



# "A 15 WATT AM AIRCRAFT TRANSMITTER POWER AMPLIFIER USING LOW COST PLASTIC TRANSISTORS"

Prepared by  
David S. Hollander  
RF Product Group

## INTRODUCTION

This application note describes a 15 watt carrier power, amplitude modulated broadband amplifier covering the 118-136 MHz AM aircraft band. Simplicity and low cost are emphasized in this design through the use of Motorola's common emitter TO-220 VHF power transistors. The power amplifier is designed to operate from 13.5 VDC. High level AM modulation is accomplished by a series modulator operating from a 27 volt supply.

## CIRCUIT DESCRIPTION

The transmitter power amplifier has three stages using an MRF340 transistor as a pre-driver, a MRF342 as a driver, and a MRF344 as the final amplifier. All three devices are common emitter where the mounting tab is the emitter. The pre-driver stage is forward biased to enhance linearity and dynamic range. Amplitude modulation is applied fully to all three stages.

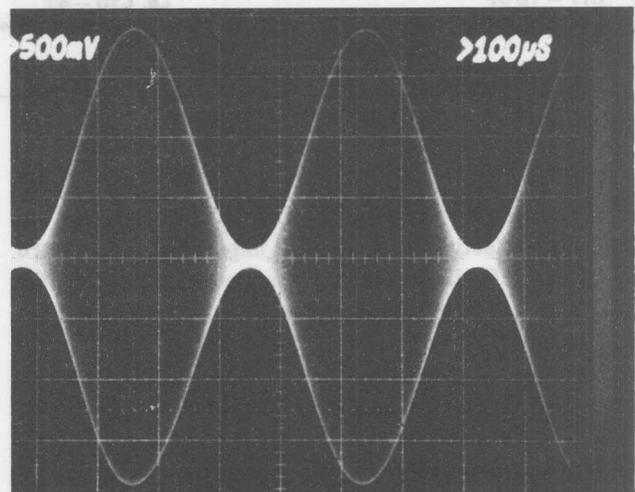
The P.A. is designed to operate with 50 ohm source and load impedances.

## DESIGN CONSIDERATIONS

The design objectives are that the transmitter must be capable of operating over the range of 118 to 136 MHz with a minimum carrier output power of 15 watts. It must also be capable of being amplitude modulated greater than +85% over the frequency range, and the transmitter should be free from instability.

Other important considerations involve the interstage and the output networks. The output network is to operate efficiently at both the carrier power of 15 watts and the peak power of 60 watts while providing harmonic suppression. The interstage networks transform the output impedance of the device to the input impedance of

FIGURE 1 — Modulated Output Waveform of Power Amplifier



$f = 136 \text{ MHz}$      $P_{\text{carrier}} = 15 \text{ Watts (2 cms)}$   
% Upward Modulation = 90%

the following device during modulation of all three stages.

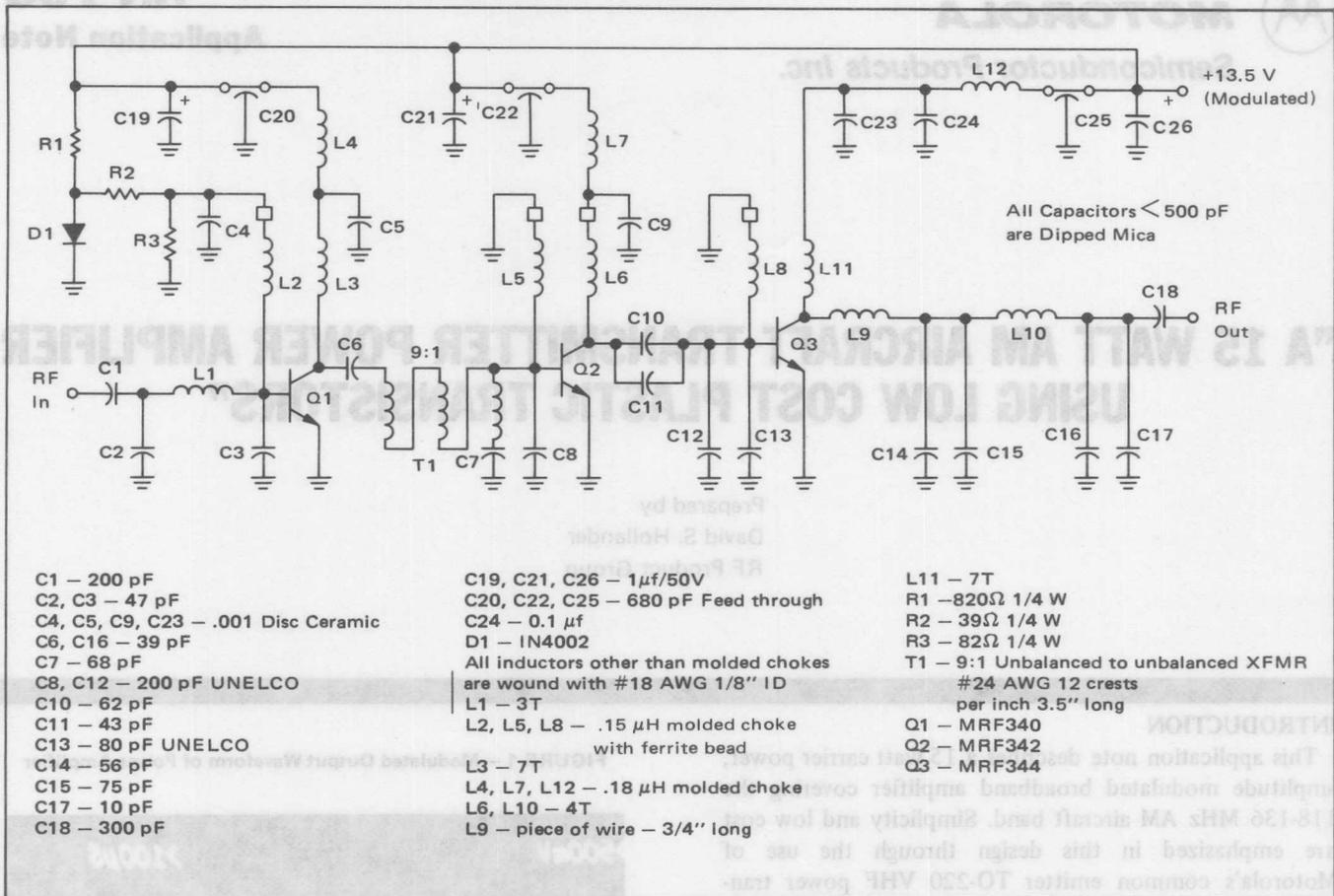
In designing the networks, the Smith Chart is used to obtain initial values. These values were then optimized using a computer aided design program.

