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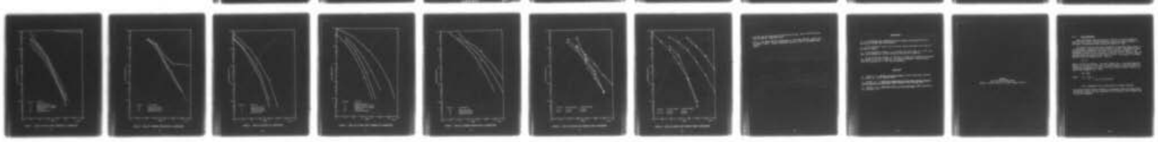

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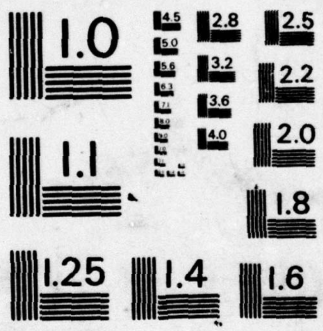

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Report No. FAA-NA-75-29

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DATA LINK SUBSYSTEM LABORATORY TESTS

Anthony J. Swezeny

NOVEMBER 1976

FINAL REPORT

Document is available to the public through the
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Springfield, Virginia 22151

Prepared for

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER

ATLANTIC CITY, N.J. 08405

NOTICE

Technical Report Documentation Page

1. Report No. FAA-NA-75-29	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: DATA LINK SUBSYSTEM LABORATORY TESTS		5. Report Date: Nov[redacted]976
		6. Performing Organization Code
7. Author(s): Anthony J. Swezeny		8. Performing Organization Report No. FAA-NA-75-29
9. Performing Organization Name and Address: Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, New Jersey 08405		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 062-222-000
12. Sponsoring Agency Name and Address: U.S. Department of Transportation, Federal Aviation Administration, Systems Research and Development Service, Washington, D.C. 20590		13. Type of Report and Period Covered: Final; Oct[redacted] - Nov[redacted]974
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Various very high frequency (VHF) transmitter-receiver combinations were used with minimum shift key (MSK) modems for bit error rate tests at 2400 and 4800 bit/second (b/s) rates and at various radiofrequency (RF) noise density levels over a simulated RF digital data link. Results indicated that to obtain the same bit error rate performance, the energy to noise (E/No) requirements differed up to 3.5 dB at 2400 b/s and up to 6 dB at 4800 b/s for the various transmitter-receiver combinations in the ground/air channel.

17. Key Words	18. Distribution Statement
Modem Testing Data Link Noise Density	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	16	

TABLE OF CONTENTS

	Page
INTRODUCTION	1
Purpose	1
Background	1
DISCUSSION	1
Description of Equipment Tested	1
Test Procedure	2
TEST RESULTS	2
CONCLUSIONS	16
REFERENCES	16
APPENDIX	

LIST OF ILLUSTRATIONS

Figure		Page
1	Subsystem Test Setup	3
2	2400 B/s AN/GRT-21 as Transmitter	7
3	2400 B/s HP 8640 Signal Generator as Transmitter	8
4	2400 B/s Airborne Transceivers as Transmitter	9
5	4800 B/s AN/GRT-21 as Transmitter	10
6	4800 B/s HP 8640 Signal Generator as Transmitter	11
7	4800 B/s Airborne Transceivers as Transmitter	12
8	2400 B/s Receiver and Transmit Modem Interchanged	13
9	4800 B/s Receive and Transmit Modems Interchanged	14

LIST OF TABLES

Table		Page
1	Test Matrix	4
2	Bit Error Rate 2400 B/s	5
3	Bit Error Rate 4800 B/s	5

INTRODUCTION

PURPOSE.

The purpose of this effort was to determine, at different radiofrequency (RF) noise density levels, the bit error rate over a simulated RF digital data link utilizing various very high frequency (VHF) transmitter-receiver combinations employing minimum shift key (MSK) modems in a simplex mode.

BACKGROUND.

The RF equipment used was representative of that used by the Federal Aviation Administration (FAA) ground facilities, air carriers, business, and general aviation aircraft. The test design was developed by Proteon Associates under contract number DOT-TSC-877. The purpose of this test was to measure the signal-to-noise ratio in dB energy per bit to noise density (appendix A). The performance and characteristics of each of the system elements were measured to establish the capability of the digital data link system. The first phase was laboratory measurements of VHF communications equipment, report No. FAA-RD-75-159; the second phase was laboratory measurements of the modems, report No. FAA-RD-75-134. This third phase was concerned with the bit error rate of a simulated data link system in the presence of controlled RF noise levels.

DISCUSSION

DESCRIPTION OF EQUIPMENT TESTED.

The modems, McDonnell-Douglas model MDL 510, were incorporated with each of the equipment groups tested. The modems can modulate the VHF transmitter or demodulate the audio output of the VHF receiver.

The RF equipment used was:

	Model	Remarks
1.	King model KTR-9100A transceiver*	ARINC characteristic No. 566A
2.	Bendix model RTA-43A transceiver*	ARINC characteristic No. 566A
3.	Collins model 618M-2B transceiver	ARINC characteristic No. 546
4.	King model KY 195B transceiver*	General Aviation Type
5.	NARCO model COM 11A transceiver	General Aviation Type
6.	Genave model Alpha 100/360 transceiver	General Aviation Type
7.	A/N model GRR-23 receiver*	FAA Ground Facility Type
8.	A/N model GRT-21 transmitter	FAA Ground Facility Type

*25-kHz equipment

For the wide-band data link operation, a modification was made to the NARCO COM-11A receiver audio output to conduct one of the tests. It was the same modification used previously for the phase I VHF communications equipment tests, report No. FAA-RD-75-159.

TEST PROCEDURE.

The equipment setup for the test is shown in figure 1. The modem test set provided a continuous pseudorandom test signal to the transmit modem. The resulting MSK waveform from the transmit modem was the modulation input to the transmitter with the modulation level set at 80 percent. The RF output was fed to a variable attenuator (GR-874) and a dummy load. This attenuator was adjusted to have a -20-dBm (decibels below 1 milliwatt) level at the input to the receiver attenuator after passing through the transmitter attenuator. The RF noise input was generated by mixing the -1-dBm noise output of the noise generator (GR 1383) with the +10 dBm RF output of the signal generator (HP 8660). This mixing was done with a HP 10514A mixer, passed through a band-pass filter to the hybrid tee (Anzac H-1-4) and adjusted for -20 dBm at the receiver attenuator. The energy (E)-to-noise (N_0) ratio was changed by varying the transmitter attenuator. Constant level to the receiver was maintained by adjusting the receiver attenuator. The receiver output was applied to the reciever modem, and the resultant bit error was measured at the modem test set. Tests were performed at the 2400 and 4800 b/s rate. The modems were interchanged (see tests 8 and 10 below) to show the difference, if any, between the modems when performing in the transmit or in the receive mode. A VHF signal generator was used as a transmitter representative of a 50 kHz ground equipment. The transmitter/receiver combinations used are shown in table 1.

