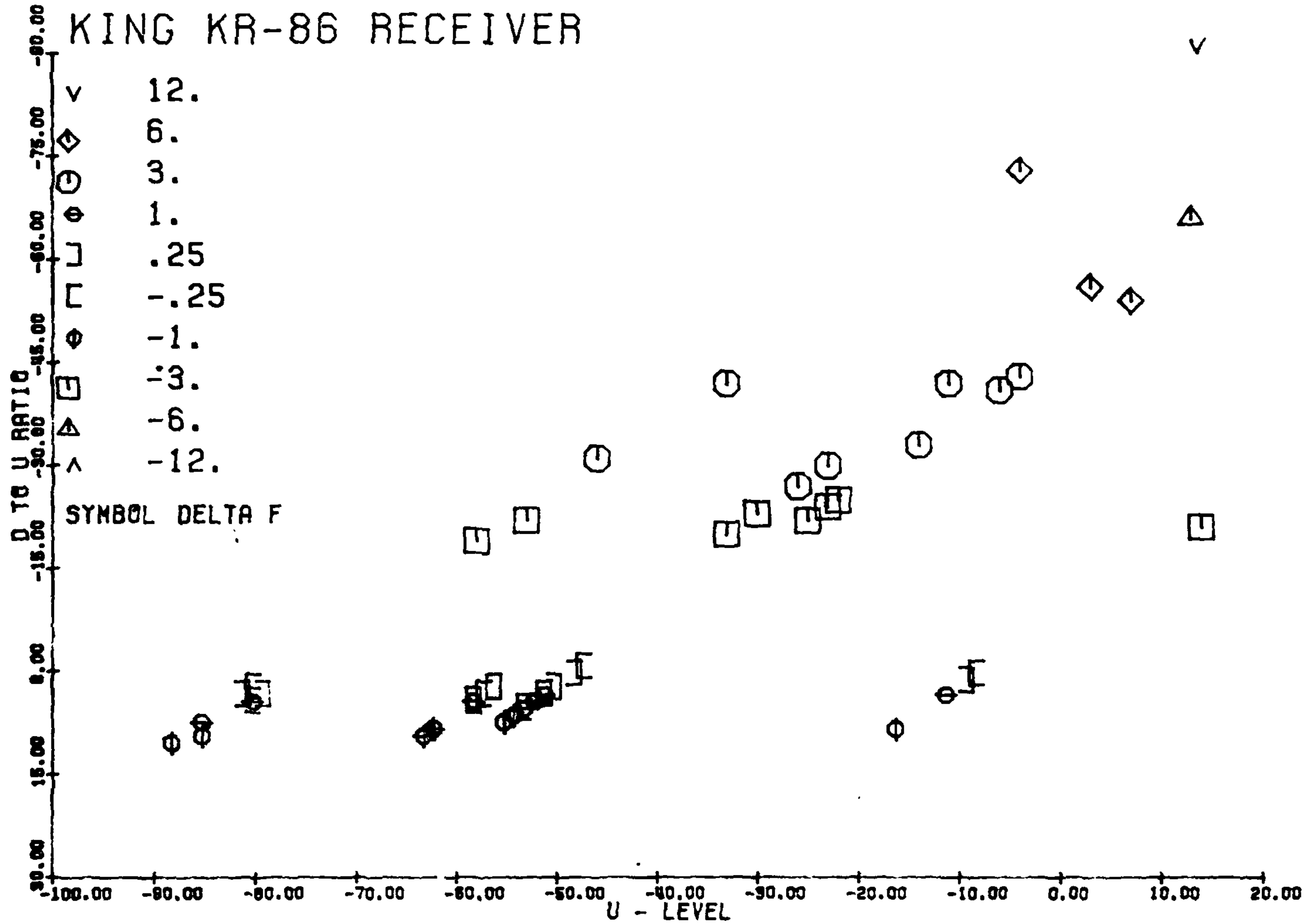


Figure 7.21 Six dB signal + noise/noise breakover points with respect to U,D/U, and delta-f for the King KR-86 receiver.

