# P-1

# SOLID-STATE TRANSMITTER/MODULATOR FOR THE MODE SELECT AIRPORT BEACON SYSTEM SENSOR

By

T.M. Nelson, M.J. Reinhart, K.J. Yoo, D.A. Poltorak and R.K. Palmer

Westinghouse Electric Corporation
Baltimore, MD

### Abstract

This solid-state communications transmitter/modulator has been developed for the Westinghouse interrogator to be used on the Mode Select (Mode S) Airport Beacon System Sensor. These all solid state Air Traffic Control Systems will be installed in 137 airports in the United States to update and improve present airport/plane communications. They are also compatible with the present air traffic communication system that they will replace, the Air Traffic Control Radar Beacon System (ATCRBS); this feature will accommodate any planes that will not yet have the updated Mode S equipment.

Two Mode S transmitter power amplifying channels are utilized, both operating at 1030 MHz. One produces 2.5 KW peak rf power at a 4.5 percent long-term duty factor that can go as high as 64 percent short-term. The other channel produces 10 KW peak rf power at a 0.1 percent long-term duty factor.

### Introduction

The solid-state transmitter architecture is modular and is depicted in figure 1. This figure illustrates the primary (directional) and auxiliary (omni) power amplification channels. Operating frequency of both channels is 1030 MHz.

The primary transmit channel includes a modulator/driver module, the primary power amplifier module and an rf level control module. The modulator/driver, shown in figure 2, modulates the local oscillator rf input (+5 dBm CW) and amplifies this to approximately 200 watts peak power. It also features a 180° phase shift reversal capability. The coding of this phase shift reversal during transmission accomplishes airport to plane communications. The primary power amplifier, shown in figure 3, amplifies the 200 watts to produce 2.5 KW peak output. The maximum average duty factor is approximately 4.5 percent. However, during short pulse bursts it can go as high as 64 percent. The rf level control (see figure 4), incorporating 2 rf diode switches and 3 rf attenuators, is capable of handling the maximum rf output of the power amplifier in either channel. It allows electronic switch variation of the output power level for both long range and close in communication. The level control also allows each airport site to mechanically tailor their output power (by changing attenuator settings) to prevent interference with other nearby sites.