The test matrix was designed to limit tests, yet reflect the in-field utilization of the various equipments. The results were plotted as bit error rate versus energy-to-noise density ratio.

TEST RESULTS

Test data were grouped in the figures by bit rate of 2400 or 4800. Further, there were two subgroups of data. These were ground-to-air or air-to-ground. The ground-to-air data were further subdivided by transmitter type, the AN/GRT-21 or the signal generator (HP 8640).

Test data are listed in tables 2 and 3 and are plotted in figures 2 through 9. Tests 2 and 6 at the 4800 b/s rate were not plotted, because of the high error rate of 1×10^{-1} or greater.

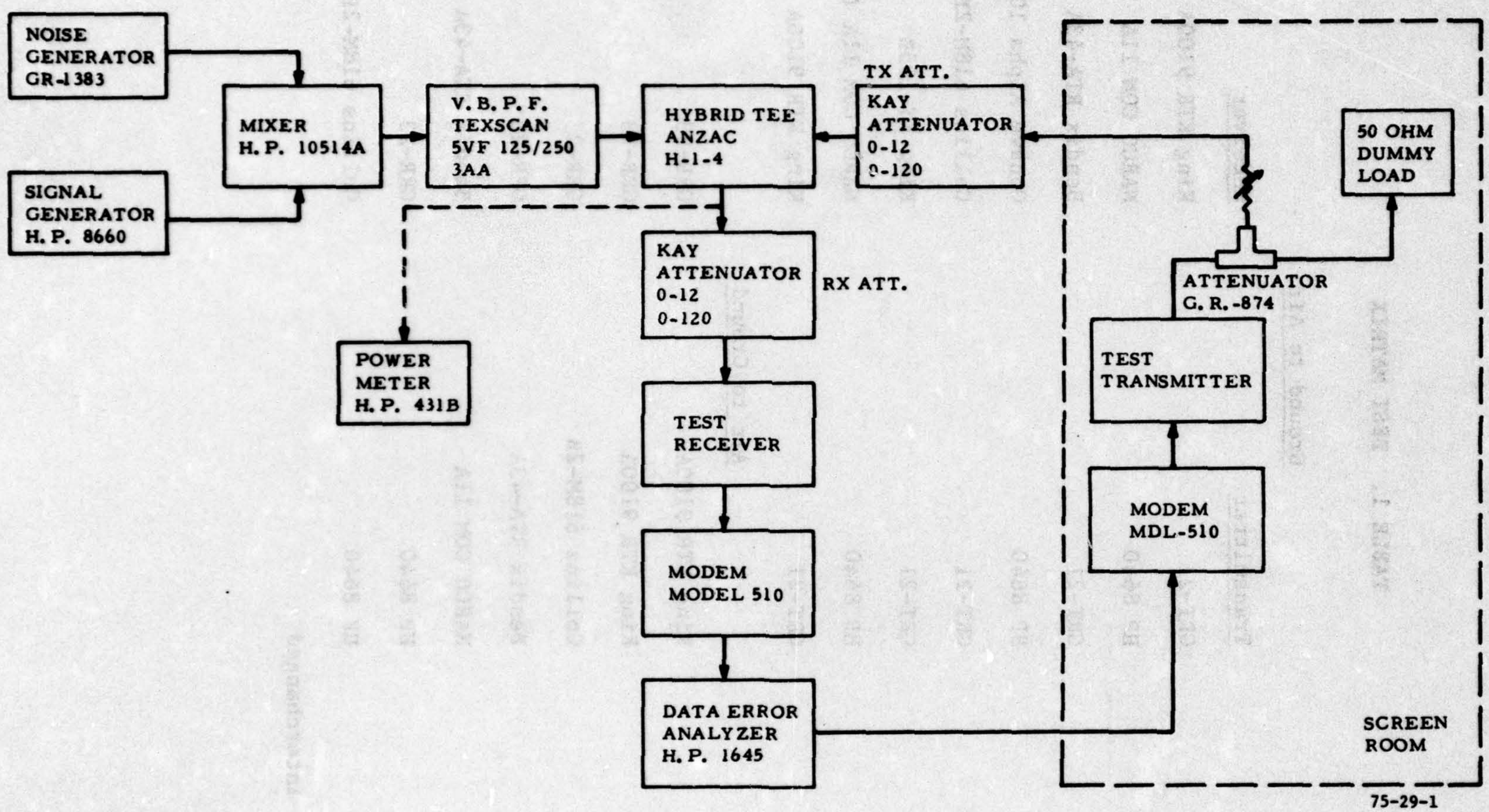

FIGURE 1. SUBSYSTEM TEST SETUP

TABLE 1. TEST MATRIX

Test	Transmitter	Receiver
	Ground to Air	
1	GRT-21	King KTR 9100A
2	HP 8640	NARCO COM 11A
3	GRT-21	Bendix RTA-43A
4	HP 8640	Genave Alpha 100/360
5	GRT-21	Collins 618M-2B
6	GRT-21	King KY-195B
7	HP 8640	NARCO COM 11A (Mod)
*8	GRT-21	King KTR 9100A
	Air to Ground	
9	King KTR 9100A	GRR-23
*10	King KTR 9100A	GRR-23
11	Collins 618M-2B	GRR-23
12	Bendix RTA-43A	GRR-23
13	NARCO COM 11A	Bendix RTA-43A
14	HP 8640	GRR-23
15	HP 8640	Collins 618M-2B

