Overview and Simulation of the Solid-state RF Power Amplifier for Plasma Heating at 40±6MHZ

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***Abstract*: This paper presents review of the design of watt-level solid-state power amplifiers (PAs). The main motive is to reach up to desired power level from CWRF solid state PA, the paper focuses on proper biasing technique and impedance matching of transistor with the Characteristic impedance of the transmission line. Reliability often sets the limits for the PA design and mismatched impedance matching results in low gain is reviewed. In this work a commercially available solid-state device MRF134 has been used for developing a power amplifier. The stability of this MOSFET is improved by parallel loading of the input and output circuit. The Transformer and L section matching technique are reviewed and the simulation of MRF134 by L section matching technique is presented.**

***Index-Terms* - Solid-State PA, MRF134, transformer matching, stability.**

I. INTRODUCTION

RF power output from radio frequency oscillators and amplifiers can be used to generate plasma at various frequencies. In RF and microwave circuits, transducers provide weak signals which need to be amplified. This amplification of power is done by using a vacuum tube or the transistor. Amplifiers increase the power of an RF signal by converting dc power to RF power. Amplification of input signal power is an important part of the RF transmitting systems. The amplifier is placed atthe last stage of the RF transmitting system. Its role is to amplify the high-frequency signal to the desired power to meet the requirements of transmitting load units.

The RF frequency bands for industrial, scientific and medical(ISM) utilization are 13.56 MHz, 27.12 MHz, and 40.68 MHz. It is widely used for an industrial heating application also. While designing an appropriate system, efficiency and optimum power transfer are main factors that must be considered. Design of an efficient system with optimum power transfer can be achieved by a suitable power amplifier. The most important parameters in the power amplifier design are operating frequency, linearity, efficiency, power output, gain and bandwidth, while designing a power amplifier, a trade-off between bandwidth and efficiency is made because improving any one of them would degrade the other.

In current development of technology, transistors have an advantage over vacuum tubes in most of the area in the electronic circuit. At most of the places, solid state devices are widely used for amplification power since it is consecrated with various advantages like high voltage gain, mechanical strength, light-weight etc. Solid state devices are highly used for the driver stage where the reflection of a wave is predictable and is not much higher.

1.1 BLOCK DIAGRAM

The circuit diagram of the proposed broadband PA is shown in Fig.1.

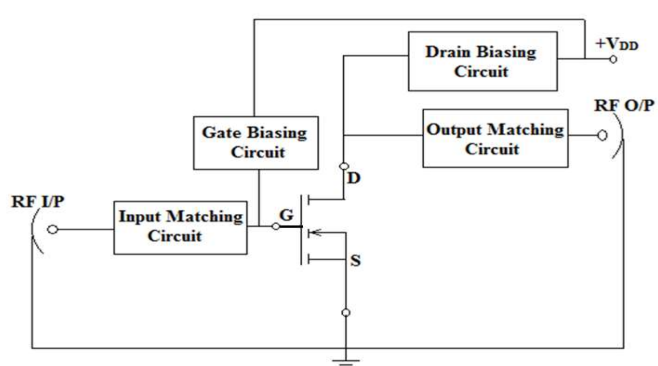


Fig. 1: Block diagram of solid-state power amplifier [10]

Above figure shows the functional block diagram of the proposed amplifier. A small RF signal at the input generates an amplified RF signal at the output. A proper matching network at the input and output side of the MOSFET other than biasing network needed for proper operating point for amplification. The matching network is formed by the passive element at the input and output terminals to match the impedances. The loss occurs in the input and output circuit of the amplifier due to improper matching is known as S (1, 1) and S (2, 2).

II. CORRELATED WORK

Table 1: Comparison of various parameters in the referred literatures.

Parameters	Ref[1]	Ref[3]	Ref[4]
Operating frequency	30-1000MHz	13.56 MHz	930-960 MHz
Efficiency	40%	94.6%	-
Gain	20Db	21.92dB	15.6 dB
Output power	60 Watts	31 Watts	26.6dBm
Operating class	Class B	Class E	Class A
Bias voltage	2.9 V	2.2 V	0.5 V
Matching technique	Trans. line transformer	L-C matching	-
Device proposed	BLF645	MRF6V2-150BNR1	ATF-50189

III. DESIGN METHODOLOGY OF THE POWER AMPLIFIER

3.1 PARAMETERS CONSIDERED FOR THE POWER AMPLIFIER DESIGN

1) The gain is defined as the ratio of the output power to RF input power [8].
2) Bandwidth is the difference between the higher operating frequency and the lower operating frequency. This is measured in Hertz. BW = f_2 - f_1
3) The ratio of the ac output power of the amplifier to the dc output power supplied by the battery of the power amplifier is known as efficiency [1].
4) Distortion in power amplifier is evaluated in terms of harmonic power level [8].