Figure 2 shows a schematic diagram of the transmitter P.A. RF circuitry.

The pre-driver stage uses a simple  $\pi$ -section input matching network. Forward bias for this stage is obtained through the network consisting of  $R_1$ ,  $R_2$ ,  $R_3$ ,  $D_1$ , and is applied to  $Q_1$  through  $L_2$ . The quiescent current is approximately 20ma for the MRF340.

Motorola reserves the right to make changes to any products herein to improve reliability, function or design. Motorola does not assume any liability arising out of the application or use of any product or circuit described herein; neither does it convey any license under its patent rights nor the rights of others.

FIGURE 2 - Schematic Diagram



The interstage between Q<sub>1</sub> and Q<sub>2</sub> is designed as follows. The effective collector load impedance is estimated to be 100-j50 ohms. The input impedance, Z<sub>IN</sub>, of the MRF 342 is 1.75+j2 ohms at 136 MHz (as taken from the data sheet). One way to match the output of the MRF340 to the input of the MRF342 with a minimum of components is through the use of a 9:1 transformer (1, 2). Figure 3 shows a Smith Chart plot of the interstage network with the chart normalized to 50 ohms. Starting at point A, this impedance is rotated to point B by a shunt capacitor C<sub>8</sub>. The impedance at this point is approximately 5 to 5.5 ohms. A 9:1 transformer transforms this impedance to approximately 50 ohms. Point C, the 50 ohm point, is rotated to D by series capacitor C<sub>6</sub>. Point D is then rotated to point E, the complex conjugate of the output impedance of Q<sub>1</sub>, by shunt inductor L<sub>3</sub>.

A different approach is used for the Q<sub>2</sub> - Q<sub>3</sub> interstage network. The MRF342 output impedance Z<sub>OL</sub>, and the MRF344 input impedance Z<sub>IN</sub>, are taken from the data sheets. Figure 4 shows a Smith Chart plot of this network with the chart normalized to 50 ohms. Point A is the input impedance of the MRF344. This impedance is rotated to the real axis by shunt capacitors - C<sub>12</sub> and C<sub>13</sub>. Point B is then rotated to point C by series capaci-

tors - C<sub>10</sub> and C<sub>11</sub>. This impedance is then transformed to the complex conjugate of the output impedance of the MRF342 by shunt inductor L<sub>6</sub>.

The MRF344 output matching network consists of a shunt inductor at the collector of Q<sub>3</sub> followed by two L-sections. L-sections were used because they provide excellent harmonic suppression and good efficiency over the entire band. Figure 5 shows a Smith Chart of the output network, with the chart normalized to 50 ohms.

All impedance matching element values calculated using the Smith Chart and optimized with the computer program were used as starting points in building the networks. The final component values shown in Figure 2 were derived through on-the-bench tuning and adjustment and differ from the calculated values as the Figure 2 values cover 118-136 MHz. The calculated values are only for 136 MHz.

Since low cost is a key factor in the use of the TO-220 devices, inexpensive components are used wherever applicable. Molded chokes, dipped mica and dipped ceramic capacitors are used throughout the circuit. One of the problems encountered when using dipped micas at VHF is their series lead inductance. The higher capacitance values approach resonance at VHF. Selected values were

measured on an HP network analyzer at 125 MHz. The results are shown in Table 1.

TABLE 1

Cnominal (PF)	Cmeasured (PF)
5	5
10	10
25	26
30	33
39	45
50	64
75	106
100	161
200	750

Note: All lead lengths kept to an absolute minimum (<0.1 inch)

The data obtained shows that values below 75pf are usable. Lead length should be kept to a minimum when using both the dipped mica and the disc ceramic capacitors. UNELCO capacitors are used in place of the dipped micas at the base of Q<sub>2</sub> and Q<sub>3</sub>, since the net required capacitance and base current is very high.

CONSTRUCTION TECHNIQUES

The amplifier is assembled on a 2" X 5" double sided printed circuit board. Board material is G-10 with a thickness of 0.062". A 1:1 photomaster of the top side of the board is shown in Figure 6. Eyelets are placed through the board at points marked by the letter "O". The eyelets are soldered to both sides of the PCB to connect the top ground to the bottom side ground return. Feed-thru capacitors are mounted on the DC feed bar which is made of G-10 PCB. A 1:1 photomaster of the feedbar is also shown in Figure 6. Eyelets are placed at points marked by an "O" and feed-thru capacitors are placed at points marked by an "X". The DC feedbar is soldered to the main board. The location of the critical components is shown in Figure 7. Construction details of the 9:1 impedance transformer are shown in Figure 8. (1,2)

For reliable operation, the transistors must not only be heatsunk, but they must also be mounted properly for emitter RF ground return. Figure 9 shows mounting details for the TO-220 package. More detailed information on mounting is available in AN-778.(3) The entire assembly is mounted on a 6" extruded aluminum heatsink using 4-40 X 1/4 machine screws. The heatsink surface should be flat and free of burrs, particularly around the transistor mounting holes.