*Modems were interchanged

TABLE 2. BIT ERROR RATE, 2400 B/S

E/N_o	TEST NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
10	2.07×10^{-1}	2.5×10^{-1}	1.17×10^{-1}	1.45×10^{-1}	1.89×10^{-1}	8.27×10^{-2}	1.95×10^{-1}	2.22×10^{-1}	2.26×10^{-1}	2.07×10^{-1}	2.08×10^{-1}	2.6×10^{-1}	3.0×10^{-1}	2.5×10^{-1}	2.5×10^{-1}
12	1.66×10^{-1}	1.8×10^{-1}	1.59×10^{-2}	3.51×10^{-2}	2.21×10^{-2}	3.17×10^{-2}	3.58×10^{-2}	2.13×10^{-1}	2.19×10^{-1}	2.52×10^{-1}	1.89×10^{-1}	1.9×10^{-1}	2.5×10^{-1}	8.0×10^{-2}	1.81×10^{-2}
14	2.08×10^{-2}	1.2×10^{-1}	3.71×10^{-3}	1.51×10^{-2}	5.11×10^{-3}	1.09×10^{-2}	8.42×10^{-3}	2.2×10^{-1}	1.7×10^{-1}	3.05×10^{-2}	3.29×10^{-2}	2.85×10^{-2}	2.23×10^{-1}	1.2×10^{-2}	5.0×10^{-3}
16	6.82×10^{-3}	1.0×10^{-1}	8.48×10^{-4}	2.92×10^{-3}	1.03×10^{-3}	2.62×10^{-3}	1.62×10^{-3}	3.74×10^{-2}	1.24×10^{-2}	1.03×10^{-2}	1.6×10^{-2}	1.55×10^{-2}	—	2.6×10^{-3}	1.01×10^{-3}
18	2.06×10^{-3}	9.1×10^{-2}	9.4×10^{-5}	1.4×10^{-4}	1.55×10^{-4}	1.64×10^{-3}	1.47×10^{-4}	2.52×10^{-3}	3.81×10^{-3}	1.4×10^{-3}	3.3×10^{-3}	1.65×10^{-3}	—	3.3×10^{-4}	9.8×10^{-5}
19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.98×10^{-5}
20	4.75×10^{-4}	8.4×10^{-2}	2.5×10^{-6}	1.37×10^{-5}	6.9×10^{-6}	2.34×10^{-4}	1.01×10^{-5}	2.89×10^{-4}	1.11×10^{-3}	1.74×10^{-4}	1.14×10^{-3}	2.58×10^{-4}	4.98×10^{-2}	2.5×10^{-5}	6.0×10^{-6}
22	2.76×10^{-5}	7.9×10^{-2}	—	—	—	2.82×10^{-5}	—	2.65×10^{-5}	2.46×10^{-4}	3.1×10^{-5}	1.14×10^{-3}	3.17×10^{-5}	—	—	—
23	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
24	—	7.8×10^{-2}	—	—	—	—	—	—	7.25×10^{-5}	—	9.26×10^{-4}	—	—	—	—

TABLE 3. BIT ERROR RATE, 4800 B/S

E/N_o	TEST NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
10	7.63×10^{-2}	2.65×10^{-1}	3.52×10^{-2}	9.4×10^{-2}	3.72×10^{-2}	2.48×10^{-1}	1.4×10^{-1}	1.96×10^{-1}	2.21×10^{-1}	2.41×10^{-1}	2.26×10^{-1}	2.45×10^{-1}	—	6.0×10^{-1}	4.2×10^{-2}
12	2.32×10^{-2}	2.5×10^{-1}	1.13×10^{-2}	5.72×10^{-2}	1.31×10^{-2}	2.05×10^{-1}	2.95×10^{-2}	1.41×10^{-1}	2.06×10^{-1}	2.83×10^{-1}	2.1×10^{-1}	8.58×10^{-2}	—	2.2×10^{-2}	1.5×10^{-2}
14	7.21×10^{-3}	2.48×10^{-1}	1.67×10^{-3}	2.97×10^{-2}	2.56×10^{-3}	1.95×10^{-2}	1.09×10^{-2}	1.12×10^{-2}	2.15×10^{-1}	3.94×10^{-2}	7.97×10^{-2}	3.3×10^{-2}	—	6.5×10^{-3}	3.02×10^{-3}
16	1.23×10^{-3}	2.48×10^{-1}	1.88×10^{-4}	1.11×10^{-2}	3.82×10^{-4}	1.7×10^{-1}	2.45×10^{-3}	3.31×10^{-3}	2.04×10^{-1}	2.08×10^{-2}	2.51×10^{-2}	1.15×10^{-2}	1.54×10^{-1}	8.3×10^{-4}	3.21×10^{-4}
18	1.57×10^{-4}	2.25×10^{-1}	4.5×10^{-6}	3.44×10^{-3}	1.0×10^{-5}	1.52×10^{-1}	3.56×10^{-4}	1.71×10^{-4}	3.46×10^{-2}	6.23×10^{-3}	1.22×10^{-2}	2.8×10^{-3}	—	4.9×10^{-5}	1.48×10^{-5}
19	—	—	—	—	—	—	—	—	—	—	—	—	—	9.0×10^{-6}	—
20	4.2×10^{-6}	2.25×10^{-1}	—	7.87×10^{-4}	—	1.42×10^{-1}	3.23×10^{-5}	8.3×10^{-6}	1.18×10^{-2}	1.49×10^{-3}	3.25×10^{-3}	3.95×10^{-4}	—	—	—
22	—	2.25×10^{-1}	—	9.7×10^{-5}	—	1.19×10^{-1}	—	—	3.25×10^{-3}	2.66×10^{-4}	9.0×10^{-4}	3.26×10^{-5}	6.3×10^{-2}	—	—
23	—	—	—	1.82×10^{-5}	—	—	—	—	—	—	—	—	—	—	—
24	—	2.25×10^{-1}	—	—	—	—	—	—	5.38×10^{-4}	2.76×10^{-5}	1.75×10^{-4}	—	—	—	—

The following matrix shows the way the data are grouped by figure numbers:

Bit Rate	Ground/Air Transmitter GRT-21	Ground/Air Signal Generator	Air/Ground Transceiver
2400	fig. 2	fig. 3	fig. 4
4800	fig. 5	fig. 6	fig. 7

Figure 2 is a plot of test 1, 3, 5, and 6 at the 2400 b/s rate. The E/N_0 required to obtain a bit error rate of 1×10^{-5} varied by 3.4 dB.

Figure 3 is a plot of tests 2, 4, 7, 14, and 15 at the 2400 b/s rate. Test 2, the NARCO COM 11A, performed poorly. Test 7, the modified NARCO COM 11A, data are grouped with the other receivers. At the bit error rate of 1×10^{-5}, there was a spread of .9 dB in the E/N_0 ratio, excluding test 2.

Comparison of tests 5 and 15 show that the HP 8640 signal generator and the AN/GRT-21 transmitter have similar bit error rate characteristics. The signal generator represents a transmitter in the ground-to-air channel at the 2400 b/s rate. The E/N_0 spread of all receivers tested at the 1×10^{-5} bit error rate was 3.4 dB. This excluded the unmodified NARCO transceiver.

Figure 4 is a plot of the test results for an air/ground channel, where the AN/GRR-23 was the receiver, with the King KTR 9100A, Bendix RTA 43A, or Collins 618M-2B as transmitters. Tests 10 and 12 data can be projected to a bit error rate of 1×10^{-5} at an E/N_0 ratio of 22.9 dB. Test 11 (Collins 618M-2B transmitter with the GRR-23 receiver) data depart from test 10 and 12 data, but the cause was considered to be a transmitter modulator malfunction.

In figures 5 and 6 for a bit error rate of 1×10^{-5}, there was a spread of 6.65 dB E/N_0 ratio for all receivers tested, excluding test 2 and 6. Test 2 and 6 were unmodified general aviation-type transceivers. As stated before, these plots represent a ground-to-air channel.

Figure 7 is a plot of the test results for the air-to-ground channel, a bit error rate of 2×10^{-4} had a spread of 3.3 dB E/N_0 ratio.

Figure 8 is the plotted results of two tests at the 2400 b/s rate in which the modems were interchanged. At a bit error rate of 6×10^{-4}, the difference of one test (1 and 8) is 0.38 dB E/N_0 ratio and 2 dB E/N_0 ratio for the other test (9 and 10).