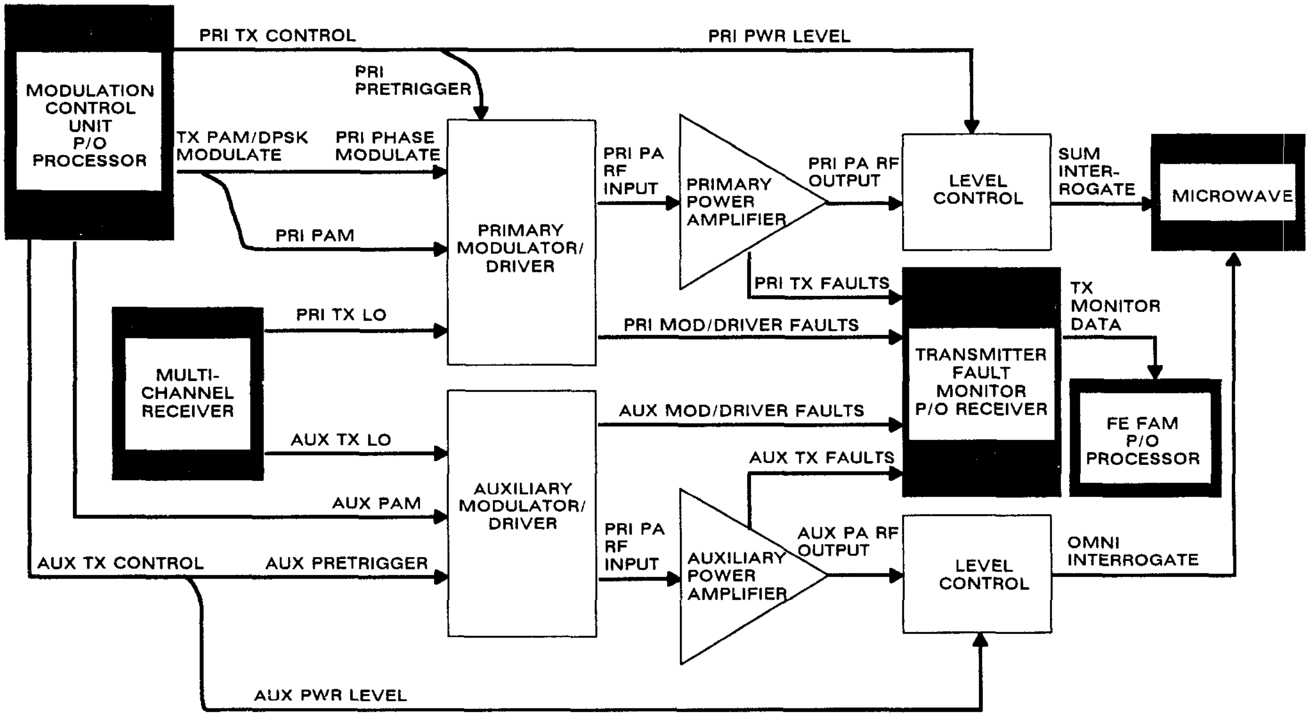


**Figure 1. Block Diagram of the Mode S Solid-State Transmitter**



0149-645X/87/0000-0531$01.00 © 1987 IEEE

The auxiliary transmit channel produces the rf power to be radiated by the omni antenna for side lobe suppression. It includes a modulator/driver module, an auxiliary power amplifier module and an rf level control. The modulator/driver is identical in design to the one in the primary channel. However the phase shift capability is not utilized here and its modulation inputs are much lower average duty, approximately 0.1 percent. There are also no high duty pulse bursts produced by this unit. The auxiliary power amplifier, shown in figure 5 amplifies the 200 watt peak output of the modulator/driver to 10 KW. The rf level control is also identical to the one in the primary channel, and serves the same purpose.

The two level controls are also operated in conjunction, to adjust the power difference between the primary and auxiliary transmit channels to meet the particular requirements of each site.