FIGURE 3 - MRF340 - MRF342 Interstage Network

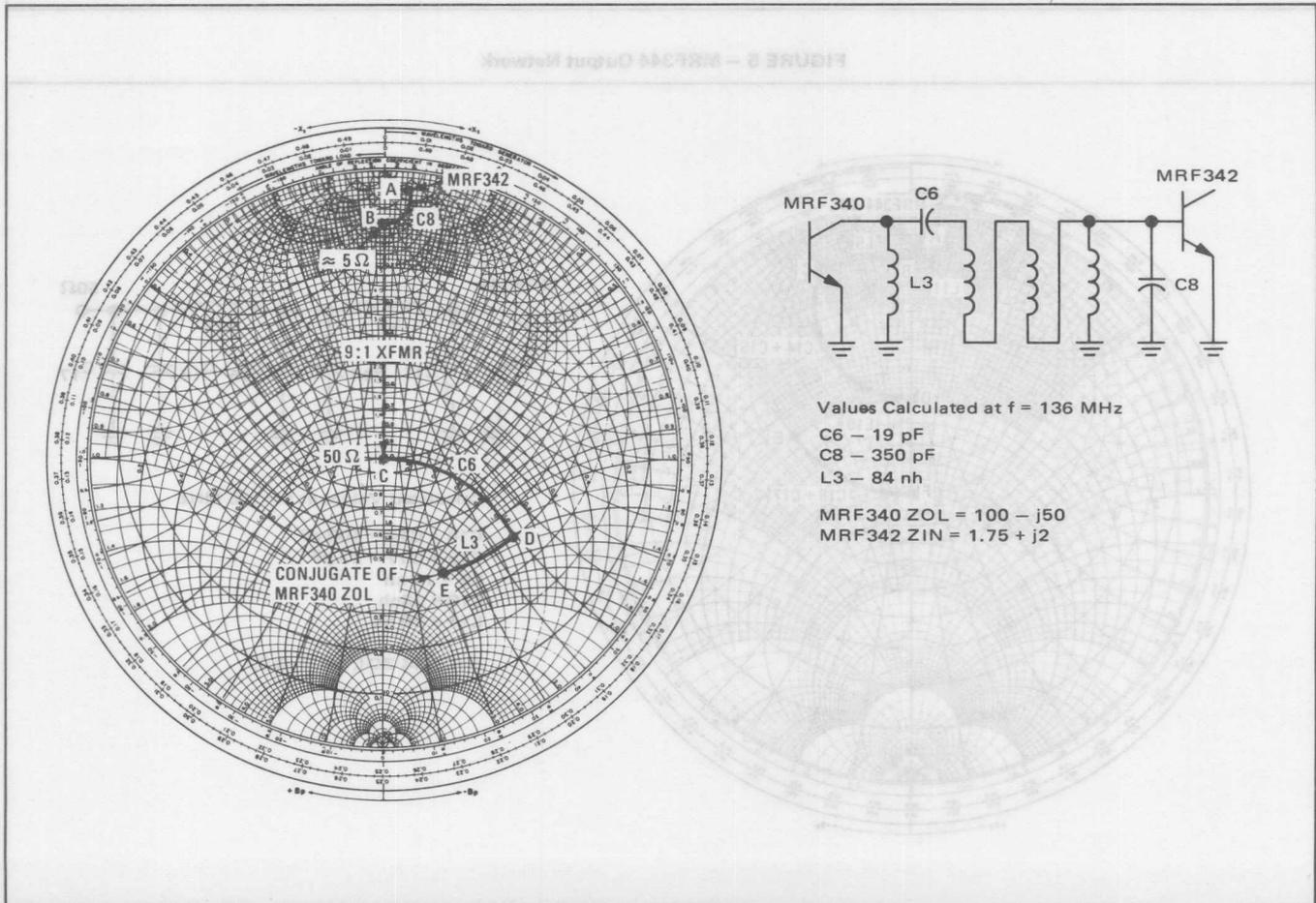


FIGURE 4 – MRF342-MRF344 Interstage Network

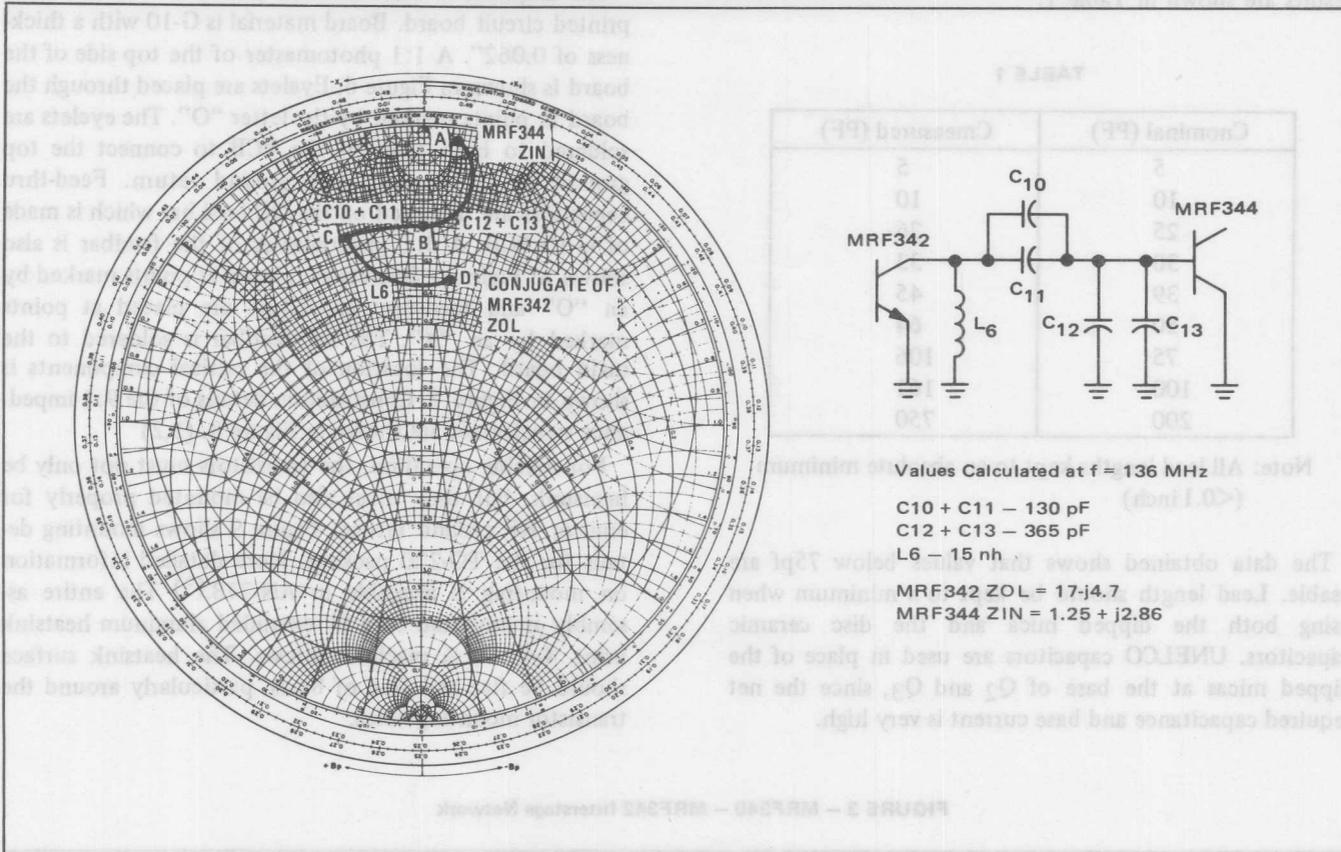


