NASA Contractor Report 172339

MLS/Airplane System Design – RF Component Design

FINAL REPORT

D. B. WALEN AND B. P. STAPLETON

BOEING COMMERCIAL AIRPLANE COMPANY
P.O. BOX 3707
SEATTLE, WASHINGTON 98124

CONTRACT NAS1-16300
JUNE 1984

NASA
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Langley Research Center
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1.0 SUMMARY

Results of analysis and design conducted as part of the multiyear microwave landing system (MLS) study are reported in this document. The work performed herein involves the design of airborne MLS radio frequency (RF) components.

This study addressed development of microstrip airborne antennas and a remote RF preamplifier. It was shown that microstrip antenna technology could be used to produce a low-profile, lightweight MLS antenna. This type of antenna would produce radiation patterns comparable to the patterns of a monopole antenna. The remote RF preamplifier was studied as a solution to received signal deficiencies due to factors such as cable attenuation and antenna pattern variations. A remote preamplifier can compensate for cable losses in excess of the limits set in the MLS functional requirements without degrading the system noise characteristics.

2.0 INTRODUCTION

This report describes work performed as part of NASA contract NAS1-16300 on MLS-airplane system design which addresses questions related to airborne MLS installations, including RF system design. The work described in this report is an extension of work performed under earlier NASA contract NAS1-14880 documented in ref. 1.

Questions remain to be answered on the actual hardware requirements for the airborne RF system installation. Therefore, practical prototype hardware, described in section 4.0, was developed to satisfy some of the performance and installation requirements for the airborne MLS RF system. Lightweight, low-profile MLS antennas were produced using microstrip techniques. A remote, low-noise, RF preamplifier was fabricated and analyzed as a means to satisfy the RF power budget.

3.0 SYMBOLS AND ABBREVIATIONS

a	microstrip antenna disk radius
dBi	decibels above an isotropic radiator
E	radiated electric field strength
E/E	electrical/electronics
ILS	instrument landing system
J_n	Bessel function of the first kind
k	wave number
MLS	microwave landing system
n	cavity mode number
NF	noise figure
RF	radio frequency
Z_o	transmission line characteristic impedance
α_{nm}	zero of the derivative of a Bessel function
ϵ_r	relative dielectric constant

4.0 MLS ANTENNA AND PREAMPLIFIER DESIGN

The performance of the airborne MLS depends in part on the RF components and installation. Primarily, the RF installation must satisfy the radiation pattern coverage requirements and the MLS power budget requirements. Additionally, the installation should have minimum weight, drag, and complexity.

Alternative antennas that produce adequate coverage were fabricated using microstrip techniques. These antennas are lightweight and low profile. A prototype remote RF preamplifier was fabricated and analyzed. The remote preamplifier can offset power budget deficiencies due to cable attenuation and antenna radiation pattern variations. Sections 4.1 and 4.2 describe the antenna and preamplifier development.

4.1 MLS MICROSTRIP ANTENNA DEVELOPMENT

Previous antenna investigations have focused on providing adequate radiation pattern coverage for normal airplane attitudes. Good coverage was found using forward and aft monopole-type antennas (ref. 1). As part of this study, airplane antennas were developed as alternatives to the standard monopole. Microstrip elements were used to produce a lightweight, low-drag antenna with performance comparable to a monopole antenna.

A circular microstrip element shown in figure 1 can produce omnidirectional azimuth pattern coverage. This type of element has a typical impedance bandwidth of less than 2% of the center frequency for normal substrate materials. This is not a disadvantage for MLS because the MLS band is from 5030 to 5090 MHz, for a bandwidth of 1.2%. Therefore the microstrip bandwidth is adequate for MLS antennas.

The circular microstrip antenna element has been analyzed using several different models. The cavity model, described in references 2 and 3, gives a good approximation for the impedance and far field radiation patterns of a circular microstrip antenna. The total far fields for an air dielectric circular microstrip element can be found (ref. 3) using the surface currents and image theory, to give:

$$E_\theta = -j^n E_o \frac{e^{-jkr}}{r} \frac{a \sin(kd \cos\theta)}{\cos\theta} \cos(n\phi) J_n(ka) J_n'(ka \sin\theta)$$

$$E_\phi = n j^n E_o \frac{e^{-jkr}}{kr} \frac{\sin(kd \cos\theta)}{\cos\theta} \sin(n\phi) J_n(ka) J_n'(ka \sin\theta)$$

J_n is a Bessel function of the first kind, n is the cavity mode number, d is the substrate thickness, a is the microstrip disk radius, and k is the wave number.

