R.F. POWER MODULES FOR L-BAND SOLID STATE TRANSMITTERS

D. J. Hoft and L. R. Lavallee
Raytheon Company
Equipment Division
Wayland, Massachusetts 01778

Abstract

The advantages of Solid-State Transmitters and typical configurations will be briefly described. Several S.S. L-band modules developed over the past two years are delineated. The technical design approach of high power S.S. amplifiers will be discussed with emphasis on design for low junction temperature (long life) and production yield. A technique utilizing Smith Chart contour curves is presented.

Introduction

Advances in high power solid state technology in recent years now permit the building of Solid State Transmitters in the L- and S-band region. Typically the transmitter is made up of an assemblage of (n) power modules combined together to yield the overall transmitted power requirement. In a phased array configuration, transmitter power combination is achieved in space. Typically 5000 modules, each with approximately 50 watts of output power, are combined to yield a total of 250 Kwatts of output. In this case each module ordinarily contains a T/R switch, Receiver Amplifier, and phase shifter (for beam steering), along with the transmitter (amplifier) element. In the second case the module outputs are combined via a corporate feed structure to produce the total output power. In this case the (n) transmitter power amplifiers are required, while only one receiver is necessary. Typically 64 (2^6) modules, each with approximately 150 watts output, are combined to yield approximately 10 Kwatts total.

The advantages of Solid State Transmitters are:

1. Improved MTBF when compared with comparable tube type transmitters. Typical module MTBF's are greater than 10^5 hours. Recent literature [1,2] reports (output) transistor median life at near 10^9 hours for operation at junction temperatures below 140°C.
2. Graceful Degradation. It is significant that as individual modules (or stages) fail when operated, that overall power output degrades by only that power associated with the failed module which in most cases is relatively insignificant. Logistics, fault isolation and replacement are all extremely simple.
3. Projected Lower Cost.
4. Amplitude Modulation (weighting). SS transmitter configurations lend themselves more readily to AM'ing than tubes. Several techniques have been proposed which show great promise. Thus weighting, AM'ing and droop compensation are all possible for improved system performance.
5. Space Applications. Since transistor circuits are low impedance and lower voltage than power tubes, multipactor problems are significantly reduced.

A typical module configuration is shown in Fig. 1. This paper will focus on the SS Transmitter section of the module. More specifically it will concentrate on the power output stage design which, as might be expected, contributes most to performance, i.e., efficiency, reliability, etc.

Design Considerations

Table 1 shows three modules developed over the past two years (roughly in the chronological order shown). Several points are of particular significance; (1) the power output per stage has increased with the passage of time, (2) the power output per stage is an inverse function of the pulse width, (3) with the advent of device internal matching and ballasting the bandwidth capability/performance has improved markedly, (4) device junction temperatures have improved with time thus producing improved MTBF, and (5) the performance is consistent with transmission of high quality, wideband waveforms.

The exact configuration of the transmitter amplifier depends on the particular application and is heavily dependent on the design parameters Po, P.W., D.F., gain, Tj and load VSWR. The power output per stage is very much a function of the device, permitted Tj, and P.W.; Fig. 2 plots typical Po and Tj vs P.W. for the MSC 1214-30. The "knee" of both curves occurs at approximately 200 µsec due to the thermal time constant of the semiconductor. It is of fundamental importance that Tj be minimized to assure maximum life (recall the rough "rule-of-thumb" that -10°C change in Tj doubles the MTBF). Towards this end the stages are operated Class-C, and collector matched properly (VSWR) to assure maximum efficiency and Po as well as Tj (min). Typical efficiencies for the module output stages is between 50-65%.

Technical Approach

In depth investigations into junction temperatures on several types of microwave Class C amplifiers has led to the conclusion that designing an amplifier to work into a well matched load is not sufficient. It must be designed so that its performance does not exceed certain bounds as a load VSWR equal to or slightly higher than the worst expected to be encountered by the amplifier is swung through its phases.