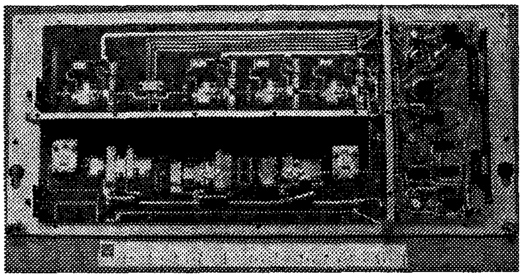

Figure 2. Modulator/Driver

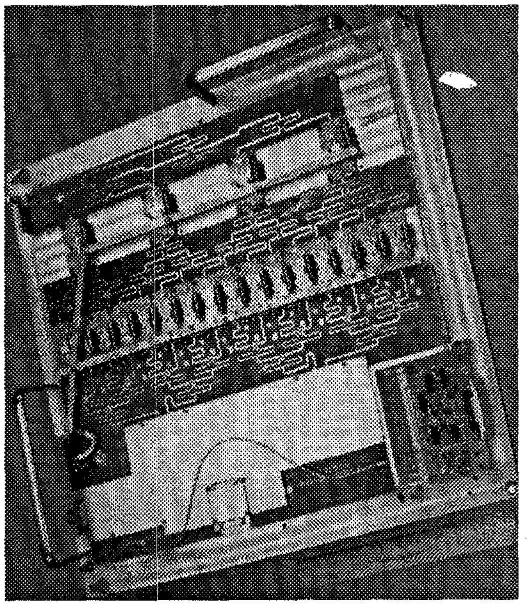

Figure 3. Primary Power Amplifier

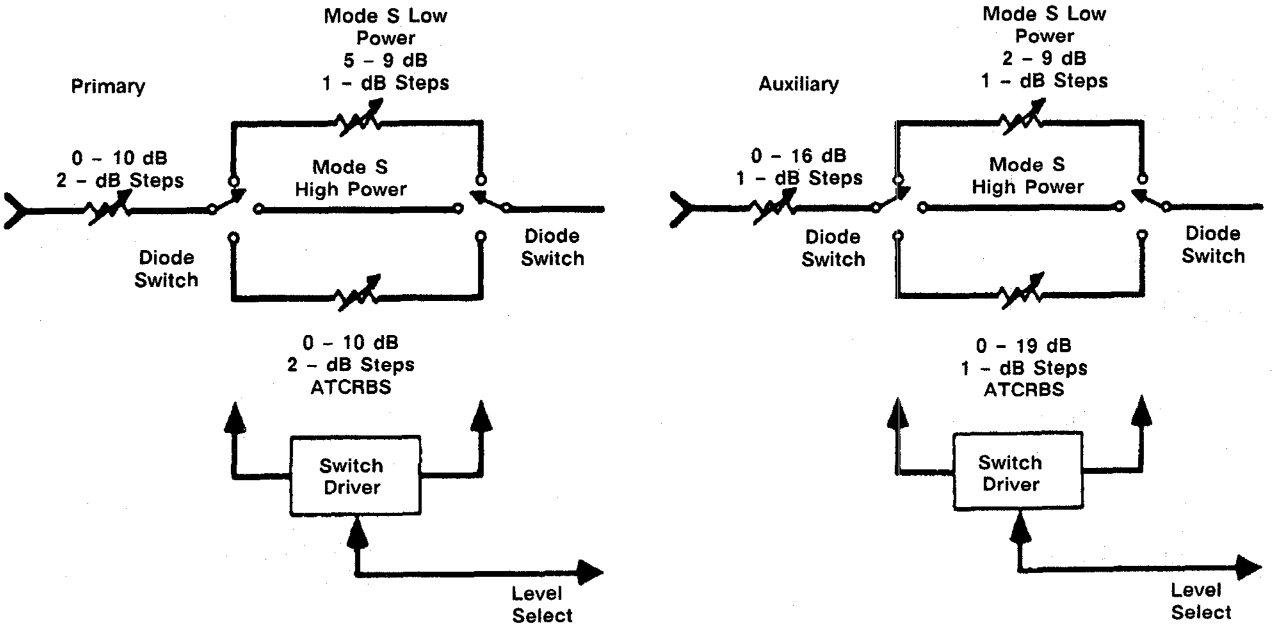


Figure 4. Block Diagram of the RF Level Controls

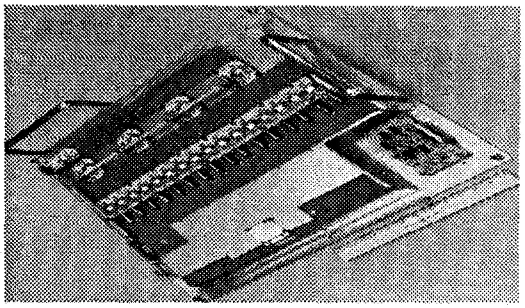

**Figure 5. Auxiliary Power Amplifier**

## Design

In the design of the microwave transmission circuits for the modulator/drivers and power amplifiers, soft substrates were employed throughout. In the modulator/drivers and in the power amplifier splitter and combiner circuits, a low loss PTFE woven glass laminate with a relative dielectric constant of 2.2 was used. In the power amplifier transistor circuits, however, a high dielectric constant (Er=10.3) PTFE ceramic filled soft substrate was used. This was done to minimize the space needed for tuning; both amplifiers have sixteen closely spaced transistors in the output circuit.

The modulator/driver has seven rf transistor stages, four class A bipolar transistors, followed by three class C bipolar transistors. Between the first two class A transistors is the packaged modulator unit, which contains a diode bridge circuit. The modulator bias is switched to pulse modulate the unit or to change the rf phase by 180°. These are controlled using TTL logic. The electrical specifications of the modulator/driver are given in table 1.