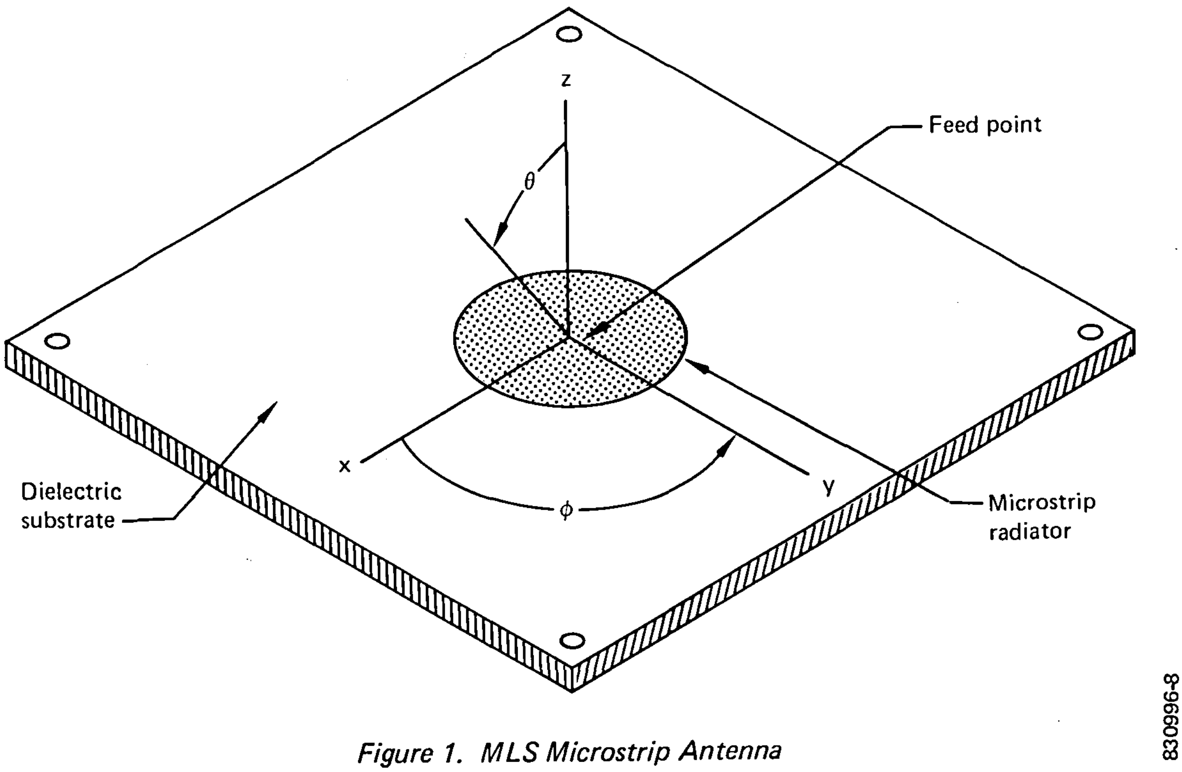


Figure 1. MLS Microstrip Antenna

For the mode n = 0, E_ϕ is zero and E_θ is a constant function of ϕ. Therefore, a microstrip element with this mode produces omnidirectional azimuth coverage. The elevation radiation pattern is similar to the pattern of a monopole, but with a slightly wider elevation beamwidth.

The mode excited in the microstrip element depends on the radius of the element and the position of the antenna feed point. The resonant frequency for a circular microstrip disk is given by reference 2 as:

$$f_{nm} = \frac{\alpha_{nm} \, c}{2 \pi a_{eff} \sqrt{\epsilon_r}}$$

where c is the free space velocity of light, ϵ_r is the relative dielectric constant of the substrate, and a_{eff} is the effective radius of the circular element, taking into account stray fields at the element edge. The term α_{nm} is the mth zero of the derivative of the Bessel function of order n, which for the mode n = 0 is 3.83. The equations predicted the resonant frequency to within 2%. However, this variation as well as substrate thickness and dielectric constant variations made radius adjustments necessary to tune the antenna to the desired resonant frequency.

The antenna feed point impedance depends on the feed configuration and the position of the feed on the microstrip element. For the prototype antennas the element radius was adjusted for the proper resonant frequency, and then the feed position was changed to produce the lowest return loss. For this type of material and excitation the lowest return loss was produced with the feed offset from the center by 37% of the radius. The prototype antennas were fabricated on woven teflon fiberglass substrate with 1-oz copper conductors. The substrate was 1.6 mm (0.060 in) thick, with a relative dielectric constant of 2.45.

Figure 2 shows the impedance of the microstrip antenna. The radiation patterns in figures 3 and 4 show omnidirectional azimuth coverage. The elevation coverage can be compared to the coverage of a standard monopole shown in figure 5. Gain and directivity measurements show that the microstrip antenna peak directivity is 5.7 dBi and its efficiency is 81%.

Substrate dimensional and dielectric constant variations have to be tightly controlled for microstrip antennas. Small variations would have little effect on the antenna patterns. However, the impedance could change significantly in the MLS band, due to the narrow impedance bandwidth of the microstrip antenna. An attractive feature of microstrip antennas is that a power divider can be fabricated as an integral part of the antenna. Therefore, a single antenna can be used for two MLS receivers. Two-port glide slope and localizer antennas are commonly used for the instrument landing system (ILS).