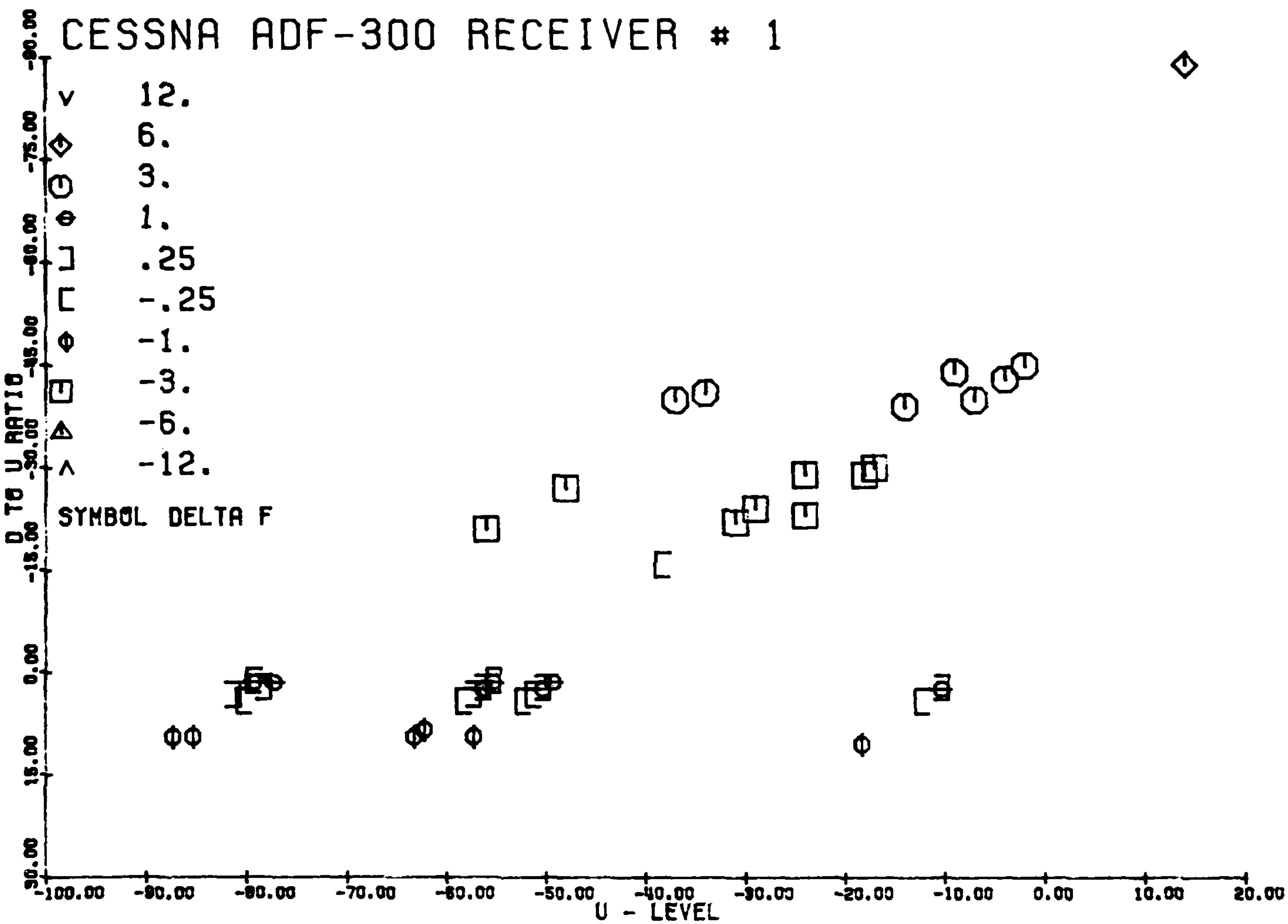


Figure 7.22 Six dB signal + noise/noise breakover points with respect to U,D/U, and delta-f for the first Cessna ADF-300 receiver.

