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RADAR MICROWAVE LINK PILOT SYSTEM UPGRADE AND EVALUATION.(U)
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RADAR MICROWAVE LINK PILOT SYSTEM UPGRADE AND EVALUATION

D. Smith
F.G. Kimmett

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Office of Telecommunications
Institute for Telecommunication Sciences
Boulder, Colorado 80302

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16. Abstract

Methods of upgrading the existing Radar Microwave Link systems were developed and tested in the laboratory. Replacement of existing klystron and other tube-type components with solid-state units can be expected to provide additional system fade margin and greater system equipment reliability.

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METRIC CONVERSION FACTORS

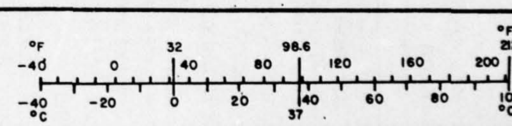
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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RADAR MICROWAVE LINK PILOT SYSTEM
UPGRADE AND EVALUATION

D. Smith and F.G. Kimmett*

Methods of upgrading the existing Radar Microwave Link systems were developed and tested in the laboratory. Replacement of existing klystron and other tube-type components with solid-state units can be expected to provide additional system fade margin and greater system equipment reliability.

Key words: Radar, microwave, retrofit, solid-state

1. INTRODUCTION

The Radar Microwave Link (RML) systems of the Federal Aviation Administration (FAA) are used to transmit radar scope pictures and related data on air-space occupancy from outlying long-range air route surveillance radars to associated air traffic control centers. The RML systems are a vital element in enabling air traffic controllers to handle the ever-increasing air traffic.

Most of the existing links are nearly 20 years old and, while modifications have been made on the equipment in order to improve performance, the basic system does not reflect the state of the art in microwave communications. The FAA requested that the Office of Telecommunications/Institute for Telecommunication Sciences (OT/ITS) provide consultation, experimentation, and analytical services to upgrade a pilot RML link consisting of two terminals and one repeater. This task was an extension of retrofit and evaluation which were done previously on a single-radio basis (Smith, et al., 1973).

2. SUMMARY OF PROJECT OBJECTIVES

The primary objective of the RML upgrade was to improve the system fade margin and thereby improve the performance of the system. The fade margin can be improved by increasing the overall system gain, improving the linearity, delay, and noise performance of various modules to increase the dynamic range and reduce system distortion. The resulting increases in system reliability will depend on the characteristics of the individual link, but those increases are expected to be substantial on many marginal links. The system reliability (maintenance and life expectancy) can be improved by using solid-state devices where they are applicalbe. The project initially consisted of three primary tasks:

1. Selection and procurement of new devices, laboratory modification, and testing of these units.

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2. Survey for a fault alarm and control system that could be incorporated into the RML system. Included in this task was a survey for voice grade service channel equipment to replace the current vacuum tube service channel equipment. This task is reported in Appendix A.

3. Field installation and a three-month in-service evaluation of the modified system. This task was discontinued because the radar terminal equipment was not available and funds were not approved.

This report is a compilation of those test results which occurred utilizing three versions of the RML system. Measurements were made using the original radio configuration (klystron tube-type), a radio receiver retrofitted only with a solid-state Mixer Oscillator, and a complete transmitter and receiver retrofitted to all solid-state components.

3. EQUIPMENT FURNISHED BY FAA

An RML-3 repeater, consisting of two transmitters and four receivers in one rack and two receivers and four transmitters in another rack, was furnished by the sponsor for modification and testing. A complete indicator terminal, including multiplexing equipment, four receivers, and two transmitters was also supplied to ITS.

A photograph of the modified RML-3 indicator terminal with some of the test equipment used, is shown in figure 1.

4. SELECTION OF RETROFIT UNITS

The objective of this task was to survey the commercial market to locate solid-state retrofit units which could be readily modified and installed in the RML-3 radios. After contacting various radio equipment manufacturers, solid-state local oscillators, balanced mixers, IF preamplifiers, IF amplifiers, and associated power supplies were purchased to modify ten receivers. The transmitter modification consisted of a solid-state unit for complete replacement of the existing unit.

Several difficulties were encountered during the equipment survey and procurement. Very few manufacturers had product lines in the government band, although they did have products for the commercial communication bands. At the time ITS was expecting delivery of some retrofit units, the manufacturer advised us that they could not meet the noise-figure, space, and power-supply requirements, so this order was canceled. The original plan was to obtain retrofit units from more than one supplier for product comparison, but this plan was changed because of time and funding limitations, and a lack of second-source vendors.

4.1 Receiver Modification

Retrofit units were received and information required to convert the receiver from vacuum-tube operation to a receiver utilizing solid-state components was provided in two retrofit instruction booklets (Microwave Engineering, 1972). With the exception of two units, all receivers were

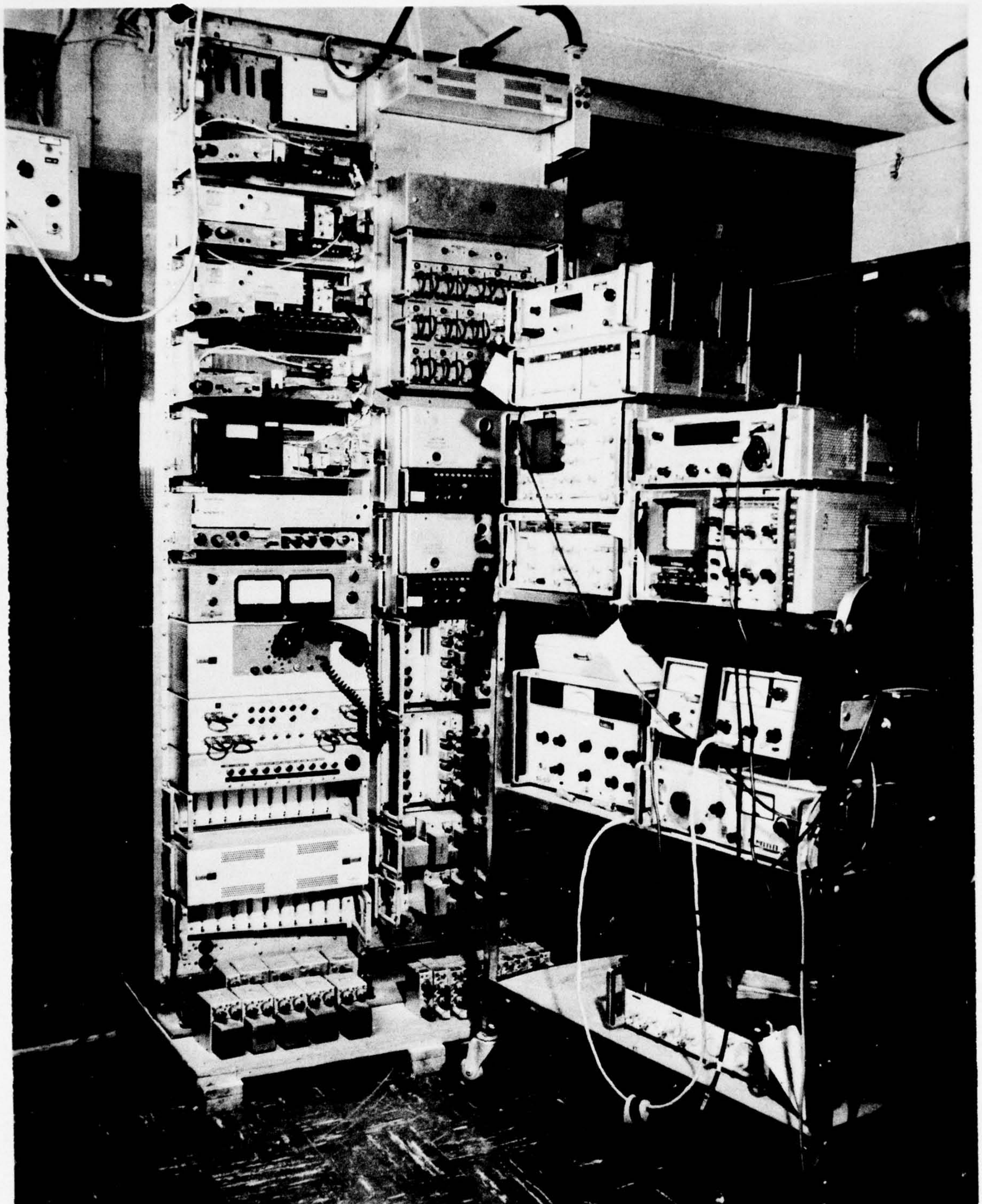


Figure 1. Photograph of RML-3 radio with modifications, and test equipment used.

modified by removing the klystron and tube components and replacing them with a solid-state oscillator-mixer, preamplifier, and a 70 MHz IF amplifier. A power supply unit of ±12 Vdc was attached to each receiver. Of the two remaining units, one was left unmodified and the klystron was replaced with an oscillator-mixer in the other. Due to the relative difficulty encountered in tuning the oscillator-mixer, it is recommended that the oscillator be adjusted to the operating carrier frequency prior to its attachment to the filter-isolator. The waveguide filter should be swept to insure that the filter cavity is set for the correct carrier frequency (see figs. 2 through 7). The oscilloscope trace was not calibrated; insertion loss and bandwidth measurements were made using a power meter and frequency counter. Also all DC voltages should be verified prior to making the retrofit connections.

The retrofit receiver units were tuned to the desired operating frequency as indicated in the frequency plan shown in figure 8. A photograph showing both the modified receiver and modified transmitter in the rack, is shown in figure 9. A block diagram of the original receiver configuration and the full modified receiver units as tested is shown in figure 10.

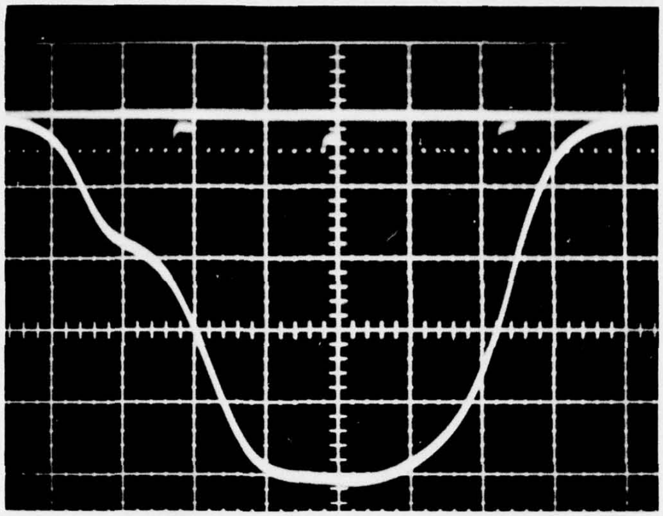
The noise figures of the units were measured following completion of the frequency adjustments. The noise figures ranged from 7.5 to 8.5 dB, and were within one dB of the value on the specification sheets supplied with them. The units were installed and operated in the radio bay. After a period of 3 months of operation, the noise figures of seven of the ten units had deteriorated to values between 10.5 dB and 14 dB.

An investigation was conducted to determine the cause of this deterioration. Three units were returned to the manufacturer for inspection. The manufacturer stated that the deterioration in the returned units was caused by several components. The Gunn diode was contributing several dB to the overall noise and its power level had decreased. The mixer conversion loss was greater than it should be, and the noise figure of the IF preamplifier had increased.

Since we had a unit with an acceptable noise figure, it was decided to substitute components, one at a time, from a good unit into a noisy unit to determine the contribution of each item. The test indicated that the Gunn diode is adding about 4 dB of noise, the mixer 3 dB of noise, and the preamplifier about 1 dB of additional noise.

One mixer was returned to the manufacturer to check whether their measurement would show that the unit was within specifications originally ordered.

The Gunn diode oscillator manufacturer was contacted and it was learned that the units were designed to operate from 7.6 GHz to 8.4 GHz, but the receiver front-end manufacturer had tuned them down to cover the 7.1- to 7.6-GHz band. The original manufacturer stated that this could easily account for the additional noise, as well as the difficulty encountered in setting the units on frequency. The Gunn oscillator units were checked for AM noise only, since equipment was not available for us to investigate the FM noise.



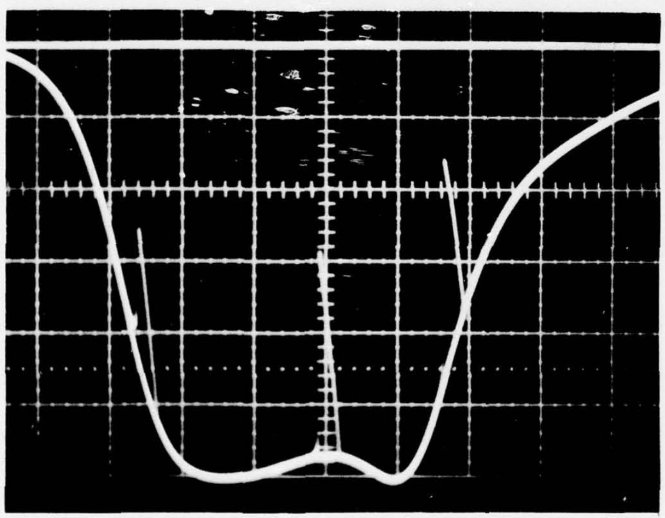
Filter Bandpass

f_o = 7425 MHz

Insertion Loss = 2.9 dB

Bandpass = 23 MHz

Figure 2. 7425 MHz receiver, filter response characteristic.



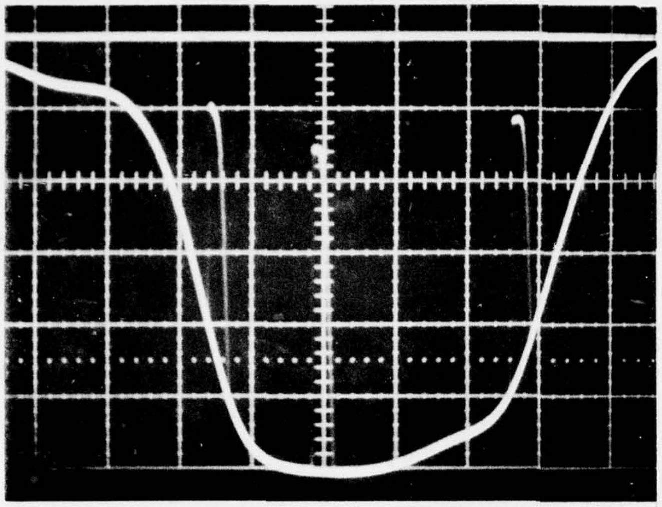
Filter Bandpass

f_o = 7475 MHz

Insertion Loss = 2.5 dB

Bandpass = 23 MHz

Figure 3. 7475 MHz receiver, filter response characteristic



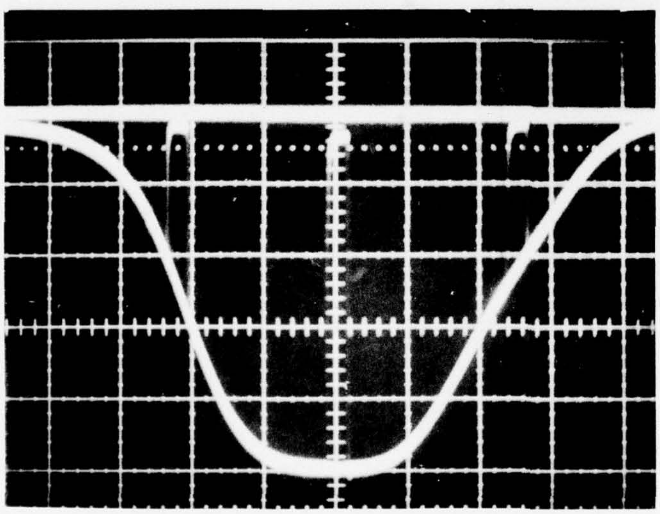
Filter Bandpass

f_o = 7595 MHz

Insertion Loss = 2.6 dB

Bandpass = 25 MHz

Figure 4. 7595 MHz receiver, filter response characteristic.



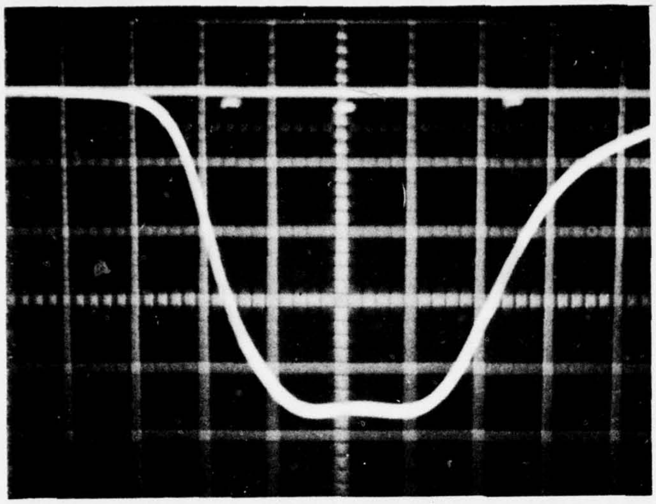
Filter Bandpass

f_o = 7635 MHz

Insertion loss = 2.4 dB

Bandpass = 25 MHz

Figure 5. 7635 MHz receiver, filter response characteristic.



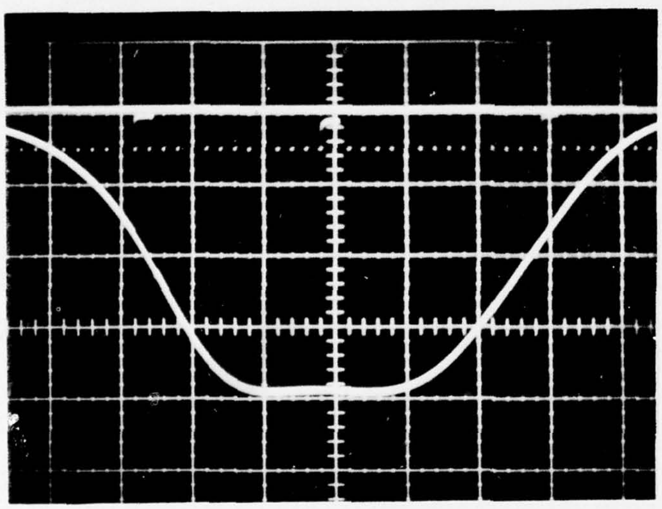
Filter Bandpass

f_o = 7240 MHz

Insertion Loss = 1.9 dB

Bandpass = 23 MHz

Figure 6. 7240 MHz transmitter, filter response characteristic.



Filter Bandpass

f_o = 7335 MHz

Insertion Loss = 2.4 dB

Bandpass = 22 MHz

Figure 7. 7335 MHz transmitter, filter response characteristic.