FIGURE 5 – MRF344 Output Network

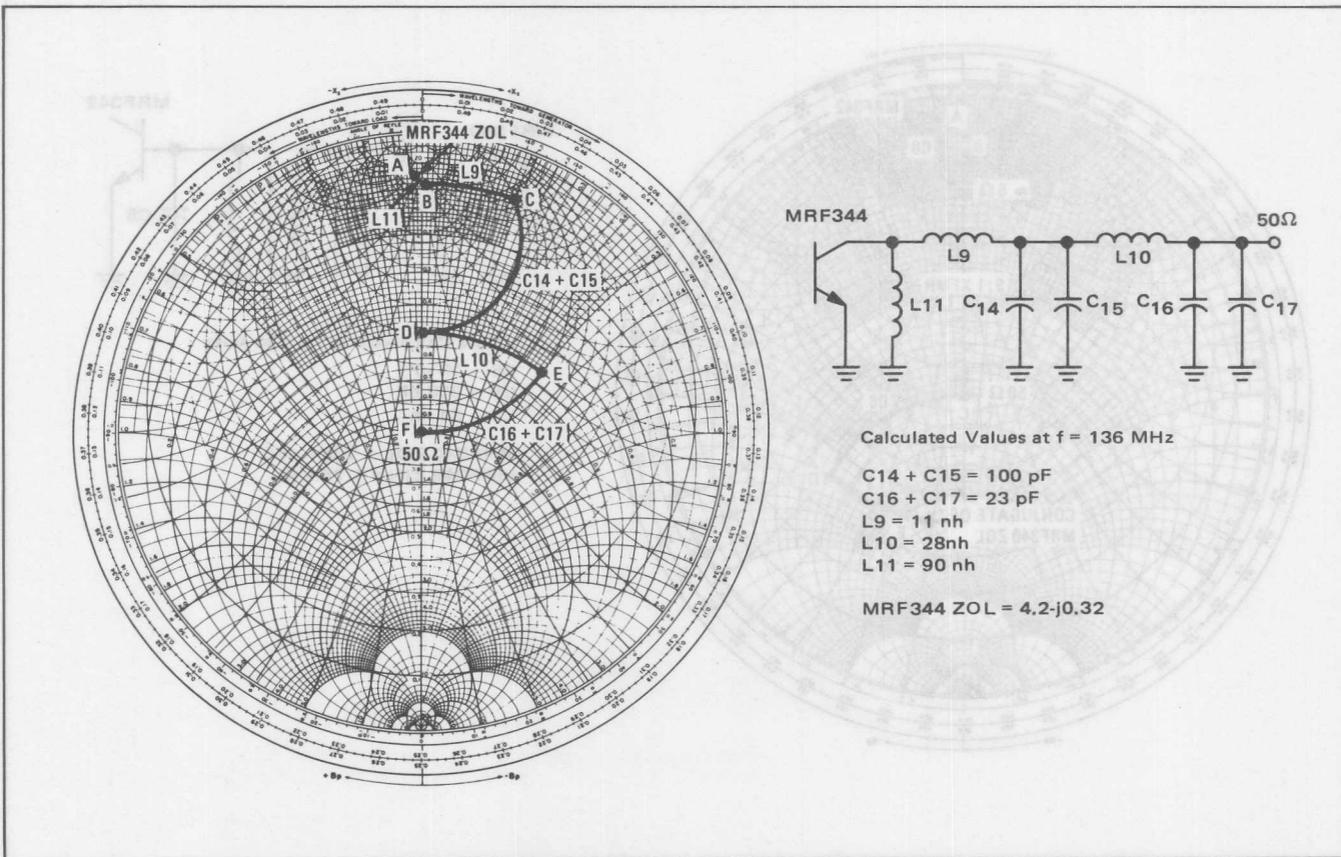


FIGURE 6 - 1:1 Photomaster

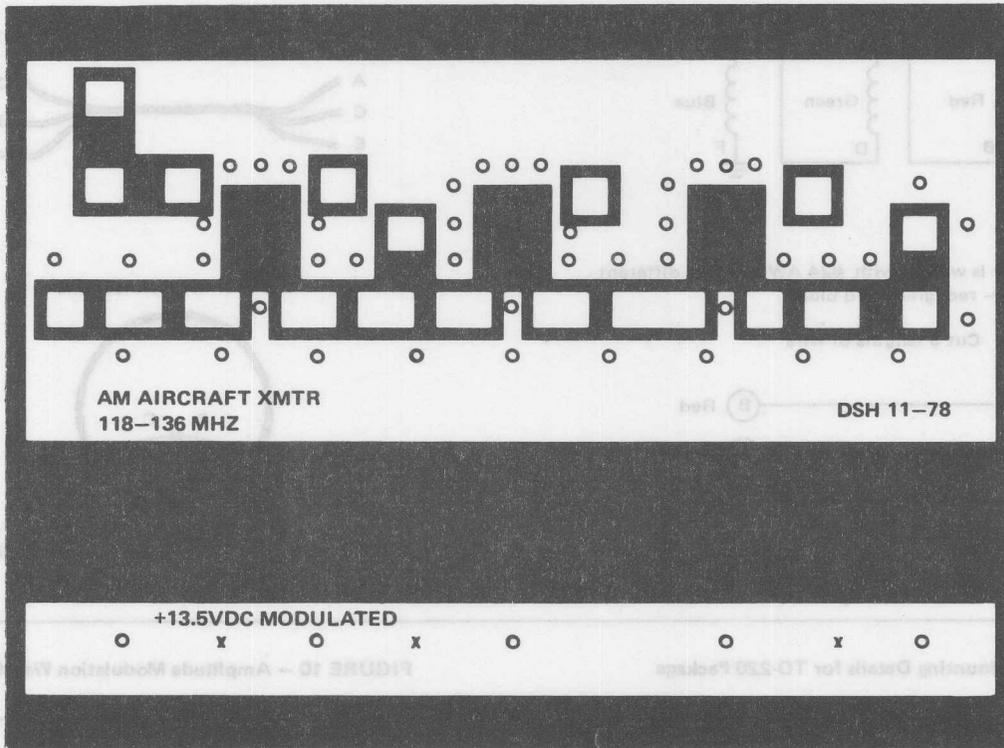


