HIGH POWER 14 GHZ SSPA FOR SATCOM APPLICATIONS

R.Mallavarpu and M.P.Puri

Raytheon Co
Equipment Division / ECO
Waltham , MA

ABSTRACT

This paper describes the development of a 14.0GHz, 30W FET combiner/amplifier intended as a replacement for 50W TWTAs used in SATCOM uplink transmitter applications. The output stage of the amplifier consists of four 8W power FETs that are combined using a three dimensional combining circuit known as the spatial field power combiner. The entire amplifier is a self-contained unit with its own heat sink, high velocity blower and a regulator/sequencing circuitry for FET biasing. The amplifier results presented here show a P_{sat}=30Wmin, P_{1dB}=25W, AM/PM conversion=2°/dB max, Noise Figure= 4dB, and a typical two tone IM3=-25dBc with single carrier backed off 6dB from saturation. The high power handling capacity of the output combiner will enable development of 60 and 100W KU band SSPAs in the near future.

INTRODUCTION

With recent advances in the output power capability of power FETs from C to KU bands, there has been an accelerated effort to combine these devices to produce even higher power for possible TWTA replacements in SATCOM applications. Advantages of such an approach are the inherent low voltage, low noise, high reliability and large MTBF features of the FETs along with the graceful degradation scheme of the combiner used. There is a limit, however, to the number of such devices that may be combined since efficiency, thermal dissipation, size and cost are some key factors that must be considered before such an amplifier becomes a viable TWT replacement candidate.

An important component in the cascaded amplifier chain is the output combiner which must have both high combining efficiency (>90%) and a high power handling capacity. The standard technique employed in combining power FETs is to use a 3dB planar hybrid in a corporate arrangement. Such a scheme is commonly employed to combine two or four output devices. An attempt to combine eight or sixteen power FETs will result in an increase in the combining loss in proportion to the number of junctions used, increase in microstrip losses with frequency and an increase in area required for circuit realization. Another scheme that could be employed is to use a cavity combiner[1] where low loss, high efficiency combining may be achieved. The limitation here is that the bandwidth is restricted by the cavity resonance to about 3% and the circuit fails to utilize the operating bandwidth of the power FET which is typically at 5 to 6% at KU band frequencies. Different versions of the radial combiner[2,3], as well as Wilkinson and traveling wave are types of combiners used in combining FET amplifiers depending on the power and bandwidth requirements.

In this paper we describe the development of a 30W, 14.0-14.5 GHz SSPA using 8W internally matched power FETs and a three-dimensional power combining circuit known as the spatial field power combiner. The amplifier is a self-contained unit with its own heat-sink and a high velocity blower. This combining technique has been used to combine 70W CW mini-TWTs for a total power handling capacity of 500W CW. Results obtained in combining four mini-TWTs for 250W CW output were presented previously[4]. Results presented here include passive test results on the output combiner, RF performance of the 8W unit amplifier modules and RF performance of the integrated 30W amplifier unit.

High Power Combining Circuit

The output of the amplifier uses a combining circuit known as the spatial field power combiner[5], shown in the photograph of figures 1&2. It consists of a coaxial output that splits n-ways into TEM parallel plane lines each of which is transformed from a high impedance to the desired 50 ohms using a Tchebycheff or binomial distribution. The device normally operates in the balanced TEM mode. Should any asymmetry be set up at the input ports resulting from phase imbalance or device failure, then balanced and unbalanced modes are set up in the combiner. Two loads are provided internal to the combiner but external to the circuit path that serve to damp out the unbalanced mode content and leave only a pure TEM mode propagating in the device under all conditions and maintain interport isolation of 20-25 dB.

The 30W amplifier described here uses a four-way spatial combiner. This combiner has bandwidth capability from 7 to 18 GHz; passive test data is shown in figure 3 over the band 12 to 16 GHz. The results show insertion loss in the range of 0.5 to 0.6dB, with a 1.2 to 1 VSWR, and a typical interport isolation of 25 dB.