**Table 1. Modulator/Driver Electrical Specifications**

| | |
|---|---|
| Power Output | 165 Watts Peak Minimum<br>200 Watts Peak Nominal |
| Power Input | +5 dBm CW |
| Frequency | 1030 MHz |
| RF Gain | 48 dB |
| Modulator | |
| - PAM | 5 Pulse Modes |
| - Differential Phase Shift | $\Delta\phi$ = 180±5 Degrees |

A protection circuit is used in the modulator/driver modules, on a separate PC board, to limit excessive pulse widths and duty factors that are higher than system specifications and could damage the transmitter rf transistors. It utilizes a diode detection circuit in the modulator/driver rf section to provide comparator voltages. Identical protection circuits are used in the primary and auxiliary modulator/driver, even though pulse formats are very different. These differences are accommodated by adjustment of a potentiometer. A BITE circuit is included on the same PC board as the protection circuit, and along with a second detection diode rf power monitor in the rf section, signals an rf power level fault in the modulator/driver. Fault TTL logic signals are sent to a fault indicator box in another part of the system.

The primary and auxiliary power amplifiers feature a great deal of commonality in design as can be seen in figure 3 and 5. The rf splitting and combining circuits are identical. The amplifiers use different rf transistors. However in the primary amplifier, the four drivers and sixteen output transistors are identical and in the auxiliary amplifier, the single predriver, four drivers, and sixteen output transistors are identical. The primary amplifier employs 200 watt peak power high duty class C bipolar transistors and the auxiliary amplifier uses 720 watt peak power low duty class C bipolar transistors. Table 2 and table 3 give the electrical specifications for each amplifier.

**Table 2. Primary Power Amplifier Electrical Specifications**

| | |
|---|---|
| Power Output | 2500 Watts Peak |
| Power Input | 165 Watts Peak Minimum<br>200 Watts Peak Nominal |
| Pulsewidth | 31.85 $\mu$sec Max |
| Duty Factor | 64% for 1.6 msec<br>50% for 6 msec<br>7.6% for 40 msec<br>5.5% for 3 sec<br>4.5% Long-Term |
| $V_{cc}$ | 36 Volts |
| $I_{Peak}$ | 195 Amps |
| Efficiency (PA) | 33% |
| Power Dissipated | 210 Watts Long-Term Average |
| Frequency | 1030 MHz |

**Table 3. Auxiliary Power Amplifier Electrical Specifications**

| | |
|---|---|
| Power Output | 10,000 Watts Peak |
| Power Input | 165 Watts Peak Minimum<br>200 Watts Peak Nominal |
| Pulsewidth | 0.8 $\mu$sec Max |
| Duty Factor | 0.46% for 6 ms<br>0.1% Long Term |
| $V_{cc}$ | 50 Volts |
| $I_{Peak}$ | 840 Amps |
| Efficiency (PA) | 22.5% |
| Power Dissipated | 33 Watts Long-Term Average |
| Frequency | 1030 MHz |

The very high burst duty factor required of the primary power amplifier is reliably achieved by derating the output power of the microwave transistors from 300 watts to 200 watts each, with a resulting junction temperature limited to 120°C with a 60°C flange temperature. A 60°C flange temperature is the maximum that will be experienced in the system. The auxiliary power amplifier transistors operate at low duty, with a 0.8 microsecond pulse width; junction temperatures only get as high as 66°C with a 60°C flange temperature.

Each power amplifier includes an identical 16 to 1 Wilkinson power combiner with an isolator at its output to protect the transistors from potential output mismatches. The power combiner, its design depicted in figure 6, is realized in both microstrip and suspended dielectric air stripline. Both are etched on a single continuous piece of copper clad dielectric so that there is no need for rf interconnections. The dielectric circuit is screwed to an aluminum ground plane to form a 16 to 4 microstrip combiner. A step has been put in the ground plane at the microstrip to stripline interface. The unbroken dielectric circuit is supported in stripline by dielectric spacers. An upper ground plane is added to complete the suspended stripline where the final 4 to 1 combining is accomplished. The 4 to 1 combining in stripline has lower loss and higher peak power capabilities than would a similar microstrip 4 to 1 combiner.