FIGURE 7 - Location of Critical Components

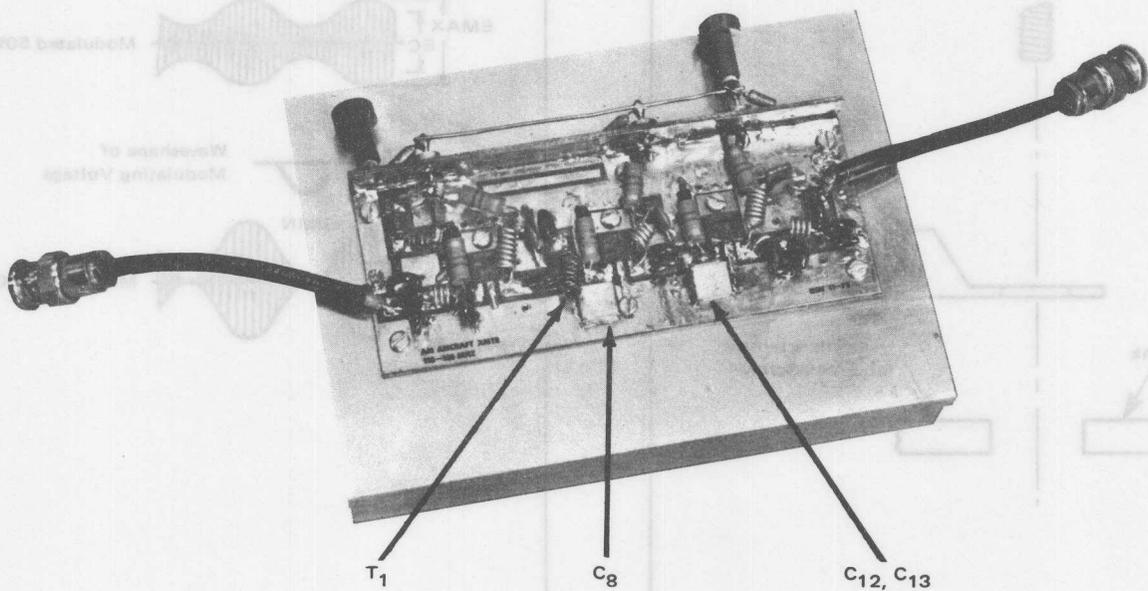


FIGURE 8 – Construction Details of the 9:1 Unbalanced to Unbalanced Transformer