Amplifier Design and Layout

A general schematic of the microwave section of the amplifier layout is shown in figure 4. The RF section consists of five 8W cascaded amplifier modules each of which consists of an 8W and a 4W FET device. Four such amplifier modules are connected to the input ports of a four -way spatial power combiner. The input drive to these amplifiers is obtained by splitting the output of another 8 W amplifier module using a planar-type power splitter. At the input to the RF section is a 1W, 40 dB gain low noise amplifier. The 8W and 4W FET devices manufactured by Toshiba operate at a gate bias of -1.9V, drain bias of 9V and draw approximately 4 A and 2 A of drain current respectively. The RF section is mounted on a heat sink which is designed to dissipate 250W of power while maintaining the FET channel temperature at approximately 85°C for a given ambient temperature of 25° C. A high velocity air blower is mounted at one end of the heat sink. A regulator circuit is provided that ensures bias protection to the FETs and sequential turn-on/off. The entire amplifier, shown in figure 5, is housed in a container 19"x17.7"x17"

CH3277-1/93/0000-1217$01.00 © 1993 IEEE

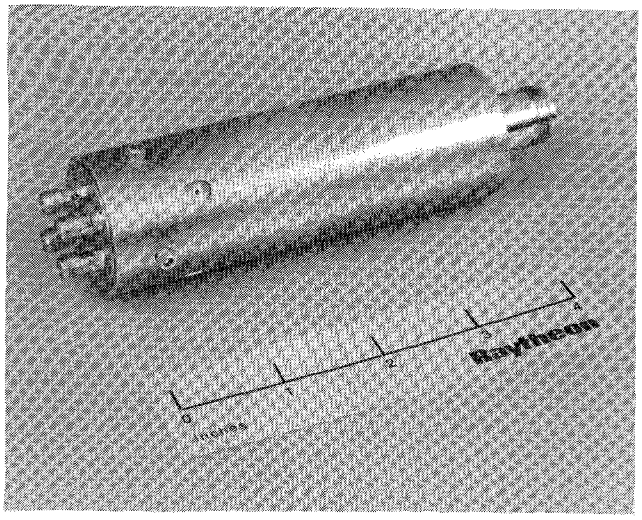

Figure 1. Four-Way Spatial Field Power Combiner

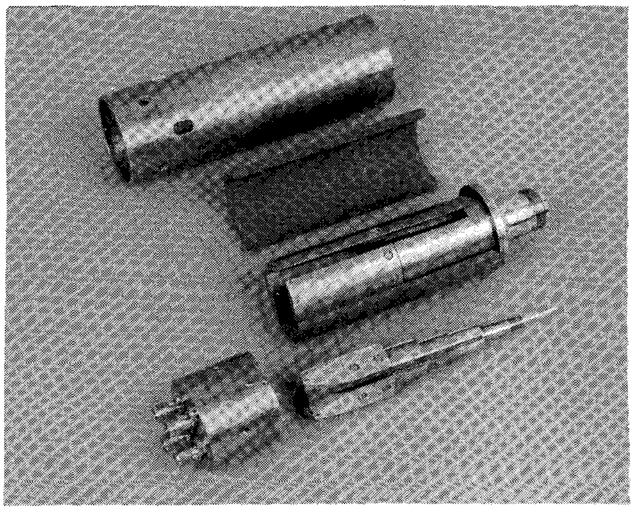

Figure 2. Components, Four-Way Spatial Combiner

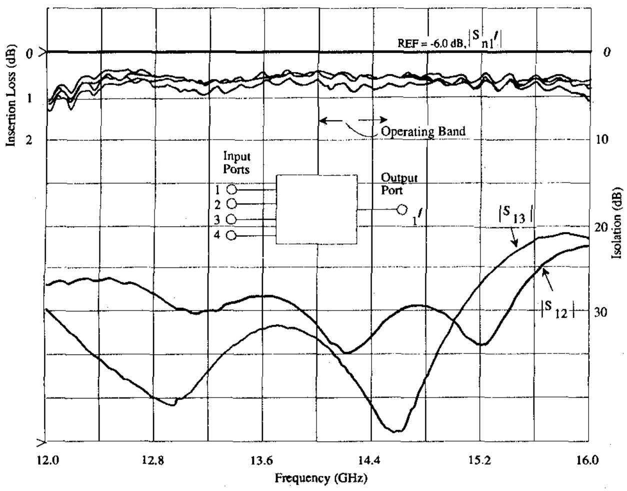

Figure 3. Passive Test Data, Four-Way Spatial Combiner

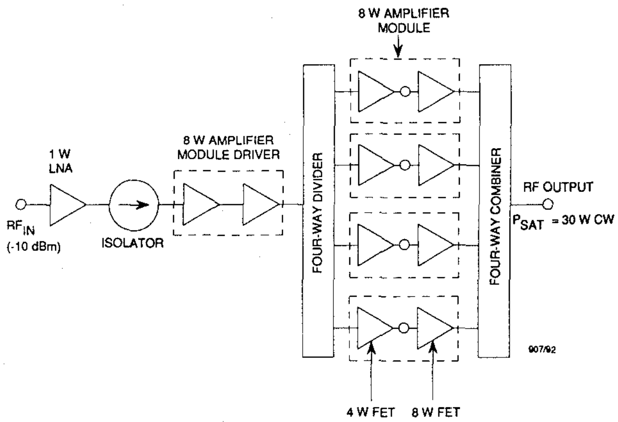

Figure 4. Schematic, Microwave Section of 30 W, 14 GHz Amplifier

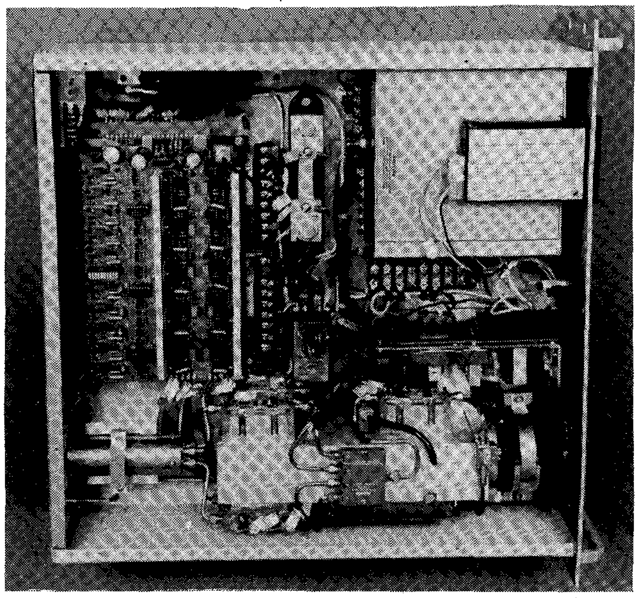

Figure 5. 14 GHz, 30 W SSPA

