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Design and Implementation of High Gain High Stability Power Amplifier for X band Radar Transmitter

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***Abstract*— Power Amplifier (PA) is an important part of transmitter's front end. The main function is to amplify extremely high gain high stability power amplifier for radar transmitter. In this paper, PA used in transmitter portion of radar is designed and implemented. DC biasing, stability checking and input/output impedance matching of the RF transistor design procedures are considered. The stability analysis of power amplifiers is one of the most critical and the most challenging aspects of power amplifier design. Stability analysis is shown an analysis technique, which accurately predicts the oscillations in power amplifiers. The power amplifier (PA) design project is simulated with Electronic Workbench Multisim8 software. The simulation results are considered on the frequency used in 9.35GHz of X-band.**

***Keywords*- Power Amplifier, 9.35GHz, High Gain, High Stability, Radar Transmitter, X- band**

I. Introduction

The power amplifier is designed to drive for radar front end transmitter in Fig. 1.

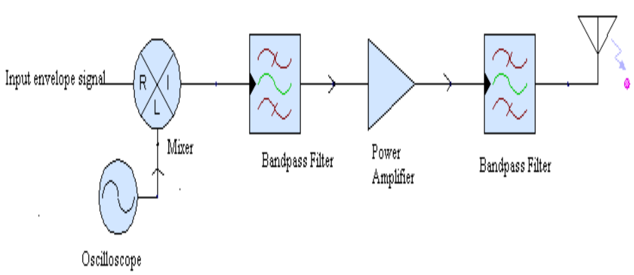

Fig. 1 Block diagram of radar front end transmitter

Class-A, Class-AB, Class-B, and Class-C amplifiers are conventional Tranconductance amplifiers. They are widely used in today's wireless transmitters A Class AB amplifier is considered as a combination of Class A and Class B amplifiers in term of linearity and efficiency. [5] The Class AB bias point is between that of Class A and Class B. Class AB amplifiers have efficiency between Class A and Class B amplifiers. The bias point of Class AB is located between that of Class A and Class B. Class-AB operation is characterized by a constant from Class-A to Class-B operation. Collector voltage and (unlike Class-A) a quiescent collector current that increases with drive power. The distortion behaviour is also different to that of Class-A. Class-AB, An important factor affecting distortion is the load operation is used for linear amplifiers [1].

The stability analysis of power amplifiers is one of the most critical and the most challenging aspects of power amplifier design. This work shows an analysis technique, which accurately predicts the oscillations in power amplifiers. Power amplifiers are widely used in wireless communication applications and radar applications. Due to the variety of applications, there is a great variety of requirements for power amplifiers. Some of the most basic requirements in power amplifier design include frequency of operation, output power level, bandwidth, efficiency, gain, linearity, size, and cost. It is almost never possible to simultaneously maximize all design criteria at the same time. Thereby tradeoffs must be made, and only a subset of the requirements can be satisfied. Some of the classic tradeoffs include: gain vs. bandwidth, operating frequency vs. output power, and linearity vs. efficiency. Low noise figure and good input match is really simultaneously obtained without using feedback arrangements.

Unconditional stability are always required a certain gain reduction because of either shunt or series resistive loading of the collector. Initially, DC biasing, stability checking and input/output impedance matching of the RF transistor design procedures are considered by using Electronic Workbench Multisim8 software [3].

II. Design Consideration

The proposed design of power amplifier requirements has been determined as follow:

- The stability factor K>>1.
- Input and the output match to the source and the load, where the impedance is $50\ \Omega + j0$
- VSWR<2.00:1.00
- Optimum gain for the required bandwidth
- Bandwidth: 100MHz from 9.3GHz to 9.4GHz

– The PA can be single stage and multi-stage, which requires interstage matching.

Transistor selection is the first and most important step in an High Power Amplifier (HPA) design. The designer has to carefully review the transistor selection, keeping the most important HPA design trade-offs in mind.

III. DC BIASING AND STABILITY CHECKING

DC biasing represents the next step in HPA design. The chosen DC bias circuit is exhibited the stable thermal performance and reduced the influence of h_{FE} spread. For bipolar transistors, a more sophisticated circuit is required. The circuit has to deliver a constant voltage of about 0.7V (adjustable over a restricted range) and should have very low internal resistance. The latter is required to accommodate a wide range of 'load' currents (i.e. base drive currents for the RF transistor), whilst maintaining a nearly constant output voltage. Other desire properties are temperature compensation and the lowest possible current consumption. Fig. 2 shows a circuit meeting these requirements [5].

