A 25KW SOLID STATE TRANSMITTER FOR L-BAND RADARS

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Abstract

A 25KW L-Band solid state radar transmitter which uses forty high power, parallel modules in its output stage has been developed. The high power techniques which preserve inter-module stability and efficient power combining at this power level are presented. The overall transmitter design approach and resultant characteristics are discussed.

Introduction

Microwave solid state power amplifiers have advanced in capability over the last several years to the point now where entirely solid state transmitters are practical at very high power levels. The basic reasons for this are twofold. First, evolving technology has increased the output power of individual transistors by roughly a factor of four over the last five years. Second, the cost of each watt produced at the transistor level has decreased by a factor of four. These facts are especially true in the 400-4000MHz region for pulsed transistors. Since this band covers many of the prime search radar frequencies, the greatest effort in solid state amplifier and transmitter development has been for radars.

The first attempts toward entirely solid state radars took place in the forms of active aperture phased arrays. This was a natural starting point, since in those systems each element contributes only a limited amount of power toward the total. The combining of these separate powers is done in space, thus eliminating the loss of large combining networks. The special attributes and missions of phased arrays also allowed for a more competitive economical position for solid state transmitters when compared to tube alternatives.

Recently though, transistors have progressed sufficienty to allow the economical intra-transmitter combining of individual module powers to high levels. Single port transmitter output powers of 100-200KW at UHF and 25-50KW at L-Band are now conceivable. Such solid state transmitters are likely to be used in future radar systems and as retrofits into existing systems. In these applications, solid state will have these advantages over tube type transmitters:

- Higher reliability
- Lower life cycle cost
- Lower weight and volume
- Lower (and safer) operating voltages
- Higher efficiency

These transmitters will have additional benefits over solid state arrays. These are lower acquisition cost, a higher degree of maintainability, true graceful degradation (no beam shape change with module failures) and far fewer interconnections.

The remainder of this paper describes the design approach and results for a 25KW L-Band solid state radar transmitter. Considerations pertaining to the RF modules and the high level power combining of these modules will be presented. A photograph of this transmitter is presented in Figure 1.

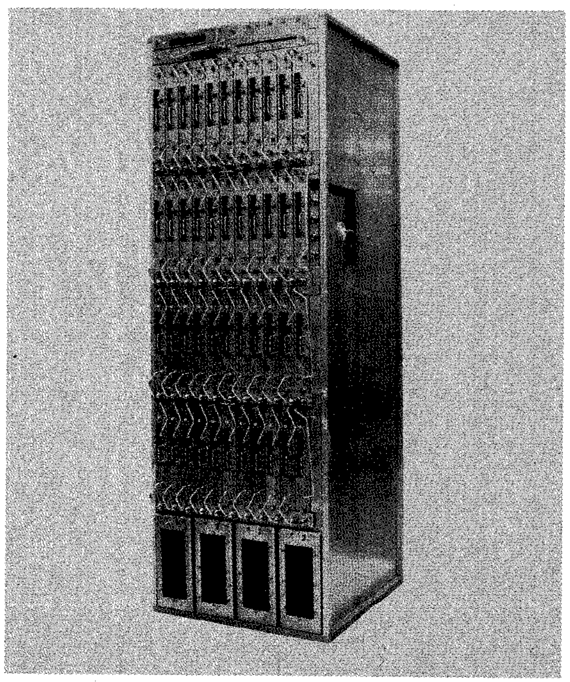

Figure 1. 25KW Solid State L-Band Transmitter

Power Module

The basic building block for the 25KW transmitter is the 650 watt module, which is shown in Figure 2. Forty-five of these modules are used in the transmitter. Forty of these are combined in the output stage.

The module is designed around the characteristics of a 110 watt microwave bipolar transistor. This device is rated for 40 volt operation and produces 110 watts minimum output over the 1200MHz to 1375MHz frequency band at a nominal 6 dB power gain and 42% collector efficiency. As shown in Figure 3, eight of these transistors are operated in parallel in the module's output stage. The output powers of these are combined with a phase compensated, Wilkinson 8:1 microstrip combiner which has a typical insertion loss of 0.6 dB. This combiner provides full isolation between the outputs of the eight transistors so that both module stability and high transistor reliability are maintained. With this isolation each transistor operates independent of its neighbors, even in the case of adjacent device failures.