Figure 9 is a plot of the results of the same test as figure 8, except at the 4800 b/s rate. The E/N_0 ratio difference of the first test (1 and 8) is

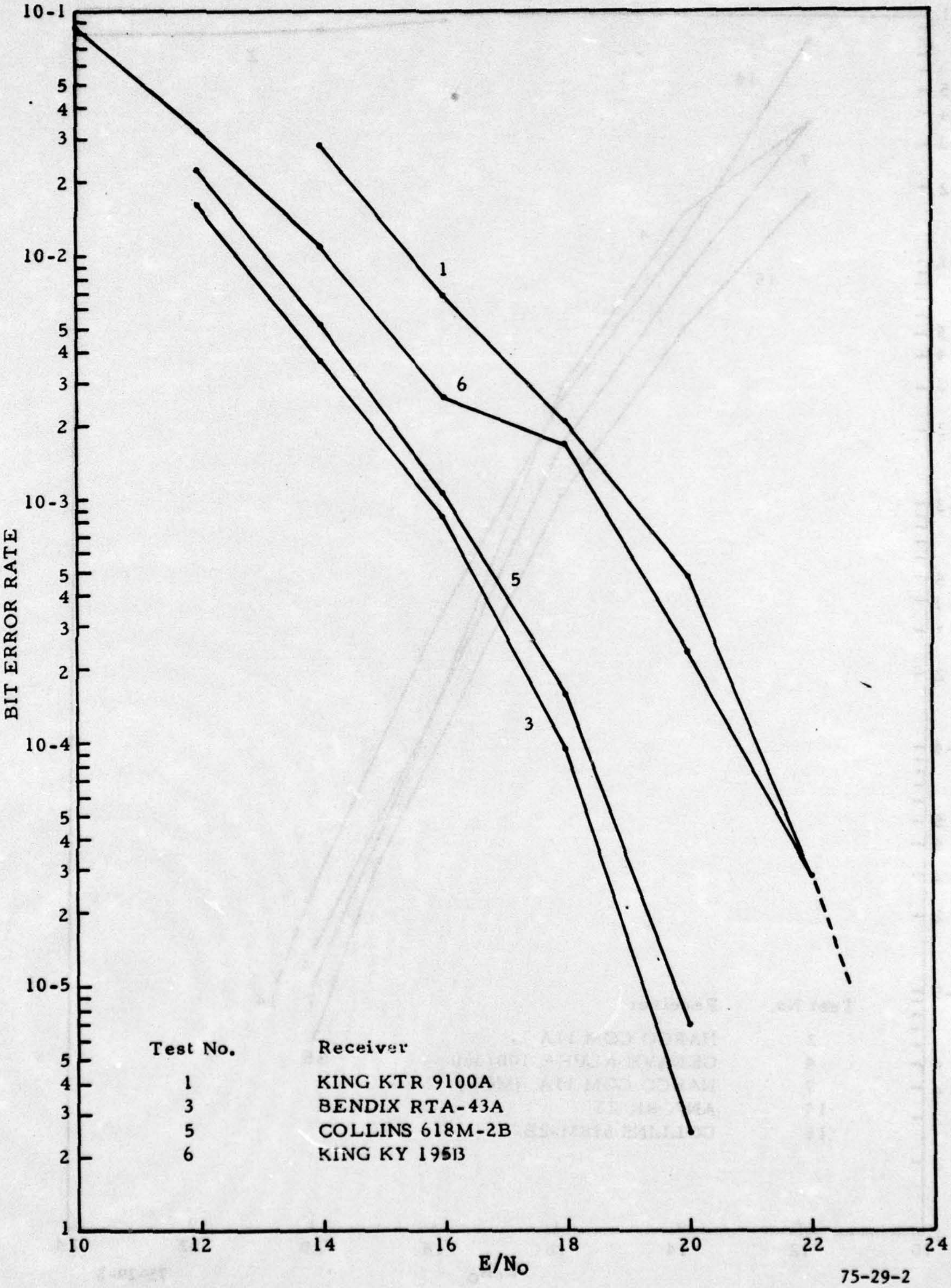

FIGURE 2. 2400 B/S AN/GRT-21 AS TRANSMITTER

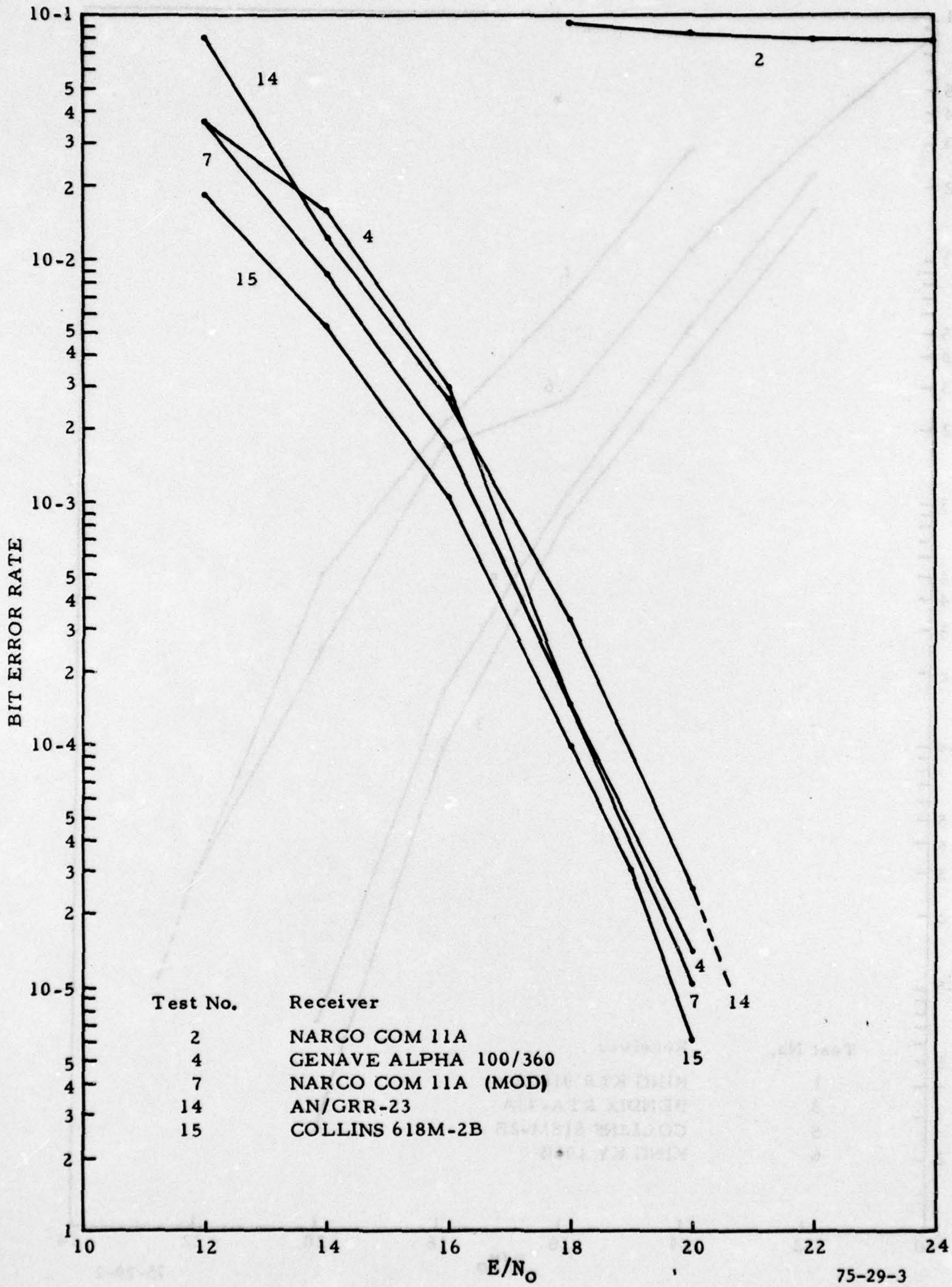

FIGURE 3. 2400 B/S HP 8640 SIGNAL GENERATOR AS TRANSMITTER

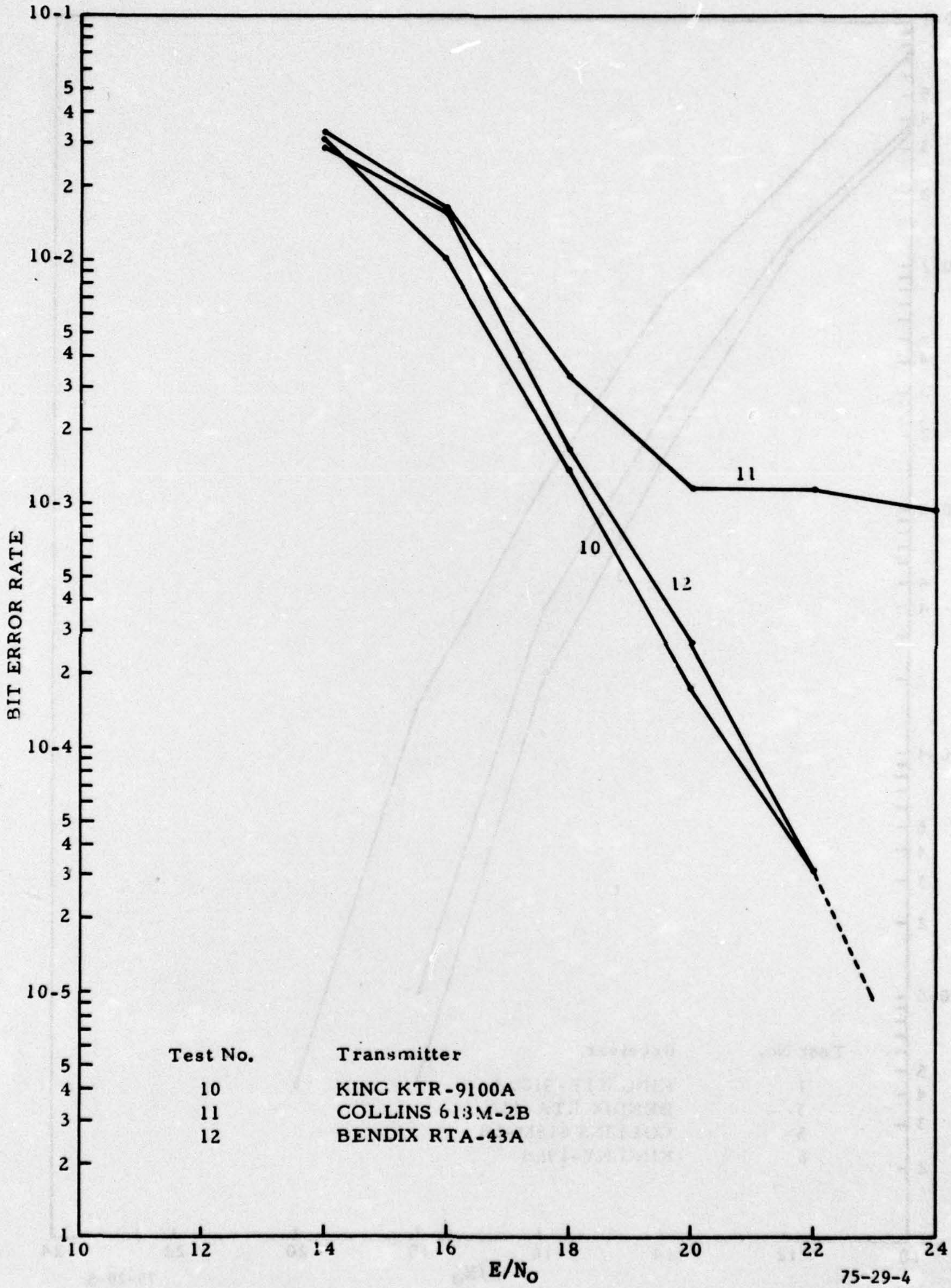

FIGURE 4. 2400 B/S AIRBORNE TRANSCEIVERS AS TRANSMITTER

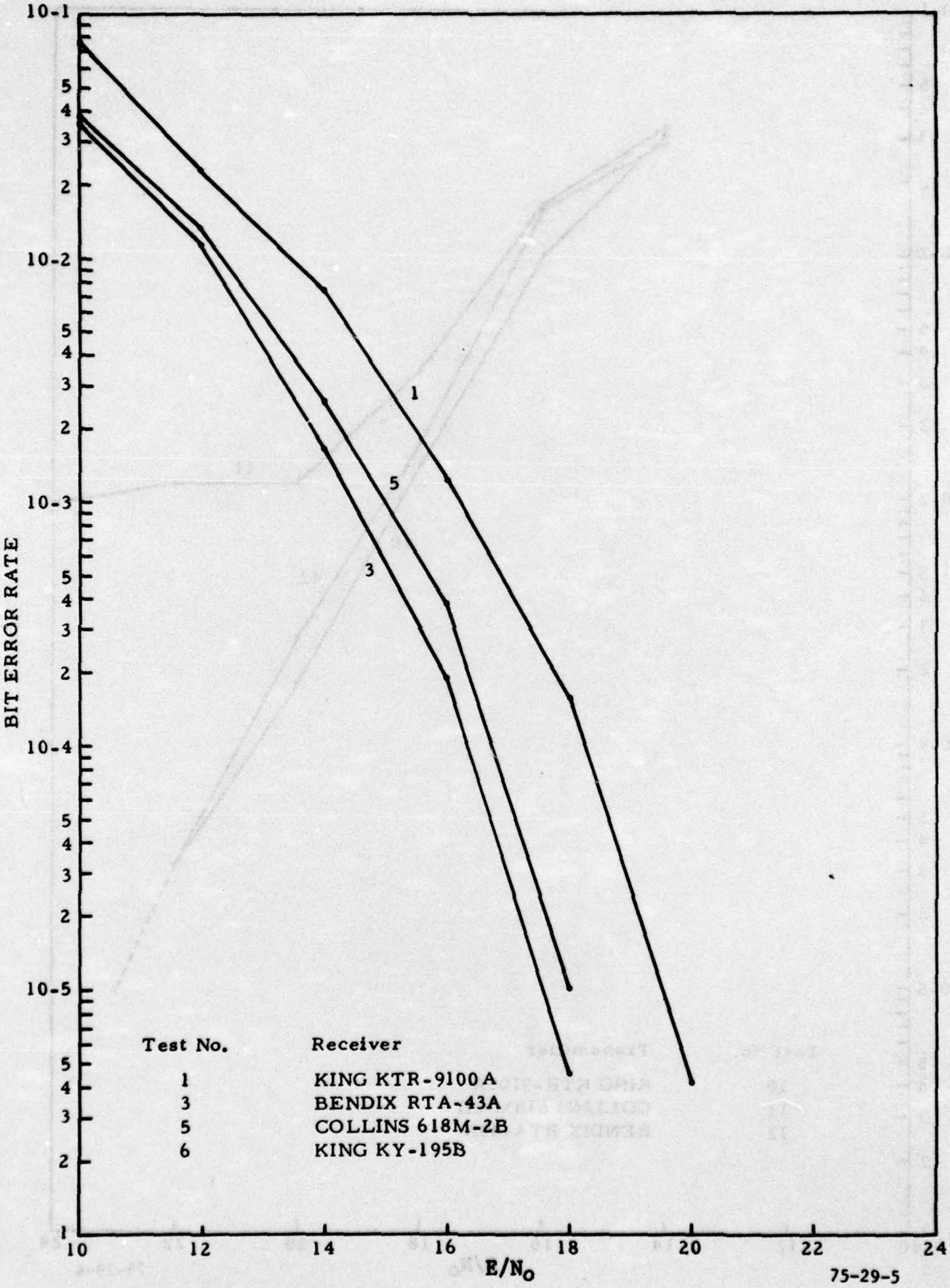

FIGURE 5. 4800 B/S AN/GRT-21 AS TRANSMITTER

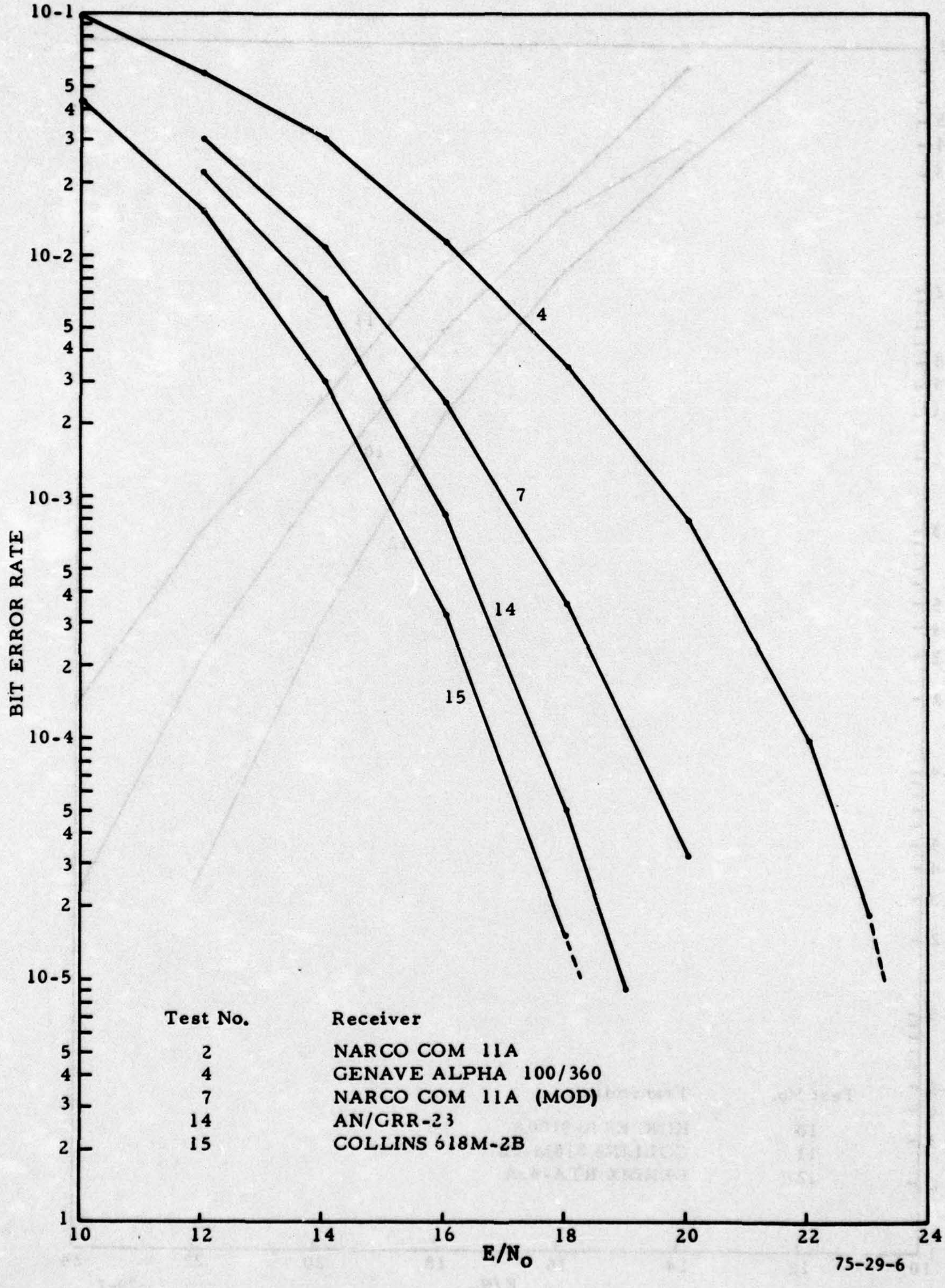

FIGURE 6. 4800 B/S HP 8640 SIGNAL GENERATOR AS TRANSMITTER

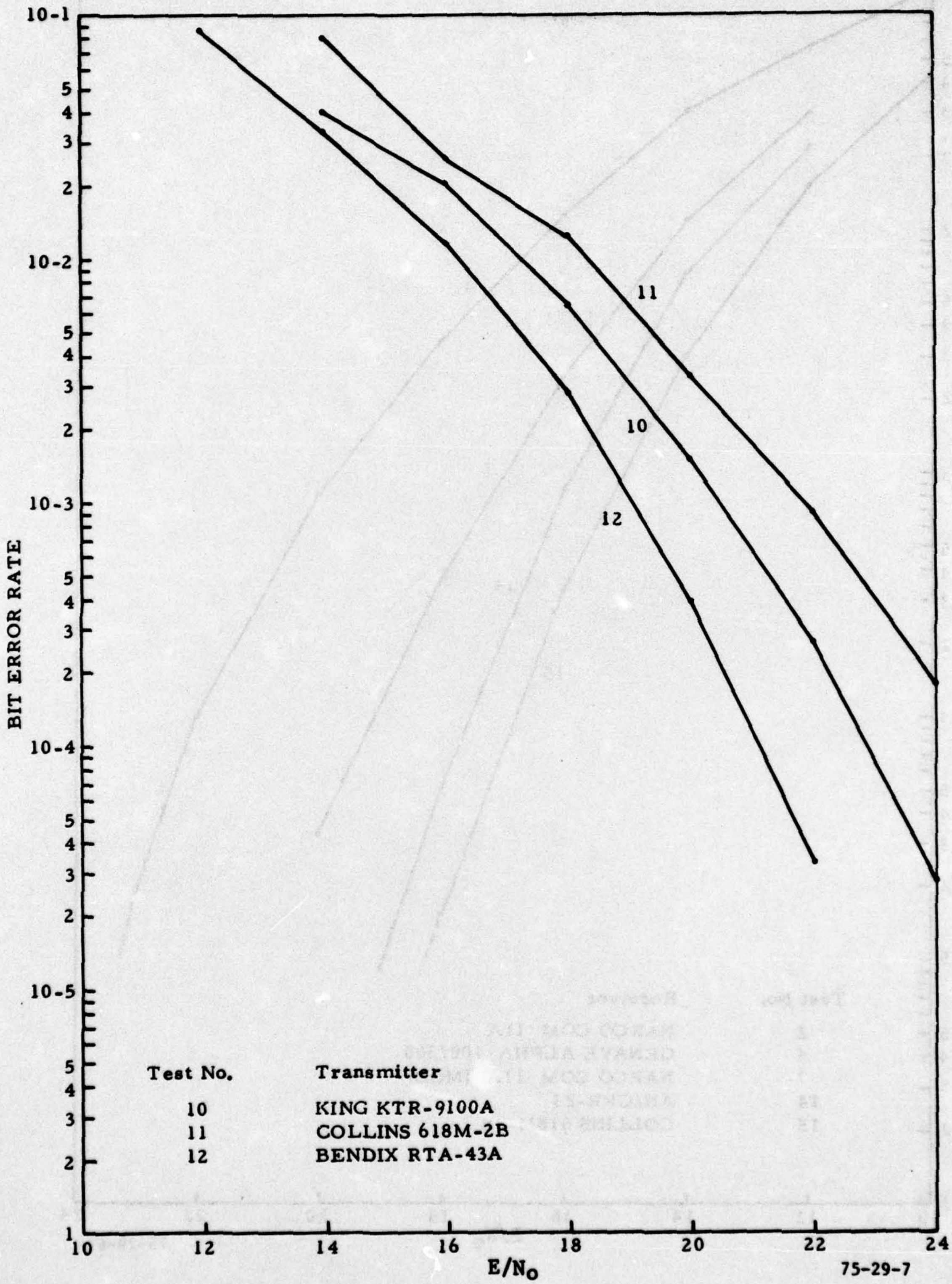

FIGURE 7. 4800 B/S AIRBORNE TRANSCEIVERS AS TRANSMITTER