The bias circuit has large negative feedback. If the load current increases, the output voltage drops slightly, decreasing the collector current of the BD135 whose collector voltage increases to counteract the drop in output voltage. it is assumed that the bias circuit is for an amplifier delivering an output power of 100W at a supply voltage of 28V. So, if the minimum amplifier efficiency is 50%, the required DC input power is 200W, corresponding to a collector current of 7.14A. If the transistors used have a minimum h_{FE} of15, the maximum base current can be 0.48A. Such an amplifier could be the final stage of an SSB transmitter where the output power and therefore also the base current vary from almost zero to 0.48A. In the bias circuit, a pre-loading resistor, R_1, is used to reduce the base current variations. To draw 15mA at 0.7V, R_1 must be 0.7/0.015=47 Ω .The maximum emitter current of the BD237 will then be nearly 0.5A. From the published h_{FE} data for this type, the base current is 15mA maximum [5].

The current through the collector resistor, R_2, of the BD135 is chosen to be twice this value, i.e. 30mA, to restrict the variations in the collector current of the BD135. The V_{BE} of he BD237 is about 0.8V, so the voltage across R_2 is 26.5V, giving a value of: 26.5/0.03=883 Ω (Nearest preferred value: 820 Ω , 1W.)At first sight, the choice of a BD135 in this circuit seems a bit over specified for a transistor that has to draw only 30mA. Yet this has been done deliberately because then the V required by the BD135 is low (smaller than the bias voltage to be delivered to the RF amplifier.)The difference is corrected by the variable resistor, R_3, in the emitter of the BD135. The output voltage of the bias circuit, and thus the quiescent current of the RF amplifier, can now be adjusted. With a resistor of 5 Ω max, the output voltage can be adjusted by at least 100mV, sufficient for this application. To protect the BD237 against the consequences of a short-circuit of the output voltage, it is advisable to include a resistor, R_4, in the collector lead. As the BD237 has a V_{ce} (sat) of 0.8V max., a voltage drop of 26.5V across R_4 is allowed at the maximum collector current of 0.5A. The maximum value of this resistor is therefore 26.5/0.5=53 Ω (nearest value: 47 Ω .) Note: R_4 must be rated at 12W $(I^2R = 0.5^2 \times 47 = 11.75)$.

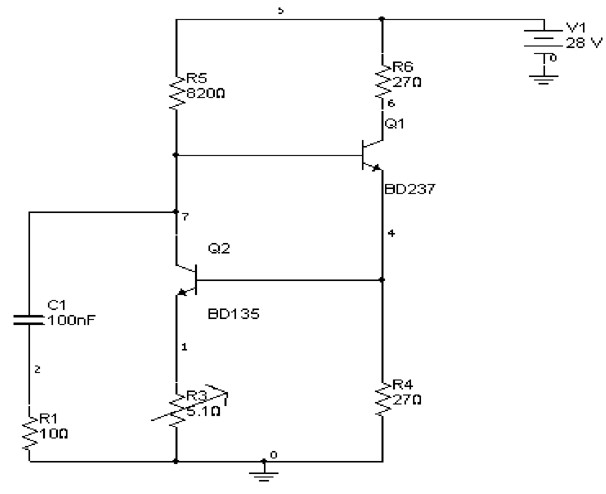

Fig. 2 Biasing circuit for high power amplifier (HPA)

Stability checking should be consequent step in HPA design. Unconditional stability of the circuit is the goal of the HPA designer. Unconditional stability means that with any load present to the output or output of the device, the circuit will not become unstable and will not oscillate. Instabilities are primarily caused by three phenomena: internal feedback of the transistor, external feedback around the transistor caused by external circuit, or excess gain at frequencies outside of the band of operation. S-parameters provided by manufacturer of the transistor will aid in stability analysis: numerical and graphical [4] numerical analysis consists of calculating a term called Rolette Stability Factor (K-factor). An intermitted quantity called delta (Δ) should be calculated first in order to simplify the final equation for the K-factor.

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

then,

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

When K-factor is greater than unity, the circuit will be unconditionally stable for any combinations of source and load impedance. When K-factor is less than unity, the circuit is potentially unstable and oscillation may occur with a certain combination of source and /or load impedance present to the transistor.

The K-factor represents a quick check for stability at given biasing condition. A sweep of the K-factor over frequency for a given biasing point should be performed to ensure unconditional stability outside of the band of operation. The stability of the designed HPA circuit is simulated by using Electronics Workbench Multisim8 Software. It was found that the designed HPA biasing circuit has a result of unconditionally stable with K value of 1.2649.

IV. Input and Output Matching

The next step in HPA design consists of Noise Match and Input Return Loss (IRL). IRL defines how well the circuit is matched to 50 Ω matching of the source. A typical approach in HPA design is to develop an input matching circuit that terminates the transistor with conjugate of Gamma optimum (Γopt), which represents the terminating impedance of the transistor for the best noise match. In many cases, this means that the input return loss of the HPA will be sacrificed. The optimal IRL can be achieved only when the input-matching network terminates the device with a conjugate of S11, which in many cases is different from the conjugate of Γopt. An emitter inductor feedback can rotate S11 closer to Γopt, which can help with obtaining close to minimum noise figure and respectable IRL simultaneously. A typical method used in designing input matching network is to display noise circles and gain/loss circles of the input network on the same Smith chart. This provides a visual tool in establishing an input matching network for the best IRL and noise trade off.