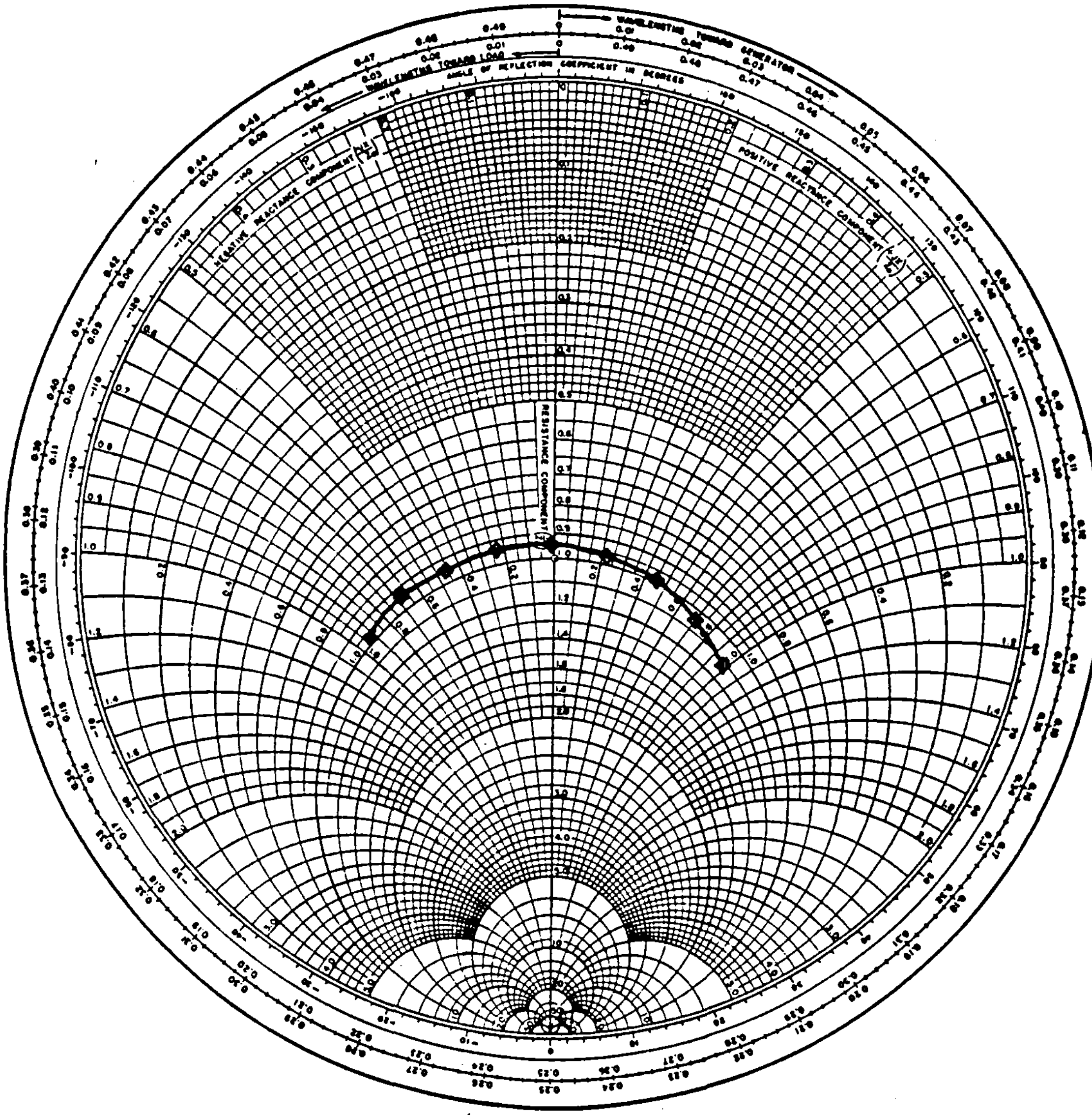
4.2 MLS RF PREAMPLIFIER

As proposed in reference 1, we have constructed a prototype RF preamplifier to preserve the system noise figure. The preamplifier is constructed from a basic preamplifier building block preceded by a stripline bandpass filter. An integral regulated power supply has been designed and packaged with the preamplifier. Figure 6 shows the completed part and figure 7 shows a block diagram of the functions included in the unit. This unit is intended to be used with candidate aircraft antennas to provide MLS coverage in excess of 37 km (20 nmi) when using the ordinary RG 214 type of coax cable. The unit is designed to operate from an aircraft quality 28V dc supply.

The preamplifier is built from the Watkins Johnson R41-101 MINPAC microwave amplifier, which is supplied in a connectorless package for ease of integration into stripline construction (fig. 8).

The transistors are gallium arsenide Schottky barrier field effect with thin-film matching circuitry for operation at microwave frequencies. Model R41-101 is not an off-the-shelf unit, but Watkins Johnson builds units covering the frequency bands above and below the MLS band. The R41-101 has a nominal gain of 20 dB with a noise figure of 3 dB and is flat to within 0.5 dB over the desired band.

A stripline bandpass filter was designed to precede the amplifier and provide front end selectivity. Its main purpose is to provide immunity from other avionics systems such as the low-range radio altimeter at 4.3 GHz and C-band weather radar at 5.4 GHz. Figure 9 shows a plan layout of the filter, which is built on 1.6-mm (0.060-in) thick teflon fiberglass



- Z_o = 50 ohms
- F_{start} = 4950 MHz
- F_{stop} = 5150 MHz
- F_{step} = 25 MHz

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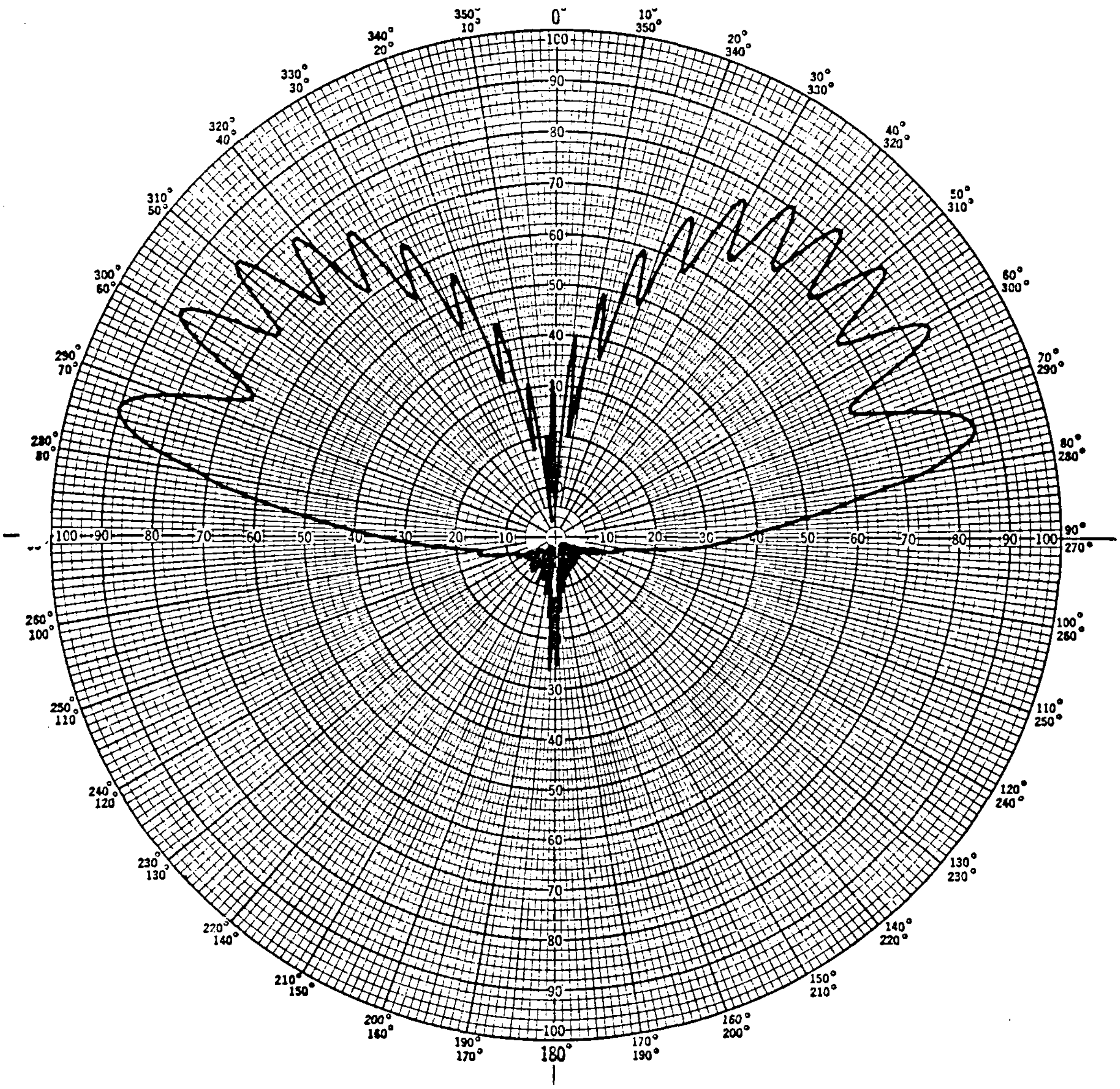
Figure 2. MLS Microstrip Antenna Impedance