3.2 DESIGN STEPS FOR AMPLIFIER DESIGN

Step 1-Understanding of the given targeted specification and selection of proper MOSFET for RF power amplification
Step 2- Designing of input and output matching circuit network for maximum power transfer
Step 3- Design of input and output circuit biasing network to get proper operating point
Step 4- Simulation of the whole circuit at desired frequency of operation i.e. 40 MHz
Step 5- Checking targeted specification in simulation
Step 6- Fabrication of the amplifier as per simulated value of the components
Step 7- Testing of the amplifier and comparing the results with simulation outcome

3.3 SPECIFICATIONS OF MOSFET

The M/A-COM make RF MOSFET MRF134 is selected out of the available choices from various manufacturers due to expected optimized performance as per requirement. MRF134 MOSFET has been selected, which is an RF power N–Channel enhancement-mode field–effect transistor (FET) designed especially for HF and VHF power amplifier applications. This n–Channel enhancement mode amplifier applications is limited up to 400 MHz for this transistor. Output power engendered is 5.0 watts. In MRF134, the value of input impedance $Z_{in}$is 28 - j25 Ω and output impedance Z_{out} is 25 – j60 Ωat40MHz and changes to 20-j150 Ω and50-j150 Ω respectively at 13.56 MHz.

IV. STABILITY

Sometimes available transistors are stable or unstable at the desired frequency of operation. It is necessary to check the stability of a device even beyond the operating band of interest to check for the undesired potential oscillations for the maximum gain [6], the amplifier should be stable at the desired frequency. There is one of the methods to check stability, it is known as Rollet's stability criteria i.e. K factor

$$K= \frac{1-|S_{11}|^2-|S_{22}|^2-|\Delta|^2}{2|S_{12}||S_{21}|} \quad (1)$$

$$\Delta= |S_{11}S_{22} - S_{12}S_{21}| < 1 \quad (2)$$

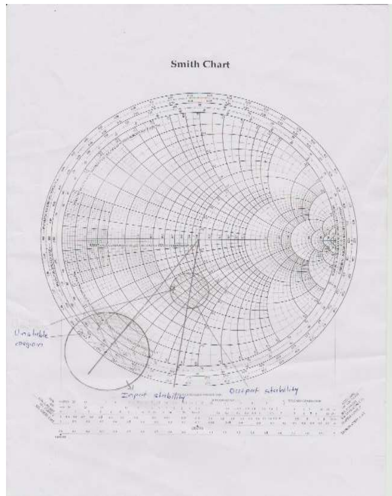


Fig. 2: Unstable regions at input and output side of MRF134

The value of k should be greater than one for unconditional stability of the amplifier. The design of an amplifier becomes more difficult when value of the stability factor is nearly one or less than one. We can improve the stability of transistor by adding the resistive load on both of the sides.

Calculated results show that k-factor attained for MRF134 is 0.49 which is not stable for the desired frequency of 40MHz. A parallel resistor is loaded on both sides of MOSFET, input side has been loaded with 1.8 $K\Omega$ and output side with 1 $K\Omega$. The k factor becomes 0.99which is close to 1. The obtained value of k shows that the matching circuit design will become complex.

V. MATCHING

The maximum power transfer and minimum reflection loss are the main objectives in the RF and microwave circuit design. The load impedance should look like a source impedance, it is an important reason for matching network, L section matching, T-matching, π- network and transformer matching. As Q of the circuit increases bandwidth decreases. The maximum power transfer will occur only if the load impedance matches with the source impedance. Any difference between load impedance and source impedance would result in standing waves generated along the line. Transmission lines may be coaxial cables or twisted pair. For perfect matching condition, the SWR should be one and reflection coefficient should be zero.