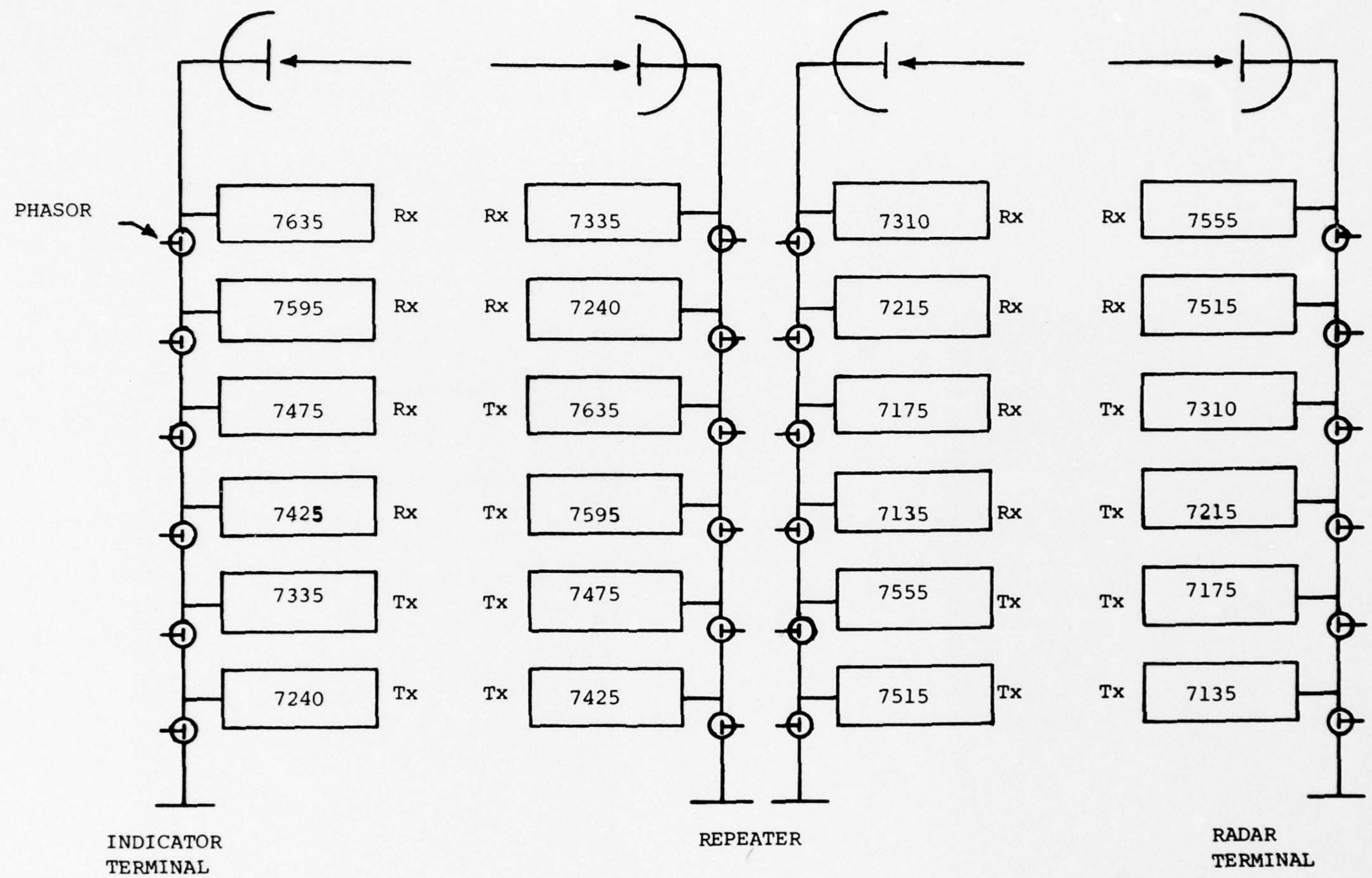


Figure 8. RML system configuration and frequency plan.

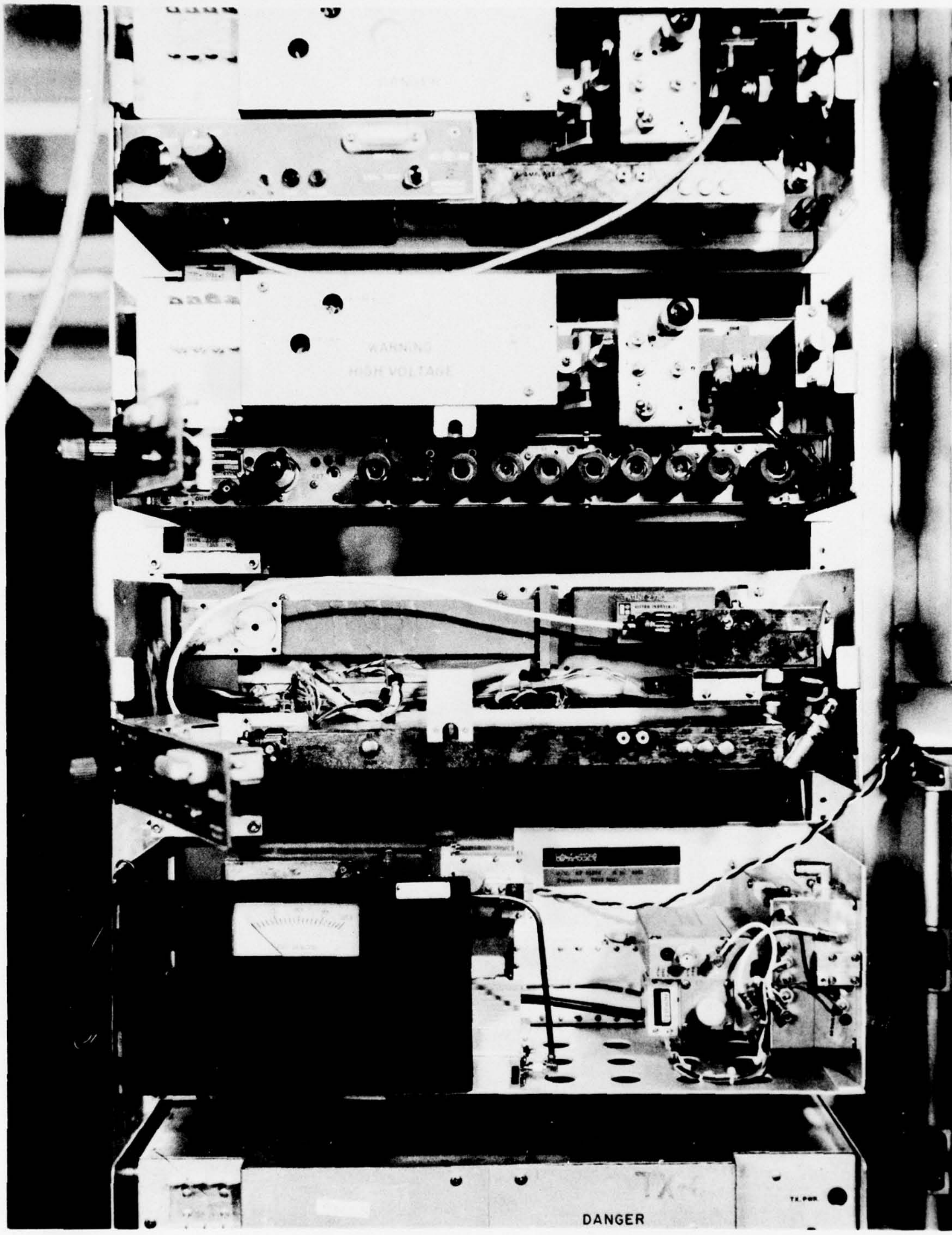


Figure 9. Photograph of modified receiver and transmitter units.

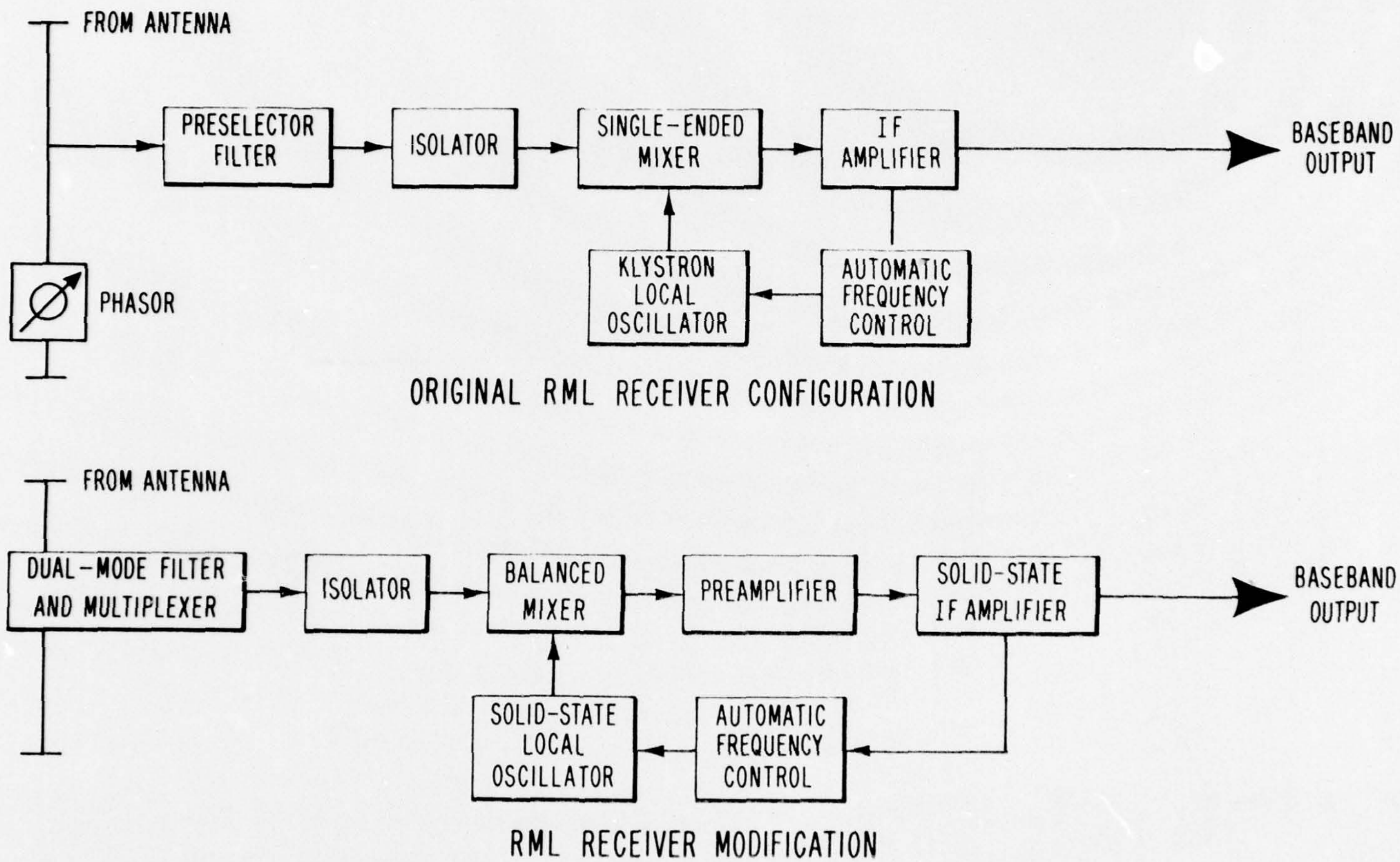


Figure 10. Block diagram of original receiver configuration and retrofit modification.

4.2 Transmitter Modification

Converting the vacuum tube transmitter to a unit using all solid-state components requires removal of all tube-type components and mounting the solid-state devices in a rebuilt transmitter housing. A photograph of the solid-state transmitter is shown in figure 11. The retrofit components consist of transmitter, FM exciter with baseband amplifier, iso-adapter, amplifier/multiplier assembly, and semi-rigid coax cabling. Figure 12 is a block diagram of the complete transmitter configuration, while figure 13 is a diagram of the phase-locked transmitter only.

The three-section waveguide filter should be swept to insure that the filter cavity is set for the correct carrier frequency. Heat sink sections are used because the amplifier must dissipate power levels of nearly nine watts, while the multiplier must dissipate about one watt.

A supply voltage of -20 Vdc at 2.5 amperes is required to power the amplifier. The -24 Vdc from the power supply in the RML-3 racks could have been used, however, a -20 volt regulator is needed.

The output at the final power amplifier is 1200 mW (30.8 dBm). Insertion loss is 0.7 dB for the semi-rigid waveguide and about 2.6 dB for the iso-adaptor. The output at the top of the stack is 360 mW (25.6 dBm). The iso-adaptor has a nominal 25-dB isolation. The baseband gain provided ±4 MHz peak deviation for -14 dBm input signal.

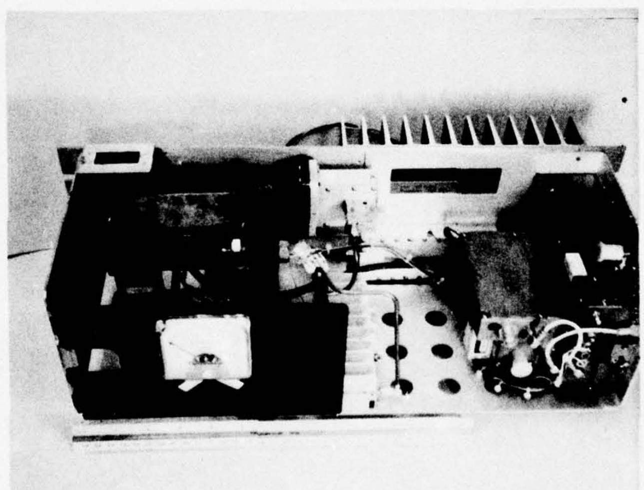


Figure 11. Installation configuration of crystal controlled phase-locked transmitter with bandpass filter and phasor section.

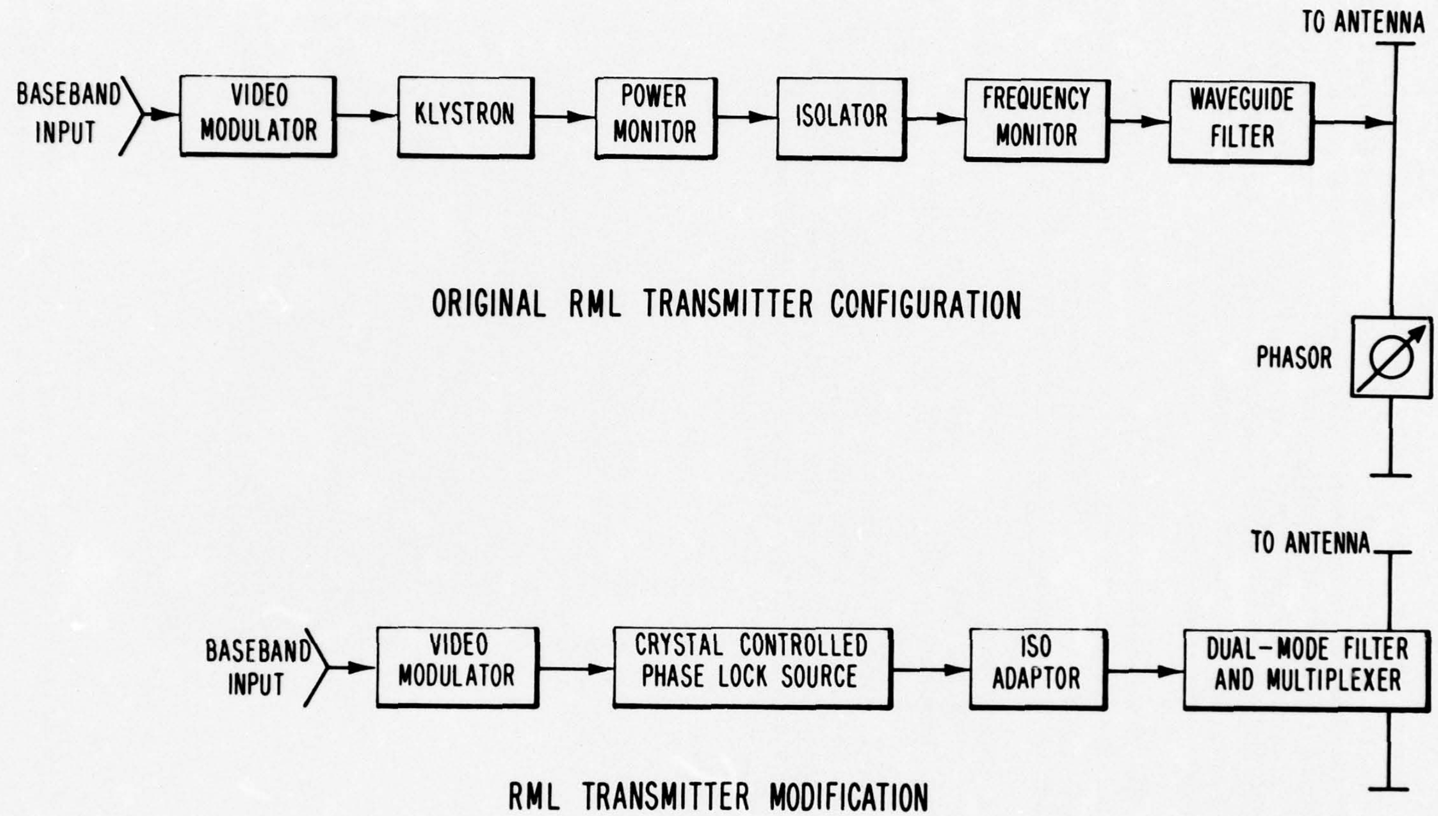


Figure 12. Block diagram of original transmitter configuration and modified transmitter unit.

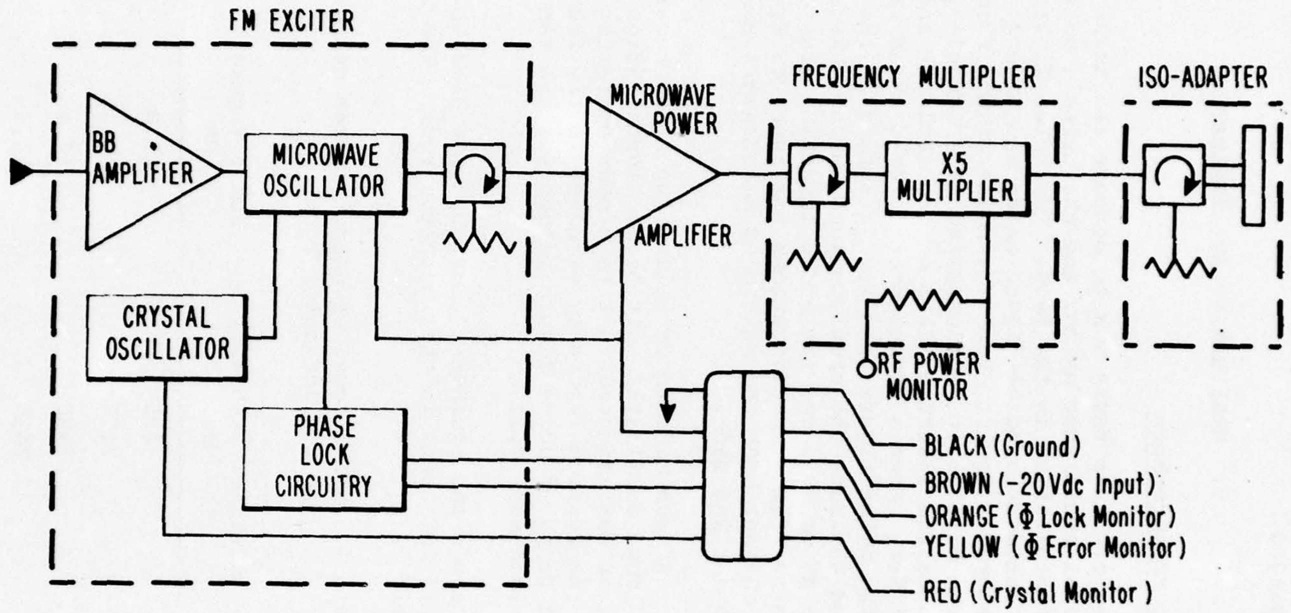


Figure 13. Block diagram of phase-locked transmitter source.

To cover the lower FAA frequency band, from 7135 MHz to 7650 MHz, the transmitter uses two subbands, 7135 to 7385 MHz and 7385 to 7650 MHz. Crystals must be replaced and the unit retuned when the frequency of the transmitter is changed.

5. MEASUREMENT AND EVALUATION

5.1 Noise Figure Measurements

The purpose of these tests was to measure the noise figures of the balanced mixer-local oscillator units, and the overall noise figure of the receivers after installation in the rack. The noise figure measurements were made with an automatic noise figure meter and an argon gas discharge waveguide noise source (Hewlett-Packard, Noise Figure Primer, 1973). The noise figure of the mixer unit is classified as a "double-sideband noise figure" and includes the insertion loss of the isolator and a contribution from the IF amplifier. When a preselector is used ahead of the receiver front-end unit, the noise figure then is classified as the "single-sideband noise figure", and includes the previous loss but now has an entire image contribution of 3 dB or more and the added insertion loss of the filter. When comparing noise figure specifications for receiver front-end units, it is necessary to consider both the method of measurement and the frequency at which the measurement was made.

The first test was made to determine the noise figure of the balanced mixer/Gunn diode local oscillator unit before installation in the receiver. The local oscillator was adjusted to t he proper operating frequency, which was 70 MHz below the desired frequency as noted in the frequency plan (figure 10). The range of noise figure values for the ten units was from 7.5 dB to 8.5 dB (see sec. 4.1).

Figure 14 shows the equipment configuration used to measure the noise figure of the RML-3 receivers in the indicator rack. The values measured are listed in table 1.

Table 1. RML-3 receiver noise figures measured in the indicator rack

Carrier frequency MHz	Noise figure dB
7425	15.0
7475	12.2
7595	17.4
7635	15.9

Receiver #3 (f_o = 7595 MHz) was an unmodified RML-3 receiver with IF = 60 MHz.

