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Design of a 15Watt Broadband Rugged Power Amplifier for 50-500MHz Band

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Abstract: *This paper presents the design of a broadband rugged power amplifier (PA) operating from 50 to 500MHz, with an output power of more than 15W. The intended application is in the transmitter module of a manpack military radio. The implemented power amplifier exhibits a power gain of 17±1.5dB from 50 to 500MHz band with its power added efficiency (PAE) being greater than 35%, and the second and third-harmonic distortions are below -16dBc and -15dBc, respectively, at an output power of 15W over the entire frequency band. The design incorporates transmission line transformers for broadband impedance matching. A highly rugged Laterally-Diffused Metal-Oxide Semiconductor (LDMOS) Transistor, which is capable of operating into a high voltage standing wave ratio (VSWR) is used in the design, since it is mainly intended for military applications, where it must operate under adverse conditions. The design approach was to find a solution for the best compromise between efficiency and linearity. The design was done using NI AWR Microwave Office and Visual System Simulator and further evaluation was done on the developed prototype.*
Keywords: *RF Power Amplifier, Rugged PA, Broadband PA, High VSWR, Transmission line transformer.*

I. Introduction

The Power Amplifier forms the major building block of the radio transmitter, which amplifies a signal presented at its input to the required power level at its output, by consuming energy from the DC power supply. A lion's share of the radio power consumption and cost is contributed by the power amplifier. By improving the efficiency, power consumption can be reduced for a particular RF output. But linearity is also important for new generation military radios, which uses non-constant envelope modulation schemes. Efficiency and linearity are contradictory parameters [1]. So here in this design, a compromise between the two is given importance. Ruggedness is another key requirement for next-generation military tactical radios, which are often subjected to high-voltage standing wave ratio (VSWR) conditions. This can occur when a radio is turned on without the antenna connected or, in an extreme case, when an antenna is damaged in combat while the radio is transmitting. Such events create an infinite VSWR condition and the radio, and hence the transistors, have to survive without catastrophic failure [2]. This is a device parameter and the selected transistor can operate into a high VSWR. Broadband input and output impedance matching is done using transmission line transformers (TLT). The TLT work by transmittting energy from input to output by a transmission line mode and not by flux-linkages, as in the conventional transformer. As a result the TLT has much wider bandwidth and higher efficiencies than its conventional counterpart [3,4].

II. Power Amplifier Design and Simulation Results

A single stage amplifier is designed for wideband operation from 50 to 500MHz. NI AWR Microwave Office software is used in the design. Design requirements:
Gain: 17±1.5dB
PAE: >35%
Second and third harmonics: <15dBc
Power at 1dB compression: >15W
The design procedure is given below in a sequential order.

1. Transistor selection

The NXP LDMOS device with part number MRFE6VS25LR5 was selected for the design due to its enhanced ruggedness, which makes it suitable for use in applications where high VSWRs are encountered. It is an unmatched transistor with frequency of operation upto 6GHz, maximum 25W Peak Envelope Power (PEP) Output and typical drain efficiency of 32%. The device is capable of operating into a VSWR upto 65:1. The spice model is imported to NI AWR Microwave Office [5].

2. DC biasing

The DC Bias on these amplifiers is set by applying a DC voltage to the gate (VGS) and monitoring the Drain current (Idd). Here a multi-turn potentiometer was used to set the bias voltage, with a divided output from the drain supply. The DC source is isolated from RF signal by providing high impedance inductors and coupling capacitors. LDMOS power transistors require temperature-compensated gate bias voltages, to maintain constant quiescent drain currents with temperature. So in the final implementation, such a circuitry is required to prevent bias current fluctuations with temperature. Quiescent current was set for 650 mA under 32 volts. The bias current was chosen as a good compromise between gain, linearity and efficiency [6,7].

3. Stability Analysis

The amplifier is made unconditionally stable by giving feedback. Stability factor k is made greater than 1 to ensure stability of operation. The graph of stability factor k versus frequency after adding stabilisation network is shown in Fig 1.