The value of VSWR is referred as the intensity of standing waves. VSWR, reflection coefficient, mismatch loss and return loss can characterize impedance mismatch and ultimately power transfer to the load. Following terms must be well understood,

$$\text{Reflection coefficient } (T) = \frac{Z_L - Z_S}{Z_L + Z_S} \tag{3}$$

$$VSWR = \frac{E_{max}}{E_{min}} = \frac{E_{in}+E_{ref}}{E_{in}-E_{ref}} = \frac{(1+T)}{(1-T)} \tag{4}$$

$$\text{Return loss} = 10\log\left(\frac{P_r}{P_i}\right) = 20\log\left(\frac{E_r}{E_i}\right) \tag{5}$$

$$\text{Mismatch loss} = 10\log(1 - T_2) \tag{6}$$

Here, Z_0= Characteristic impedance of the transmission line

Capacitor is placed parallel with stray capacitances and inductors in series with stray inductances to absorb stray energy. Resonance resonate at any stray reactance with an equal and opposite reactance at the frequency of interest [11].

5.1 L SECTION MATCHING

The manufacturer's data of MRF134, the values of Z_{in} is 28 - j25 Ω and Z_{out} is 25 – j60 Ω. At the input sideR_s should be 50 Ω matching with the Z_{in}. The calculated values of inductance and capacitance are 230 nH and 158 pF respectively. At the output side R_L=50 Ω matching with the Z_{out}, the values of L and C are 233 nH and 160pF.