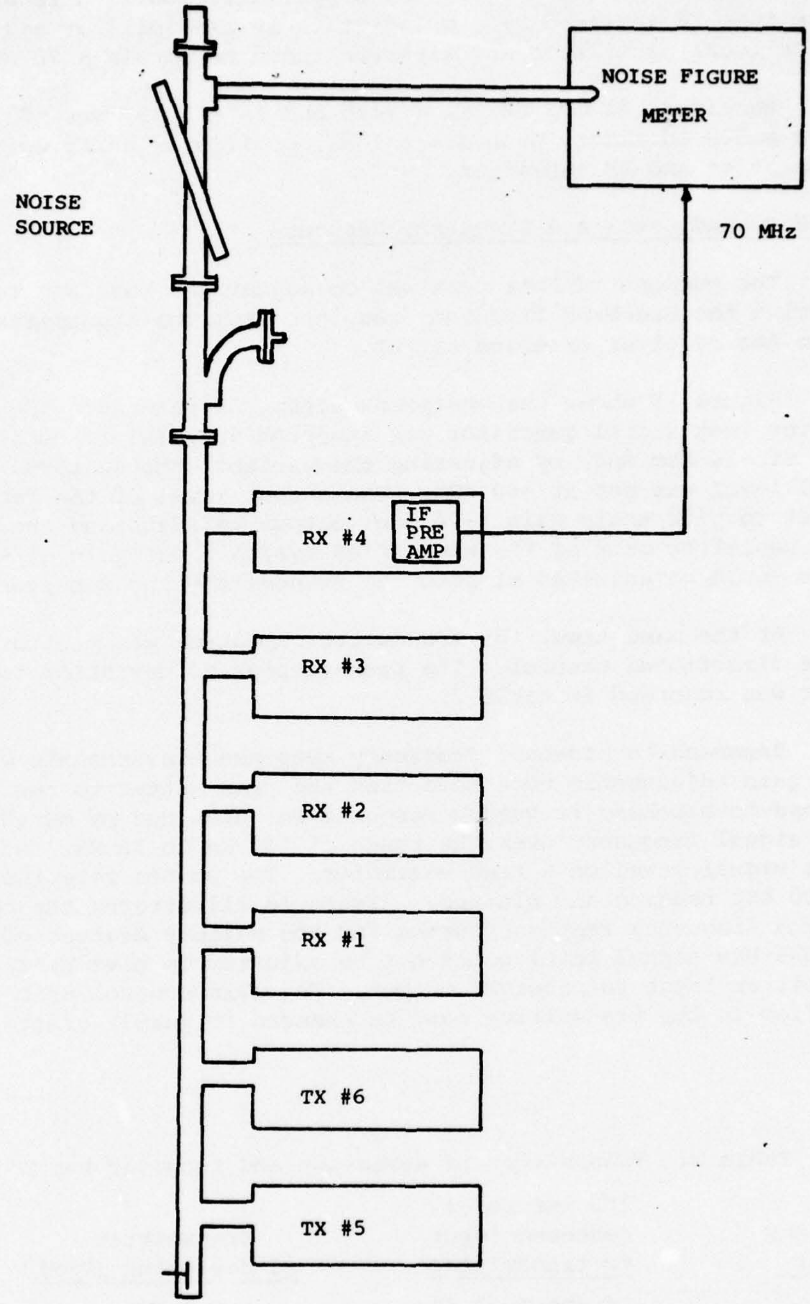


Figure 14. Test equipment for noise figure measurement.

Receiver #2 (f_o = 7475) was a partially modified receiver with the vacuum tube IF replaced by a solid-state IF preamplifier and IF amplifier, and the local oscillator and klystron tuned to obtain a 70 MHz IF.

Receivers #1 and #4 (f_o = 7425 and f_o = 7635) were fully modified with a balanced mixer, Gunn diode local oscillator unit, solid-state IF preamplifier and IF amplifier.

5.2 Baseband Level and Frequency Response

The purpose of this test was to adjust the baseband level and to determine the baseband frequency response from the transmitter baseband input to the receiver baseband output.

Figure 15 shows the equipment setup. A reference 100 kHz test tone from the test signal generator was inserted into the transmit baseband at a level of -24 dBm and, by adjusting the variable attenuators, the received rf signal level was set at -40 dBm. The output level of the receiver baseband was set to give unity gain (-24 dBm) output by adjusting the transmitter video amplifier gain of the unmodified system. The gain of the modified system could be adjusted at both the transmitter and receiver.

At the same time, the transmitter spectrum was monitored at the output of the directional coupler. The peak-to-peak rf deviation for each transmitter was recorded in table 2.

Baseband-to-baseband frequency response measurements were made after unity gain adjustments were made from the transmitter to the receiver. The baseband-to-baseband frequency response was obtained by manually varying the input signal frequency over the range of 100 Hz to 10 MHz and recording the output signal level on a true voltmeter. The points were then normalized to the 100 kHz reading and plotted. Figure 16 illustrates the baseband-to-baseband frequency response curves for the various degrees of modification. The 7635-MHz signal level could not be adjusted to give unity gain from transmitter input to receiver output. The gain control of the baseband amplifier in the transmitter must be changed to permit greater reduction of gain.

Table 2. Transmitter rf deviation and receiver baseband output.

Frequency (MHz)	100 kHz refer. baseband input to transmitter	Transmitter rf deviation (P-P)	Baseband output of receiver
7425	-24 dBm (-33 dBc)	1.2 MHz	33 dBc
7475	-24 dBm (-33 dBc)	1.0 MHz	33 dBc
7595	-24 dBm (-33 dBc)	1.4 MHz	33 dBc
7635	-24 dBm (-33 dBc)	1.7 MHz	29 dBc

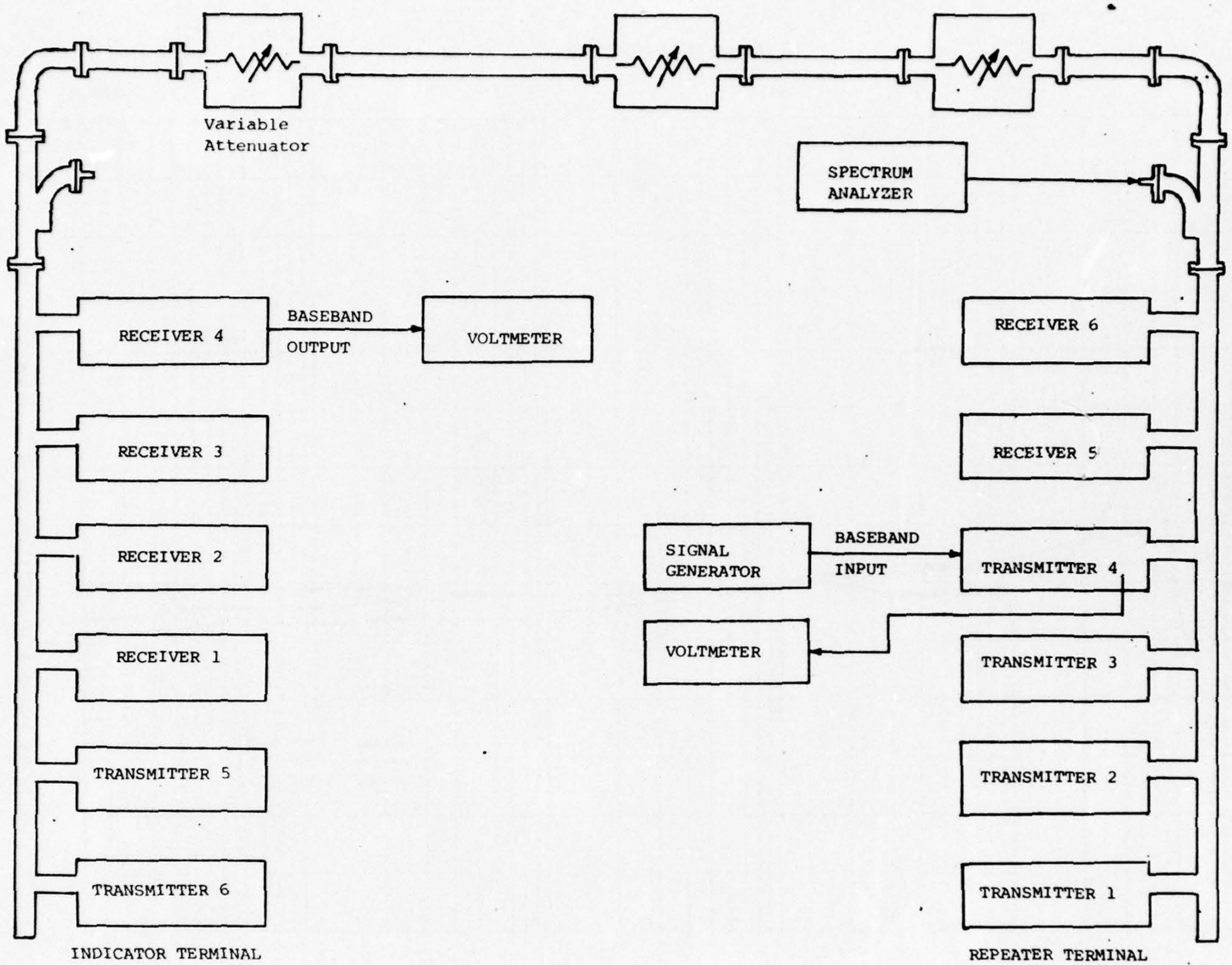


Figure 15. Test equipment for modulator frequency response and baseband level.

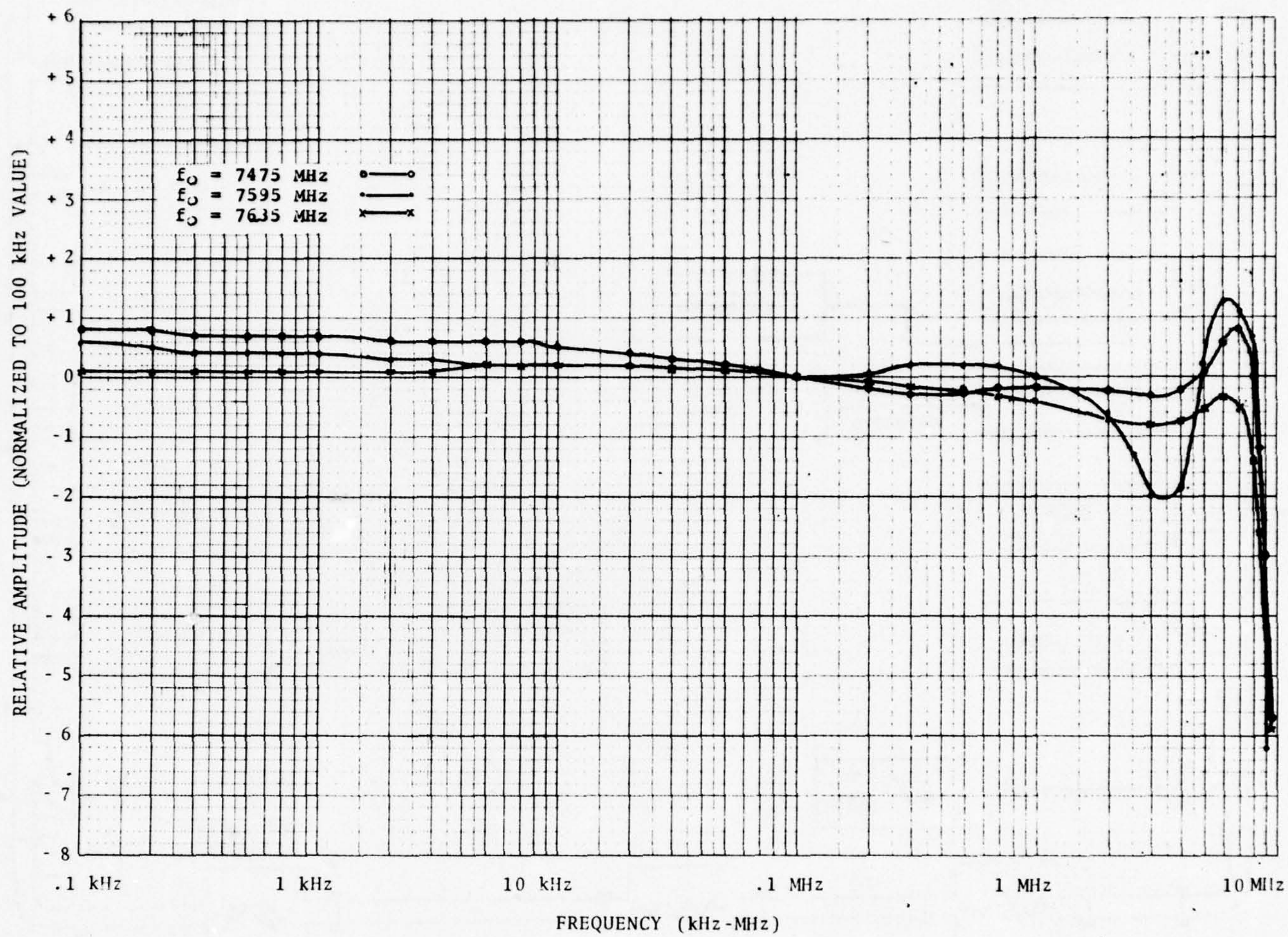


Figure 16. Frequency response, baseband-to-baseband frequency (Hz).

5.3 Transfer-Characteristic Curves

Transfer-characteristic curves were obtained from the IF preamplifier and IF amplifier with the test setup shown in figure 17. The 70-MHz input signal was varied from -25 dBm to -100 dBm. The wideband noise power was measured with a true RMS voltmeter at the baseband output.

The receiver transfer-characteristic curves (quieting curves) were obtained for the modified and unmodified receivers by injecting an unmodulated signal from a signal generator at the top of the rack and measuring the wideband noise power at the baseband monitor output. The results of these measurements are shown in figure 18. After all receivers were fully modified, tests were made using a solid-state signal source for the signal and the results are shown in figure 19.

5.4 Receiver Interference (Susceptibility Curves)

The measurement of the susceptibility characteristics of an RML-3 receiver consisted of making measurements on three receivers with varying degrees of modifications. One receiver was left unmodified but was aligned for the best operation before the measurements were made. This receiver had a 5-cell pre-selector filter, klystron local oscillator, single-ended mixer, and vacuum-tube IF strip. The frequency was 7595 MHz and the IF frequency was 60 MHz.

Another receiver (f_o = 7475 MHz) was partially modified by replacing the 60-MHz vacuum tube IF strip with a solid-state IF preamplifier and IF amplifier.

The third receiver (f_o = 7425 MHz) was modified by replacing the klystron local-oscillator and single-ended mixer with a Gunn diode oscillator, balanced mixer unit, preampliifier, and IF amplifier. This unit also has built-in AFC circuitry.

The purpose of the measurements was to obtain curves for the receivers which would indicate the threshold above which an interfering unmodulated carrier would cause the noise level of the receiver bandpass to increase.

Figure 20 shows the equipment setup for the measurements. The receiver was locked to an unmodulated reference carrier from a stable, clear signal source set at a -40 dBm level. An unmodulated interference signal was injected into the input of the receiver. The frequency of the interfering signal was varied manually ±200 MHz from the reference carrier frequency. At the same time the amplitude of the interfering signal was increased until an interference frequency was observed in the baseband spectrum as observed on the spectrum analyzer. When the interference product was observed in the receiver baseband spectrum, the amplitude of the interference carrier was attenuated until the interference (product) disappeared into the normal baseband noise. At this time, the frequency and amplitude of the interference were recorded. The procedure was repeated for ±200 MHz from the reference signal and for each interference product, and several readings at various

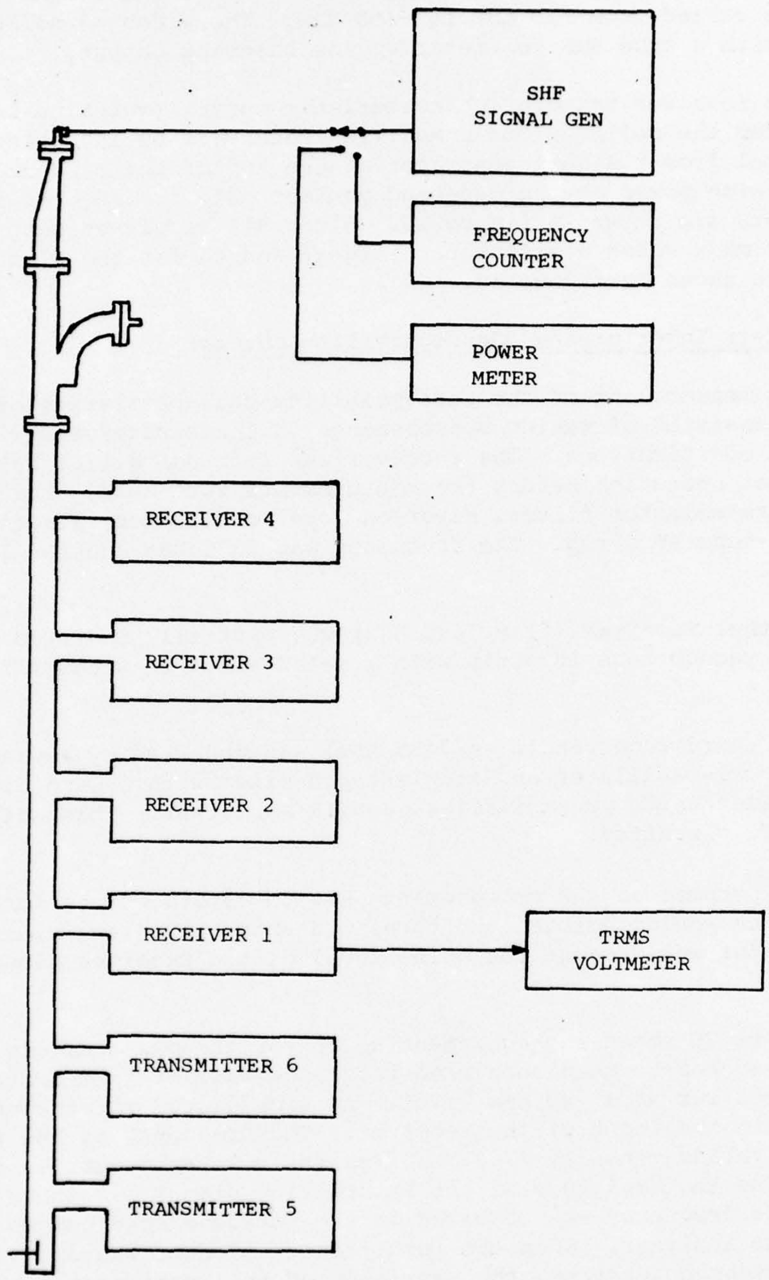


Figure 17. Test equipment for wide band noise measurement.

