S BAND AMPLIFIER MODULE FOR SOLID STATE TRANSMITTER

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ABSTRACT - This paper describes the realization,the performance and the application of an amplifier module that for its characteristics can be used to build High Power Amplifiers in Solid State Radar Transmitters (SST).

INTRODUCTION

As the cost of S-band transistors has decreased and the power output has increased, solid state radar transmitters have become cost competitive with respect to tube transmitters.
The High Power Amplifier module is the heart of the SST because in its multiplicity, it represents the major cost item, as well as being the key to good performance and reliability of the whole transmitter.
For the above mentioned reasons, in the HPA design phase, the project and technological choices are strategical and particularly important.
In detail this paper deals with a suitable two transistor parallel module that can be considered as the building block of high power amplifiers with different power output levels, used in solid state transmitter applications.

MICROWAVE TRANSISTORS

Silicon bipolar power transistors under class-C operation are used to ensure high efficiency and high peak power at S band.
In recent years microwave bipolar power transistors, using silicon technology, have shown significant progress and today in the S band for medium pulse width (100μsec - 10% of Duty cycle), bipolar transistors have been developed producing over 100W of peak power output with good efficiency.
Device efficiency and power output together with amplitude/phase droop and pulse variations are basic characteristics in solid state radar transmitters.
In order to obtain the performances on a wider bandwidth, about 10%, a careful external matching networks design has been carried out to avoid performance degradation due to wide bandwidth especially for power output.
After a preliminary matching networks impedance design, the device has been characterized and optimized on a first prototype circuit to satisfy requirements such as power output, collector efficiency and amplitude droop in the whole frequency band [1],[2].
Table 1 shows transistor performances with the definitive matching networks.
In these applications, thermal design and junction temperature analysis are fundamental as all power transistor performances degrade when temperature increases.
Furthermore, junction temperature effects are strongly connected with device reliability, indeed ten degrees increase

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FREQ. GHz	Pout Wpk	EFF. %	GAIN dB	Input VSWR
2.65	88	39	6.9	2.1
2.7	88	39	6.9	1.5
2.8	90	41	7.0	1.35
2.9	85	41	6.7	2.4
2.95	80	39	6.4	2.6

Table 1 - Transistor performances

gives about a 60 percent increase in failure rate (MTTF).
To guarantee the estimated system reliability, the junction temperature of the active devices must not exceed 135°C in the 0-60 °C temperature operative range.
Figure 1 shows a typical power device thermal map, measured using an IR microscope (Barnes computerm) useful for finding hot points in the active area.
Figure 2 shows the hot spot junction temperature measured using a different IR microscope (Barnes model RM-2A).
With a flange temperature Tf=50 °C and dissipated power Pd=13 W, a DT=70 °C has been measured.

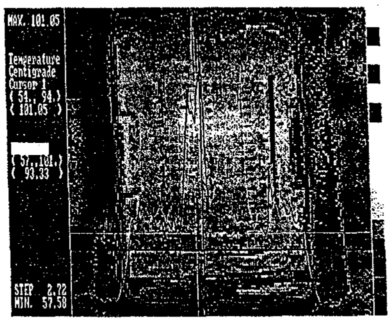

Fig.1 - Transistor Thermal Map

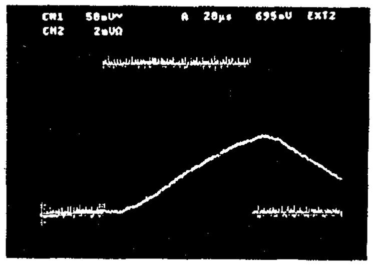

Fig.2 - Junction Temperature (DTjf = 70°C)

AMPLIFIER MODULE DESCRIPTION

The module, used as a primary component to build high power amplifiers for solid state transmitter applications, is a balanced amplifier with two identical parallel connected transistors.
Each module can drive four identical units operating in parallel. In this way the same amplifiers are used as final or driver stages, so that 500W and 1000W amplifiers can be built by a suitable modules combination.
The high degree of modularization performed with this design approach guarantees a low cost of maintenance, manufacturing and spare parts.
In the module design phase a careful analysis has been performed to match power handling and electrical requirements, to minimize the insertion loss and VSWR, to optimize the RF circuits and thermal aspects and to accommodate a reasonable mechanical configuration for the amplifier assembly. Photos of the module are shown in fig. 3.