RF results on six 8W amplifier modules tested individually are shown in figure 6 . P_{sat} varies from 8 to 10W with a corresponding gain variation of 9 to 11 dB. Transmission phase measurements were made on each of the output 8W amplifier modules and the ΔØ spread was brought to within a +/- 8° window by trimming the line length between the power divider and the amplifier modules.

30W Amplifier Test Results

Figure 7 shows saturated output power across the band 14.0 to 14.5 GHz. A minimum of 30W CW is achieved with a maximum value of 34W CW at 14.3 GHz. The minimum saturated gain is 54 dB. Transfer characteristics at three frequencies 14.0, 14.25, and 14.5 GHz are presented in figure 8. P_{1dB} min of 44dBm is achieved with linear gain varying from 60 to 65 dB across the band. Third order intermodulation tests were performed on the amplifier with two signals each 6dB below saturation and 10MHz apart. Results summarized in Table 1 show IM3 variation from -26 to -24 dBc across the operating band and figure 9 shows a spectrum representative of the data at 14.25 GHz . Additional test measurements on the amplifier such as AM/PM conversion and the noise power measurements are also summarized in Table 1. The results correspond to an equivalent noise figure of 4dB for the entire amplifier. The 1W, 40dB gain LNA used at the input to the high power stage contributes primarily to the low noise figure of the amplifier while some reduction may also be attributed to the output power combiner which transmits only one-fourth of the total noise power with the rest absorbed as unbalanced mode power in the combiner loads. The efficiency of the microwave section of the amplifier is 11%. Additional improvement in the amplifier efficiency is contingent on an increase in the power-added efficiency of the output 8W power FETs from 22 to 25% and in the gain from 5 to 6 dB. This will enable replacement of the 4W FETs with 2W devices, making an efficiency goal of 13 to 15% for the microwave section feasible.