Fig. 3 is taken from an infrared scanning of a Class C transistor operating at 1260 MHz with a P.W. of 1500 µsec and Po of 15 W peak. The horizontal and vertical axis are time and Tj respectively; for a near perfect 50 ohm load it is seen that at the end of the 1500 µsec RF pulse the temperature at the hottest portion of the junction is only 117°C. Performance in all areas was normal, i.e., output power, efficiency, phase settling, etc. However, when this same device under otherwise identical conditions is subjected to a load VSWR of 1.3:1 swung into its worst phase, its hot spot Tj has risen to a dangerous level of 180°C at 1500 µsec and the inverted slope of the temperature-time profile shows it to be approaching thermal runaway. A longer pulse period or a slightly higher load VSWR would undoubtedly cause the device to burn itself up. As it is MTBF would be seriously degraded over that predicted from its 50 ohm temperature performance. Yet its performance into 50 ohms gave no indication as to this serious degradation with such a modest load VSWR on its output.

This test was run on approximately 25 devices from different lots. The output impedance of the unit amplifier was then altered to an operating point that was more tolerant of VSWR. The test was then repeated with the new output circuit - no other changes were made. From the original test certain devices were found to be more tolerant of the load VSWR than others with hot spot temperatures ranging from a low 67°C to a high 180°C. None of the devices gave any indication of this in their 50 ohm performance - all their junction temperatures were low. This appears to be due to variations in internal reactances and thermal resistances from device to device. The second run with the new output impedance point resulted in a reduction in average hot spot Tj from 121°C to 82°C under worst case VSWR conditions, an equivalent increase in MTBF of approximately sixteen times. All 25 devices were not far more tolerant of the 1.3:1 VSWR. The new impedance point also improved the phase settling performance by 22° while the output power decreased only 0.9 watts from its original 16 watt level.

A series of contour plots provide the means for understanding the dramatic difference in performance. Fig. 4 (an expanded section of the Smith chart) is a contour plot of output power for a 30 watt device (having both internal matching and ballasting) with constant Po contour curves plotted for varying collector load impedances. These show a maximum output of 40.8 watts at an impedance point slightly to the left of the selected operating point. Fig. 5 is a plot of constant temperature contours vs collector impedance. Note the bunching of the contours at higher Tj's, definitely an undesirable operating area. Notice however, we can still obtain good output power if we simply move slightly to the right of the maximum Po point. With this operating point a 2.0:1 VSWR swing keeps us well away from the high temperature contours. The approximate 15% reduction in output power achieves the same effect as a mismatch loss - it stabilizes the amplifier making it more tolerant of device and circuit variations. Thus for a small loss in power output and efficiency, dramatic improvements can be made in other performance areas - notably junction temperature/MTBF and phase settling.

As can be seen from the temperature values on the curves the ballasting has the effect of making the device far less susceptible to load VSWR than the unballasted 15 watt device mentioned previously. At 1150 MHz the device delivered 34.8 W into a 50 ohm load. Swinging a 2:1 load VSWR around it produced a hot spot Tj (max) of only 104°C. Again the curves provide a powerful tool for determining the "goodness" of a selected operating point. In this case they tell us that we are on or very close to the lowest temperature contour in the area so there should be no problem running devices at the selected operating point. Any reasonable in-circuit VSWR's will degrade the reliability from its 50 ohm value but the degradation will be relatively minor.

Technical Results

The techniques described here have been used in designing unit amplifiers at 15, 30 and 50 watt levels using both Microwave Semiconductor and Power Hybrids devices. Fig. 6 summarizes the performance obtained with the MSC 1214-30 and a PH 1520C across an 1150 to 1400 MHz frequency range. The maximum junction temperature on the MSC device ran only 84°C across this band and even with a 2:1 load VSWR never exceeded 116°C; at 10,000 μsecs and 50% D.F. maximum Tj was 120°C. With a 1.5:1 load VSWR the junction temperature on the PHI device never exceeded 114°C over the 250 MHz range.

Three Power Hybrid devices have been combined into a complete transmitter assembly with output power in excess of 47 watts over the 1150 to 1400 MHz range. The maximum measured in - circuit junction temperatures were 100°C for the driver and 90°C for the dual final amplifiers. These temperatures should result in extremely reliable operation.

For a shorter pulse application (50 μsec) the MSC 1214-60 produced the results shown in Fig. 6. The module using four of these finals produced over 150 watts across the 1200-1400 MHz band.