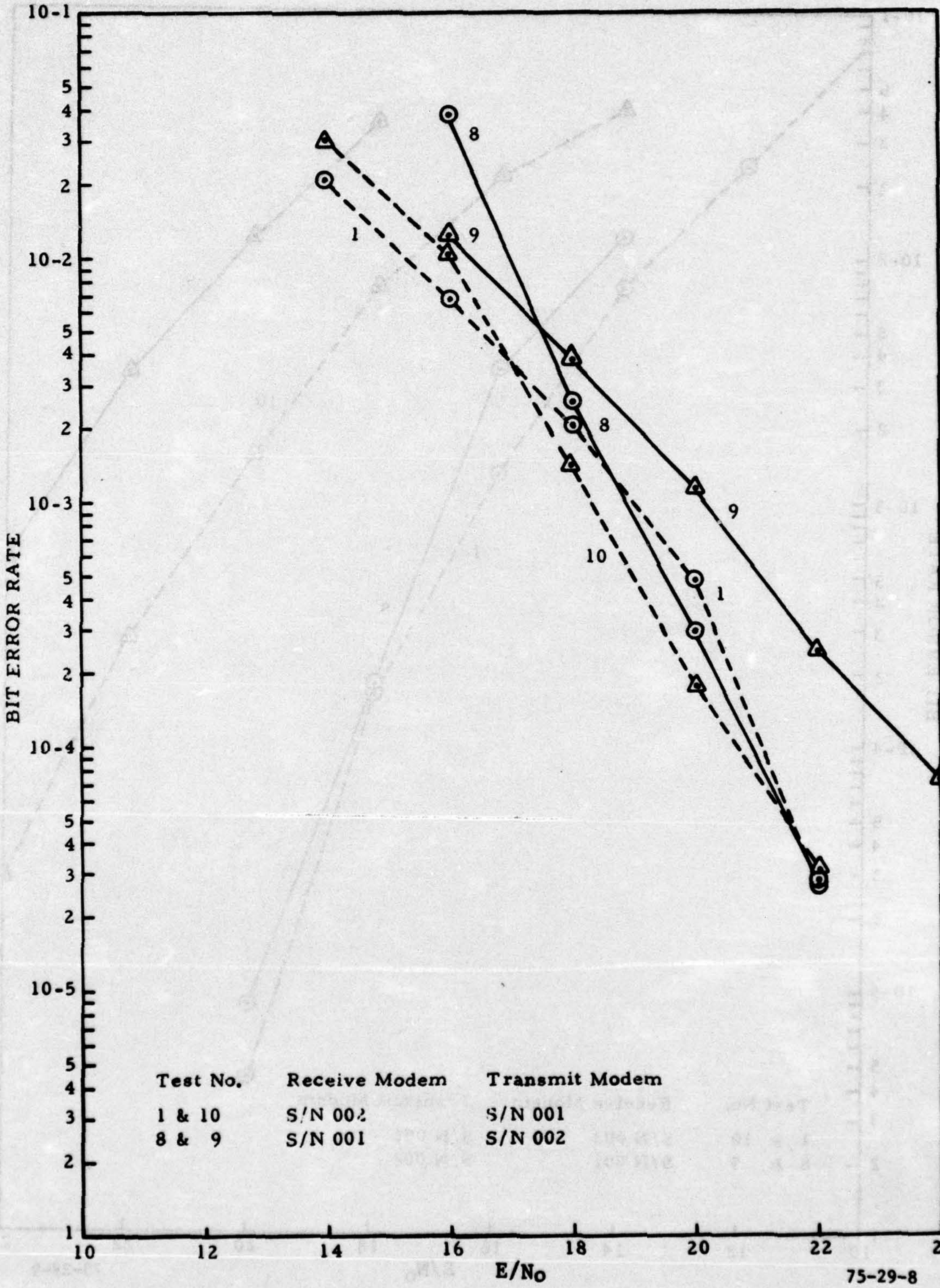

FIGURE 8. 2400 B/S RECEIVER AND TRANSMIT MODEM INTERCHANGED

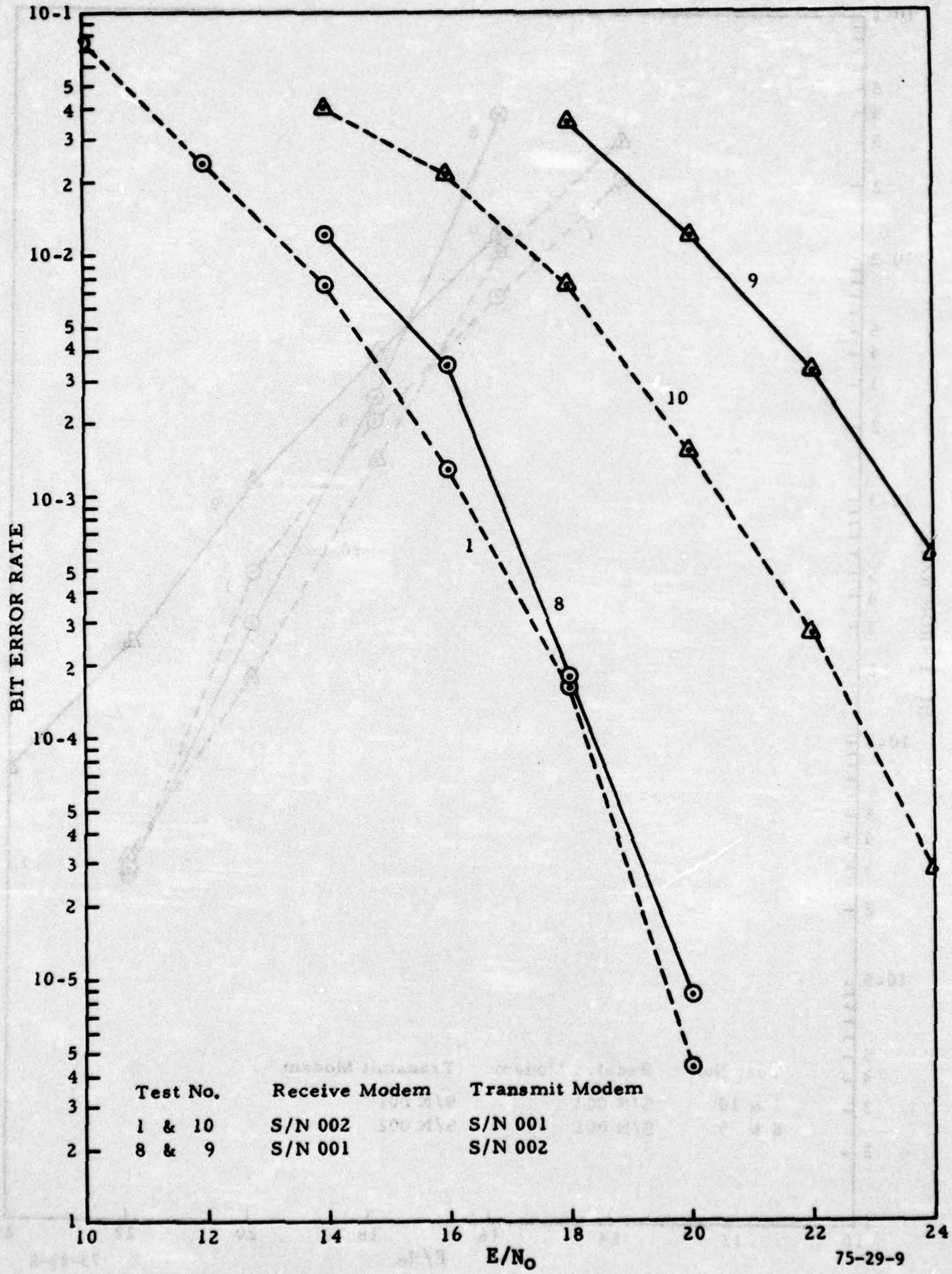

FIGURE 9. 4800 B/S RECEIVE AND TRANSMIT MODEMS INTERCHANGED

0.45 dB, and the second test (9 and 10) is 2.4 dB. The 6 x 10^{-4} bit error rate is used as a reference point.

Test 13, the NARCO COM-11A transmitting to the Bendix RTA-43A, results are in tables 2 and 3. Because performance was poor, only a few samples were taken.

CONCLUSIONS

1. It is probable that unmodified general aviation transceivers will not perform well as MSK data link devices.

2. Of the equipment tested, the air/ground channel performed worse than the ground/air channel.