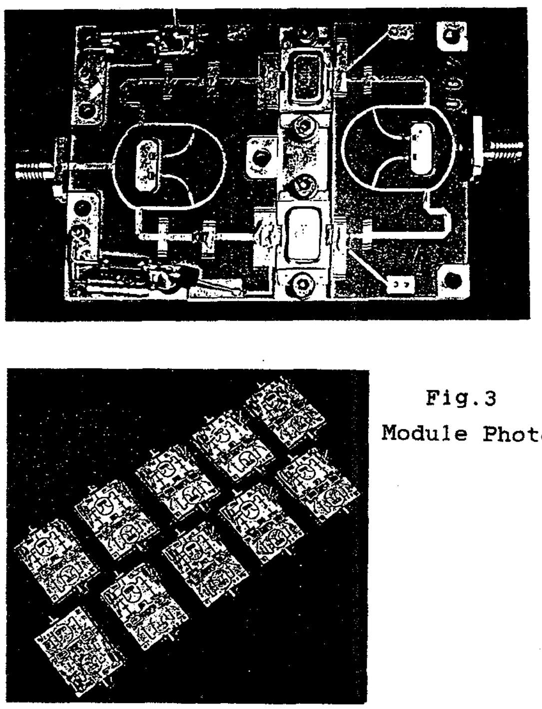

Fig.3 Module Photos

The balanced amplifier is realized on a microstrip circuit (6010 substrate), by two 85W derated transistors, combined in parallel with a planar Gysel divider/combiner to produce a nominal 160W of peak power output.
An 90 degree offset line in conjunction with a power divider is employed in order to reduce the input voltage standing wave ratio.
The use of Gysel dividers [3] is very advantageous in these applications because broadband, high isolation, low VSWR and mainly a good heat sink for load resistors due to a direct ground connection can be obtained.
Infact when one of the two module transistors is in failure, one-half power of the remaining active working device is dissipated in the two load resistors of the unit combiner.
Two 10W tantalum chip resistors with ground connection are used to guarantee a high average power dissipation that permits good reliability with any power transistor failure scenario.
Gysel hybrid has a RF isolation of 20 dB minimum between the output ports so that transistor interaction is negligible.
Electrical performances measured on the divider/combiner are shown in figure 4.
Transistors are derated by 10% of the collector voltage nominal value to increase the system reliability and to operate close to saturation point, in order to maintain modules quite insensible to drive level variations [4].
Energy storage capacitors are necessary to maintain supply voltage during pulse transmission. After a suitable analysis, a total of 2000μF tantalum capacitors have been chosen for each RF power amplifier module to guarantee the performances.
A high power amplifier with a nominal peak power of 1000W shown in fig. 5, has been realized by two 500W amplifiers operating in parallel and as previously mentioned, only modules with two transistor configuration, were employed.

