MOSFET RF POWER AMPLIFIER FOR ACCELERATOR APPLICATIONS[1]

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Abstract

An inexpensive reliable 500 MHz 1 kW CW MOSFET solid state linear amplifier has been developed for accelerator applications. It presents the following advantages : Each 150 W module is protected by a surface mount circulator and is equipped with input and output trimmer capacitors to assure perfect matching, equal gain and high efficiency ; Only two pieces of simple 8-way impedance transformer are used for RF power distribution and combination. Based on this modular amplifier, low cost, very high power solid state amplifiers may easily be developed.

1. INTRODUCTION

A 1 kW amplifier is needed to drive the TH563 tetrode in the new 500 MHz fifth harmonic RF system for the storage ring Super-ACO [1].

New generation solid-state devices, i.e. silicon RF power MOSFETs are used. They have a number of advantages over their bipolar counterparts : high power gain ; no thermal runaway ; low noise figure; low feedback capacitance; easy biasing ; gold metallization ensuring excellent reliability ; etc.

For a storage ring, the RF frequency is fixed, allowing the design and development of a special-purpose amplifier for optimum performance : higher efficiency, perfect matching, lower harmonics [2].

2. MODULE

The principal basic unit of the 1 kW amplifier is a 500 MHz 150 W amplifier module. Its schematic diagram is shown in Figure 1.

In Figure 1, Q1 is a BLF548 power MOSFET made by Philips Semiconductors. It has a push-pull configuration. Therefore on the input and output circuits, the Baluns B1 and B2 are necessary, both consist of a section of 50 Ω semi-rigid coaxial cable. We take their length equal to 67 mm. Therefore the striplines T1, T2, T3 and T4 act as the 3rd harmonic filters.

T3 and T4 are striplines. They are used for input and output matching.

C3, C4, C9 and C10 are trimmer capacitors. They are used for adjusting input and output matching.

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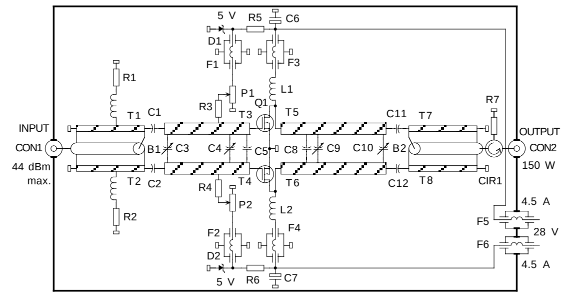

Figure 1. Schematic diagram of 150 W module.

A surface mount circulator CIR1 with a termination R7 is used for protecting the MOSFET, it improves amplifier stability and simplifies the power combiner.

R1 and R2 are used for improving the stability at low frequency (about 180 MHz).

In order to obtain a compromise between efficiency and linearity, Class-AB operation is used. The 2×160 mA quiescent drain-source currents are set by adjusting the potentiometers P1 and P2.

3. MEASUREMENT CIRCUIT

In order to obtain optimum operation conditions and identical gain for all amplifier modules, the measurement circuit, shown in Figure 2, is used.

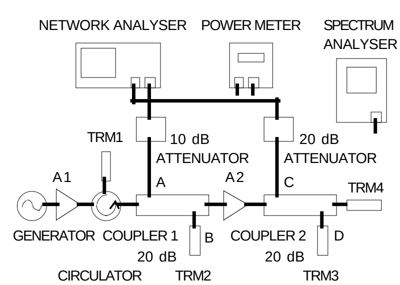

Figure 2. Measurement block diagram.

In Figure 2, A2 is one of the 150 W amplifier modules that we want to measure.

The Generator (R/S SMT03) delivers an RF signal, which is amplified by a 25 W amplifier A1 and passes through the Circulator and Directional Coupler 1 to drive the 150 W amplifier module.

Because all instrument inputs are low level, we must insert the Directional Couplers 1 and 2.

The network analyser (HP 58753D) is set to A/B mode and its internal generator is switched off. When testing the power gain, we compare the Signal C with Signal A from the Directional Couplers 2 and 1. When testing S11, we compare Signal B with Signal A from the Directional Coupler 1.

TRM4 is a 50 Ω 1 kW load resistor.