3. In the ground/air channel, at a reference bit error rate of 1×10^{-5}, the E/N_0 ratio differed by 3.4 dB at 2400 b/s and 5.65 dB at 4800 b/s.

4. In the air/ground channel, at 2400 b/s, the E/N_0 ratio exceeded the ground/air channel by 0.3 dB; at 4800 b/s, performance degraded to such an extent that the reference of 1×10^{-5} was not achieved.

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1. Salwen, H. C., VHF Data Link System Tests, Proteon Associates, DOT-TSC-877, Report No. A112F, February 1975.

2. Swezeny, A. J., Laboratory Measurements of Very High Frequency Communications Equipment for Data Link, NAFEC, FAA-RD-75-159, October 1975.

3. Bilello, J. A., Laboratory Tests of a Data Link Modem, NAFEC, FAA-RD-75-134, September 1975.

APPENDIX

VHF DATA LINK SYSTEM TESTS

Howard C. Salwen, Report No. A112F, Pages 10 and 11

2.2.1 Test Parameters

Modem performance was determined as a function of three parameters: signal-to-noise ratio, signal-to-multipath ratio, and Doppler spread. In all cases, the multipath delay spread was nominally 8 μsec.

The signal-to-noise ratio was established by measuring signal power, S, in the absence of multipath and noise power, N, at RF. Specifically, these parameters were measured at the input to the receiver of figure 1. The performance results are not plotted as a function of S/N. Instead, they are plotted versus the energy-to-noise density ratio. The energy, E, is simply defined as the RF energy per bit. That is,

$$E = ST$$

where T is the bit duration. The noise density, N_o, is the power spectral density of the noise in the center of the RF channel. The noise density is determined by measuring the total noise power output through a filter with known noise bandwidth, B_n. Then,

$$N_o = N/B_n$$

where $$B_n = \left[\frac{1}{2\pi} \int_{-\infty}^{\infty} |H(\omega)|^2 d\omega \Big/ \left[H(\omega_c)\right]^2\right.$$

$H(\omega)$ = Bandpass filter characteristics transfer function

The energy-to-noise density parameter is generally chosen for presentation because the results are then independent of the specific filter shapes used in the test equipment.