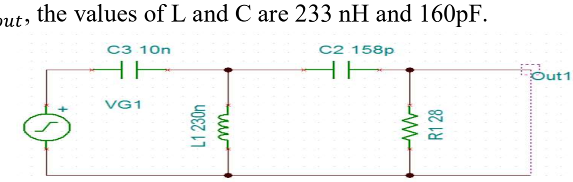


Fig. 3: This is input matching circuit of MRF134 at 40 MHz

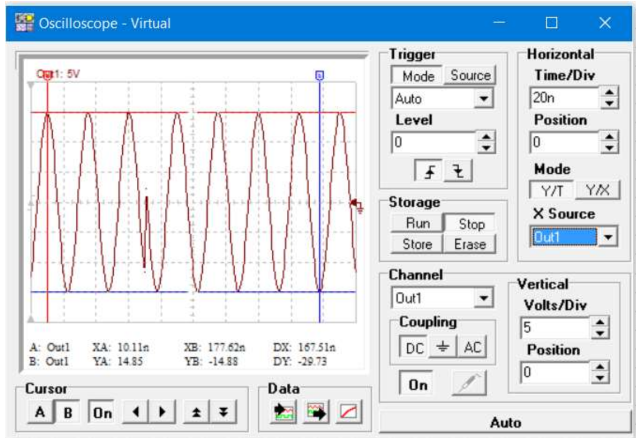


Fig. 4: For input circuit simulation at 4W and output power is 3.94W

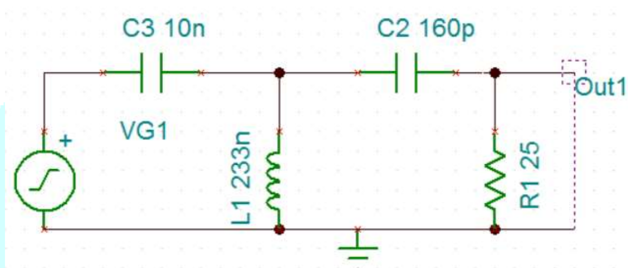


Fig. 5: This is output matching circuit of MRF134

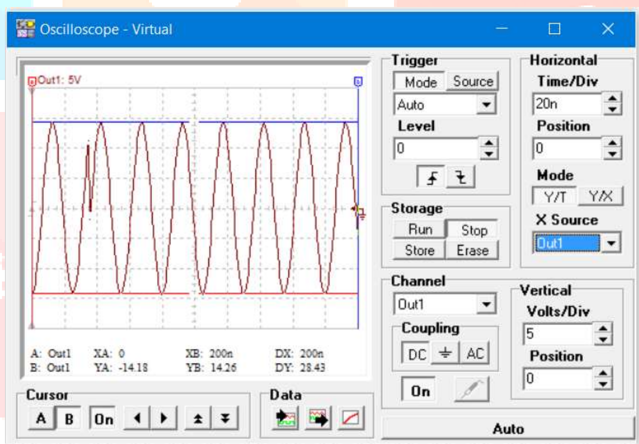
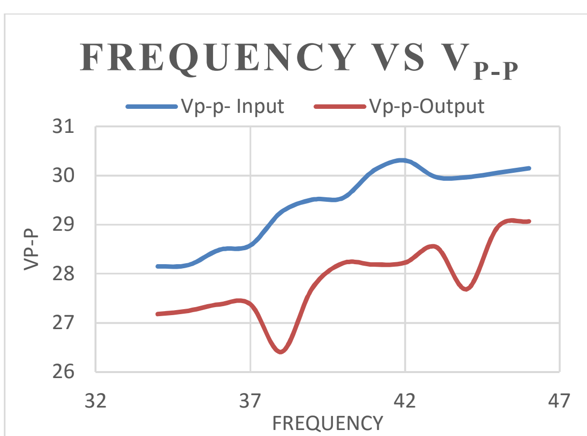
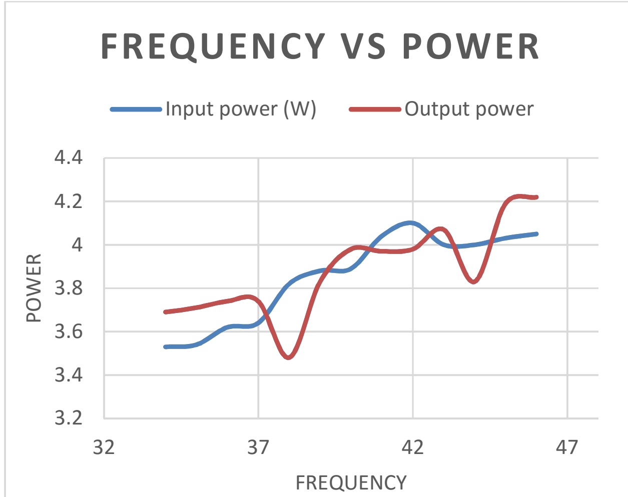


Fig. 6: For output circuit simulation at 4W and output power is 3.89W



Graph 1: Input and output Vp-p variation with frequency



Graph 2: Input and Output Powers variation with frequency

5.2 TRANSFORMER MATCHING

In the transformer matching, appropriate selection of ferrite core needs to be done for stable operation. The core losses will increase the self-heating. In practical design application, this becomes important to acknowledge heating as an important design limitation.

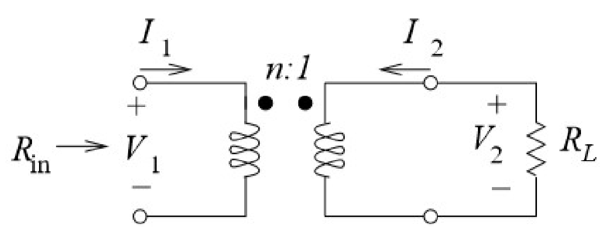


Fig. 7: A transformer as a matching network [10].

$$\left(\frac{N_1}{N_2}\right) = \sqrt{\frac{Z_S}{Z_L}} \tag{7}$$

N_1 turns ratio at the primary side and N_2 is the turns ration at secondary side Z_S and Z_L are the impedances which needs to be matched at source and load side.

$$B_{\max\,(ac)} = \frac{E_{rms} \times 10^4}{4.44 f N_p A_e} \tag{8}$$

To match the transformer with the load, primary reactance should be approximately four times the impedance of the50Ω. The selected core must have relatively high saturation density (B_s), the turn ratio is calculated by using the following equation.

$$N = 1000\sqrt{L_{mH} \div A_L} \tag{9}$$

Where N is a number of turns required, L is the desired inductance and Al factor is the number assigned by the manufacturer for a used core. In a data sheet, the B_{max} is affected by the change in the frequency, but lowering frequency while keeping the core same and number of turns greatly elevate the B_{max}. This also depends on the E_{peak} voltage and area of the core (A_e). There is various ferrite available now a day but toroidal core has some special advantages like lower stray magnetic field, less volume and weight, less audible hum, higher efficiency transformer has some advantages over L section matching like device size will be reduced, ferrite permeability is higher than air core so that coil turn will be reduced. There will be an isolation between input and output matching circuit which would further reduce the fluctuation of power. The diameter of the core is kept small so that there will be no losses.

VI. CONCLUSION

As discussed in the paper, we successfully compared the different techniques of the parameters of power amplifiers like power gain, efficiency, class of amplifier, operating frequency. Matching technique has been studied in detail. With the two different techniques L section matching and transformer matching. We have verified the stability of MOSFET which is k=0.99. The change in frequency in L section matching technique, results change in power. All the respective change has been shown.

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