SOLID STATE POWER AMPLIFIERS AT L- AND S-BAND

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Summary Efficient solid state amplifiers in the L- and S-band have been accomplished with transistors and varactors. Power outputs of 10 W and more have been realized in microstrip technique with efficiencies of 40 % in the L-band and 30 % in the S-band.

Introduction A development of space borne solid state power amplifiers was started 2 years ago, in order to investigate the efficiency of new semiconductor elements. The amplifiers were realized in microstrip technique to reduce volume and weight. The investigations were concentrated to power amplifiers in the L- and S-band. The L-band at 1.60 GHz is especially of interest for communications and navigations with aeronautical and maritime satellites, the S-band at 2.30 GHz is for deep space probes. Some results of these investigations will be demonstrated.

L-band Amplifier A power output of 10 W can be realized with 2 transistors, as shown in the block diagram of Fig. 1. Fig. 2 shows a laboratory model of this 1.60 GHz amplifier with 2 MSC 3005 transistors. In a further step of development the power divider at the left and the power combiner at the right are integrated in the microstrip layout. An input power of 1.05 W was amplified to 12.2 W with an efficiency of 43 %. Efficiency is here defined as (output power - input power)/DC-power. Output power as a function of input power is shown in Fig. 3. At low levels the curve is linear. Since power transistors operate class C the amplification began with an input level far above zero. Fig. 4 illustrates the output power versus frequency at a constant input level of 1.22 W. A 1-dB-bandwidth of 100 MHz was measured, the 0.5-dB-bandwidth has a value of 70 MHz. An interesting point is the suppression of harmonics, the second harmonic lies 32 dB, the third 58 dB below the level of the desired frequency of 1.60 GHz. The power transistors were not driven at maximum level because of decreasing gain and efficiency at higher levels. Fig. 5 demonstrates this fact.

For completeness it should be mentioned that one transistor delivers 7.5 W at 1.60 GHz with a collector efficiency of 55 % and a gain of 11.6 dB.
**S-band Amplifier**  Different concepts were studied at the 2.3 GHz telemetry band. Similar to the 1.6 GHz amplifier a 10 W amplifier was developed using 2 MSC 3005 transistors in parallel. Tests have demonstrated, that the transistors offer 6 to 6.5 W at 2.30 GHz with a collector efficiency of 40 % and a gain of 7.5 dB. Four chains would offer 22 W with an efficiency of about 25 %, as illustrated in the block diagram of Fig. 6. A realization with two chains shown in Fig. 7 lead to 11 W with 26.3 % efficiency and 5.7 dB gain. The low Q-value of microstrip technique delivers a 1-dB-bandwidth of 100 MHz, the 0.5-dB-bandwidth is 60 MHz. These datas are taken from Fig. 8 where output power is a function of frequency for constant input power.

One or two years ago power transistors alone were not the best semiconductors to offer at 2.3 GHz 20 W rf-power with optimum efficiencies. Transistor stages followed by multipliers, especially doublers, were the best devices in solid state technique until 1972. Power transistors operating at the half output frequency, possess higher efficiencies and gains, which offer, in spite of the converting losses of the frequency doubler, a better efficiency for the whole circuit in comparison with a MSC 3005 transistor version. Fig. 9 and 10 show the block diagram of two possible solutions. Power transistors operate at 1.15 GHz using the RCA transistor TA 7205. The following frequency doubler consists either of a MA 43000 varactor from Microwave Associate or of the BXY 19 GB varactor from Siemens. The Siemens diode can absorb the output power of 2 transistors. A development of a 10 W amplifier (Fig. 11) possesses an efficiency of 29.3 % and a gain of 7.3 dB. The bandwidth is only the half of the transistor version; this depends on the smaller bandwidth of the doubler existing of two λ/4-resonance circuits. Fig. 12 and 13 show the output power versus temperature resp. frequency of a transistor-varactor combination.

The superiority of transistor-doubler-stages at the 2.3 GHz telemetry band seems to be lost by new transistor developments introduced into the market in the early 1972. This transistor, the MSC 4005 from Microwave Semiconductor Corp., delivers 8 W at 2.3 GHz with a collector efficiency of 50 % and a gain of 10 dB. Two parallel chains would offer 14.5 W and an efficiency over 40 % (Fig. 14), a value which only could be achieved till now by travelling wave tube amplifiers. Developments with the MSC 4005 are still going on.

**Conclusions**  The replacement of high efficiency travelling wave tubes by solid state technique becomes now interesting also for the S-band. Fig. 15 gives a survey about the feasibilities of power amplifiers in the L- and S-band with some of the best microwave transistors, Fig. 16 shows the corresponding efficiencies for these transistors.

A transistor amplifier should be preferred to an amplifier-doubler-version because of lower volume and weight. The bandwidth does not act a great part in telemetry
amplifiers like in those for commercial communications. The advantages of semiconductor power amplifiers, consisting of compact realization in microstrip technique, no high voltage power supply, may accelerate the replacement of travelling wave tube amplifiers by solid state technique.

**Acknowledgement**  I am indebted to my colleague R. Stoiber, who developed the transistor-doubler version.

![Fig. 1 Block Diagram of the 1.6 GHz Amplifier](image1)

**Fig. 1 Block Diagram of the 1.6 GHz Amplifier**

![Fig. 2 Realization of the L-Band Amplifier](image2)

**Fig. 2 Realization of the L-Band Amplifier**
Fig. 3 Output Power and Transistor Currents versus Input Power

Fig. 4 Output Power versus Frequency
Fig. 5 Gain and Efficiency versus Input Power

Fig. 6 Block Diagram of the 2.3 GHz Amplifier
Fig. 7 S-Band Transistor Amplifier

Fig. 8 Output Power versus Frequency

Fig. 9 Transistor-Varactor-Combination with MA 43000 Diode
Fig. 10 Transistor-Varactor-Combination with BXY 19 GB Diode

Fig. 11 Transistor-Varactor-Amplifier for the S-Band

Fig. 12 Output Power and Efficiency versus Temperature
Fig. 13 Output Power versus Input Frequency

Fig. 14 Block Diagram of a Transistor Amplifier with MSC 4005
Fig. 15 Feasibility of Microwave Power Transistors

Fig. 16 Achievable Efficiencies of Transistor Power Amplifiers