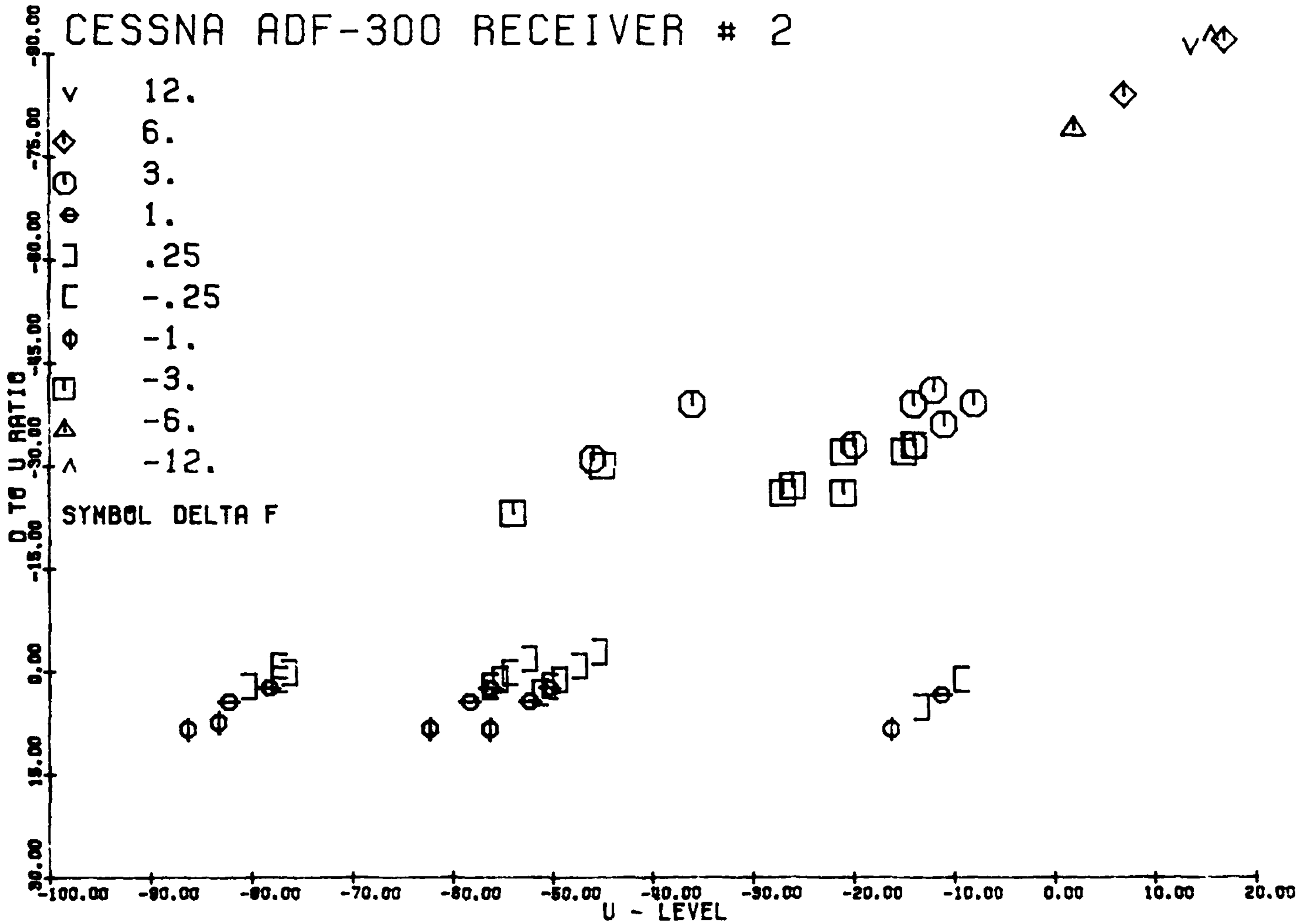


Figure 7.23 Six dB signal + noise/noise breakover points with respect to U,D/U, and delta-f for the second Cessna ADF-300 receiver.