- Roll plane pattern
- $\phi = 90^{o}$; θ = variable
- E_{θ} polarization
- 4-ft-diameter ground plane
- Frequency = 5060 MHz
- Plotted in voltage

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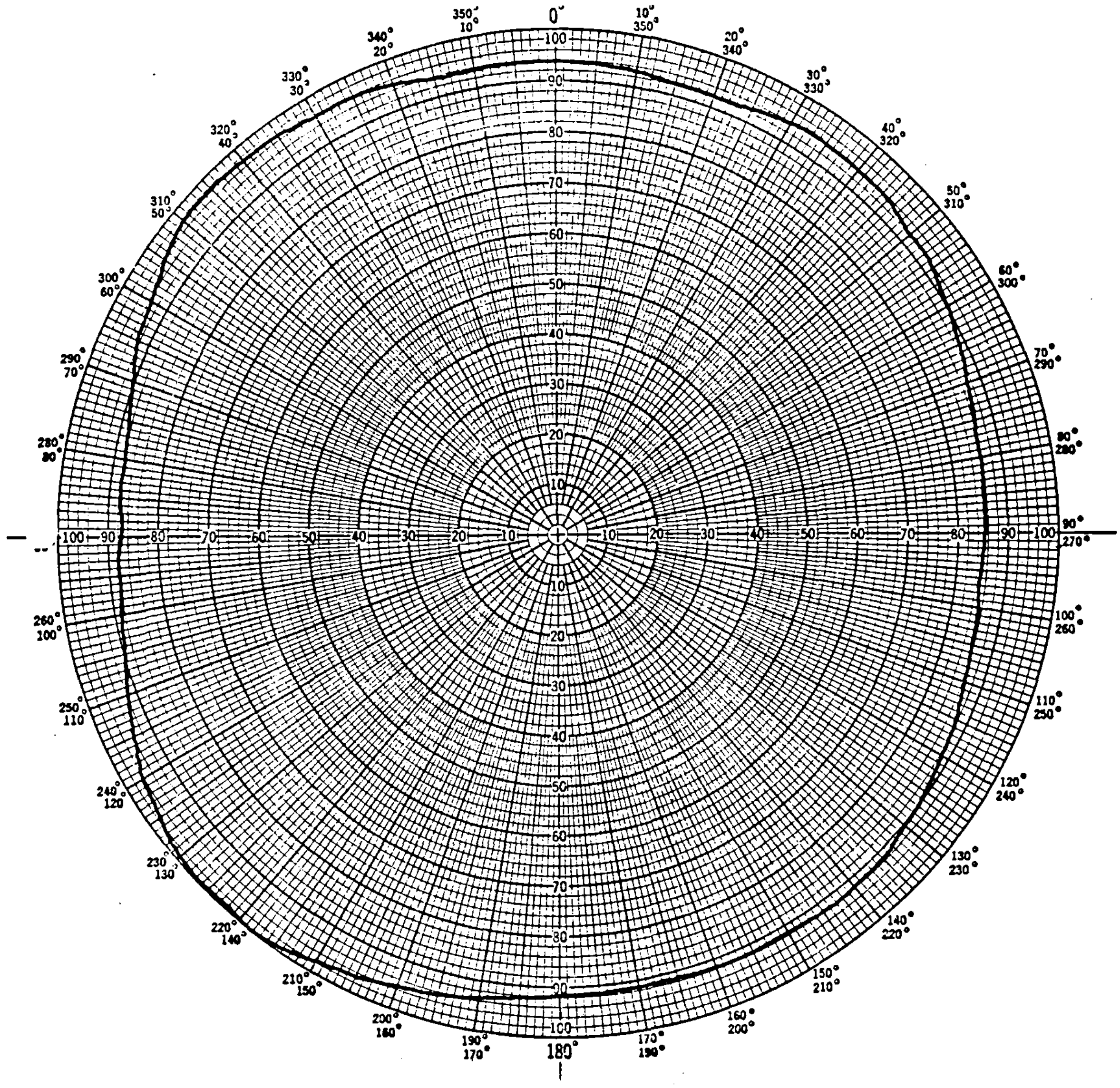
Figure 3. MLS Microstrip Antenna Radiation Pattern



- Conic pattern
- $\theta = 60^{\circ}$; ϕ = variable
- E_θ polarization
- 4-ft-diameter ground plane
- Frequency = 5060 MHz
- Plotted in voltage