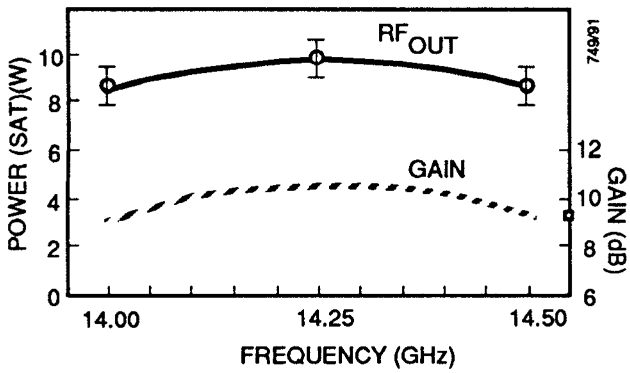

Figure 6. Saturated Power Output from Six 8W Cascaded Amplifier Units

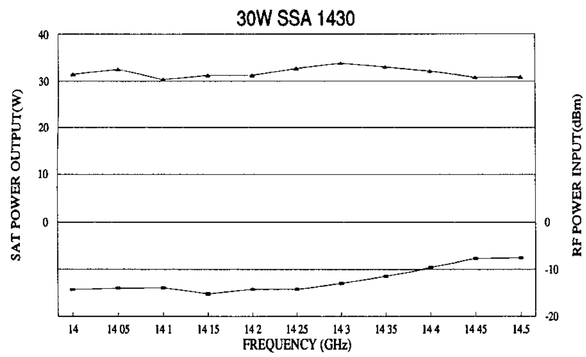

Figure 7. Saturated Power Output 14.0 to 14.5 GHz

Reliability and long-term life of the amplifier are dependent on at least two factors. One of these is the device channel temperature, which should be maintained below 130°C for an MTTF of 10^7 hours. The second factor concerns the extended period operation of the amplifier at various power levels. Manufacturer's life test data indicates an MTTF in excess of 10^5 hours for device operation at 1 dB compression. No such data is available for RF drive into additional compression although laboratory tests indicate a gradual decline (0.1 to 0.2 dB) in output power over a period of several days for devices driven 2 dB into compression.

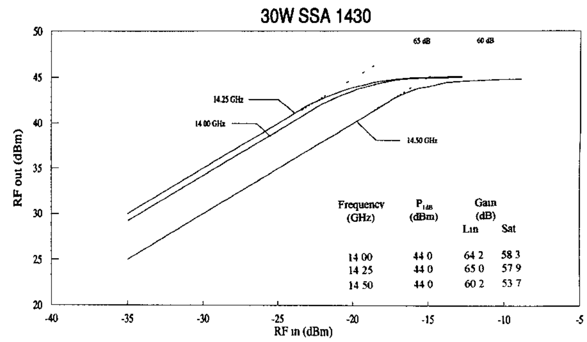

Figure 8. Transfer Charactistics at 14.0, 14.25 and 14.5 GHz

Table 1

A. IM3 Tests

Frequency(GHz)	Objective (dBc)	Measured(dBc)
14.00		-26.80
14.25	-25.0	-25.04
14.50		-23.77

B. Noise Power Measurements

Objective (dBm/4kHz)	Measured (dBm/4kHz)
-65	-76

C. AM/PM Conversion

Frequency	Measured AM/PM(°/dB)
14.0	2
14.5	2

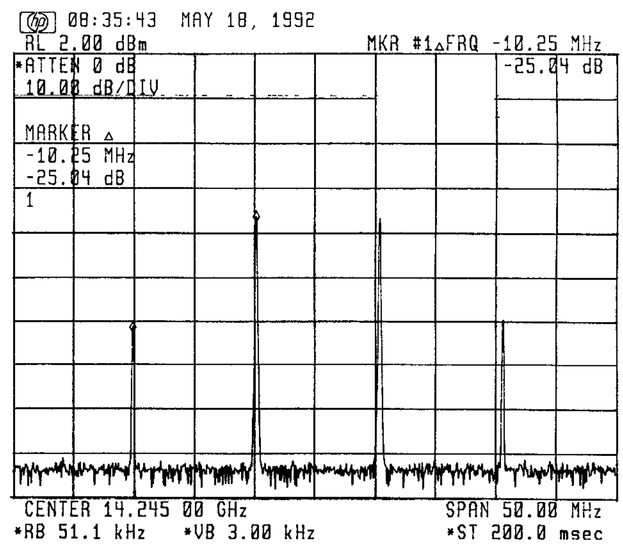

Figure 9. IM^3 Spectrum at 14.25 GHz

CONCLUSION

A 30W SSPA has been designed and demonstrated for the SATCOM band 14.0 to 14.5 GHz, using a three dimensional combiner at the output known as the spatial field power combiner. The amplifier has a saturated power output of 30W with 54dB gain and a typical linear gain of 62dB. Typical noise figure of the amplifier is 4dB. The high power handling capacity of the output combiner along with its low loss characteristics will enable the development of a 60W SSPA followed by a 100W SSPA.

REFERENCES

1. H.Mizuno, H.Mitsumoto, N.Yazawa, " A 12.5 GHz-Band 50W Solid State Power Amplifier for Future Broadcasting Satellites", 1990 IEEE MTT-S Digest, pp.1337.
2. I. Stones, et at , "An 18 GHz 8-Way Radial Combiner", 1983 IEEE, MTT-S Int. Microwave Symposium Digest, pp. 162-165.
3. E. Belohoubek, et al, 30-Way Radial Power Combiner for Miniature GaAs FET Power Amplifiers", 1986 IEEE, MTT-S Int. Microwave Symposium Digest, pp. 515-518.
4. R.Mallavarpu and M.P.Puri, "High CW Power with multi-octave bandwidth from power combined mini-TWTs", 1990 IEEE MTT-S Digest, pp.1333.
5. Mallavarpu , R., et al., U.S. Patent 5,142,253, 1992.