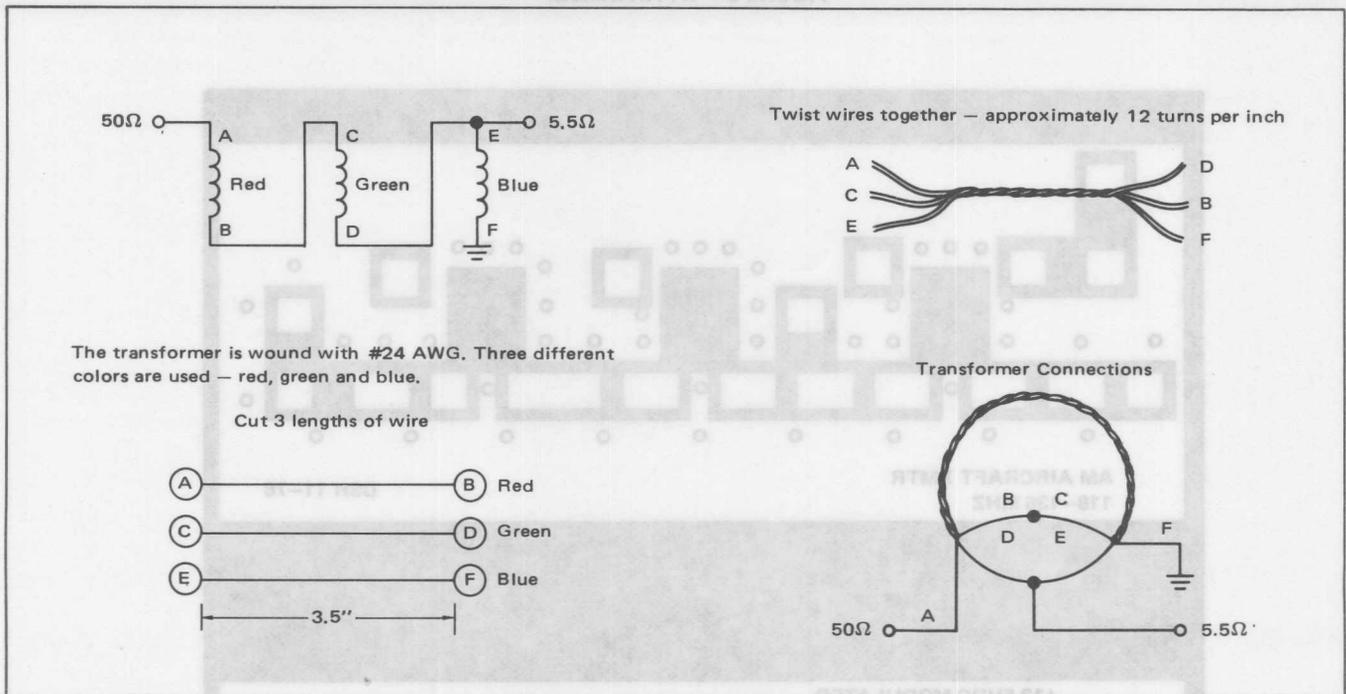


FIGURE 9 – Mounting Details for TO-220 Package

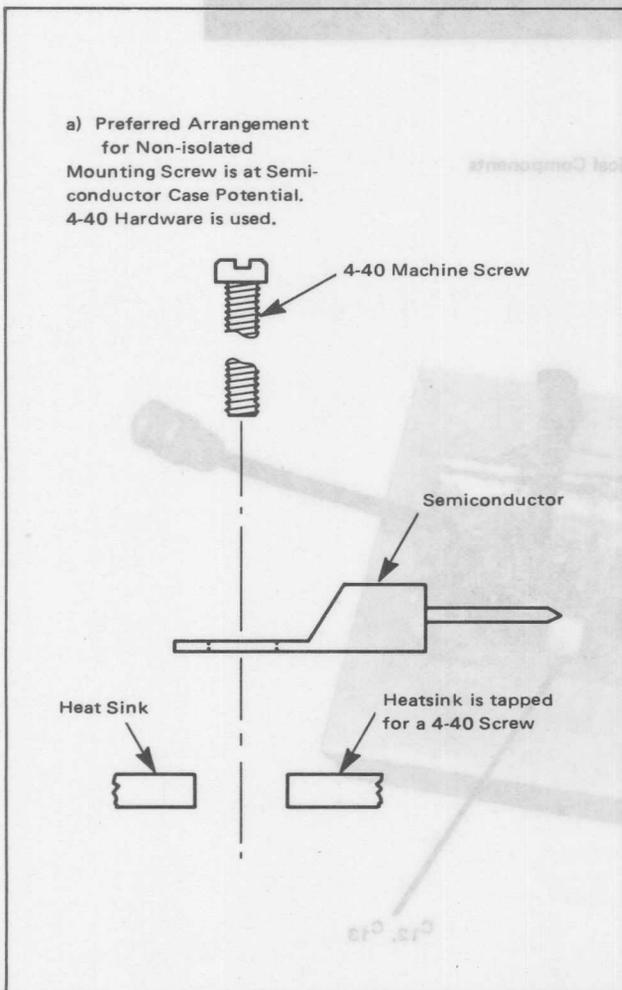
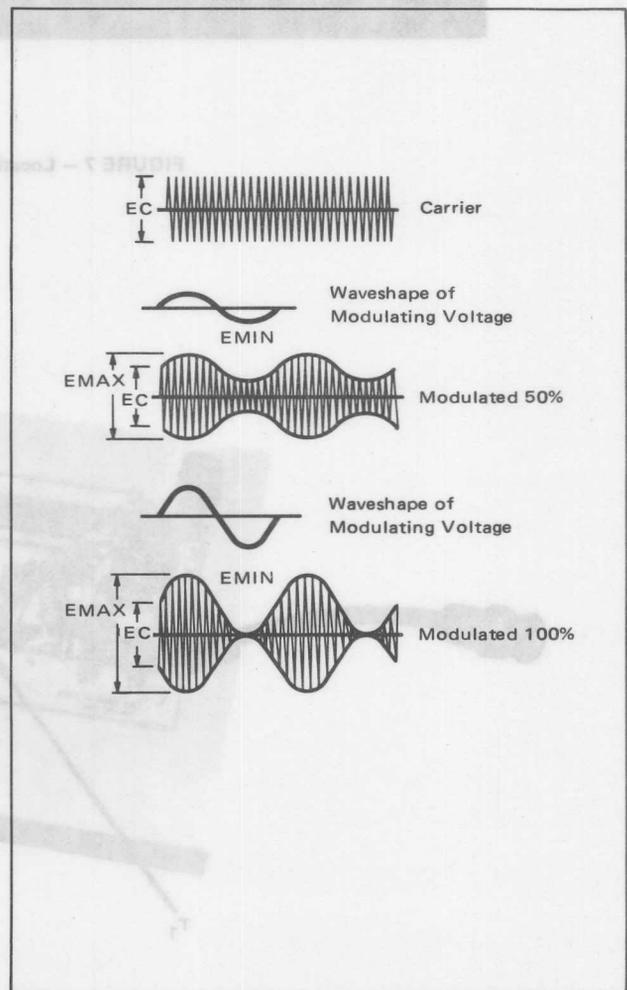