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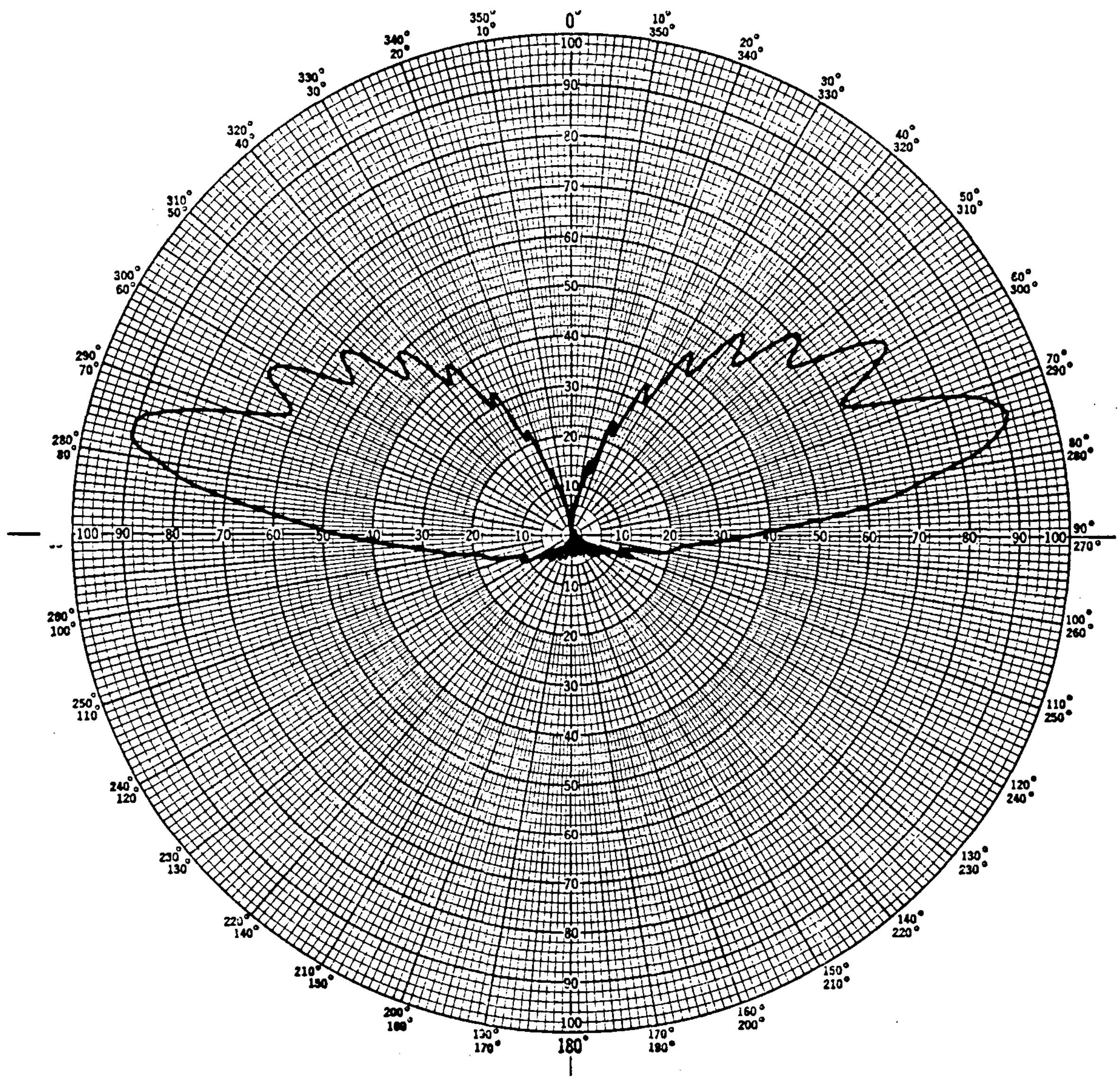
Figure 4. MLS Microstrip Antenna Radiation Pattern



- Roll plane pattern
- $\phi = 90^{\circ}$; θ = variable
- E_{θ} polarization
- Frequency = 5060 MHz
- 4-ft-square ground plane
- Plotted in voltage

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Figure 5. Monopole Antenna Pattern

Note: Input and output connectors are TNC female.