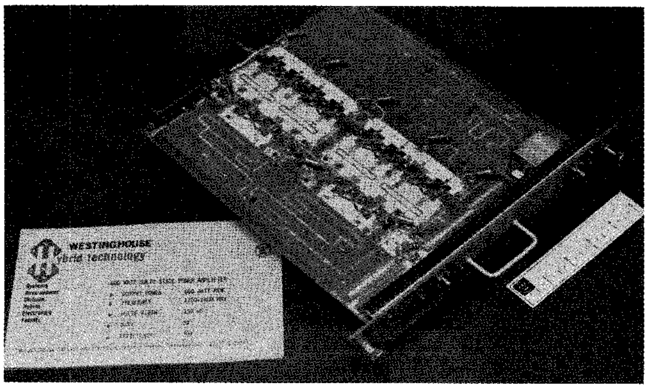

Figure 2. 650 Watt Basic Building Block Module

The eight outputs are driven in pairs by four half power driver transistors through four 1:2 quadrature splitters. These transistors are driven by a single half power transistor. All of the splitters used in the module are quadrature branch line in style. These maintain a higher degree of output to input isolation under non-optimum load conditions, while still being relatively economical to fabricate. This isolation is important in microwave amplifiers since it would not be desirable to allow the varying input impedences of output transistors to pull the load impedences of driving transistors.

A module output power monitor coupler and diode detector are located at the output of the 8:1 combiner. This status signal is provided for automatic fault isolation at the transmitter level. The RF coupler is followed by an output isolator which protects the RF transistors from output standing waves that may be caused by a transmitter output line or antenna fault. Providing this protection at the relatively low power module level is a more manageable approach than providing a transmitter output circulator and load at high power. Also, this approach allows the power combiners which sum the modules' power to be non-isolating and thus lower loss.

The 650 watt module circuitry is realized using microstrip techniques. Transistor matching circuits are fabricated on both 0.025 inch Al_2O_3 substrates and E-10 soft substrates. These high dielectric constant materials are used to decrease the size of the overall module and to assure repeatable and stable circuits. Teflon-glass material is used for the splitter and combiner circuits in order to provide low loss.

Transmitter Power Combining

As is shown in the transmitter block diagram in Figure 4, forty of the 650 watt modules are combined to the 25KW level. This is accomplished in two steps. The modules are first combined in groups of ten each with four 10:1 combiners. These four groups are then combined with one 4:1 combiner.

The design approach used to combine these modules emphasized three primary considerations. These were the needs for high combining efficiency, inter-module isolation and high power capability. High combining efficiency is essential in combining since it has a direct impact on transmitter output power, efficiency, size and weight.

Eq. (1) presents the generalized output power of a combiner driven by N elements:

$$(1)\quad P_o = \frac{1}{N} \times \left[\left[\sqrt{P_1} + \sum_{n=2}^{N} \sqrt{P_n}\cos\Theta_n\right]^2 + \left[\sum_{n=2}^{N}\sqrt{P_n}\sin\Theta_n\right]^2 \right] \times EFF_c$$

where N = number of driving elements

P_n = output power of the N^{th} element

Θ_n = relative insertion phase of N^{th} element

EFF_c = combining efficiency

P_o = total output power

EFF_c can be treated in terms of a combiner insertion loss if it has negligible port to port insertion phase and amplitude differences or if these differences are added to the driving element variances. To maximize output power, it is therefore important to keep both amplitude and phase variances small and to maximize combining efficiency.

In the transmitter, amplitude differences were smaller than 1.0 dB and phase differences were less than $\pm 5^{o}$. In a worst case analysis these numbers account for only a 0.04 dB difference in P_o versus $\sum_{n=1}^{N} P_n$. Therefore, the ratio of the total output power to the algebraic sum of the driving elements' powers is the combining efficiency:

$$(2)\quad \frac{P_o}{\left[\sum_{n=1}^{N} P_n\right]} = EFF_c, \text{ for } P_1 \simeq P_2 \simeq \ldots P_n \text{ and } \theta_2 \simeq \theta_3 \simeq \ldots \theta_n$$

The above equations are applicable for combining circuitry which is either isolating in itself or which is driven by isolated elements (generators). If this isolation is not provided, then each element may be affected by the characteristics of its neighbors. Since this is not desirable, many combiners are isolating in themselves and employ various quadrature or in-phase Wilkinson techniques. In general, these provide lossy elements (usually terminations) which absorb imbalance power. However, the inclusion of these techniques increases overall combiner loss, due to longer electrical insertion lengths and load imperfections, over that obtainable with a non-isolating impedence transformation circuit. This is especially true at high powers where high power capability terminations with good microwave characteristics are difficult to realize.

The alternative to this was used in the 25KW transmitter. That is, the driving elements themselves are isolated by means of their output terminated circulators. Thus low insertion length, low loss combiners were developed which use convenient line impedences to transform N fifty ohm inputs to one fifty ohm output.