Conclusions

A Class C RF amplifier can only be reliable if it is made tolerant of load VSWR's. The power, efficiency, and junction temperature contour curves technique allows the designer to optimize this tolerance, resulting in extremely reliable solid state transmitter modules.

Acknowledgements

This work was supported in part by U.S. Army Electronics Command under Contract DAAB07-72-C-0075 and in part by the U.S. Army SAFEGUARD System Command under Contract DAHC60-73-C-0045.

References

1. K.H. Fischer, "Pulsed RF Life of an L-Band Power Transistor", IEEE Symposium on Reliability Physics, 1973.

2. W.E. Poole, "Median-Time-To-Failure (MTF) of Microwave Power Transistors Under RF Conditions", IEEE Symposium on Reliability Physics, 1973.

Table 1. Parameters of three solid-state modules

	I	II	III
POWER OUTPUT (NOM)	50 ± 10 W	50 ± 10 W	160 W MIN
NUMBER OF OUTPUT STAGES	4	2	4
BANDWIDTH	135 MHz	250 MHz	200 MHz
PULSE WIDTH (MAX)	1500 μSEC	1500 μSEC	45 μSEC
D.F	30%	30%	14%
DEVICE INTERNALLY MATCHED/BALLASTED	NO	YES	YES
TYPICAL JUNCTION TEMP T_j	120°C	90°C	80°C
PHASE SETTLING	25° PEAK	25° PEAK	25° PEAK
PHASE TRACKING (BETWEEN MODULES)	14° RMS	14° RMS	14° RMS
INTRAPULSE PHASE VARIATION	1° PEAK/30 MHz	1° PEAK/30 MHz	1° PEAK/30 MHz
INTRAPULSE AMPLITUDE VARIATION	0.2 dB PEAK/30 MHz	0.2 dB PEAK/30 MHz	0.2 dB PEAK/30 MHz
MBTF, DESIGN FOR	$>10^5$ HOURS	$>10^5$ HOURS	10^5 HOURS

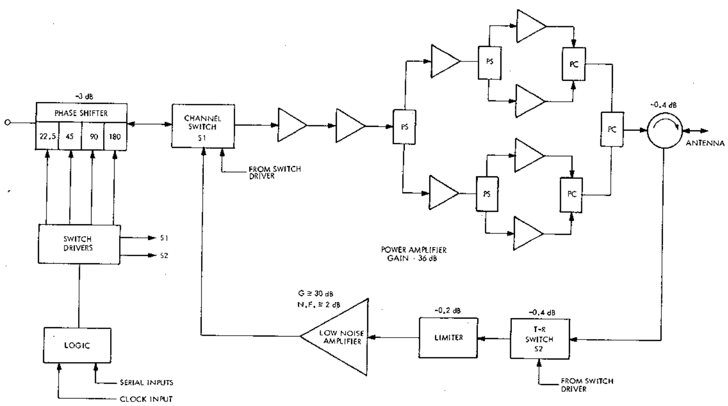


Fig. 1. Solid-state transceiver module block diagram

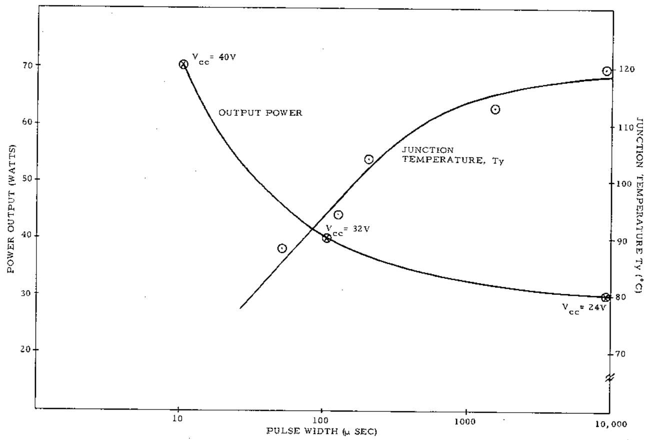
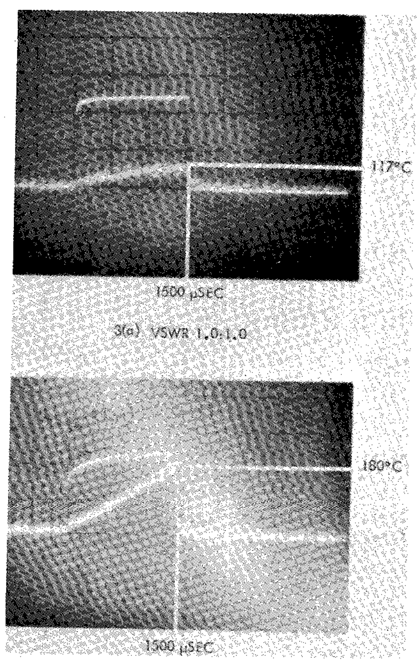