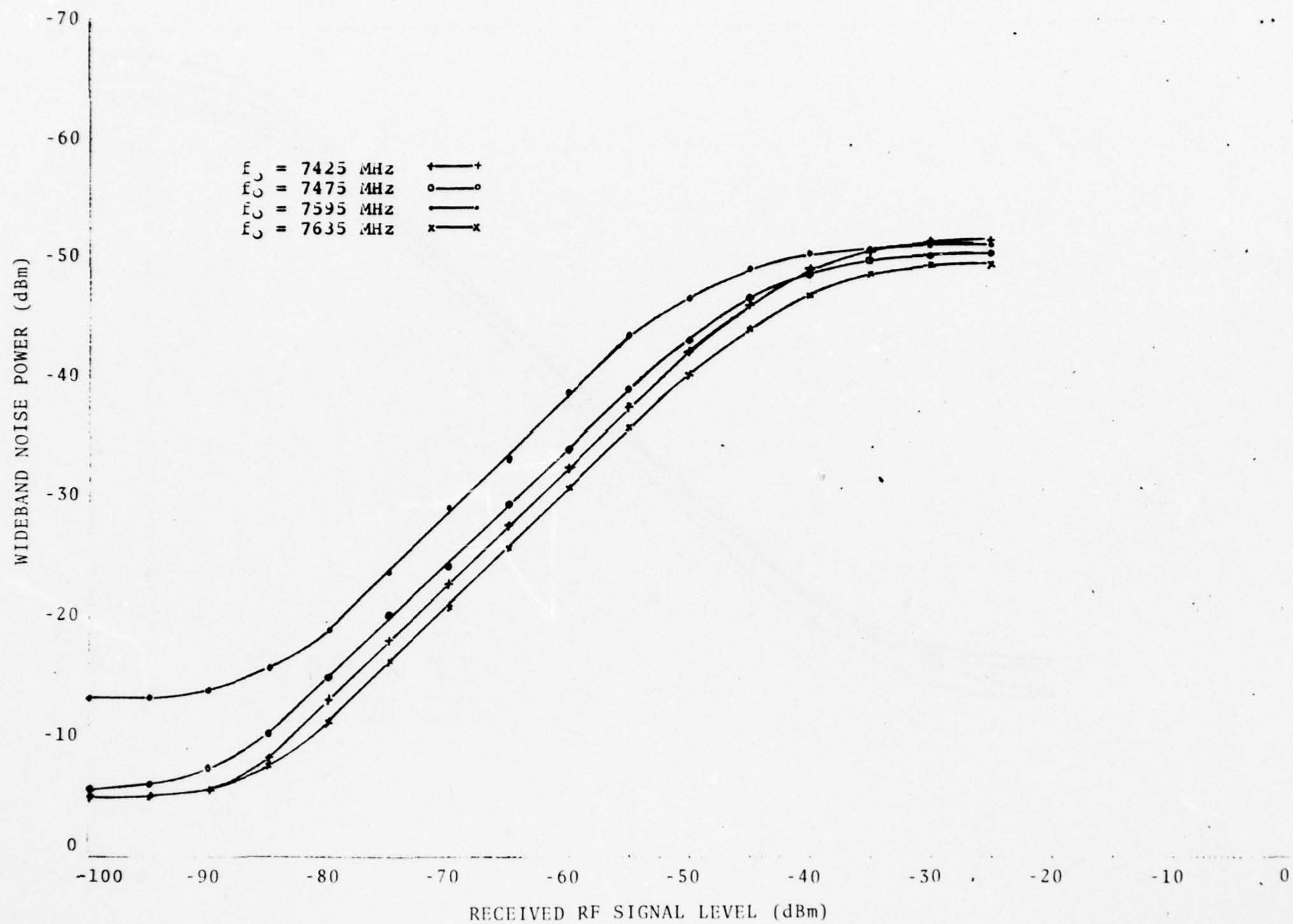


Figure 18. Receiver transfer characteristic curves for unmodified and modified receivers.

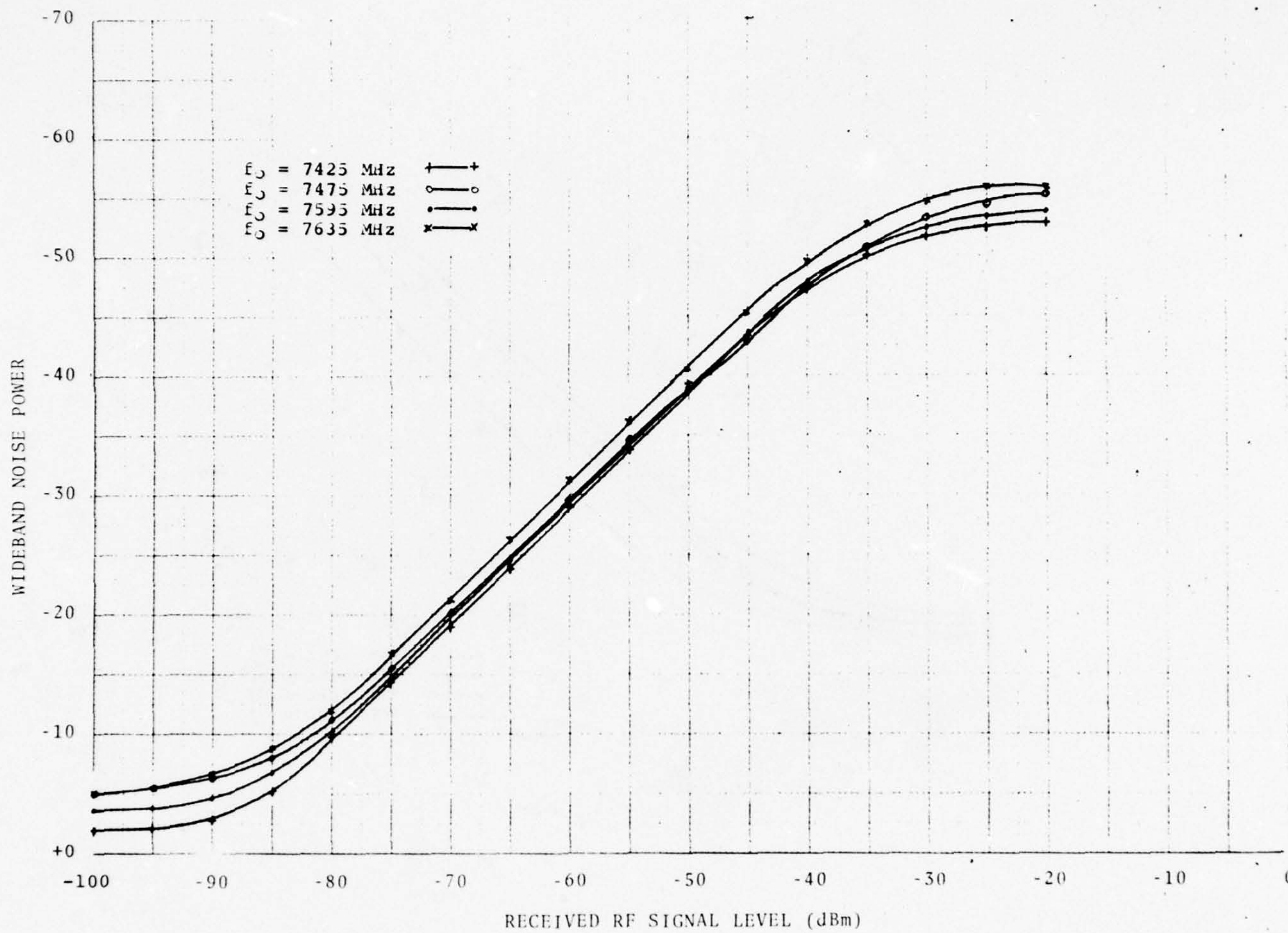


Figure 19. Receiver transfer characteristic curves for fully modified receivers.

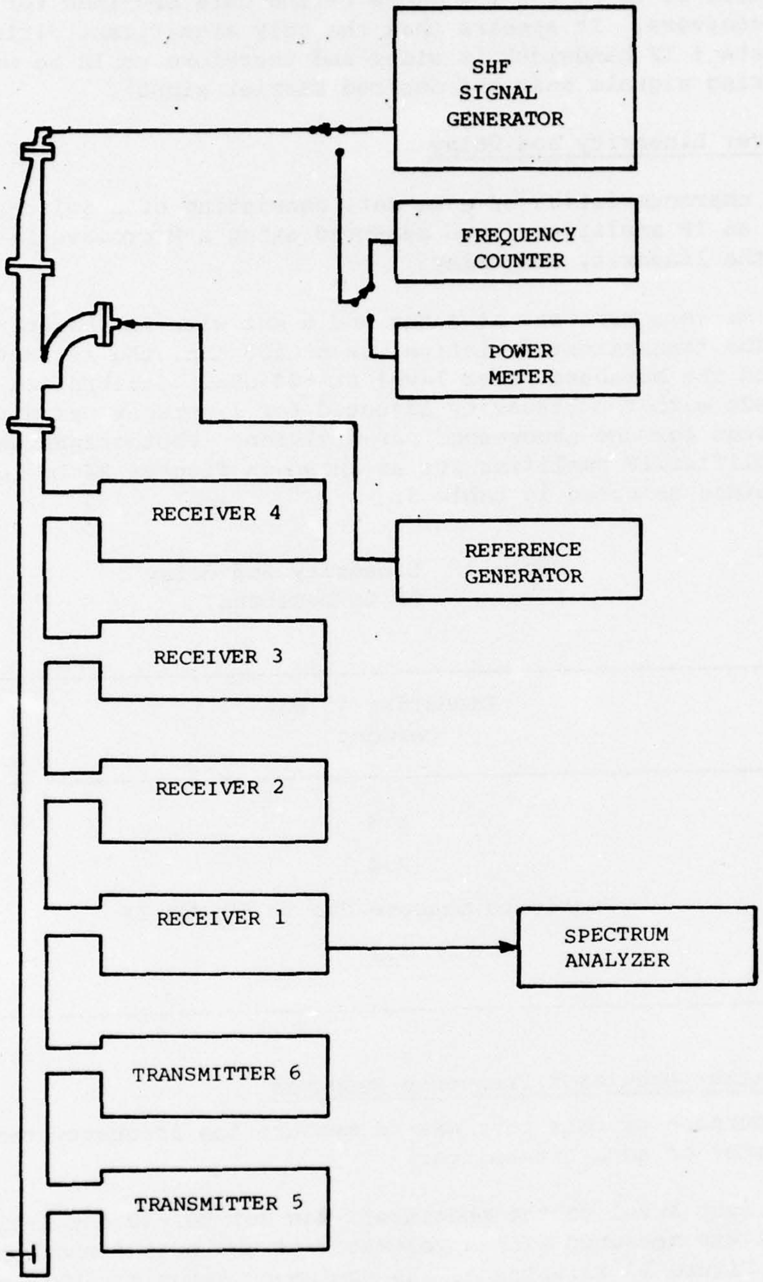


Figure 20. Test equipment configuration to determine receiver susceptibility curve.

positions of the interference products in the baseband were recorded. From these points an interference susceptibility plot was obtained.

Figures 21 to 23 are the plots of the data obtained for the three types of receivers. It appears that the only significant difference is that the solid-state IF bandwidth is wider and therefore would be more susceptible to interfering signals near the desired carrier signal.

5.5 Receiver Linearity and Delay

The characteristics of each set, consisting of a solid-state preamplifier and an IF amplifier, were measured using a Microwave Link Analyzer to determine the linearity and delay.

The markers were set at 4 MHz and 5 MHz with the baseband frequency at 500 kHz. The transmitter deviation was at 500 kHz, the set deviation at 300 kHz, and the baseband power level at -24 dBm. Calibration for all readings was made with the linearity adjusted for 1 percent per division and the delay adjusted for one nanosecond per division. Photographs were taken for each preamplifier/IF amplifier set as shown in figures 24 to 26, and the values recorded as noted in table 3.

Table 3. Linearity and delay
IF to baseband.

Receiver f_o (MHz)	Linearity ±5 MHz percent	Delay ±4 MHz nanoseconds
7425	1.8	1.2
7475	2.4	2.9
7595	Unable to measure due to 60 MHz IF	
7635	3.2	3.8

5.6 Transmitter Modulator Frequency Response

The purpose of this test was to measure the frequency response of the ra[illegible] modulator of each transmitter.

The input level to the modulators was set to -30 dBc (-21 dBm). The output level was measured with a voltmeter at the output monitor jack on the modulator. Figure 15 illustrates the equipment setup for this measurement.

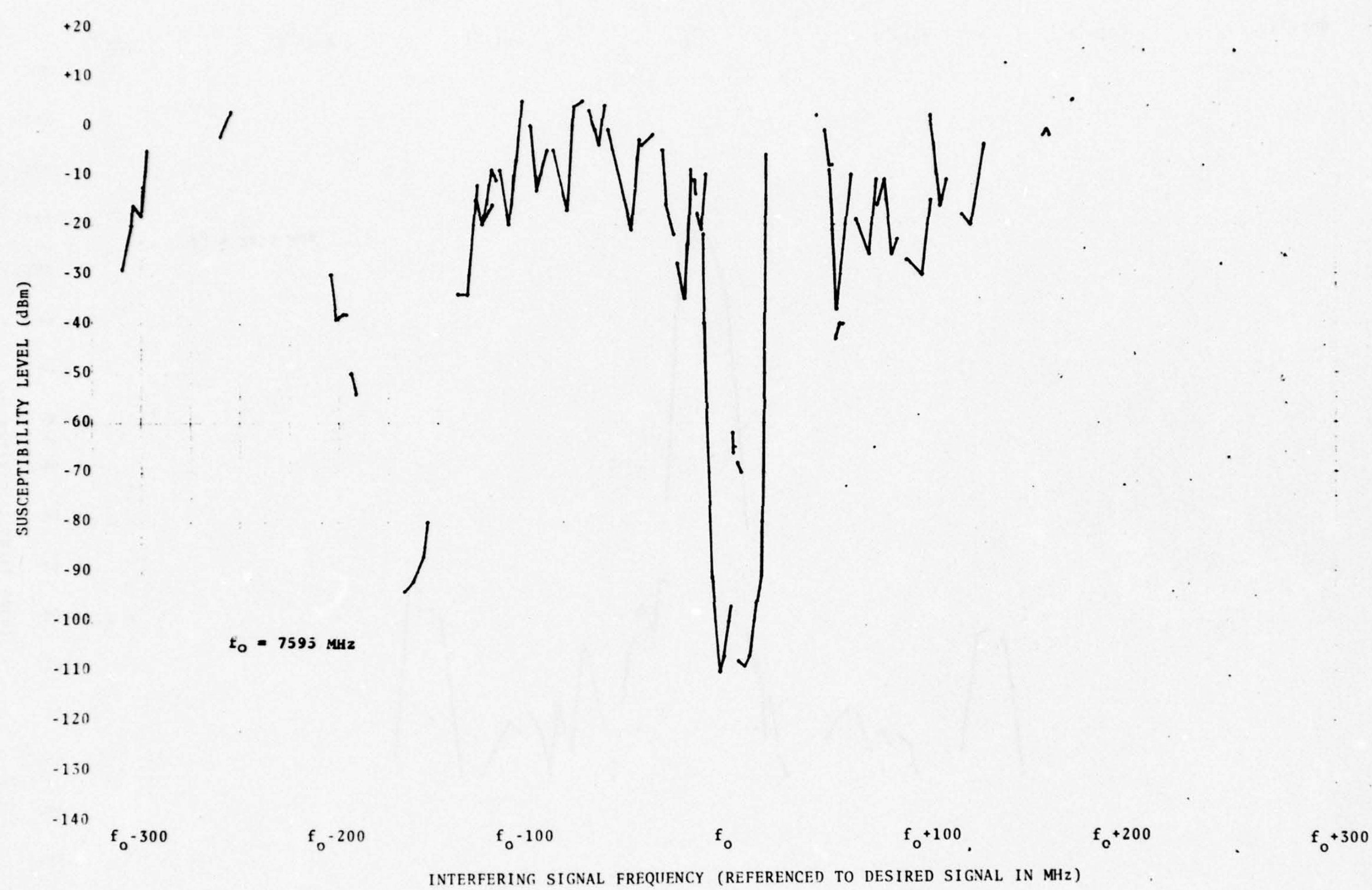


Figure 21. Interference susceptibility characteristics for unmodified receivers.

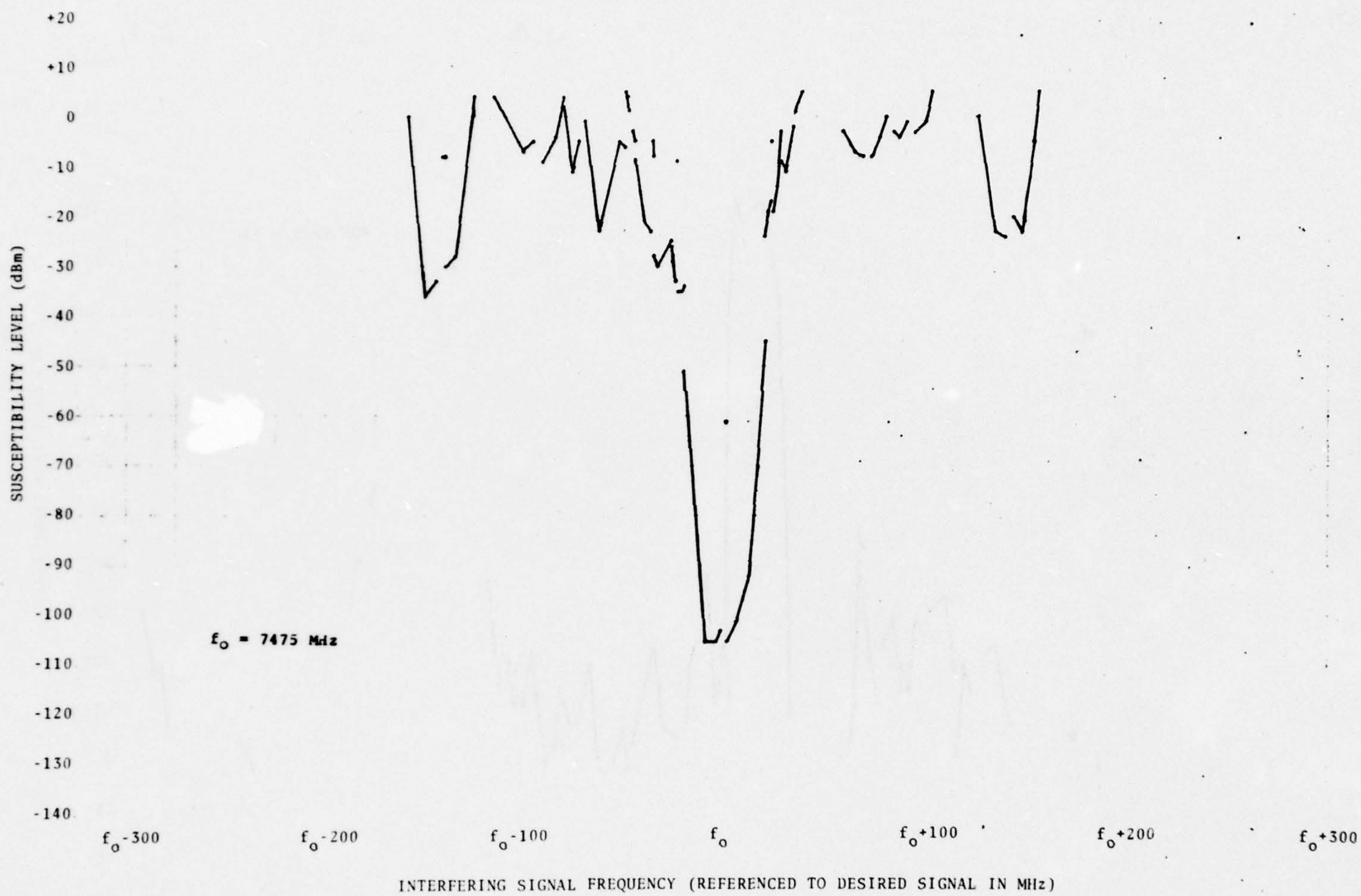


Figure 22. Interference susceptibility characteristics for partially modified receivers.