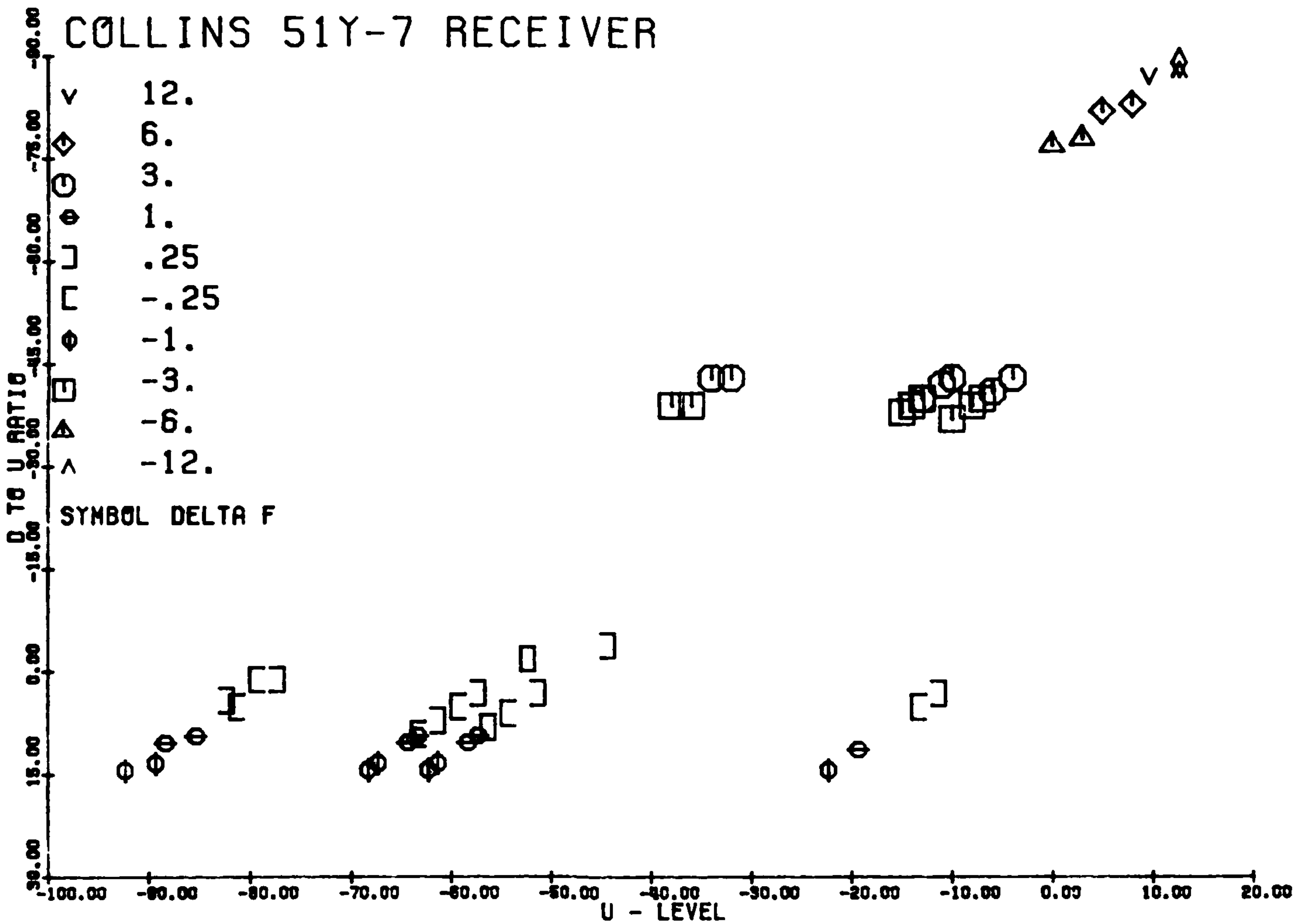


Figure 7.24 Six dB signal + noise/noise breakover points with respect to U,D/U, and delta-f for the Collins 51Y-7 receiver.

inspection that the interference susceptibility of the aircraft ADF system is primarily dependant on the D/U ratio, a detailed statistical analysis is unnecessary.