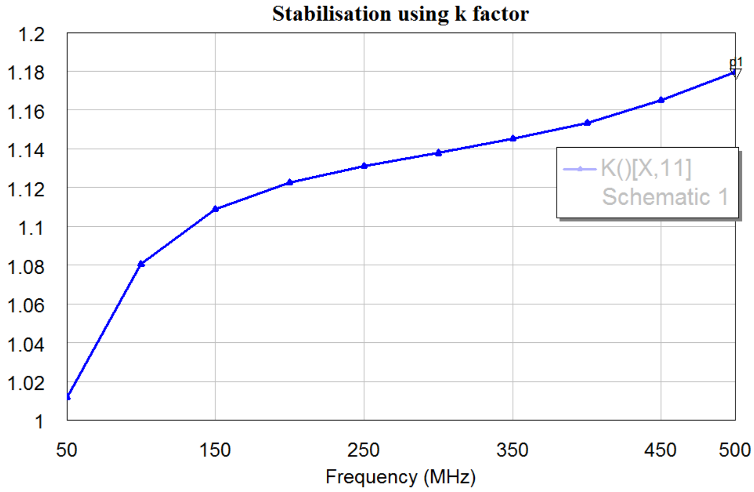

Fig 1: Stability analysis using k-factor

4. Load Pull and Load Impedance Matching

The optimum load impedance required by the device is determined using load pull techniques in NI AWR Microwave Office. The load-pull analysis function sweeps the terminating load impedances at the output side of the transistor. This enables constant performance contours to be drawn on a Smith chart, thereby showing what load should be connected so as to optimize the transistor performance. Here constant power and constant Power Added Efficiency (PAE) contours were plotted and the impedance point was selected based on a compromise between power and PAE. The contours for frequency of 400MHz is shown in Fig 2. Similarly data is taken for various frequencies and trajectory is made for the required load impedance.

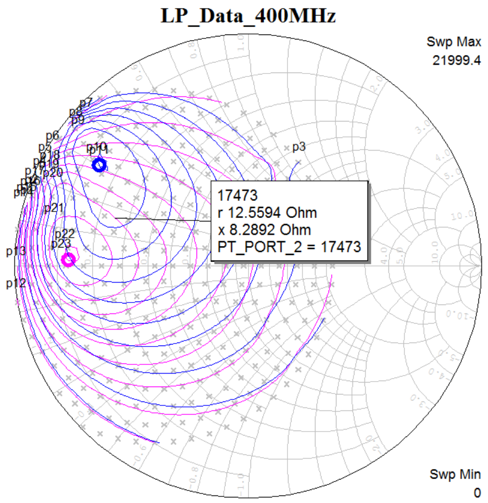

Fig 2: Load Pull power and PAE contours for 400MHz

Analyzing the various frequencies over 50-500MHz, it was found that a 2.25:1 TLT would be ideal for the output impedance matching. The 2.25:1 TLT is realised using two 1.34" lengths of 25 Ω semi-rigid coaxial cable wound through ferrite cores of material 61 [3].

5. Source Impedance Matching

A 1:4 TLT is added to the input for source matching. The 1:4 TLT is realised using 0.945" length of 25 Ω semi-rigid coaxial cable wound through ferrite core of material 61. A shunt capacitor is also added to center the input return loss.

6. Complete Circuit Simulation

Now the complete design can be simulated for it's performance, such as output power, PAE, Gain, Harmonics and linearity can be done.