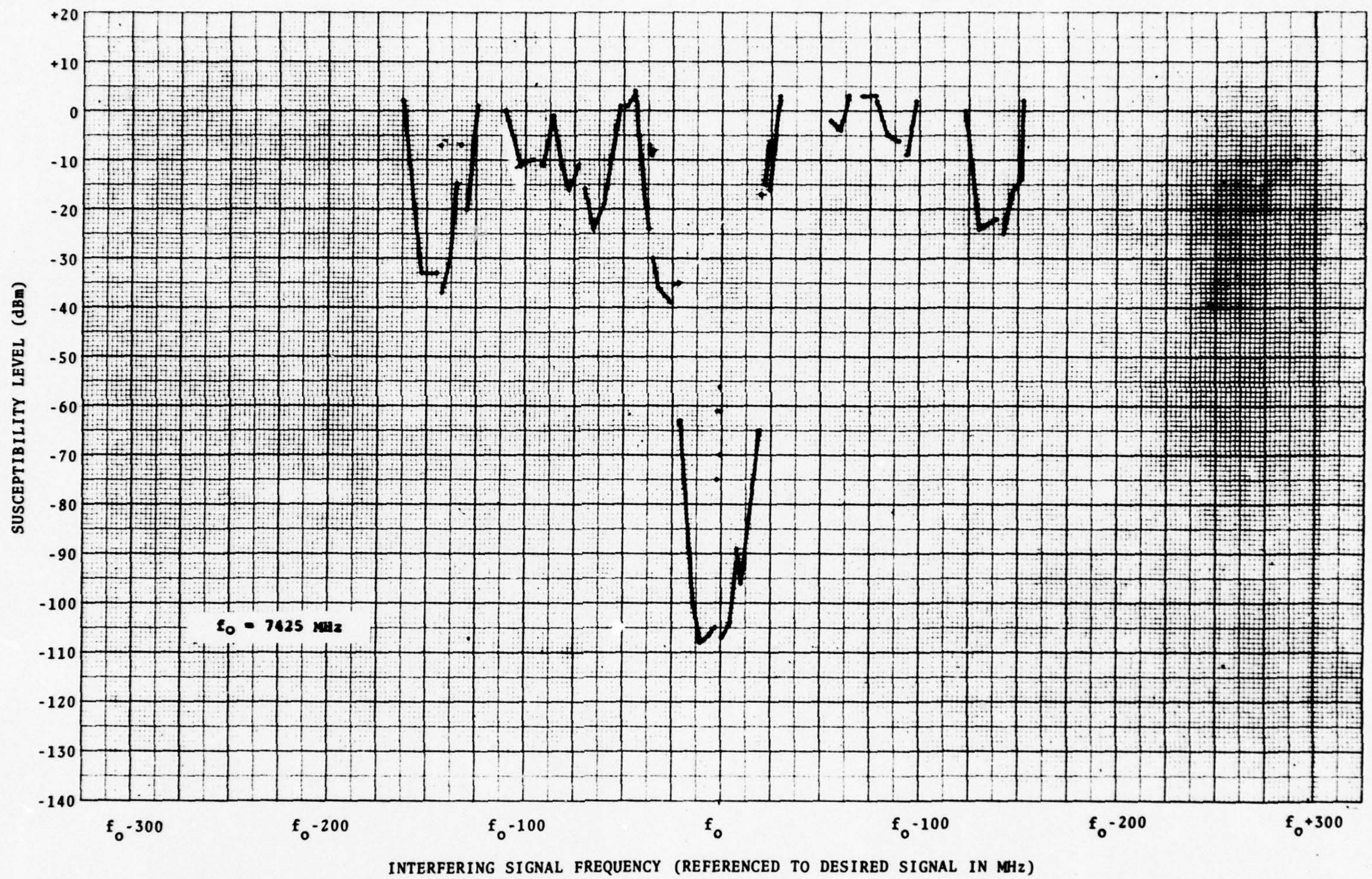
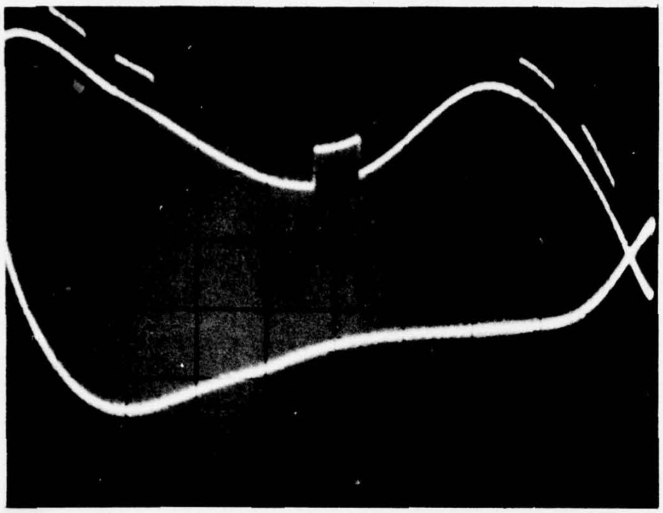


Figure 23. Interference susceptibility characteristics for fully modified receivers.



Receiver

f_o = 7425 MHz

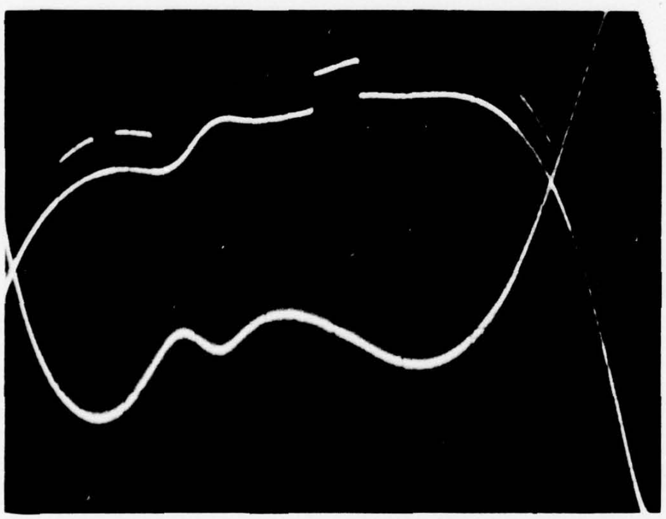
Linearity Marker = ±5 MHz

Calibration = 1%/div

Delay Marker = ±4 MHz

Calibration = 1 ns/div

Figure 24. 7425 MHz receiver, linearity, and delay.



Receiver

f_o = 7475 MHz

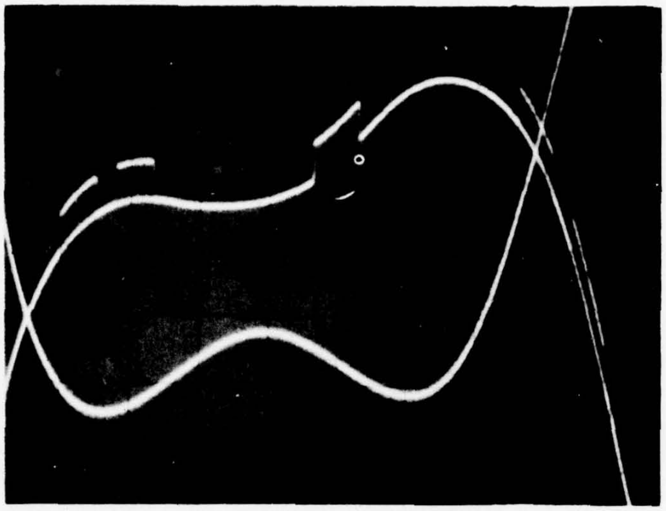
Linearity Marker = ±5 MHz

Calibration = 1%/div

Delay Marker = ±4 MHz

Calibration = 1 ns/div

Figure 25. 7475 MHz receiver, linearity, and delay.



Receiver

f = 7635 MHz

Linearity Marker = ±5 MHz

Calibration = 1%/div

Delay Marker = ±4 MHz

Calibration = 1 ns/div

Figure 26. 7635 MHz receiver, linearity, and delay.

Figure 27 shows the requency response of the modulators. To be within FAA specifications, the modulator response should be flat, but a tolerance of ±1 dB is permitted. The data points were normalized to the 100-kHz reading.

5.7 Transmitter Frequency Stability

The purpose of this measurement was to measure the stability of the output frequency of a modified (solid-state type) and an unmodified (klystron type) transmitter. Each unit was tested for one week in the laboratory with no attempt to control the temperature. The frequency monitoring point was at the output of the directional coupler located at the top of the radio rack. Figure 28 shows the measurement equipment used. Figures 29 and 30 show the frequency of the transmitters as a function of time. The klystron-type transmitter had a peak-to-peak variation in frequency of ±0.00004%. Facilities were not available to perform temperature cycle measurements.

5.8 Link Measurements: Linearity and Delay

The purpose of this measurement is to determine the baseband-to-baseband linearity and delay of radios on a link basis. These measurements were made with the use of a Microwave Link Analyzer.

Figures 31 to 33 and table 4 give a comparison of the values measured over the various types of links tested. In the photographs, for reference, a marker pulse was placed at ±4 MHz for the delay curve and at ±5 MHz for the linearity curve.

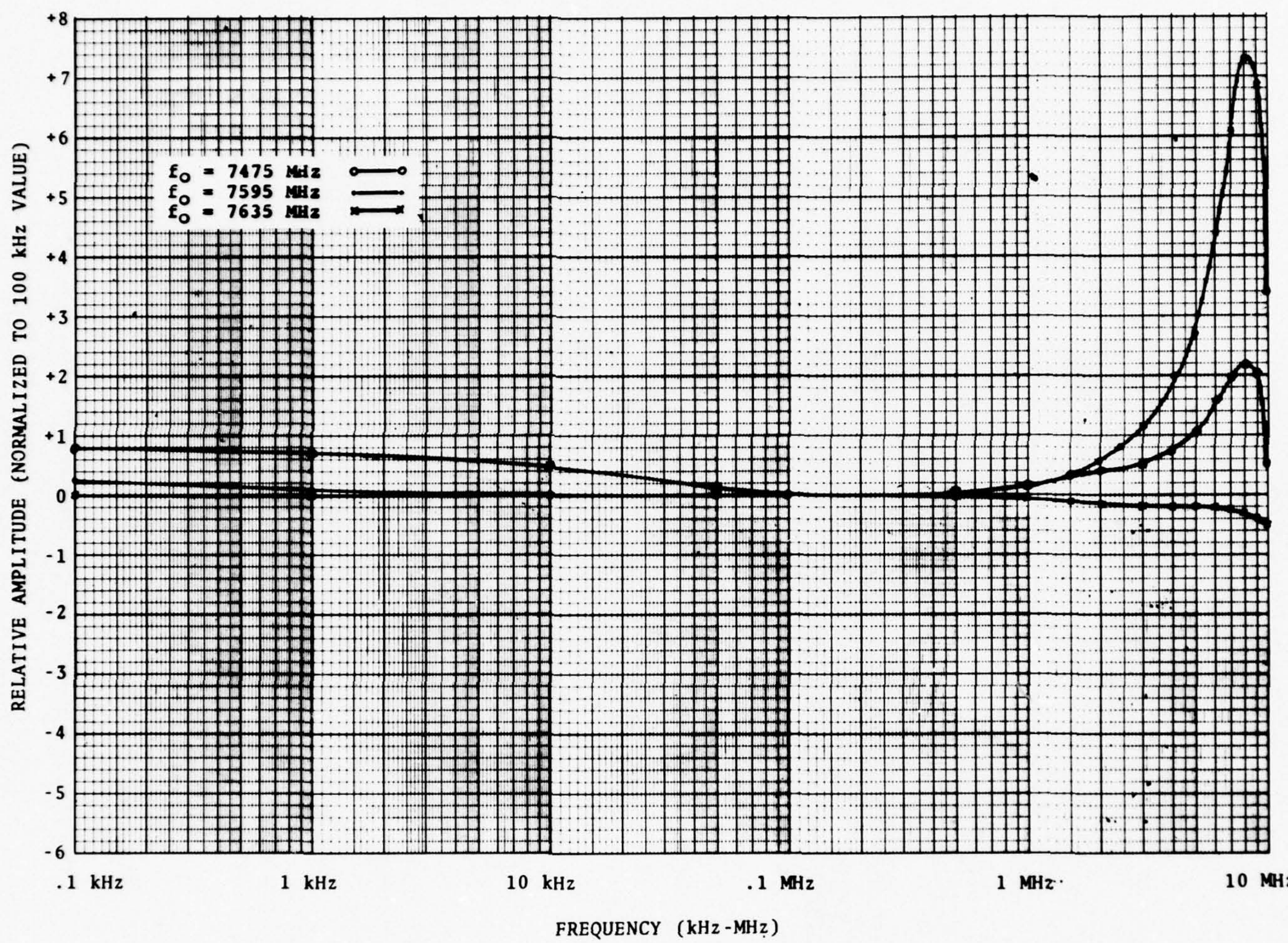


Figure 27. Modulator frequency response for unmodified and modified receivers.

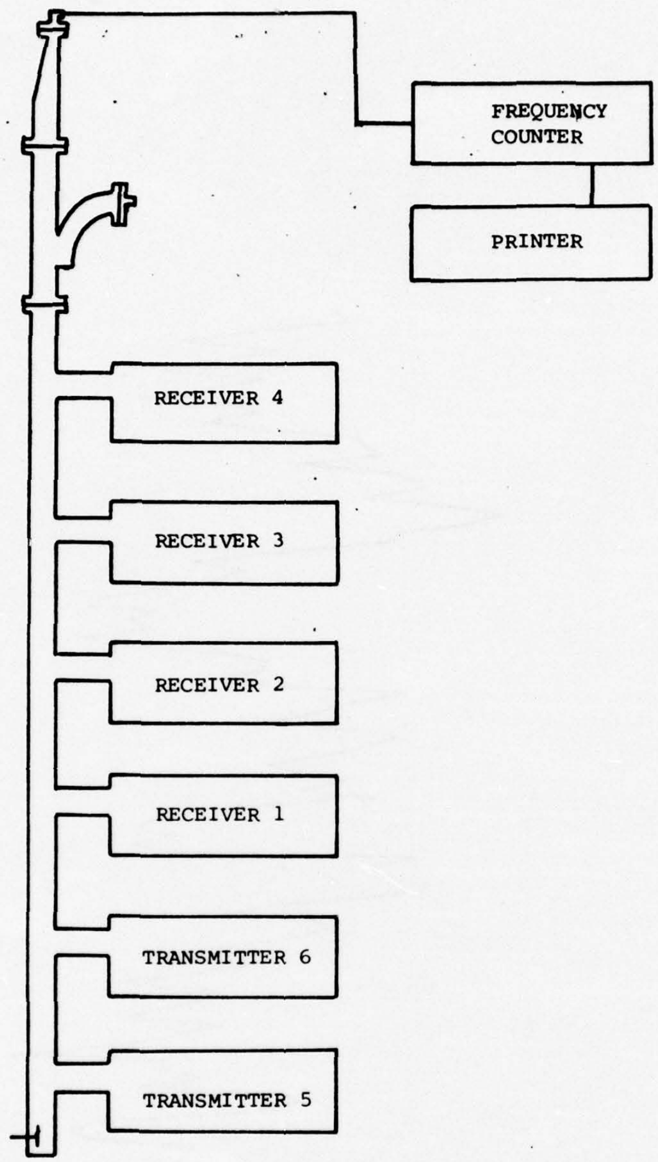


Figure 28. Test equipment for transmitter frequency stability measurements.

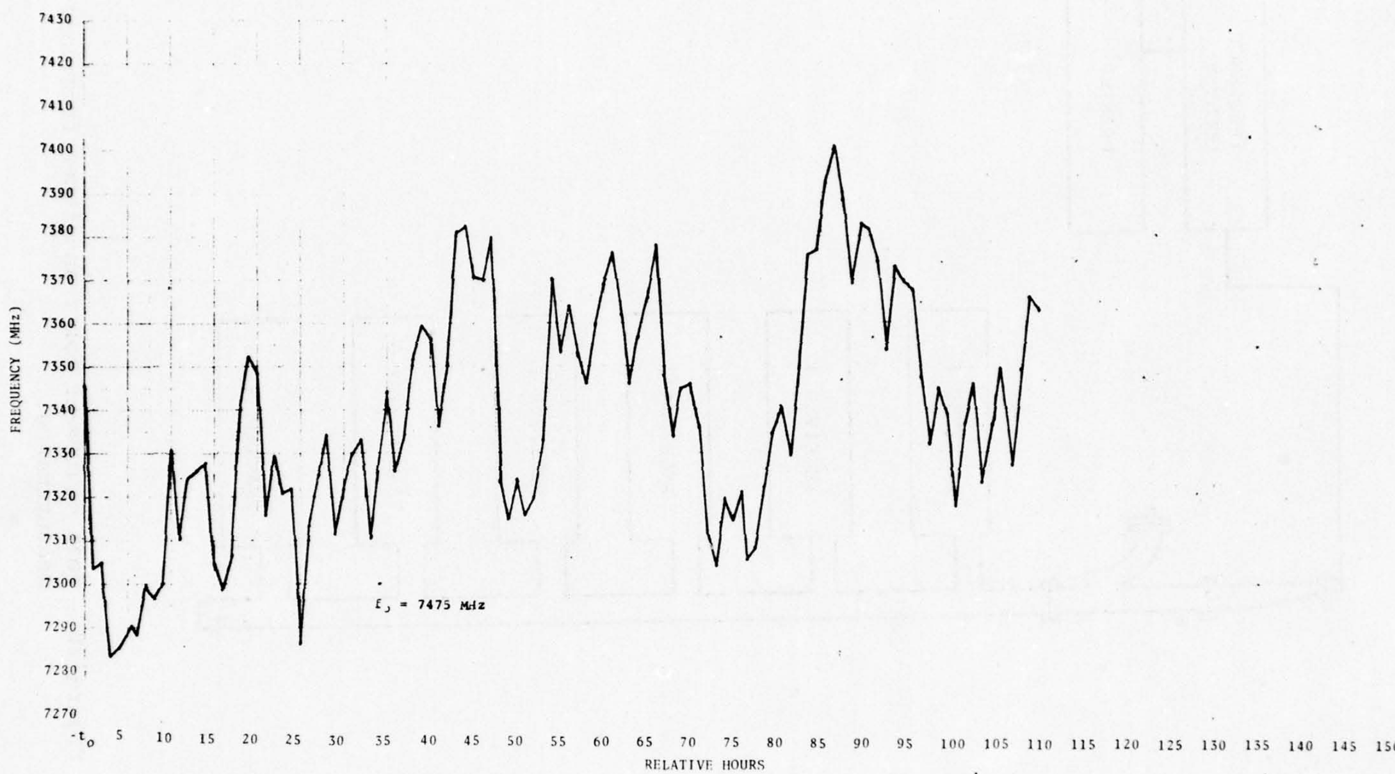


Figure 29. Klystron transmitter frequency variation.

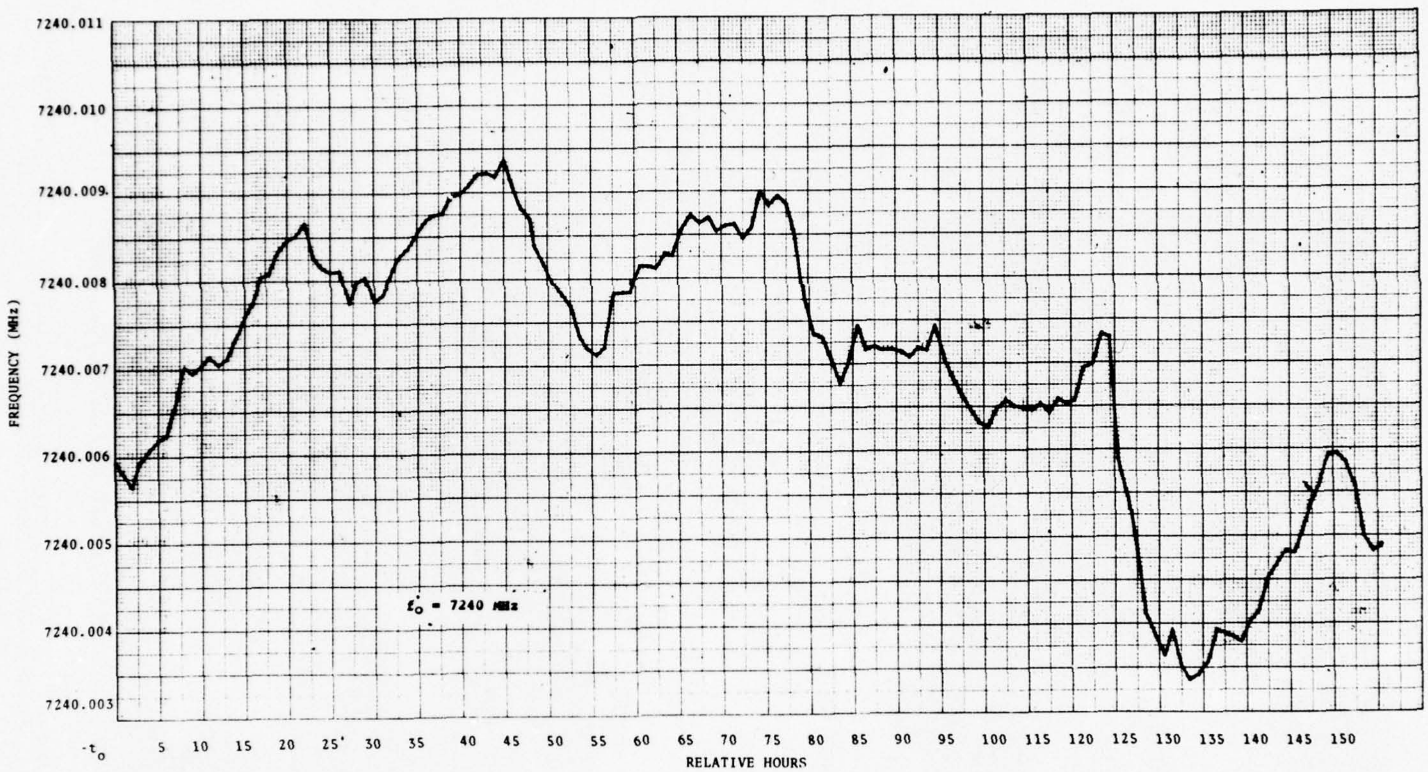
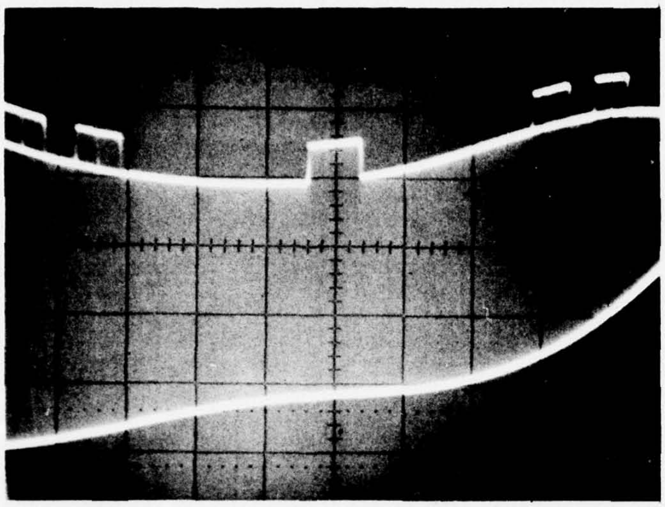


Figure 30. Phase-locked transmitter frequency variation.