The Power Meter (R/S NRVD) with the Sensors (NRV - Z5) is used for RF power measurements.

4. CHARACTERISTICS OF MODULE

4.1. Gain and Phase Shift

The RF power gain as a function of output power is shown in Figure 3.

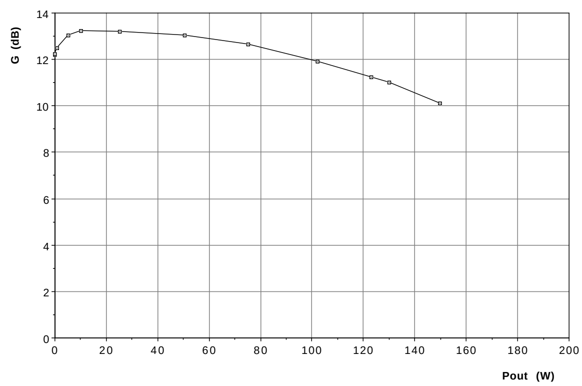

Figure 3. Gain versus output power.

Its phase shift is a function of output power also. According to measurement, between 125 W and 150 W output, the phase difference is only 1°. But between 25 W and 125 W output, it becomes -0.136°/W.

4.2. Efficiency

The efficiency as a function of output power is shown in Figure 4.

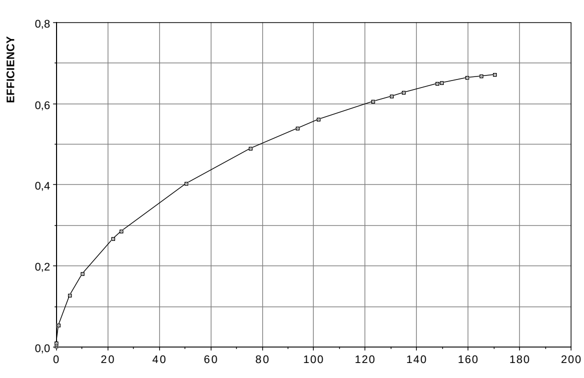

Figure 4. Efficiency versus output power.

The value of output power is measured behind a circulator, whose insertion loss is about 0.3 dB. Nevertheless the efficiency is still equal to 60 - 65 % at 150 W output power.

4.3. Input Matching

Input impedance depends on output power. The S11 parameter is shown in Figure 5.

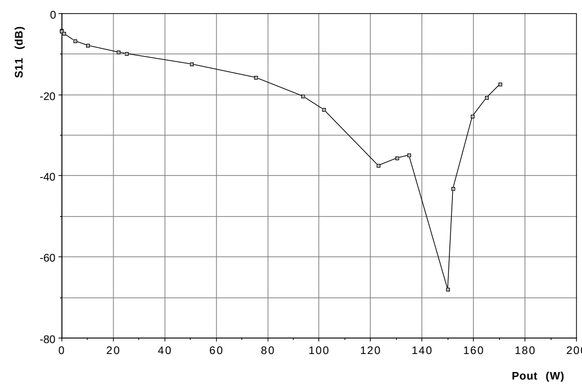

Figure 5. S11 versus output power.

From Figure 5, we see that between 137 - 152 W, S11 is less than -40 dB.

4.4. Harmonics

We measured the harmonics at 50, 100, 150 W output power with a spectrum analyser (Tektronix 497P). The maximum harmonic content occurs at 150 W output power, it is the 2nd harmonic and is equal to -42 dB. For a push-pull circuit, normally the maximum harmonic is the 3rd harmonic, however our circuit contains the equivalent of 3rd harmonic filters (T7 and T8 in Figure 1), which reduce this harmonic to -68 dB.

4.5. Frequency Characteristics

In order to study and understand the RF power MOSFET amplifier, we measured all frequency characteristics at different power levels.

At the 499.396 MHz operation frequency and 150 W output power, we can adjust the trimmer capacitors to maximize efficiency and minimize S11.

But the maximum gain S21 does not always occur at operation frequency, it is dependent on the output level. At very low level, the maximum S21 occurs at 507 MHz, at 150 W output it occurs at 489 MHz.

The phase shift characteristic is linear around the operation frequency. The group delay is about 14 ns.

At 499.396 MHz and 150 W output power, the input matching S11 is less than -50 dB, and within 6 MHz, it is less than -20 dB.