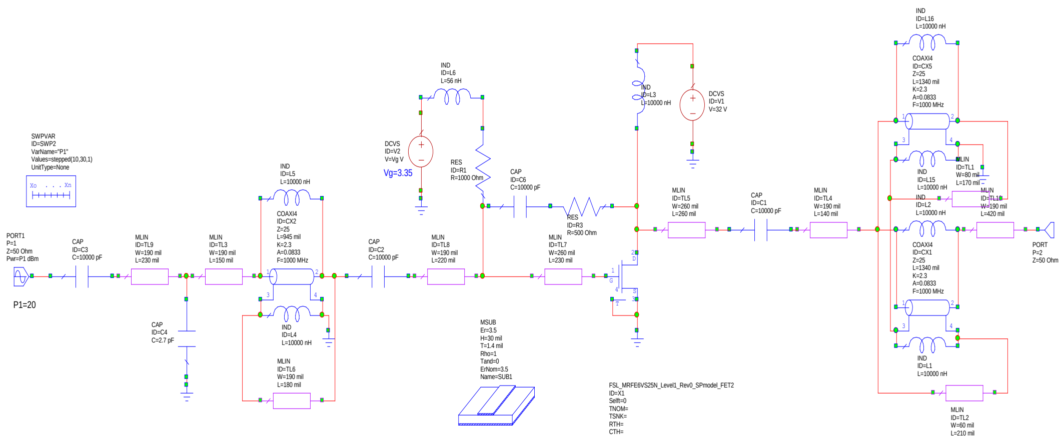

Fig 3: Complete circuit diagram

7. Simulation Results

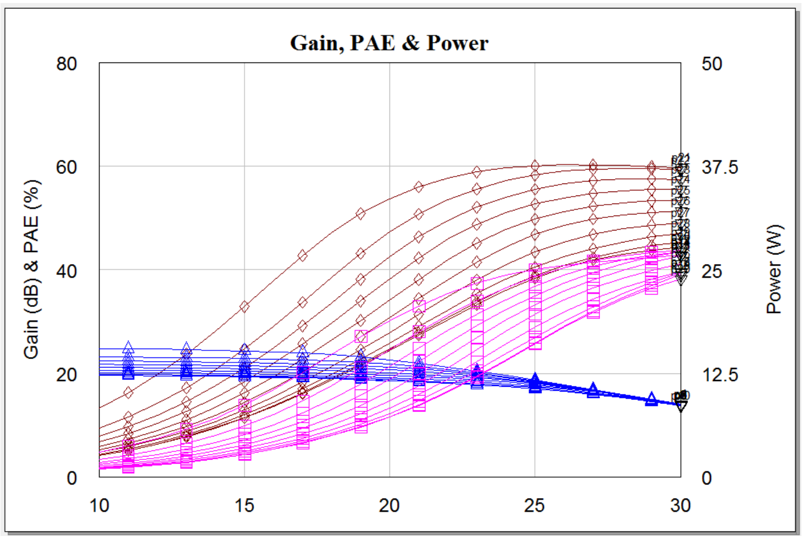

Fig 4: Gain, PAE and Power simulated plots

The simulation results are found to meet and exceed the design requirements.

III. Evaluation Results

After completing the simulation to meet the requirements, it was assembled on RO4350 Printed Circuit Board (PCB) on an aluminum heat sink. The picture of assembled PCB is shown in Fig 5.
The results are given in the plot shown in Fig 6.

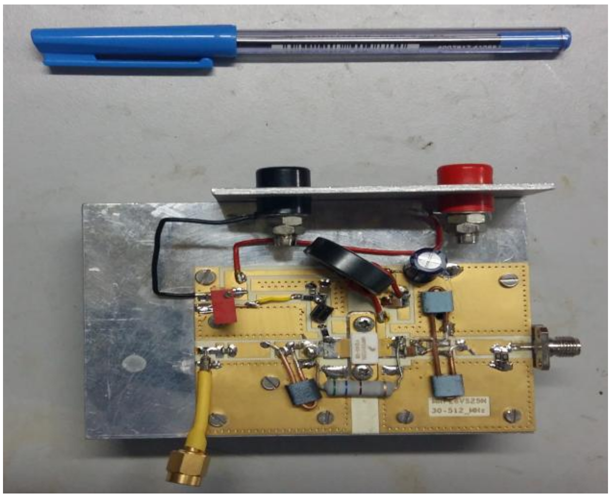

Fig 5: Prototype PCB with components assembled

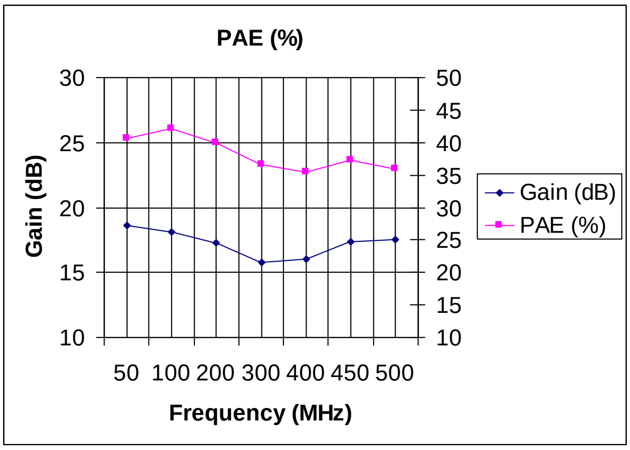

Fig 6: Gain & PAE for output power of 15W

IV. Conclusion

In this paper, a broadband 15W single stage power amplifier, operating from 50 to 500MHz has been designed and implemented. Coaxial TLT, wound around a ferrite cores, were used for broadband impedance matching. The prototype was found to meet the requirements. But some modifications must be done to improve the reliability of the unit. The ferrite cores must be upgrade to bigger sizes for the output matching network. The bias circuit must be upgraded to cater to temperature variations.

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