Transmitter-Receiver

f_o = 7425 MHz

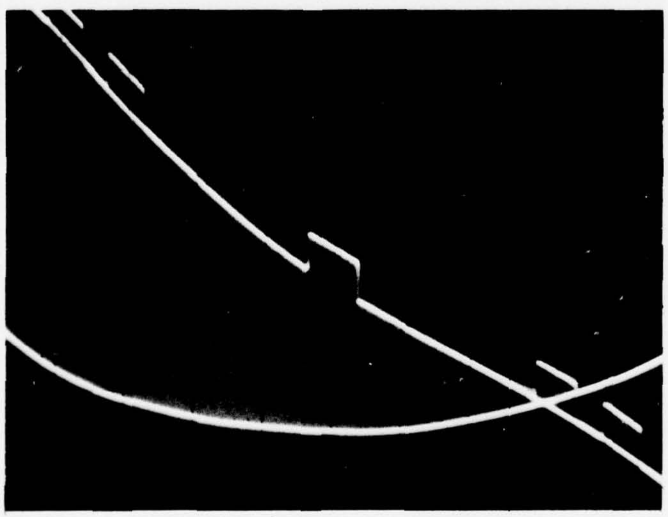
Linearity Marker = ±5 MHz

Calibration = 10%/div

Delay Marker = ±4 MHz

Calibration = 10 ns/div

Figure 31. 7425 MHz receiver, linearity, and delay, link measurement.



Transmitter-Receiver

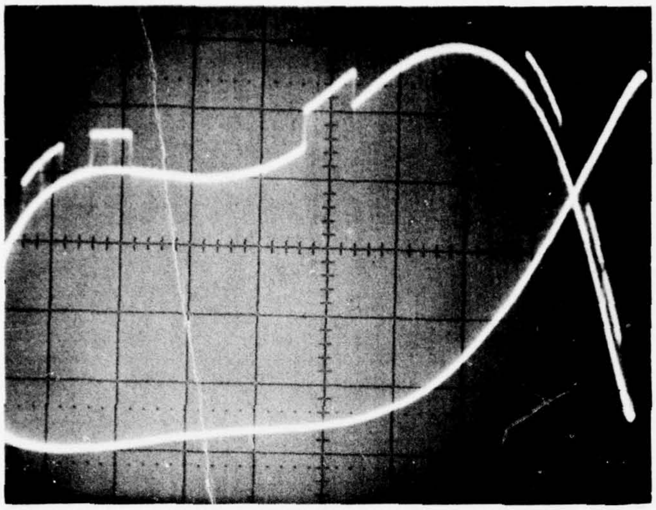
f_o = 7475 MHz

Linearity Marker = ±5 MHz

Calibration = 10%/div

Delay Marker = ±4 MHz
Calibration = 10 ns/div

Figure 32. 7475 MHz receiver, linearity, and delay, link measurement.



Transmitter-Receiver

f_o = 7635 MHz

Linearity Marker = ±5 MHz

Calibration = 1%/div

Delay Marker = ±4 MHz

Calibration = 3 ns/div

Figure 33. 7635 MHz receiver, linearity, and delay, link measurement.

Table 4. Linearity and delay, link measurements.

Frequency (MHz)	Modifications Transmitter	Receiver	Linearity ±5 MHz percent	Delay ±4 MHz nanoseconds
7425	None	Full	11	13
7475	"	Partial	57	7
7595	"	None	Unable to Measure due to 60 MHz IF	
7635	Full	Full	2.7	8

5.9 Link Measurements: Modulator Polarity and Pulse Response

The purpose of the modulator polarity test was to verify that the modulator polarity of the solid-state transmitter was the same as the modulator polarity of the original klystron transmitters. A pulse generator was used to supply the signal input to to the transmitter baseband amplifier, and the receiver baseband output was monitored with a scope.

Using the unmodified transmitter and receiver as reference, the pulse signal was inserted and the input polarity and output polarity of the pulse signal were noted. Next the same signal was applied to the solid-state transmitter and the output of the modified receiver was noted. It was then affirmed that the modulator polarities were the same.

At the same time, the pulse response of the radios with varying degrees of modification were noted. The characteristics of the pulse signal were set up to simulate the radar trigger pulse with a repetition rate of 100-pulses per second, a pulse width of 3 microseconds and with sufficient amplitude to operate in the linear operating range. Figures 34 to 37 show the input and output pulse signals. The figures indicate that the unit with a solid-state preamplifier and IF amplifier reduces the noise on the pulse signal. Further reduction of noise is noted in using a solid-state transmitter and solid-state receiver. The solid-state IF amplifier filters out the IF carrier better than the tube-type amplifiers.

5.10 Waveguide Branching Considerations

In the RML-3 pilot system, the transmitters and receivers are connected to a common antenna by a vertical waveguide run with side arms containing bandpass filters. Included in the vertical section is a phasing adjustment associated with each transmitter and receiver. The phasing adjustment is critical and the adjustment of the receiver at the top of the rack is determined by all the other phase adjustments in the stack.

Circulators can be employed to effect the duplexing and stacking of the RF channels. The advantages of the circulators are that they are passive devices and do not require any tuning. The bandpass filters would also need to be replaced because the old filters are an integral part of the branching "T".

In order to avoid the cumulative losses in the stack, it is feasible to split the stack and place the receivers in one arm and the transmitters in the other arm, and join these stacks with another circulator. With circulators having only 0.2 dB insertion loss, the worst total accumulation loss would amount to only 0.8 dB. Electrically the split circulator arrangement is feasible, but physical configuration of the racks and equipment would require some thought regarding how the waveguide runs could be made. The use of new filters, bends and circulators would allow the waveguide to be brought out between the channels.

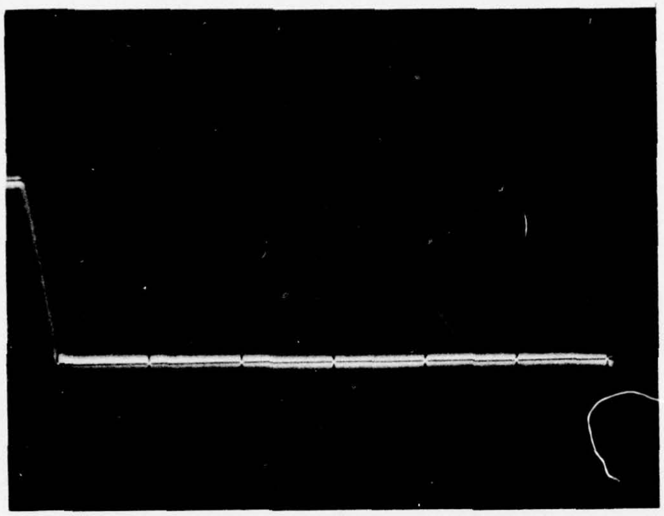
Waveguide directional filters were mentioned in the work statement as a possible replacement for the present waveguide multiplexer arrangement. This approach was discussed with several filter manufacturers, and the advantages and disadvantages of such a device are as follows:

Advantages

a. passive device
b. low insertion loss to channel
c. very little loss in vertical rise.

Disadvantages

a. narrow bandwidth
b. hard to manufacture
c. very hard to set up and tune
d. physical dimensions would make it difficult to mount in radios because of offset in waveguides due to circular cavities in between the two waveguides



Pulse Frequency
10 milliseconds

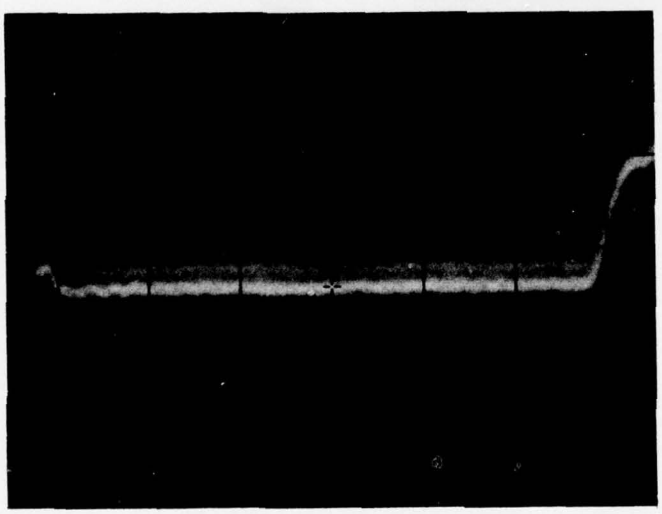
Pulse Duration:
3 microseconds

Pulse Amplitude:
0.25 volts

Rise Time:
0.15 microseconds

Decay Time:
0.2 microseconds

Figure 34. Pulse signal input to transmitter.



Pulse Frequency:
10 milliseconds

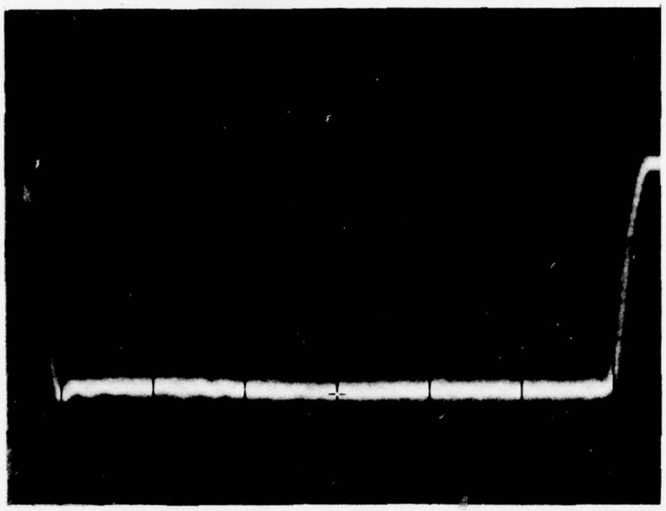
Pulse Duration:
2.9 microseconds

Pulse Amplitude:
0.14 vclts

Rise Time:
0.2 microseconds

Decay time:
0.2 microseconds

Figure 35. 7595 MHz receiver (unmodified), output pulse signal.



Pulse Frequency:
10 milliseconds

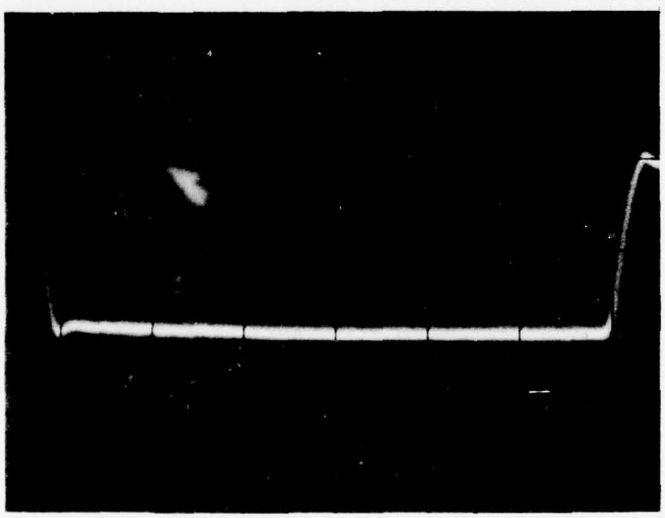
Pulse Duration:
3 microseconds

Pulse Amplitude:
0.25 volts

Rise Time:
0.2 microseconds

Decay Time:
0.2 microseconds

Figure 36. 7475 MHz receiver (partially modified) output pulse signal.



Pulse Frequency:
10 milliseconds

Pulse Duration:
3 microseconds

Pulse Amplitude:
0.38 volts

Rise Time:
0.2 microseconds

Decay Time:
0.2 microseconds

Figure 37. 7635 MHz receiver (fully modified), output pulse signal.

e. additional filters would be required to obtain an equivalent bandwidth.

The disadvantages far outweighed the advantages so this approach was not pursued.

A dual-mode cavity filter and multiplexer arrangement was proposed by one filter manufacturer. The dual-mode filter has been described in several recent technical papers (Atia and Williams, 1972, 1974; Snyder, 1974). This approach was tested in the laboratory, as outlined in the next section.

5.11 Dual-Mode Filter Multiplexer

The multiplexer unit received consisted of six separate sections similar in configuration to the old units with phasors and bandpass filters. Each vertical rise has a pair of shunt-connected bandstop resonators and the side arm contains the dual-mode bandpass filter. The filters used for the receivers have four cylindrical cavities which are equivalent to an 8-cell single-mode cavity connected in cascade. Figures 38 and 39 show the transmitter and receiver section. Figure 40 shows the six units which comprise the multiplex stack.

After the units were received several problems were encountered. The filter arm was to be attached to the narrow wall of the waveguide and the waveguide size was WR-112 instead of WR-137. The manufacturer was notified and a short transition and twist was supplied so that the units could be mounted in the radios. Insertion loss and bandwidth were measured for each individual section. At the same time, sweep-frequency measurements were made to check the filter response. Figures 41 to 46 show the individual responses with the filters connected in the stack. The oscilloscope trace was not calibrated; insertion loss and bandwidth measurements were made using a power meter and frequency counter. Measurements were also made to determine the effect of the additional twist and transition. These effects are tabulated in table 5.

Due to the possibility that in the future two of the channels will not be needed, the requirement was made that the channel could be removed and replaced by an appropriate length of waveguide. Another requirement was that no other channels could be affected when the frequency of one channel was changed. The assembled unit from the factory was tested and then the channels were switched around in the stack. Also two of the individual units were replaced by a section of waveguide. It was found that the channels could be removed without affecting the other channels, but that the interchange of frequencies caused the insertion loss of channels to deteriorate. Two examples are shown in figures 47 and 48. Table 6 is a tabulation of these measurements. The test data were sent to the manufacturer for evaluation, but at this time it is not clear why the channels cannot be interchanged.

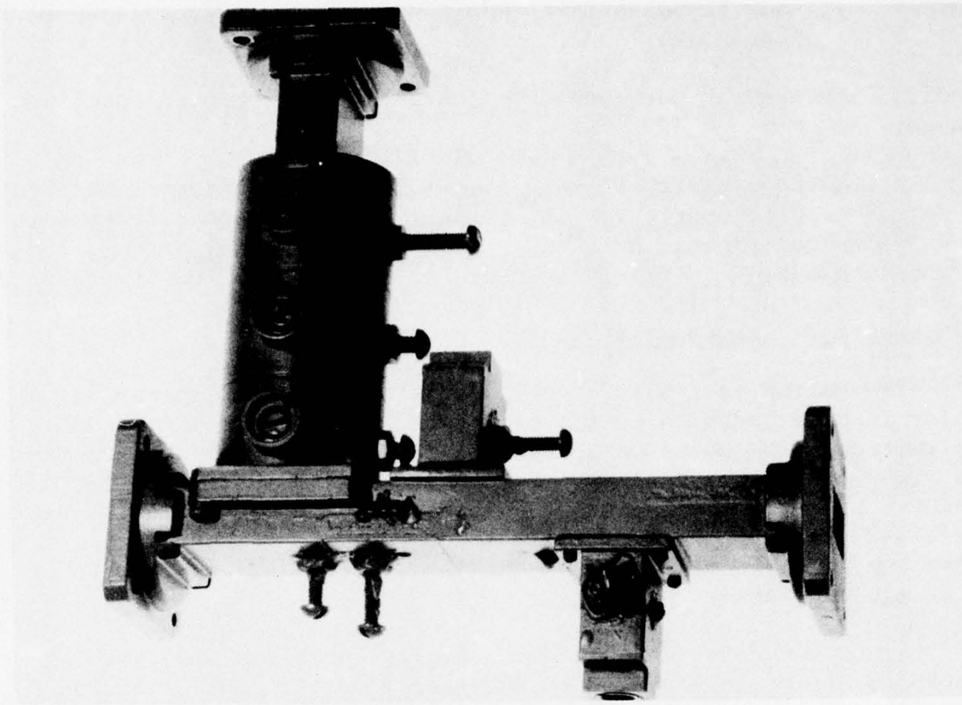


Figure 38. Dual-mode filter multiplexer unit for transmitter.

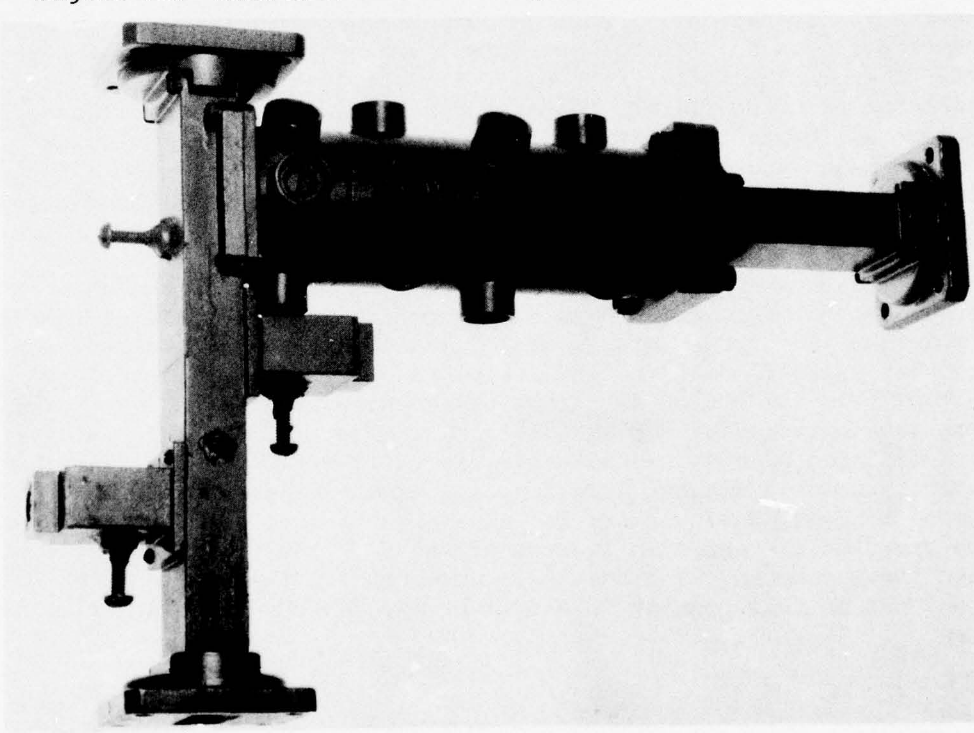


Figure 39. Dual-mode filter multiplexer unit for receiver.