Fig. 2. Typical capability of MSC 1214-30 vs pulse width (1300 MHz)



3(b) VSWR 1.3:1, WORST CASE PHASE

Fig. 3. Junction temperature, Tj, of MSC 2010 vs time

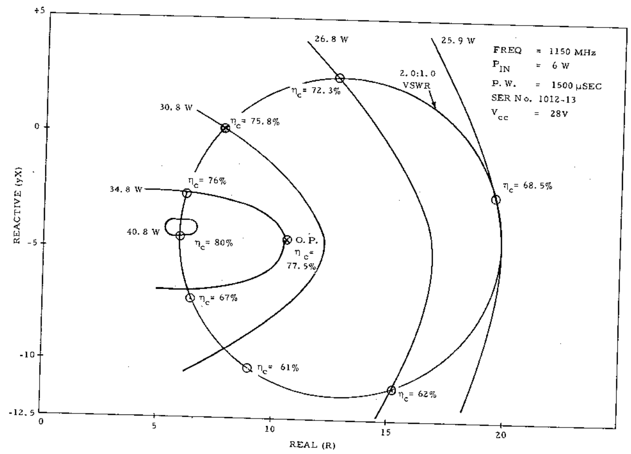


Fig. 4. Power contours vs collector load, MSC 1214-30

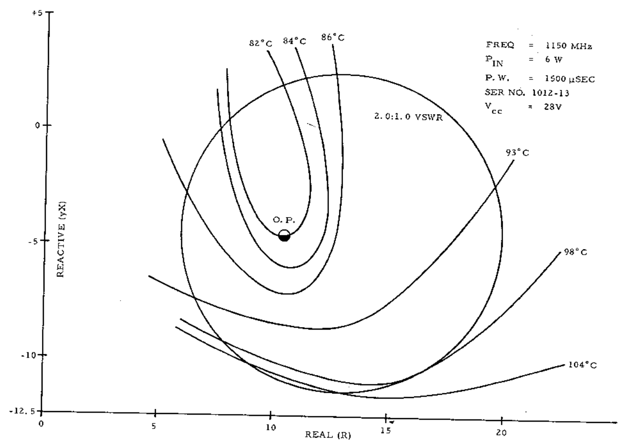


Fig. 5. Isotherms vs collector load, MSC 1214-30

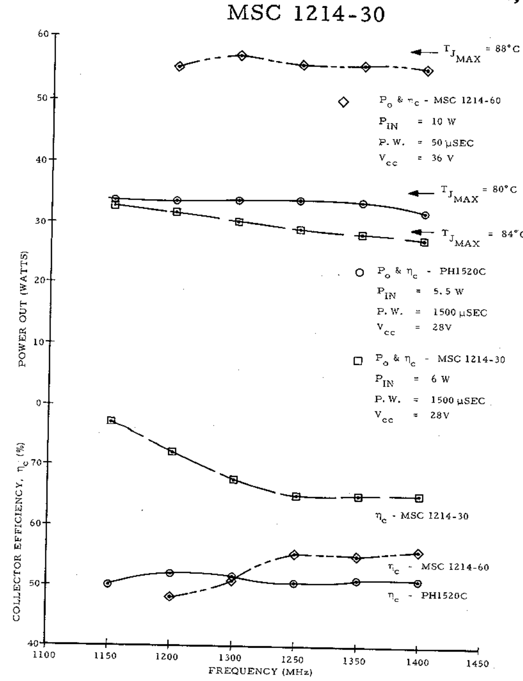


Fig. 6. Unit amplifier performance results