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Figure 6. MLS Preamplifier

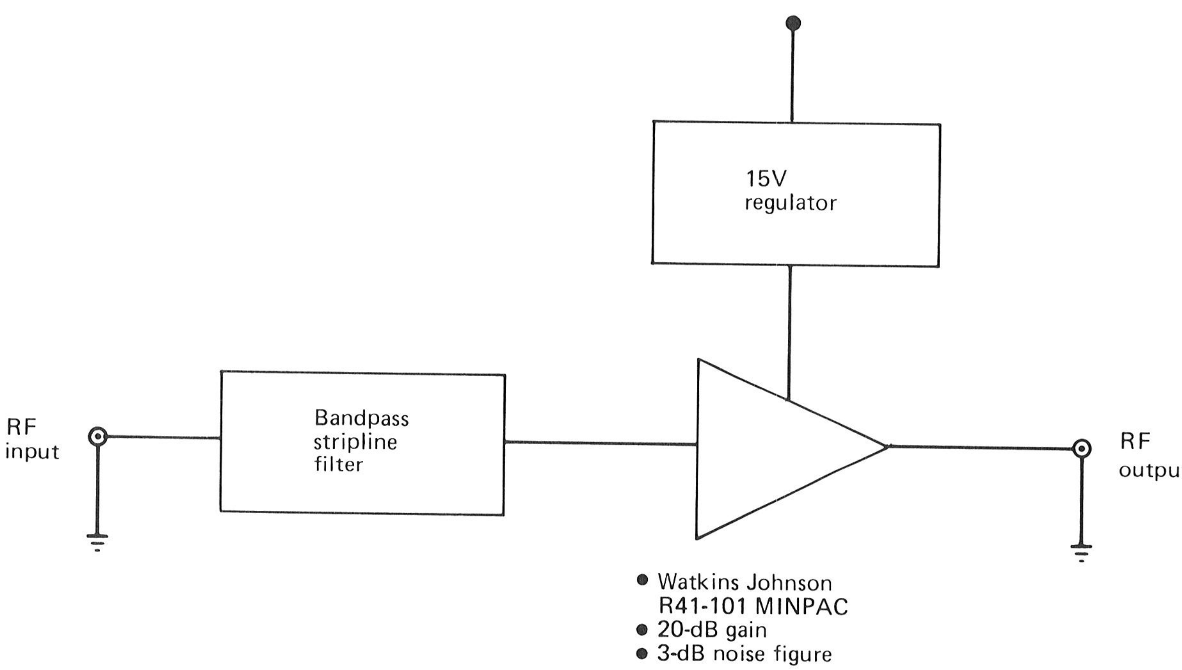

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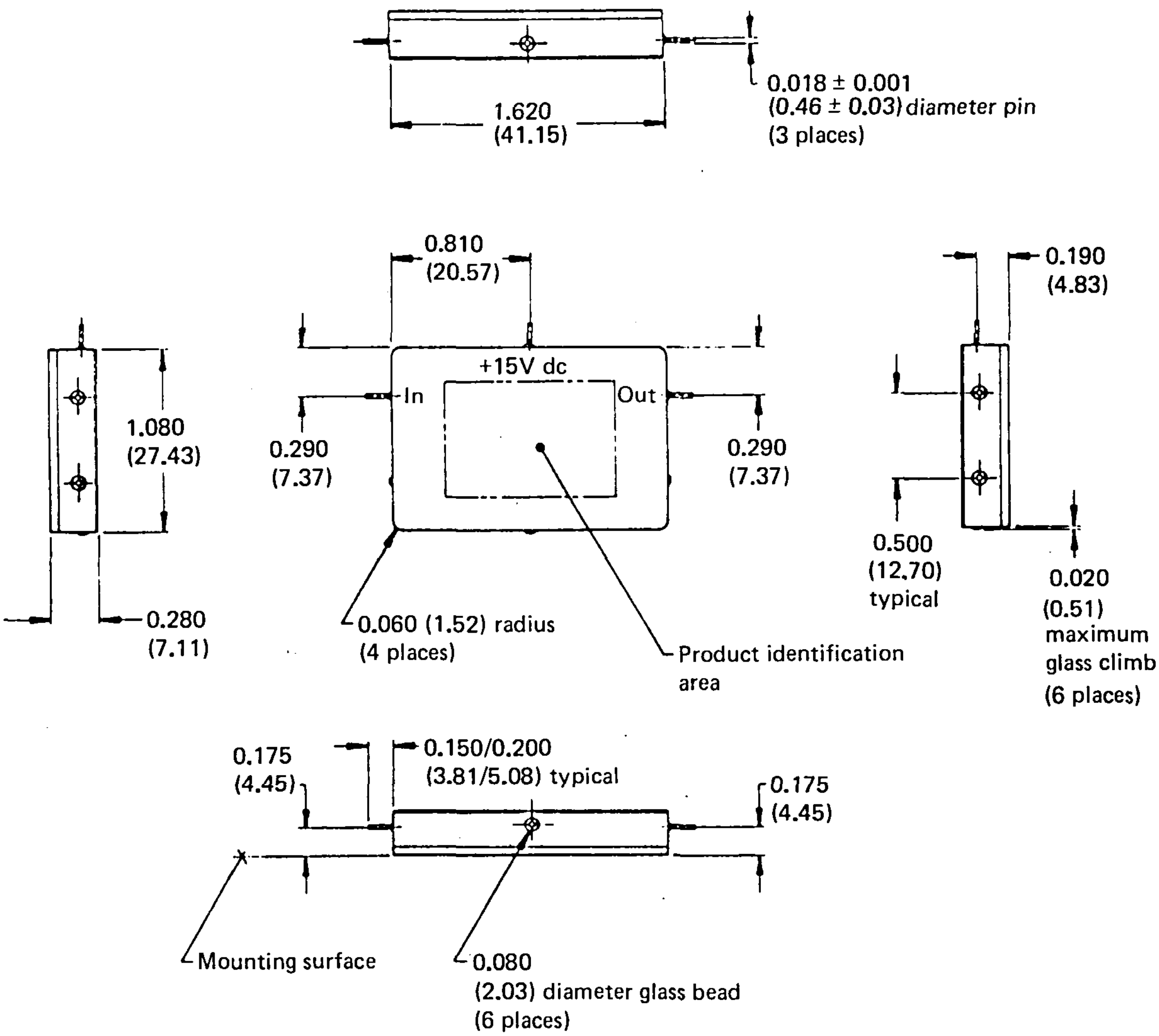
Figure 7. Block Diagram of MLS RF Preamplifier



Notes (unless otherwise specified):

- Unit weight: 2 oz (57 gr) maximum.
- Finish: gold plate per MIL-G-45204.
- Dimensions are expressed in inches with millimeter equivalents in parentheses. Tolerances are ±0.010 (0.25).

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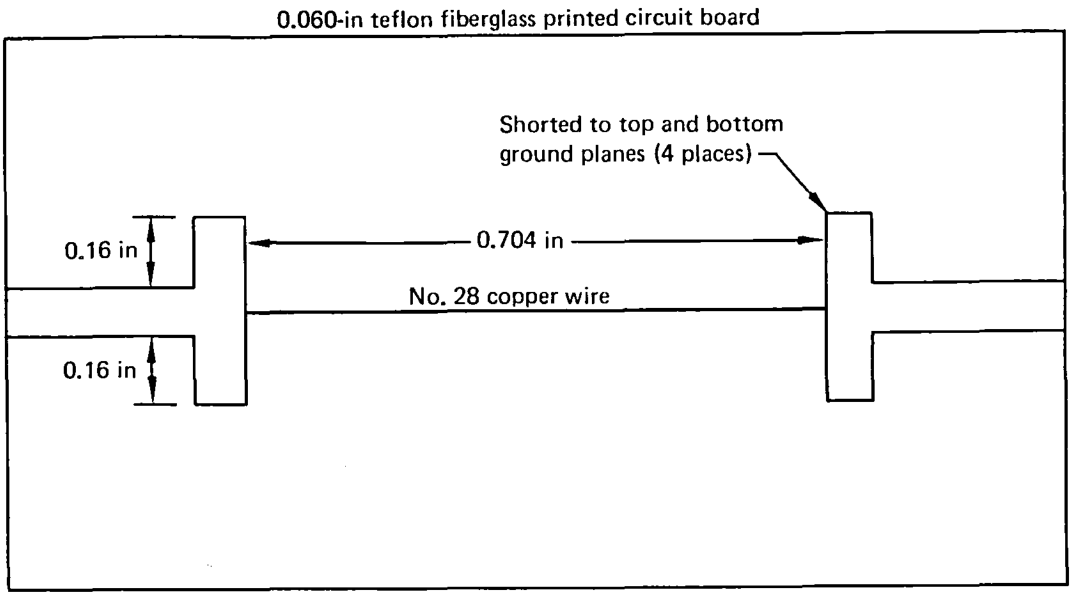
Figure 8. MINPAC Amplifier Package



Notes:

- All line widths are 0.09 in except the thin copper wire forming the half-wavelength-high Z_0 line.
- Figure not to scale.

Figure 9. MLS Bandpass Filter

circuit board. Two pairs of short-circuited transmission lines are spaced one-half wavelength apart by a high characteristic impedance transmission line.

Figure 10 shows the swept frequency response of the filter alone. Maximum insertion loss over the MLS band (5030 to 5090 MHz) is approximately 2 dB.

Figures 11 and 12 show the swept frequency response of the completed preamplifier, including the filter. Minimum gain over the MLS band is 20.7 dB. A noise figure of 2.2 dB was measured at the center of the MLS band.

Figure 13 shows a schematic diagram of the power supply. A design similar to this one has been qualified to electrical and electromagnetic compatibility requirements for the 767 aircraft. The LM 340-15 three-terminal regulator provides a constant 15V output for input voltage variations from 17.9V to 30V. The IN 5555 provides transient protection from voltage spikes that can exist on the 28V dc aircraft power line. We consider this unit to be packaged adequately for a flight test evaluation program.

The primary purpose of the preamplifier is to preserve the system noise figure and retain MLS system coverage to 37 km (20 nmi) with ordinary types of coax cables as presently used on transport aircraft. Figure 14 shows one such application in a transport aircraft using RG 214 type of coax. The length of the line has been adjusted to result in an overall system noise figure of 16 dB, which is the current system specification limit; i.e., 11-dB receiver noise figure plus 5-dB cable loss. Since the maximum cable length for a fuselage top centerline antenna location is 13m (43 ft) for a 747 installation, this design will provide MLS reception in excess of 37 km (20 nmi) for all Boeing aircraft, including the 757 and 767.