Because of the problems associated with the original test set-up described by the test plan and the PLC interference report [1,2], the receiver susceptibility data obtained when it was used are unreliable. In one case, this data suggested that interference would not occur when the undesired signal was only 250 Hz separated from the desired and nearly 13 dB stronger. The data gathered with the test set-up described in this report, however, makes much more sense in light of practical knowledge of the characteristics of communications receivers.

This chapter has summarized the results obtained by this phase of the project. The next chapter provides a summary of this report.

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Chapter 8 : Summary and Recommendations

This report has summarized the relevant work previously done in the area of ADF receiver interference susceptibility testing, and has presented the latest work in this area. The significant results obtained by this work and recommendations based on these results are the subject of this chapter.

It was found that the measurement proceedure described in the test plan [1] was in error due to several fundamental problems. A corrected plan which works for some of the ADF systems on the market today has been presented in chapter five with the given constraint that it is only valid for the older types of ADF systems which do not incorporate active receiver circuitry in their antenna assemblies.

It has been shown that the provisions of DO-142 regarding receiver testing are obsolete. Although each manufacturer now has a different method of making the required tests, RCTA should update their material on test setups when DC-142 is revised.

It has also been demonstrated that the susceptibility of an ADF system to interference from an undesired signal is only dependent on the desired to undesired signal ratio and not on the absolute levels cf the undesired signal.

In general, the equipments tested meet the requirements of DO-142, catagory A.

References

1) Kissick, William A., ADF RECEIVER SUCCEPTIBILITY MEASUREMENT PLAN, March, 1979.

2) Kissick, W. A., POWER LINE CARRIER RADIATION AND THE LOW-FREQUENCY AERONAUTICAL RADIO COMPASS ,MAY, 1980. Report number FAA-RD-80-31

3) MINIMUM PERFORMANCE STANDARDS - AIRBORNE RADIO RECEIVING AND DIRECTION FINDING EQUIPMENT OPERATING WITHIN THE RADIO FREQUENCY RANGE OF 200-850 KILOHERTZ, RTCA Document DO-142, January 8, 1970.

4) Orr, William : RADIO HANDBOOK, Editors and Engineers, Ltd.,New Augusta, Indiana, 1970

5) MINIMUM OPERATIONAL CHARACTERISTICS FOR AIRBORNE AUTOMATIC DIRECTION FINDING (ADF) SYSTEMS, RTCA Document DO-137, April 11, 1968.

6) FREQUENCY MANAGEMENT PRINCIPLES; L/MF FREQUENCY ASSIGNMENT CRITERIA , FAA HANDBOOK 6050.10, 11/23/65

List of Acronyms

ADF - Automatic Direction Finder

BAUDOT - A standard 5-level code used for transmission of digital data such as teletype signals.

CW - Continuous Wave mode of transmission

D - Desired signal level

D/U - Desired to Undesired signal ratio

E-W - The 'East-West' loop of the ADF system.

EPROM - Eraseable Programmable Read Only Memory

FAA - Federal Aviation Administration

FCC - Federal Communications Commission

FSK - Frequency Shift Keying

NDB - Non-Directional Beacon

N-S - the 'North-South' loop of the ADF system

PLC - Power Line Carrier

RF - Radio Frequency

Tds - A pin on the UART chip, refer to figure 6.1

U - Undesired signal level

UART - Universal Asynchronous Receiver / Transmitter

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