FIGURE 10 – Amplitude Modulation Waveforms



## MODULATION

In an amplitude modulated waveform the amplitude of each cycle of the modulated wave varies in accordance with the modulating signal. Using voice modulation, the resultant waveform is not only complex, but difficult to analyze. Therefore, when testing and analyzing the transmitter P.A., a simple 1 KHz sine wave is used as the modulating signal. When analyzing an AM waveform, one of the things to consider is the modulation factor (M). M is usually expressed as percent modulation and is calculated as follows:

$$M = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100\%$$

Figure 10 shows amplitude modulation waveforms.

The above formula is valid only when the modulation process is symmetrical and little distortion is present. If significant assymetry is present then up modulation and down modulation must be analyzed separately.

$$M = \frac{E_{max} - E_c}{E_c} \times 100\% \text{ For positive peak modulation}$$

$$M = \frac{E_c - E_{min}}{E_c} \times 100\% \text{ For negative peak modulation}$$

When a carrier is modulated by a pure sine wave, two sidebands are generated at the carrier frequency plus and minus the modulating frequency. The power level of the

sidebands is dependent upon the percentage of modulation. At 100% modulation, the total power contained in the sidebands is one-half the carrier power or one-fourth in each sideband. For modulation levels of less than 100%, the total power is:

$$PSB = \frac{1}{2} m^2 PC$$

where m = modulation factor

Pc = carrier power

Collector modulation is a commonly used method for modulating a solid state transmitter. Using this method, the modulating voltage is applied to a collector through a transformer. The secondary winding of the transformer must be capable of handling the DC current required by the transistor and have low DC resistance, so as not to cause a significant voltage drop. The voltage drop will reduce the voltage applied to the collector of the stage being modulated.

Another form of collector modulation uses a series modulator. This type of modulator is used to evaluate the transmitter in this application note.<sup>(4)</sup> A series modulator uses audio power transistors instead of a transformer secondary. A schematic diagram of the series modulator is shown in Figure 11. 27 volts is applied to the modulator and the quiescent DC voltage applied to the transmitter is set by the 10KΩ potentiometer.

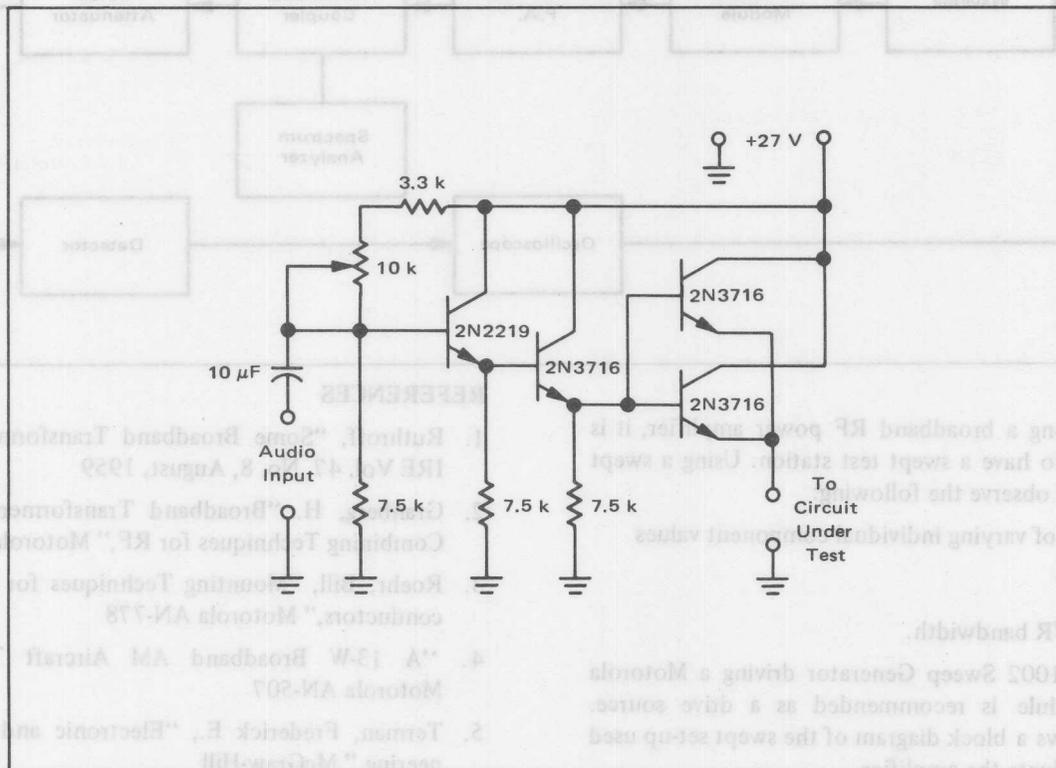
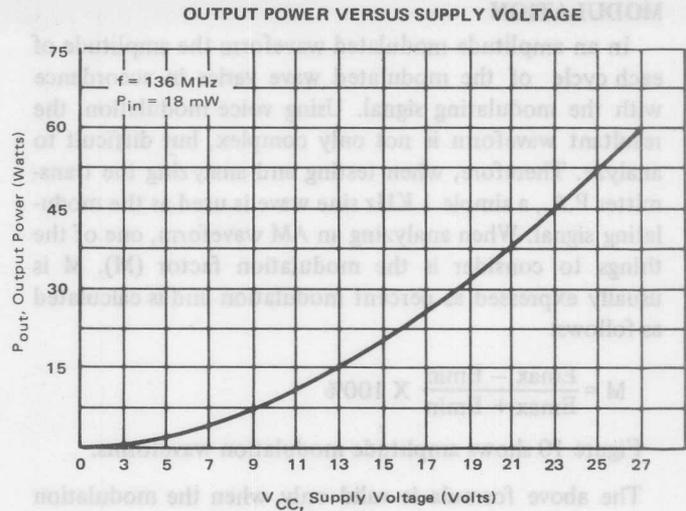