The third primary consideration for the combiners was the capability for handling large peak and average powers. The RF voltages within the transmitter vary from 180 volts RMS at the module level to over 1100 volts RMS at the 25KW level. These voltages are under matched conditions and could double in the event of an infinite VSWR in the output line. In addition, the average power in the output combiners can be greater than 2500 watts. A 0.1 dB loss in an element within the combiners would have to dissipate 60 watts of average power.

In order to satisfy these requirements in a reasonable volume, air dielectric stripline combiners were developed. A 10:1 and a 4:1 are shown in Figure 5 and Figure 6 respectively. Figure 7 shows the 4:1 combiner with one ground plane removed. The units use 0.5 inch ground plan spacings and a 0.09 inch gold plated brass center conductor. Typical insertion losses for the units are 0.25 dB and 0.15 dB for the 10:1 and 4:1 respectively. These units are capable of peak powers of 75KW peak and 5KW average.

The total loss for the combiners and interconnecting cables is 0.7 dB, which results in a total combining efficiency of 0.85 for the transmitter.

Transmitter Approach

As mentioned above, forty 650 watt modules are combined in the output stage of the 25KW transmitter. As shown in the block diagram presented in Figure 4, these modules are driven by four identical modules. These modules are run at lower input voltage both to attain the required 350 watts of drive and to increase their reliability. Each of the driver modules' output powers is divided into ten parts by a 1:10 power splitter. These splitters are realized with microstrip circuitry fabricated on teflon-glass board. 2:1 and 3:1 Wilkinson style networks are used within the units to obtain an overall 10:1 split. Some ports are internally terminated. As opposed to the combiners, the splitters are required to be isolating in type since the module inputs are not ideally matched. Non-isolating splitters driving modules with 1.3:1 input VSWR's, but not having the same relative phase, may develop a 3 dB error in split ratio. These same loads when driven by an isolating splitter will have less than 0.1 dB relative drive difference.

The four driver modules are driven by another 650 watt module which is further derated. The output of this module is 220 watts which is split into four parts by a 1:4 splitter, which is similar to the 1:10 splitters. This module is driven by a highly derated, pre-driver module. This module delivers 50 watts of output at a power gain of 53 dB.

Some key overall characteristics of the transmitter are:

- Freq (MHz) 1250 - 1350
- Po (watts) 25,000
- GAIN (db) 84 dB
- Pulse Width Up to 100μsec
- Duty Up to 10%
- Efficiency 25%
- Size 24" x 24" x 72"
- MTI Capability 70 dB

Figure 8 shows the output power response of the transmitter. In addition to the RF assemblies described above, the transmitter has integral, redundant power supplies, cooling and status monitor assemblies. The monitor assembly displays the status of all sub-assemblies within the transmitter for ease of troubleshooting and repair. The transmitter also is self protecting against the failure of key internal functions and non-specified inputs. Since the RF transistors within the modules can be damaged by excessive pulse width, excessive PRF, power supplies failures and high temperature the transmitter automatically inhibits in the event of any of these conditions.

Conclusion

The use of L-Band solid state, single output port transmitters to replace tube transmitters at power levels in the 25KW - 50KW range is now practical. These transmitters use a great deal of modularity and efficient power combining to achieve their output power. The judicious choice of transistor operating conditions and protection circuits results in solid state transmitters which attain higher reliability and much lower life cycle cost than their tube counterparts.