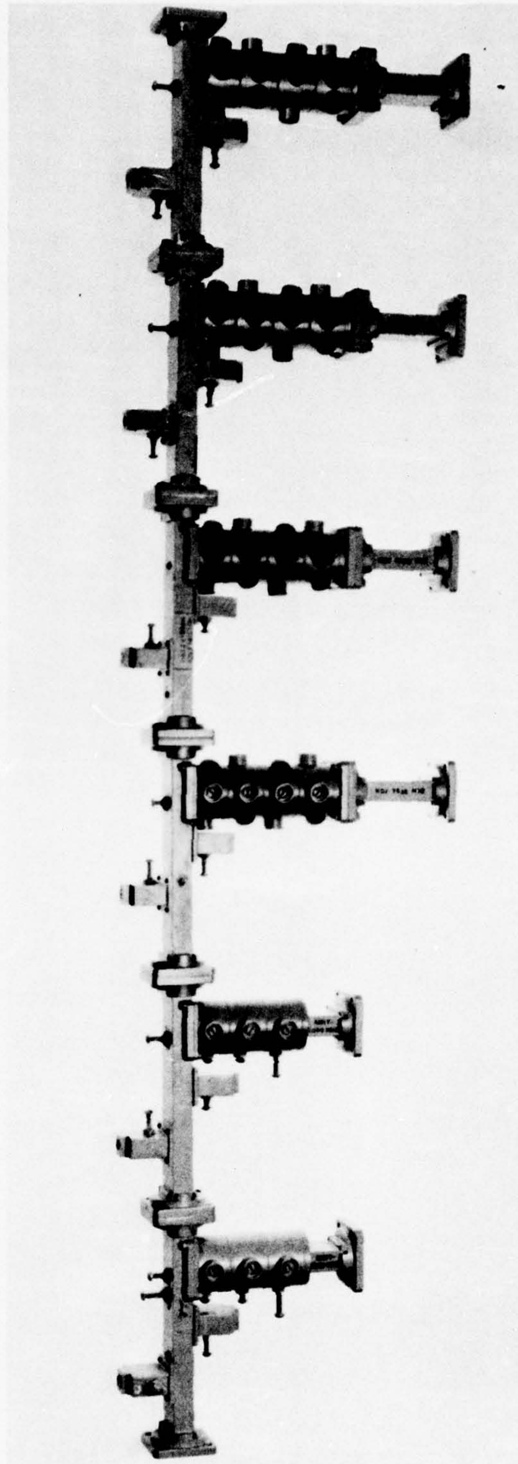
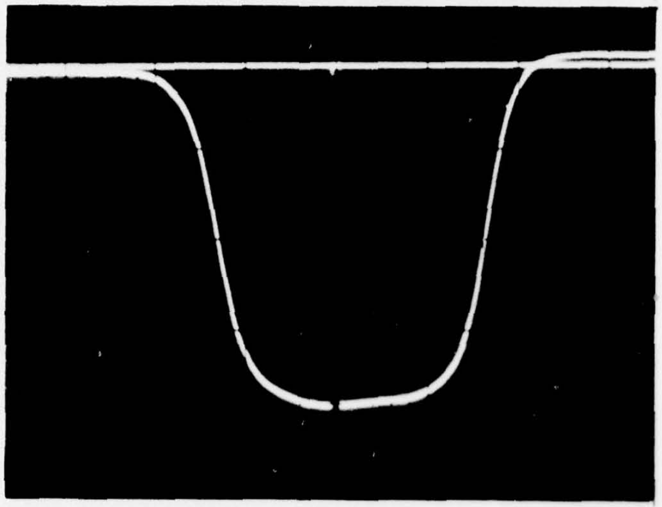


Figure 40. Dual-mode filter multiplexer units connected in stack.



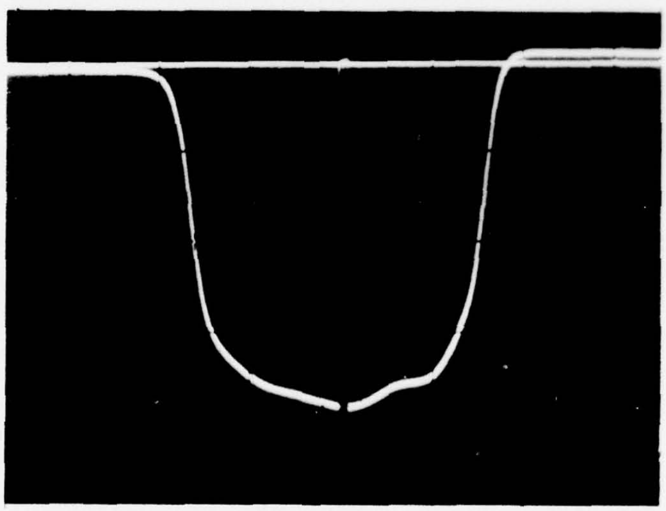
Multiplexer Filter Bandpass

f_o = 7425 MHz

Insertion Loss - 1.9 dB

Bandpass = 19.5 MHz

Figure 41. 7425 MHz receiver, bandpass response of dual-mode filter multiplexer.



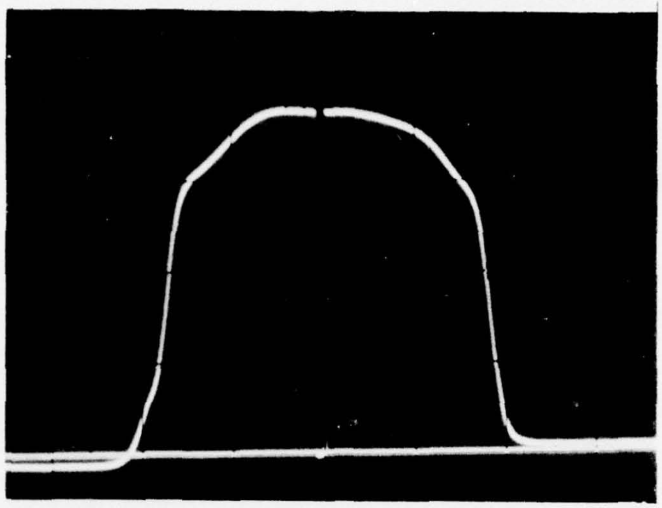
Multiplexer Filter Bandpass

f_o = 7475 MHz

Insertion Loss = 2.1 dB

Bandpass = 27.8 MHz

Figure 42. 7475 MHz receiver, bandpass response of dual-mode filter multiplexer.



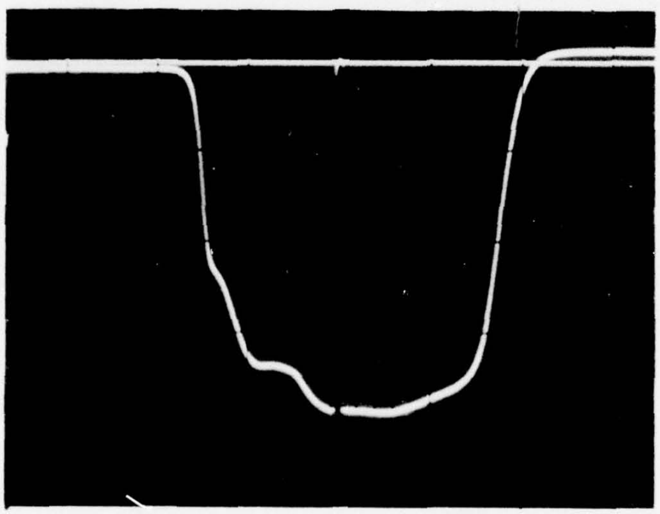
Multiplexer Filter Bandpass

f_o = 7595 MHz

Insertion Loss = 1.8 dB

Bandpass = 24.6 MHz

Figure 43. 7595 MHz receiver, bandpass response of dual-mode multiplexer filter.



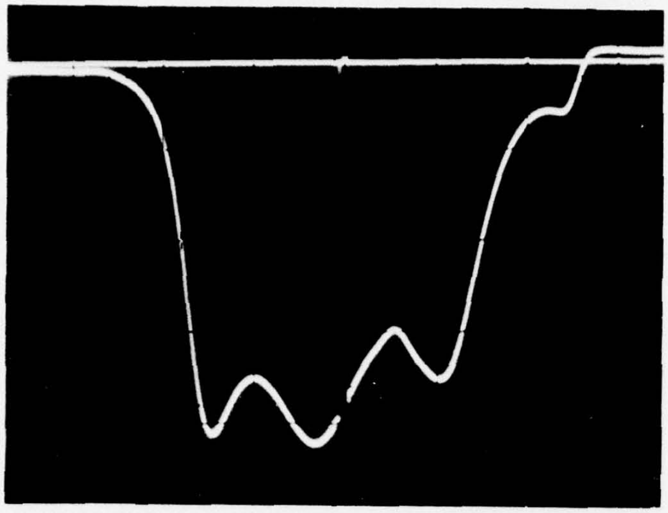
Multiplexer Filter Bandpass

f_o = 7635 MHz

Insertion Loss = 2.1 dB

Bandpass = 25.5 MHz

Figure 44. 7635 MHz receiver, bandpass response of dual-mode filter multiplexer.



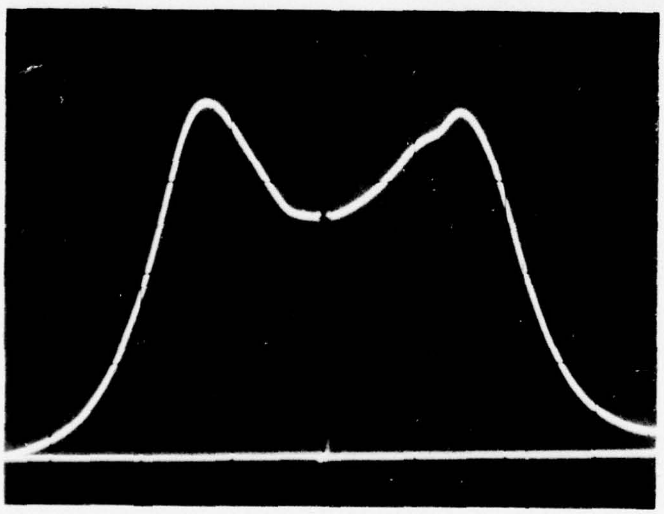
Multiplexer Filter Bandpass

f_o = 7240 MHz

Insertion Loss = 1.9 dB

Bandpass = 25.7 MHz

Figure 45. 7240 MHz transmitter, bandpass response of dual-mode filter multiplexer.



Multiplexer Filter Bandpass

f_o = 7335 MHz

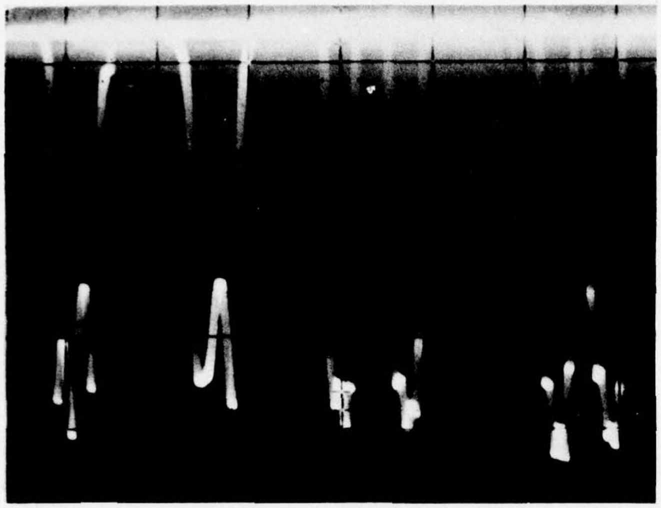
Insertion Loss = 3.4 dB

Bandpass = 29.8 MHz

Figure 46. 7335 MHz transmitter, bandpass response of dual-mode filter multiplexer.

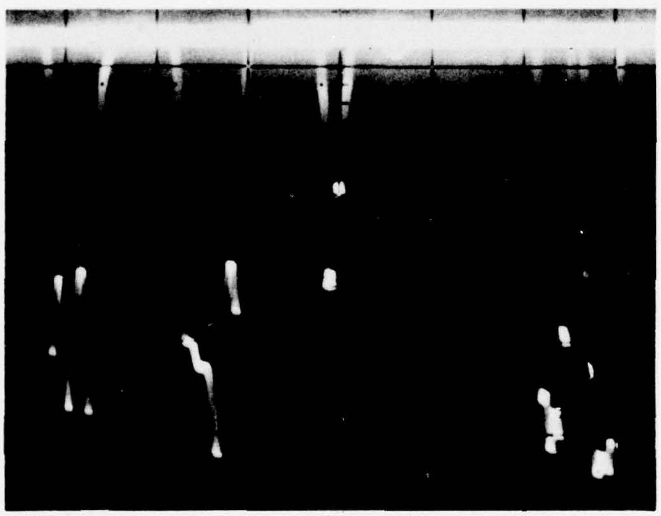
Table 5. Dual-mode filter multiplexer units, insertion loss and bandwidth.

FREQUENCY in MHS	FACTORY MEASUREMENT INDIVIDUAL FILTER		ITS LAB MEASUREMENT INDIVIDUAL FILTER Insertion loss in dB		ITS LAB MEASUREMENT FILTERS IN STACK Insertion loss in dB	
	Insertion loss in dB	Bandwidth in MHz	Without twist and transition	With twist and transition	Without twist and transition	With twist and transition
7425	2.0	22.24	1.9	4.1	1.9	2.0
7475	1.9	22.84	2.1	3.0	2.1	2.0
7595	1.7	24.92	1.7	2.9	1.8	1.8
7635	1.8	25.72	1.8	2.7	2.1	2.1
7240	0.9	33.06	1.5	1.5	1.9	2.0
7335	1.0	32.44	1.0	1.8	3.4	4.2



Filter Order in Stack	Insertion Loss
7425 MHz	2.0 dB
7475 MHz	2.0 dB
7595 MHz	1.8 dB
7635 MHz	2.1 dB
7240 MHz	2.0 dB
7335 MHz	4.2 dB

Figure 47. Insertion loss of dual-mode filter multiplexer unit (receive order: 7425 MHz at top).



Filter Order in Stack	Insertion Loss
7635 MHz	1.5 dB
7595 MHz	2.2 dB
7475 MHz	20.1 dB
7425 MHz	5.2 dB
7240 MHz	2.6 dB
7335 MHz	2.0 dB

Figure 48. Insertion loss of dual-mode filter multiplexer unit, (receive order: 7635 MHz at top).

Table 6. Dual-mode filter multiplexer insertion losses vs frequency order in stack

Frequency order in stack	Insertion loss	Frequency order in stack	Insertion loss	Frequency order in stack	Insertion loss	Frequency order in stack	Insertion loss	Frequency order in stack	Insertion loss	Frequency order in stack	Insertion loss	Frequency order in stack	Insertion loss
MHz	dB	MHz	dB	MHz	dB	MHz	dB	MHz	dB	MHz	dB	MHz	dB
7425	2.0	7635	1.8	7475	2.1	7635	1.5	7635	1.5	7425	1.9	7635	1.6
7475	2.0	7475	4.7	7425	2.6	7595	2.2	7595	1.9	Wave-guide	---	Wave-guide	---
7595	1.8	7595	2.1	7595	2.0	7475	20.1	7475	20.1	Wave-guide	---	Wave-guide	---
7635	2.1	7425	14.3	7635	1.9	7425	5.2	7425	5.3	7635	2.0	7425	8.5
7420	2.0	7240	2.7	7240	2.9	7240	2.6	7335	2.5	7240	3.2	7240	0.8
7335	4.2	7335	1.6	7335	4.3	7335	2.0	7240	2.9	7335	1.4	7335	1.7

5.12 Noise Figure Measurements

The filter multiplexer units were installed in the radio equipment as shown in figures 49 and 50. All receivers were as previously modified with new multiplexer sections, solid-state front ends, solid-state IF preamplifiers and IF amplifiers, and noise figure measurements were as shown in table 7.

Table 7. Noise figure measurements with filter multiplexer attached.

Modified Receivers f_o(MHz)	Noise Figure dB
7425	14.2
7475	18.4
7595	16.2
7635	16.5

5.13 Link Measurements - Frequency Response, Linearity and Delay

The next link tests consisted of baseband-to-baseband frequency response measurements (figure 51), linearity and delay tests. Figures 52 to 55 are photographs of the test results using the dual-mode filter multiplexers and having all receivers fully modified. These data are noted in table 8.

Table 8. Linearity and delay, link measurements with dual-mode filter multiplexer.

Frequency (MHz)	Modifications Transmitter	Modifications Receiver	Linearity ±5 MHz percent	Delay ±4 MHz Nanoseconds
7425	None	Full	0.9	11.7
7475	"	"	2.1	0.8
7595	"	"	3.2	1.3
7635	Full	"	1.9	4.2

6. CONCLUSIONS AND RECOMMENDATIONS

The solid-state preamplifier and IF strip, used with either the single-ended mixer or the balanced mixer, is quite satisfactory for use in the RML-3 links in terms of linearity and delay. However, the noise figure of the IF preamplifier and IF amplifier combination could be improved by at least 1.5 dB, and the bandwidth is too large, which contributes more noise and increases the receiver's susceptibility to interference. The IF preamplifier and IF amplifier are matched units from the factory; it would be

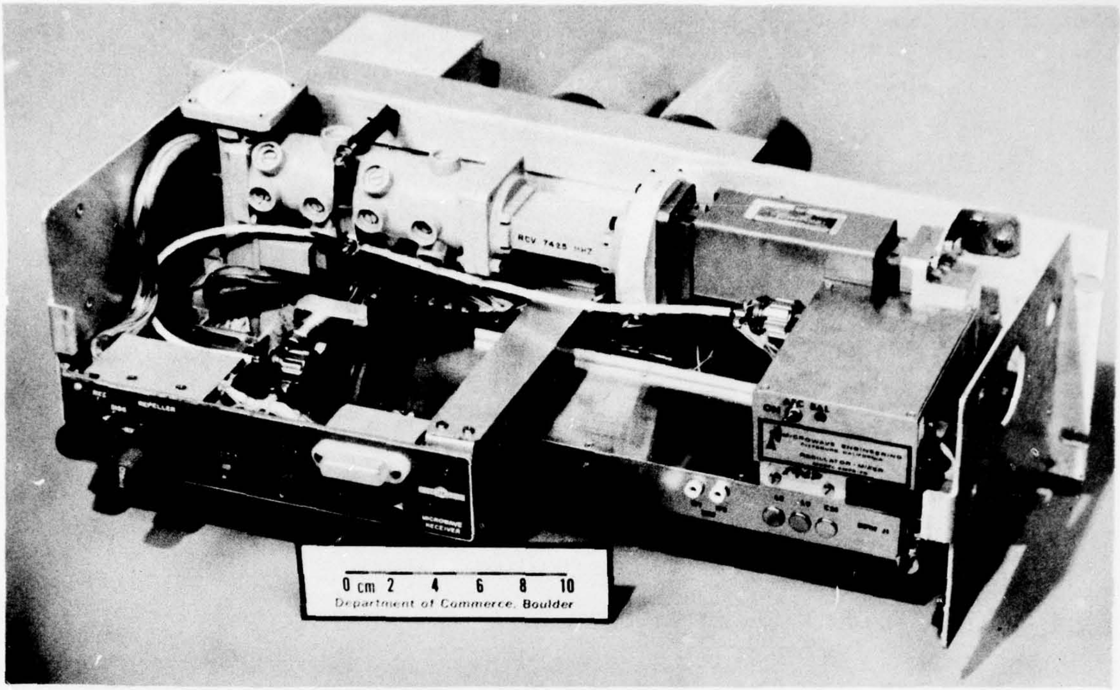


Figure 49. Fully modified receiver with dual-mode filter multiplexer unit.

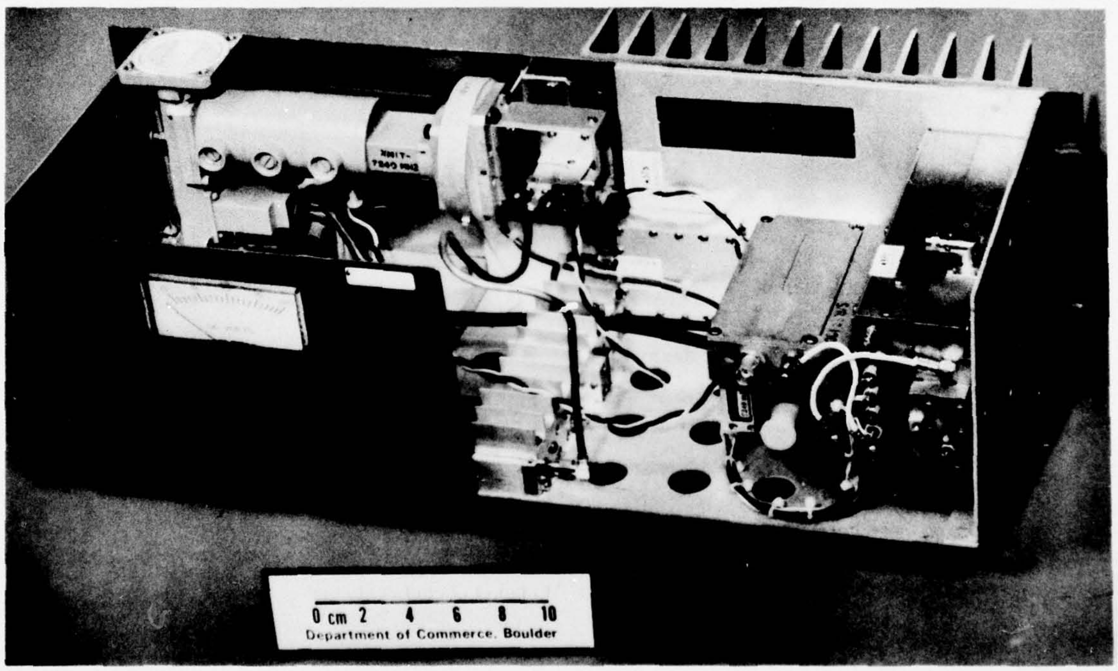


Figure 50. Fully modified transmitter with dual-mode filter multiplexer unit.