But the minimum S11 does not always occur at operation frequency. It is dependent on output power. At low level, the minimum S11 occurs at 513 MHz and is equal to -17 dB.

4.6. Stability

For an RF power amplifier, stability is very important. For accelerator applications, generally Unconditional Stability is preferred.

We measured the S parameters from 100 MHz to 2 100 MHz at low power level with the network analyser. Then we calculated the stability condition for these frequencies. The result is that the stability of our module is Unconditional with 5.6 dB gain protection, because there is a circulator with 18 dB isolation in our module. Without it, the stability would be Conditional.

5. 1 kW AMPLIFIER

The 500 MHz MOSFET 1 kW amplifier block diagram is shown in Figure 6.

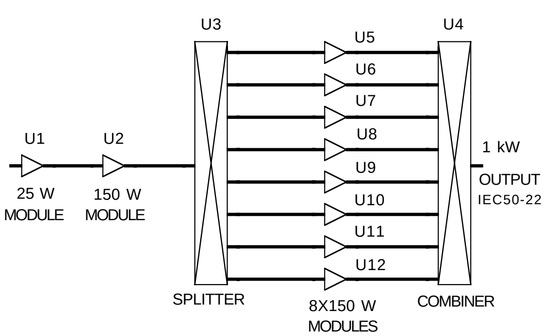

Figure 6. 1 kW amplifier block diagram.

In Figure 6, U1 is a commercial 25 W module with 39 dB of gain. It works in Class-A operation.

U2 and U5 - U12 are 150 W modules, which are water cooled. U3 is an 8-way RF power splitter. U4 is an 8-way RF power combiner. They were made in our laboratory.

At 150 W output power, among the nine 150 W modules, the maximum difference in gain is 0.045 dB and the maximum difference in phase is 7.35°.

For the RF power splitter, S11 is -41 dB. Between the 8 outputs, the maximum difference in S21 is 0.04 dB and 0.74°.

For the RF power combiner, S11 is -35 dB. Between the 8 inputs, the maximum difference in S21 is 0.04 dB and 0.53°.

For the RF coaxial cables, which are between the splitter and 150 W modules, as well as combiner, the maximum S11 is -30.3 dB and the maximum difference in S21 is 0.01 dB and 2.94°.

There is no circulator in the 25 W preamplifier U1, so the coaxial cable length, between U1 and U2, is important for linearity. Taking the optimum length can improve the total linearity of the 1 kW amplifier by 4 dB. In Figure 3, within 150 W, the maximum difference in gain is 3 dB. There are two stages of 150 W module in the 1 kW amplifier, so the maximum difference in total gain could be 6 dB. But due to this compensation, the maximum difference in total gain is only 2 dB.

At 1 kW output power, the total gain is 61 dB and the total efficiency is 50 %.

6. CONCLUSION

For accelerator applications, it is preferable to develop special-purpose RF power amplifiers, because all commercial amplifiers or modules are designed for broadband applications, so their efficiency is lower, harmonic contents are higher and matching is less good. A comparison of specifications between our module and a commercial class-AB 150 W MOSFET amplifier module is shown in Table 1.

Table 1. Comparison of specifications.

	Our Module	**Commercial**
Efficiency	60 %	30 %
Input VSWR	1.02	2
Load VSWR	Infinite	3
2nd harmonic	-42 dB	-20 dB
3rd harmonic	-68 dB	-12 dB
Stability	Unconditional	Conditional

Since March 1997, this 500 MHz 1 kW MOSFET amplifier has been functioning without incident.

In 1997, a 100 MHz 1.5 kW MOSFET amplifier was also developed to replace two 4CW800B tetrodes in parallel based pre-amplifier for driving a 4CW50000E tetrode. It also works very well.

A low cost 352 MHz 30 kW CW MOSFET amplifier for the new project SOLEIL is currently under development. Its cost could be lower than the cost of a tetrode amplifier.

ACKNOWLEDGEMENTS

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REFERENCES

[1] G. Flynn et. al., “A New 500 MHz Fifth Harmonic RF System for Super-ACO”, this conference.

[2] T. Ruan et. al., “Amplificateur 500 MHz 1 kW MOSFET”, Super-ACO/98-03.