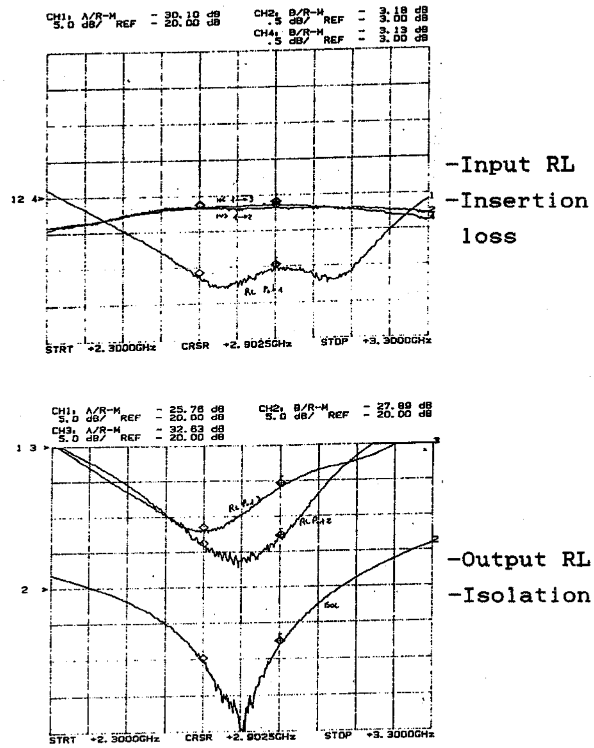

Fig.4 - Divider/Combiner Performances

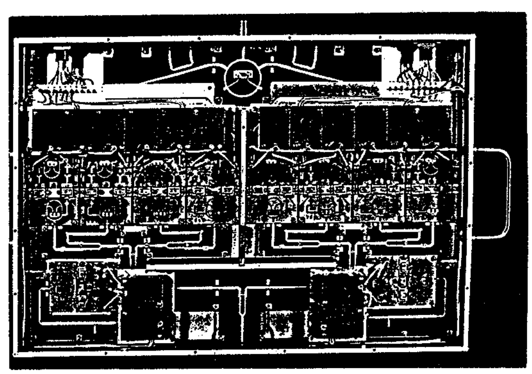

Fig.5 - High Power Amplifier Photo

MODULE PERFORMANCE

The circuits are designed and optimized, via Touchstone, software dedicated programs and experimental adjustment.

The main performances of the S band module tested in our laboratory are resumed in Tab.2 while fig.6 shows a typical output RF pulse and fig.7 shows insertion phase droop during the RF pulse measured by sampling each 2 nsec.
Table 2 shows that combining network losses reduce total efficiency to 39% while the phase offset improves the input VSWR all over the bandwidth. Performances have been measured with an automatic test equipment system that uses peak power meters and a phase correllator for insertion phase testing.

FREQ. GHz	Pout Wpk	EFF. %	GAIN dB	Trise nsec	Tfall nsec	Pulse Droop deg	Pulse Droop dB	Input VSWR
2.65	166	37	6.5	90	25	18	.2	1.25
2.7	168	37	6.5	90	20	18	.2	1.17
2.8	172	39	6.6	85	20	17	.2	1.10
2.9	160	39	6.3	85	25	9	.1	1.12
2.95	150	37	6.0	90	25	9	.1	1.15

Table 2 - Module Performances

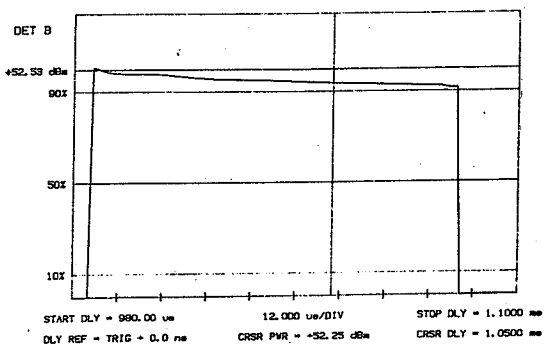

Fig.6 - Output RF Pulse (Amplitude)

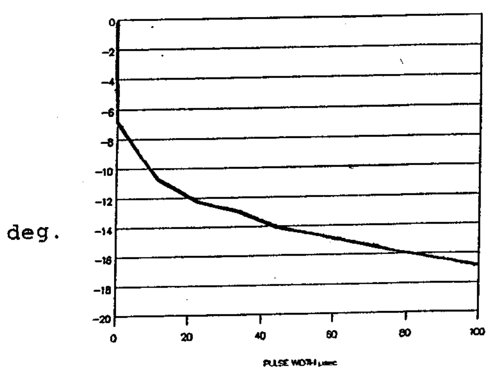

Fig.7 - Phase Droop During the RF Pulse

CONCLUSION

This module used as a building block of a solid state radar transmitter is ideal because it optimizes and resolves many critical aspects of this kind of application such as: high power output, efficiency, thermal and dissipation effects, electrical performances, reliability and mainly low production costs. A trade-off among all these aspects has been carried out to obtain the best solution.
A high number of identical modules are connected in parallel to reach the overall final power of the transmitter therefore as the cost of S band transistors decreases and the effective cost of the manufacture techniques evolves, the SST becomes even more competitive than the tube transmitter.

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