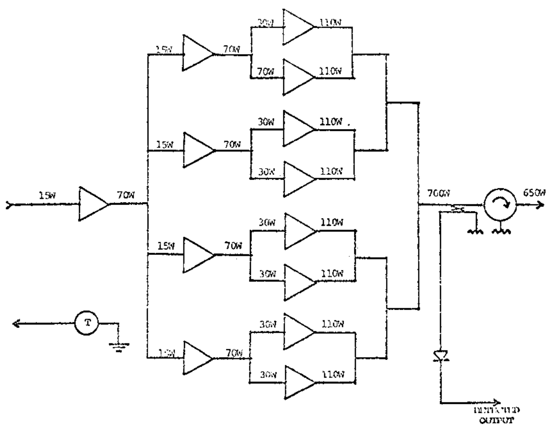

Figure 3. 650 Watt Module Block Diagram

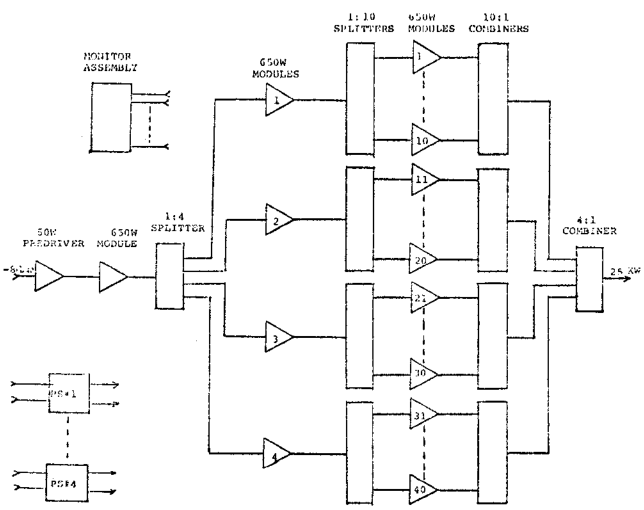

Figure 4. Transmitter Block Diagram

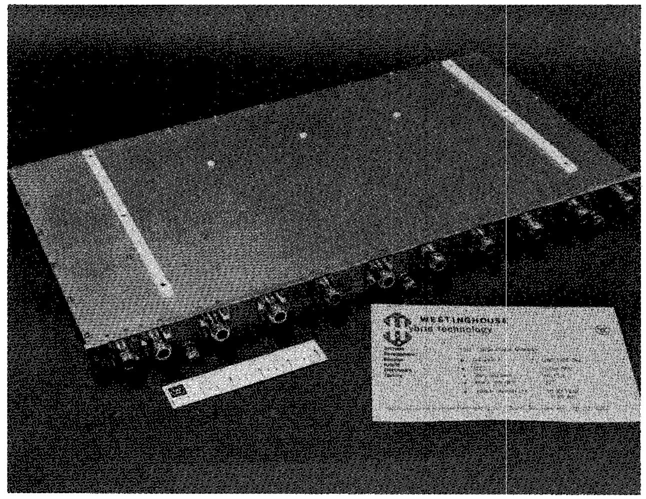

Figure 5. 10:1 Power Combiner Package

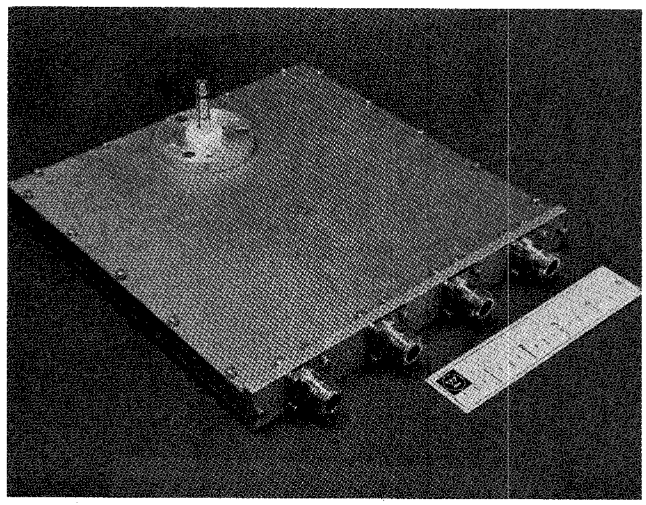

Figure 6. 4:1 25KW Power Combiner

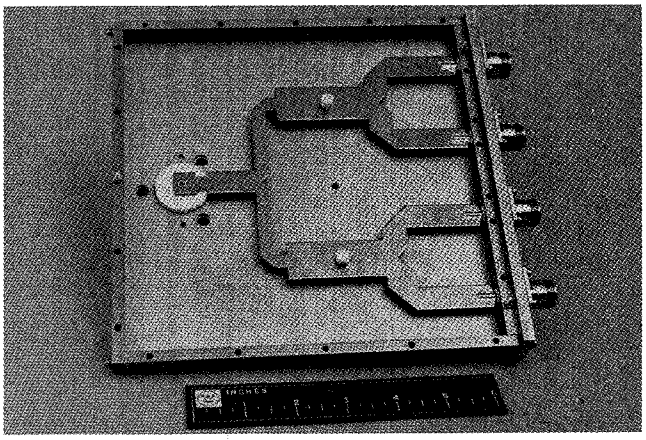

Figure 7. 4:1 Combiner Circuitry

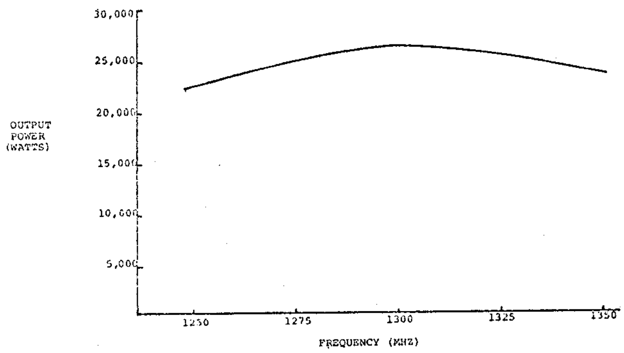

Figure 8. 25KW Transmitter Frequency Response