4.3 CONCLUSIONS AND RECOMMENDATIONS

A prototype MLS RF preamplifier was fabricated and tested to compensate for cable loss in airplane installations. The preamplifier performance permits a fuselage top centerline antenna installation using ordinary coax cable on all Boeing transport aircraft with MLS coverage in excess of 37 km (20 nmi). Also, microstrip technology was used to produce a small, lightweight airplane MLS antenna. The circular patch antenna produced radiation patterns similar to those of a monopole antenna, with impedance bandwidth adequate for MLS operation. However, further analysis should include the sensitivity of the impedance to substrate dimensional and dielectric constant variations. Additional MLS antenna design should include directional antennas to minimize reflections from airplane structure and to increase gain in specific coverage zones. Radiation patterns of the airplane antennas could be analyzed using geometrical theory of diffraction computer programs.

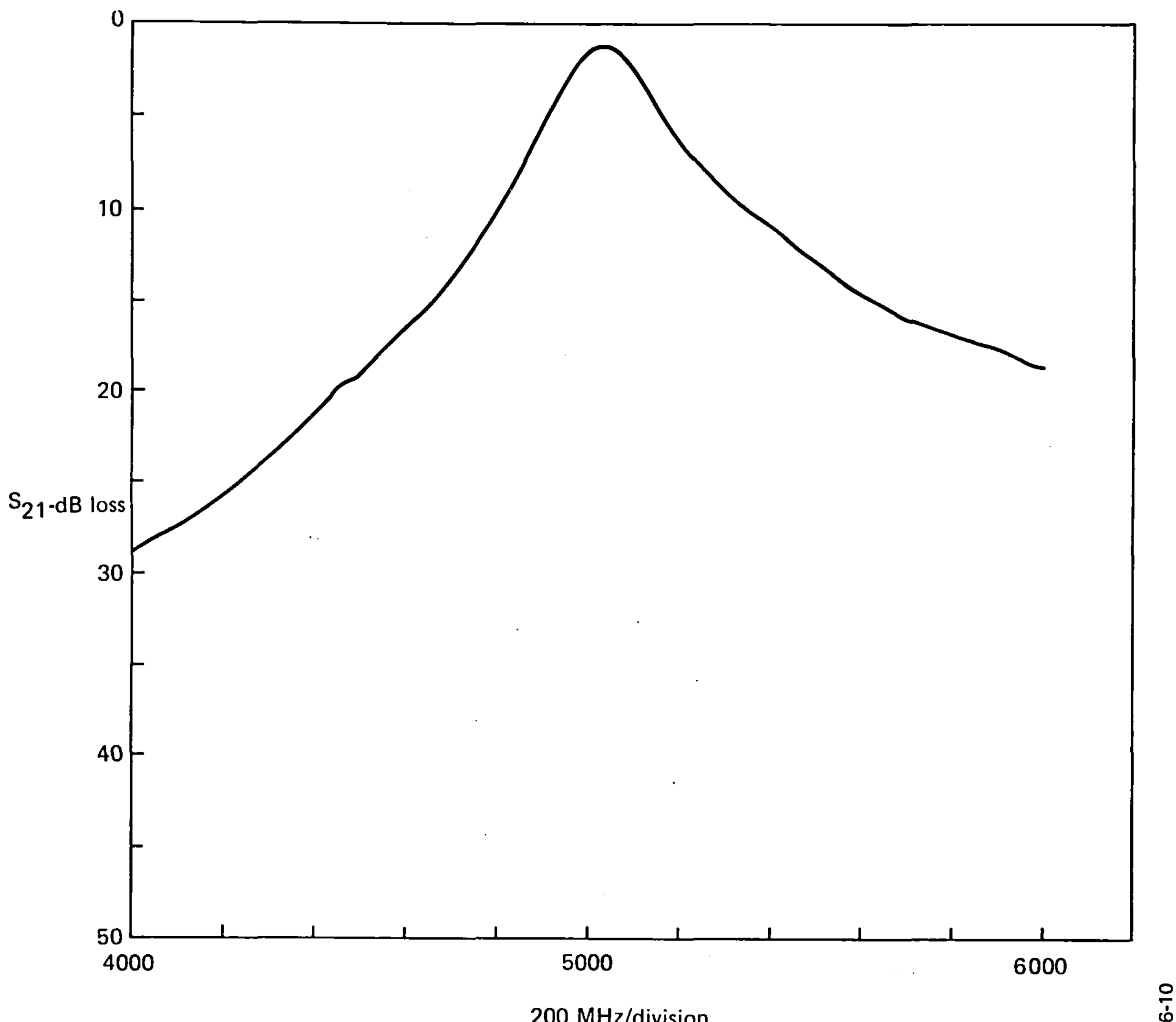


Figure 10. MLS Bandpass Filter Insertion Loss

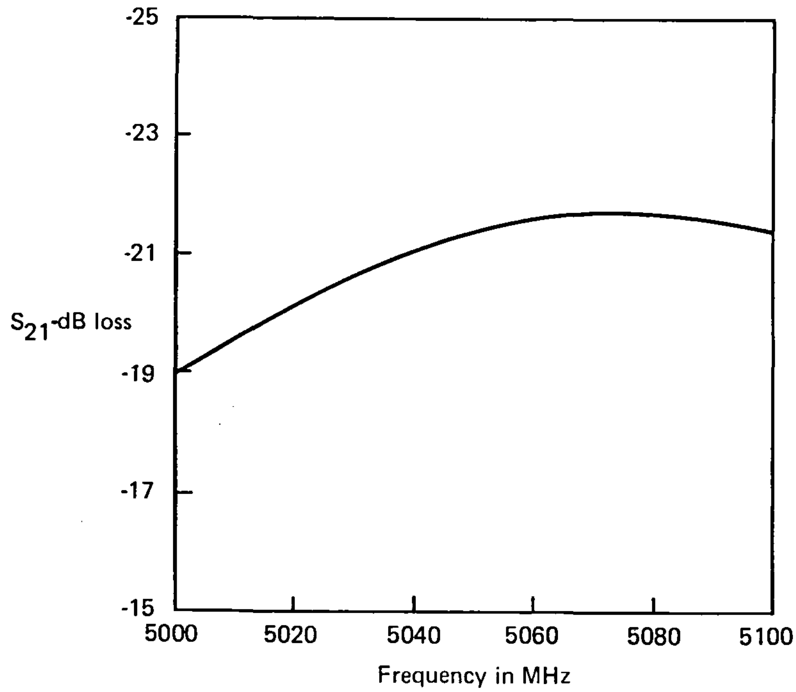


Figure 11. MLS Preamplifier Narrowband Gain Response

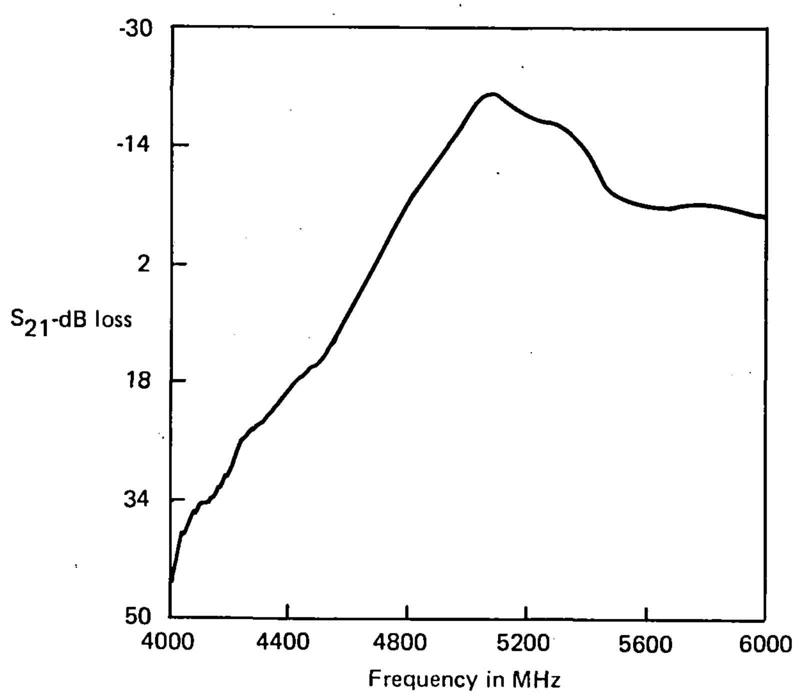


Figure 12. MLS Preamplifier Wideband Gain Response