FIGURE 11 – Series Modulator

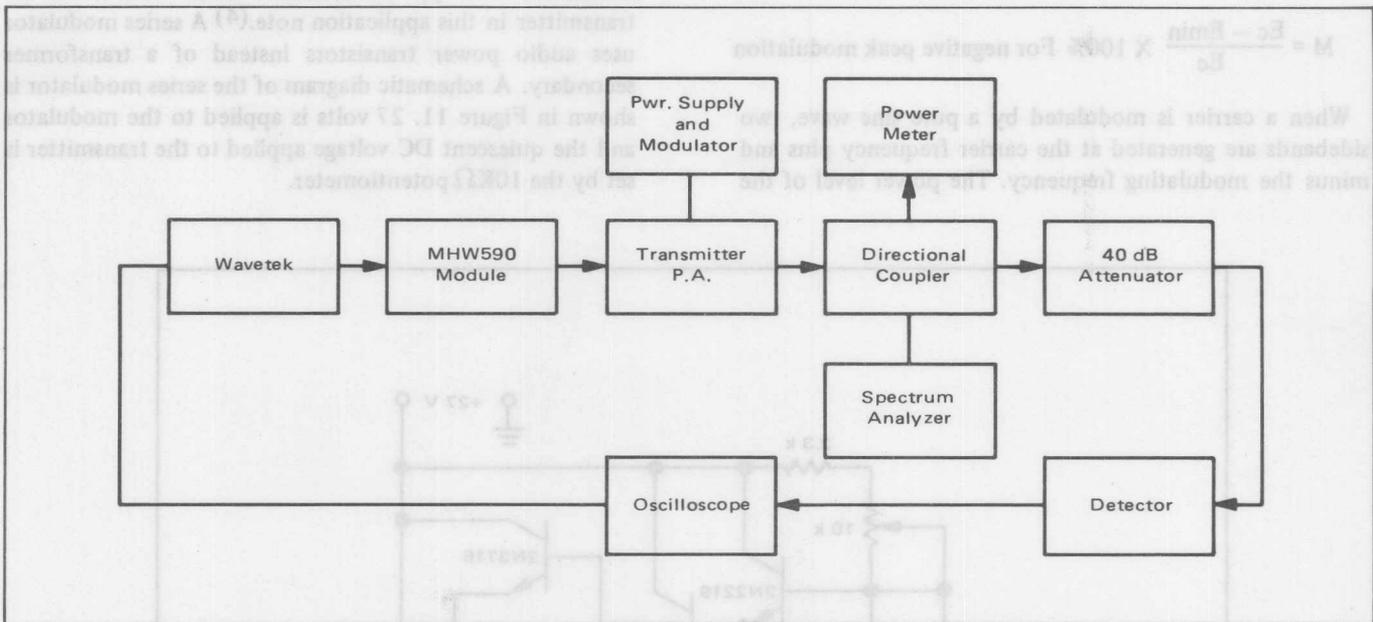
Table 2 — Performance of the 15 Watt Amplifier

	118 MHz	127 MHz	136 MHz
$P_{in}$ (mW)	14.0	15.0	18.0
$P_{carrier}$ (W)	15.0	15.0	15.0
Total Current (A <sub>dc</sub> )	2.2	2.0	2.5
Power Supply Voltage (V <sub>dc</sub> )	13.5	13.5	13.5
Upward Modulation (%)	89.0	88.0	90.0
Harmonic Rejection (dB) (Relative to Peak Power)			
2f	55.0	55.0	52.0
3f	58.0	58.0	57.0
Load Mismatch	Capable of Operating into 3:1 Load VSWR.		



$P_{out}$  is initially set at the carrier power of 15 watts at 13.5 V<sub>dc</sub>, then the supply voltage is varied from 0 to 27 V<sub>dc</sub> keeping  $P_{in}$  constant. This demonstrates the peak power output capability of the transmitter P.A.

FIGURE 12 — Block Diagram of Swept Set-Up for Tuning Up the Transmitter



**TEST SET-UP**

When adjusting a broadband RF power amplifier, it is advantageous to have a swept test station. Using a swept set-up, one can observe the following:

- 1) The effect of varying individual component values
- 2) Bandwidth
- 3) Instability
- 4) Input VSWR bandwidth.

A Wavetek 1002 Sweep Generator driving a Motorola MHW590 module is recommended as a drive source. Figure 12 shows a block diagram of the swept set-up used to test and evaluate the amplifier.

**REFERENCES**

1. Ruthroff, "Some Broadband Transformers," PROC. IRE Vol. 47, No. 8, August, 1959
2. Granberg, H. "Broadband Transformers and Power Combining Techniques for RF," Motorola AN-749
3. Roehr, Bill, "Mounting Techniques for Power Semiconductors," Motorola AN-778
4. "A 13-W Broadband AM Aircraft Transmitter," Motorola AN-507
5. Terman, Frederick E., "Electronic and Radio Engineering," McGraw-Hill



**MOTOROLA Semiconductor Products Inc.**