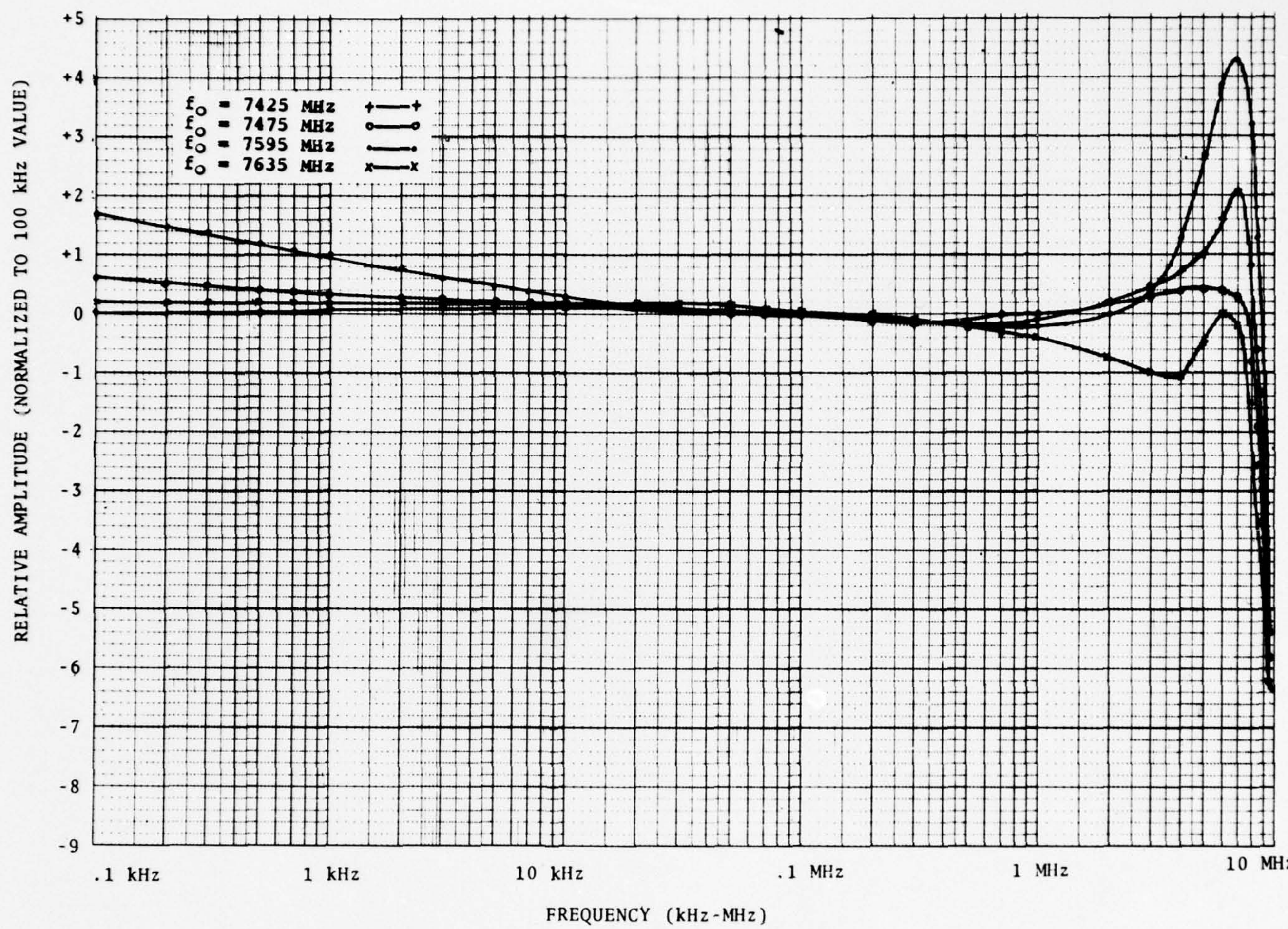
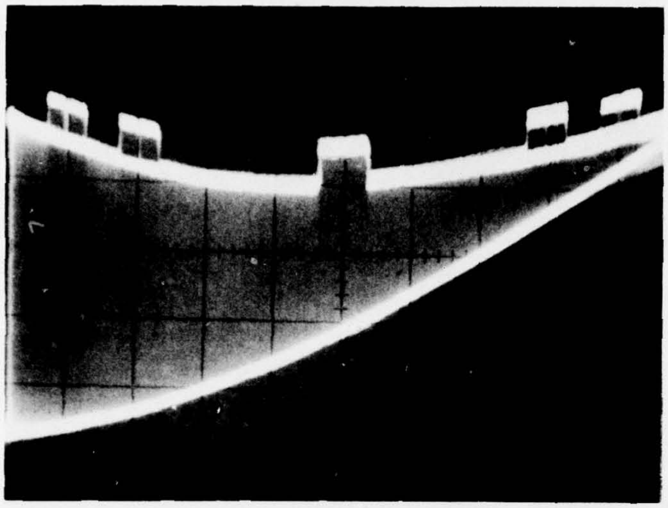


Figure 51. Frequency response, baseband-to-baseband, with dual-mode filter multiplexer.



Transmitter-Receiver

f_o = 7425 MHz

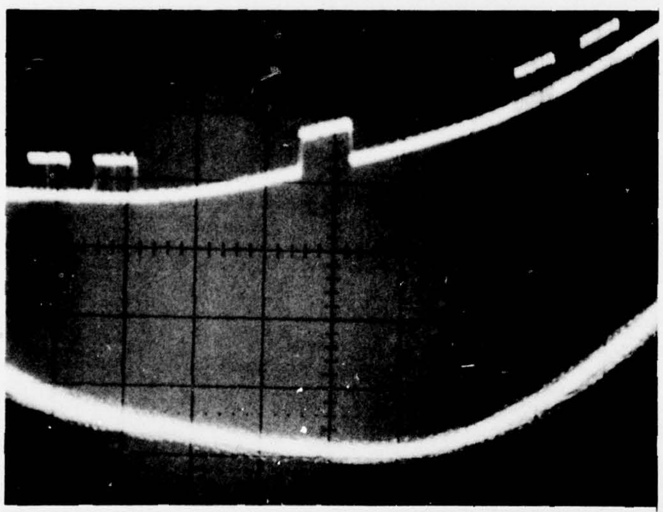
Linearity Marker = ±5 MHz

Calibration = 1%/div

Delay Marker = ±4 MHz

Calibration = 3 ns/div

Figure 52. 7425 MHz receiver, linearity and delay, link measurement with dual-mode multiplexer.



Transmitter-Receiver

f_o = 7475 MHz

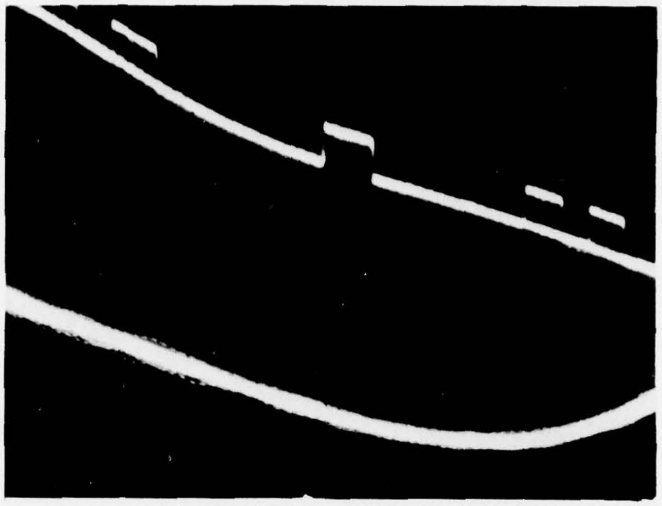
Linearity Marker = ±5 MHz

Calibration = 1%/div

Delay Marker = ±4 MHz

Calibration = 1 ns/div

Figure 53. 7475 MHz receiver, linearity and delay, link measurement with dual-mode multiplexer.



Transmitter-Receiver

f_o = 7595 MHz

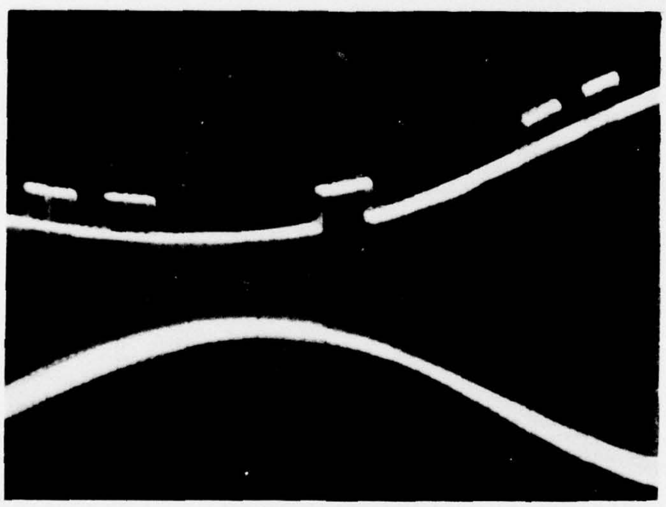
Linearity Marker = ±5 MHz

Calibration = 1%/div

Delay Marker = ±4 MHz

Calibrations = 1 ns/div

Figure 54. 7595 MHz receiver, linearity and delay, link measurement with dual-mode multiplexer.



Transmitter-Receiver

f_o = 7635 MHz

Linearity Marker = ±5 MHz

Calibration = 1%/div

Delay Marker = ±4 MHz

Calibration = 3 ns/div

Figure 55. 7635 MHz receiver, linearity and delay, link measurement with dual-mode multiplexer.

better if this could be avoided by proper isolation.

The balanced-mixer, Gunn diode local oscillator, packaged as a consolidated unit, is needed to insure proper integration of the waveguide to the mixer output to the IF preamplifier. The tuning of the local-oscillator must be such that it can be made accessible and tuned in the field.

Since the tested retrofit for the transmitters is almost a complete radio, it is recommended that consideration be given to obtaining such a radio, complete with multiplexer, filter, power source, and amplifier, rather than obtaining the individual items from separate manufacturers. The specifications of these units should be completely evaluated and bids obtained from several reliable companies.

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APPENDIX A. SURVEY FOR FAULT ALARM AND CONTROL SYSTEM AND VOICE GRADE SERVICE CHANNEL EQUIPMENT

1. Introduction

The objective of this task was to conduct a market survey to determine if off-the-shelf or readily modifiable remote control and voice service channel equipment is available for installation in existing RML terminals and repeaters under constraints imposed by usable baseband spectrum and available rack space. The system should be modularly expandable and capable of controlling from one terminal up to 32 on-off functions at one to twenty repeater locations. The status of the individual functions must be reported to the terminal initiating the command function; this means that both the indicator site and radar site can monitor and control the associated repeater sites. After an appropriate system has been selected on the basis of performance, expandability and cost, a decision by the FAA will be made on whether to purchase enough equipment for two terminals and repeaters for lab and field testing and evaluation. The voice service channel survey is included in this task.

The primary purpose of the fault alarm and control system is to monitor and report information concerning the change in status conditions of fault alarms at remote unattended microwave repeater stations, as well as to permit remote control from the master station of switching functions at the repeater sites.

The purpose of a new voice service channel is to upgrade the present service channel using state-of-the-art equipment to improve signal-to-noise performance and reliability of service.

2. Basic Requirements of System

The RML system consists of an indicator terminal, up to 20 repeater sites, and a radar terminal. At each site up to 32 alarms (on/off contacts) are to be monitored and at each site up to 32 control functions are required.

A local display of fault alarms at each repeater site is required for maintenance personnel and visible identification of fault at the site.

The indicator terminal will have the primary master unit which will consist of display unit, control unit, and data logger. The radar terminal will have a passive master which will monitor alarms but will not have control until control is released by the primary master at the indicator terminal. A data logging unit is required at the master station for automatically recording alarm/status changes which occur and the control functions used to correct or bypass the fault. Included in the print-out will be site identification, fault identification, date and time of occurrence of each fault.

3. Results of Survey

Fault alarm reporting and control systems usually employ two general techniques for alarm-reporting; interrogation, or continuous reporting.

The continuous reporting system requires each remote site to be assigned a one-way communication tone channel to the master station. This enables the remote site to update its status report continuously, without any communication from the master. In a system with remotes, each remote with a separate tone channel, the baseband allocation and loading is greater because each repeater is reporting continuously. A continuous reporting system with controls also requires separate communication tone channels from the master to each remote. The major advantage of the continuous reporting system is the fast alarm response.

In the interrogation system, the master sequentially polls each of the remote site to check each alarm status. The remote then responds and notifies the master of its status. The interrogation system requires only one communication tone channel from the remotes to the master, and one tone channel from the master to the remotes. One tone frequency can be used for both directions but usually a different tone is used in each direction of communication. The interrogation system requires more time for fault alarm response. The main advantages are:

1. baseband requirements are minimal,
2. the tone transmitters and receivers are all of the same type thereby reducing the overall spare parts requirement.

Since control functions are required, both types of systems would require 2-way communications.

This survey was undertaken to determine if off-the-shelf or readily modifiable systems for fault alarm reporting and control were available. Of the responses obtained, two companies had systems which would be directly applicable to the RML requirements. These two companies are considered to be specialists in the design and manufacture of alarm and control systems. These systems are compared in the following tables 1, 2, and 3.

Table 1. Electrical and mechanical specifications.

Electrical

	System A	System B
No. of remote stations	20	20
No. of status inputs per remote station	32	32
No. of frequencies needed	2 (1 transmit, 1 recd.)	2 (1 transmit, 1 recd.)
Transmission method	FSK	FSK
Transmit levels	+2.0 dBm to -30 dBm	0 dBm to -31 dBm
Receive levels	+6.0 dBm to -45 dBm	0 dBm to -47 dBm
Input and output impedance	600 ohm nominal - bridging option	600 ohm, or bridging
Type of coding	Binary pulse duration code	8-level (eleven bit start/stop) ASCII code
Pulse rate	15, 30, 60, 150, 600, 900, 1200 bits/s	35 to 2400 baud

Table 1 (cont.)

	System A	System B
Message security	Centralized change detector	
	1. double-transmission	1. code format check
	2. code format check	2. parity check
	3. pulse count	
	4. odd parity	
Power requirement	115 Vac, 60 Hz	115 Vac, 60 Hz
	Mechanical	
Dimensions	Remote	Remote
	3 - 1 3/4" panels	2 - 5 1/4" panels
		1 - 3 1/2" panels
	Master	Master
	4 - 1 3/4" panels	3 - 5 1/4" panels
Connectors	Wire wrap	Wire wrap

Table 2 Costs

	System A	System B
Remote	$2,675	$4,206
Master	5,855	6,545
Data logger	5,000	7,518
Submaster	5,855	6,545

4. Recommendations

From the available information, system A would be the first choice for the system best applicable for the RML requirements, with system B as second choice. System A was selected on the basis of the following features:

a. Flexible system design and modular construction.
b. Capacity: The system can be easily expanded.
c. Security.
d. Small physical size; it can be fitted in available rack space in RML facilities.
e. Display features.
f. Remote control.
g. Multiple masters.
h. Data logger capability and computer control for future expansion.
i. Price.

5. Description of Candidate System

The master will consist of five 1 3/4" panels which take up 8 3/4" of rack space. The panels are:

Panel No. 1. System display for 10 remotes.
" No. 2. System display for 10 remotes.
" No. 3. Shared alarm display for 32 alarm points.
" No. 4. Control panel.
" No. 5. Power supply for above units.

The master terminal contains a command encoder unit which has its own clock and which sequentially addresses the command decoder at the various remote terminals on a timed routine. When each remote receives its proper address it reports its status to the master. The ability of the master to take corrective action and bypass the faulty unit indicated by the alarm will be accomplished by control commands addressed to a remote by the use of a thumbwheel switch and a push button.

The system display unit will indicate which remote has an alarm by means of a visual as well as an audible indication. The remote terminal is selected for display in one of two ways:

1. it can be manually selected by the operator, or
2. it may be selected automatically when a change of status of a point is detected. If additional remotes have an alarm, the first reporting remote will display its status.

The remote terminal consists of a local alarm display unit which includes FSK receiver, FSK transmitter and display, and two control relay units each containing up to 20 latching relays. The total rack space requirement is 5 1/4".

The remote unit with display has 32 indicators, and all indicators are normally dark. When a display button is pressed, the indicators associated with the points that are an alarm will be lighted.

The remote consists of three 1 3/4" panels or a total of 5 1/4" rack space:

1. Display panel
2. Control part
3. Relay panel.

The data logger consists of a hardwire program read-only memory (PROM) processor and a teletype console.

6. Interface Problems

Integration of an alarm and control system such as described above would require the addition of sensors and switches in the transmitters and receivers of the RML system. At the repeater sites of the RML 1, 2, and 3 systems, only 8 alarms which consist of six 5-MHz pilot sensors, tower lights, and auxiliary power, are available. The RML-4 system has 6 additional sensors for transmitter off-frequency conditions. Control functions are only available at the radar site. Additional alarm functions such as the following would be desirable:

a. Transmitter power monitors
b. Received signal level monitor
c. Building security
d. Personnel at site.

Control functions at each repeater site would include the following:

a. Baseband switching of channel 1, 2, and 3 to channel 4, with channel 2 having priority.
b. Baseband switching of channel 5 to channel 6.
c. Orderwire switching when channel 3 switches to 4, and 5 switches to 6.
d. Proper termination of receivers switched out of use.
e. Control of receiver AFC.

After review of the above recommended system by the FAA, and if it is desired to incorporate such equipment in the upgrading of the pilot system, a detailed work statement and cost estimate will be submitted by OT/ITS. Due to the interfacing of sensors to the radio equipment and alarm system, it would be advantageous to install this equipment at the time the pilot system is being modified.

7. Voice Channel Service Survey

A fully transistorized voice grade service channel with its own power supply can be obtained to replace the existing vacuum tube service channel. The basic price which includes an in-band signaling tone would be approximately $1200.

APPENDIX B. RML RECEIVER SPECIFICATIONS

The RML receiver shall consist of a solid-state local oscillator, balanced mixer, IF preamplifier and Automatic Frequency Control circuitry.

Frequency range	7135 to 7635 MHz
Noise figure, SSB	7.5 dB or less
Gain (nominal)	25 dB
Lo-to-signal isolation	20 dB minimum
Frequency stability (exclusive of AFC) (0-50°C)	±1.5 MHz
Output IF	70 MHz
Bandwidth	40 MHz to 1 dB points
rf tuning bandwidth	500 MHz
Size	2" × 3" × 6"
rf connector	Waveguide 137 with R-137 flange
dc power	+12 Vdc -12 Vdc
Connector	5 pin
IF connector	BNC
IF output	75 ohms unbalanced to gnd.

SOLID-STATE FM TRANSMITTER SPECIFICATIONS

Power output	1 watt to 1.5 watts
Frequency Band	7.1 to 7.7 GHz
Modulation linearity	±1% for f_o±10 MHz
Differential group delay	±1 N sec for f_o±10 MHz
Frequency stability	50 PPM
Power supply	-20 Vdc
Output power stability	+1, -1.5 dB over the operating range of -30°C to +60°C
Baseband input level	Sufficient adjustable baseband gain provided such that 0.1 V into a 75-ohm load will give ±3 MHz peak deviation
Modulation type	FM
Baseband response of video modulator	±0.1 dB from 50 Hz to 10 MHz
Baseband input connector	BNC

Input impedance	75 ohms unbalanced, return loss will be 26 dB
Output connector	Waveguide = CMR-137 type flange WR-137 waveguide
Monitor provisions	Frequency monitor Power monitor
Mechanical size	5" × 6" × 8"
Tuneable overband	7.1 to 7.7 GHz

GPO 912-831