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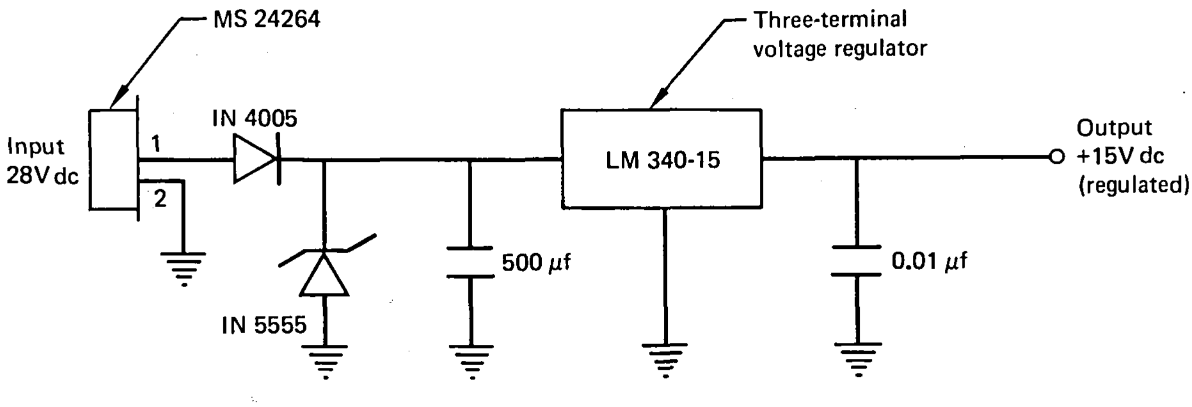
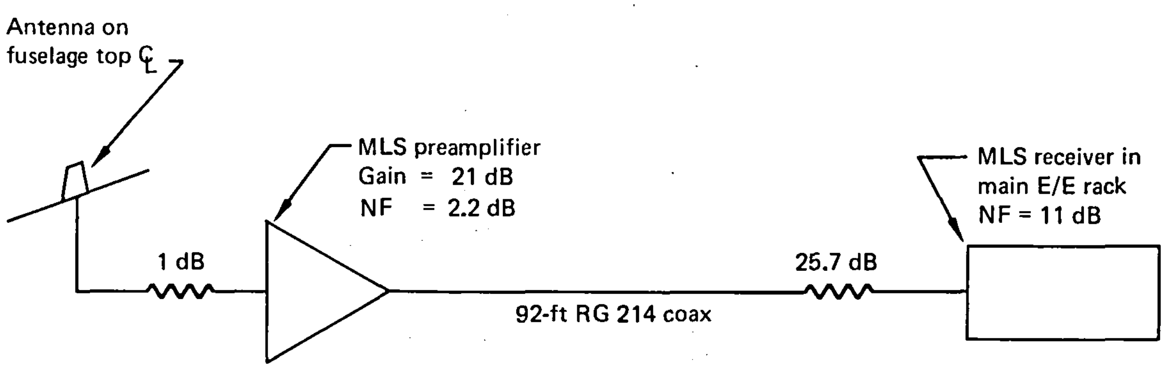


Figure 13. Schematic Diagram of Regulated Power Supply



Notes:

- System noise figure = 16 dB.
- System performance will provide 20-nmi range based on an airborne antenna gain of 0 dBi.
- The 92-ft cable length exceeds that required for any Boeing commercial transport aircraft for a fuselage top centerline location above the crew cab.

830996-13

Figure 14. MLS Preamplifier Application

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3 P. B. Morel, S. A. Long, and L. C. Shen, "A Theoretical Investigation of the Circular Disc Antenna," 1976 Region V IEEE Conf. Dig., IEEE Cat. No. 76CH1068 REG5, April 1976.

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Hampton, VA 23665

16. Abstract

Results of analysis and design conducted as part of a multiyear microwave landing system (MLS) study are reported in this document. Design of airborne RF MLS components was performed. MLS omnidirectional antennas were developed using microstrip technology. A remote, low-noise, radio frequency (RF) preamplifier was designed for airborne MLS installations.

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