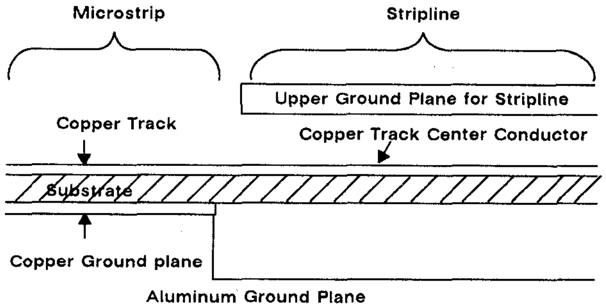


**Figure 6. Power Combiner Design**

The power amplifier modules also contain built-in test equipment circuitry that monitors the rf output power and gives a digital fault indication if two or more transistors fail. A single transistor failure in either power amplifier module will not lower the rf power below the minimum requirements of the primary or omni antennas.

The rf level control, as already mentioned, consists of two high-power electronic switches and three high-power attenuators, (see figure 4). The rf level controls allow adjustment of the output power of the primary and auxiliary amplifiers for three modes of operation: Mode S high power, Mode S low power, and ATCRBS.

The high power electronic switch is a reflective single pole, triple throw device. It consists of a transmission line shunted by diodes (see figure 7), and a switch driver board and bias supply board (see figure 8). The bias supply board converts an input of 15V into -200V. The switch driver under TTL logic control places a reverse bias of -200V or a forward bias of 100 mA on the diodes. In a switch the one "on" position, which passes rf, has the diode reverse biased and at the same time the two "off" positions, which prevent rf passage, have their diodes forward biased. The high reverse bias of -200V is required to keep the diodes nonconducting in the "on" position with 10 KW input. The high-power electronic switches have been tested without damage into an infinite VSWR at all phases with the primary amplifier (2.5 KW) and the auxiliary amplifier (10 KW).

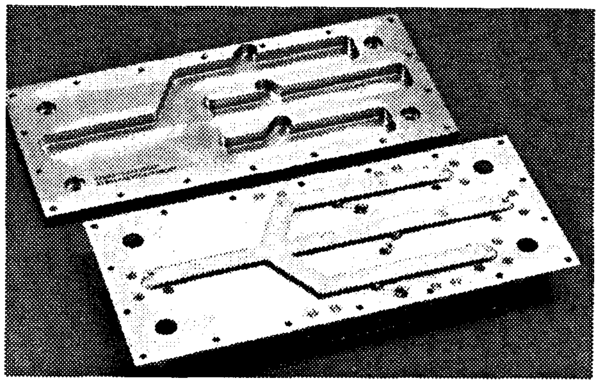

**Figure 7. Level Control Electronic Switch**

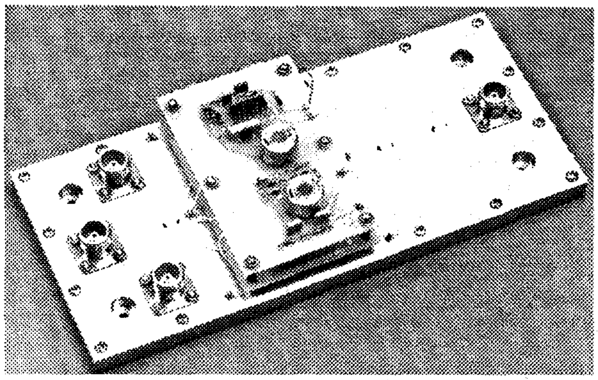

**Figure 8. Switch Driver Board (Below) and Bias Supply Board Above Mounted Atop the Electronic Switch RF Package**

The insertion loss of one switch position with the diode reverse biased is typically 0.30 dB. For one level control, containing two switches, and with the attenuators at their minimum setting, the insertion loss is typically 1.0 dB. Isolation of one switch in either of its off positions is typically 30 dB, so that a level control unit provides 60 dB isolation.

The high power attenuators are adjustable in 1 dB steps and are stable to $\pm$.25 dB from -10°C to +60°C.

**Conclusion**

A high-power rf solid-state transmitter has been designed for the Mode S Air Traffic Control System. Despite formidable differences in rf power, duty factor, and pulse widths in the primary and auxiliary amplifying channels, a great deal of commonality was achieved. This included identical modulator/driver modules and level control modules, along with very similar power amplifier modules.

Westinghouse is now producing the interrogators, which include the transmitters, for the Mode S Systems. In the next several years, the Mode S Systems will be installed in airports throughout the United States, with worldwide distribution expected.