The last step in HPA design involves output matching of the transistor. An additional resistor, either in series or parallel, has been placed on the collector of the transistor for circuit stabilization. Conjugate matching has been exclusively used for narrow band HPA design to maximize the gain out of the circuit [7].

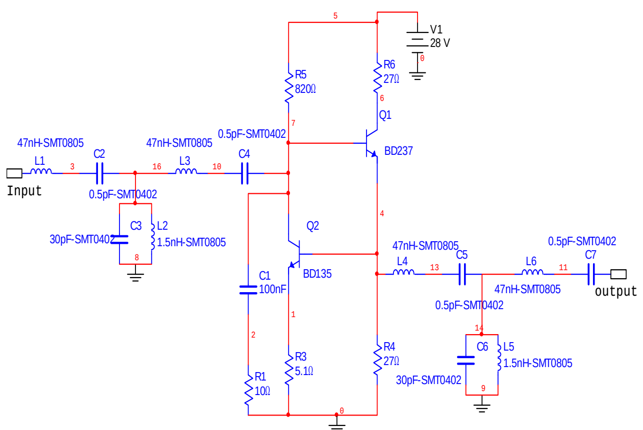

Fig. 3 Circuit diagram of 9.35 GHz HPA

Fig. 3 shows 9.3GHz HPA with BD135 and BD237(Class-AB amplifier).Capacitor C_2, C_3, C_4 and L_1, L_2, L_3 will resonate at input frequency of operation.C_5, C_6, C_7 and L_4, L_5, L_6 combination will work at output matching. These values have been acquired from the simulation results by using Electronics Workbench Multisim8 Software.

V. Simulation Results

The biasing analysis and stability checking of high power amplifier design are simulated firstly with Electronics Workbench Multisim8 software. Fig. 4 shows the initial simulation of HPA circuit. After that the input and output matching network circuit is simulated. The auto matched command of the software is utilized in order to yield the matching networks when the simulated circuit has been unconditionally stable. Fig. 5 and 6 show the simulation results of the stability checking and matching network analysis at 9.35 GHz frequency of high power amplifier. Fig. 5 shows the stability factor value K is about 1.264, thus, the system is unconditionally stable with this biasing network. Then, the input and output matching network is carried out and the complete network is yielded in order to simulate with software.

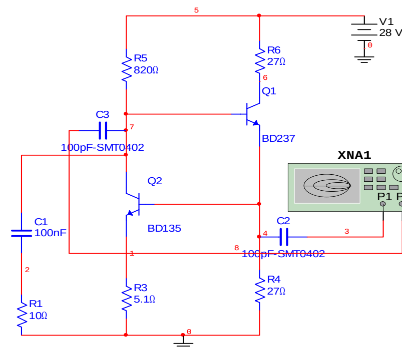

Fig. 4 The biasing analysis of simulated HPA

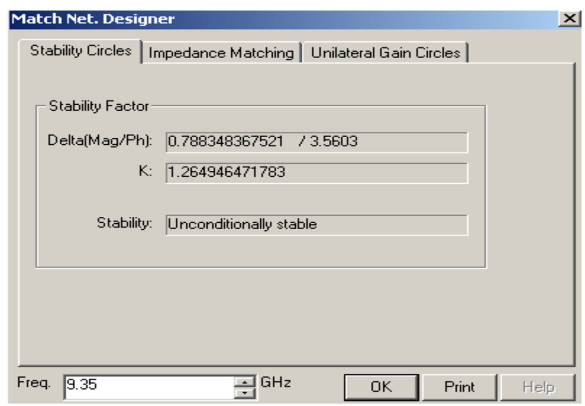

Fig. 5The stability analysis of simulated result of HPA

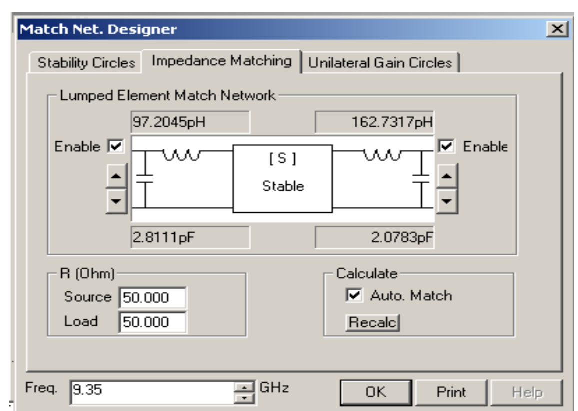

Fig. 6 The input and output matching network analysis of HPA

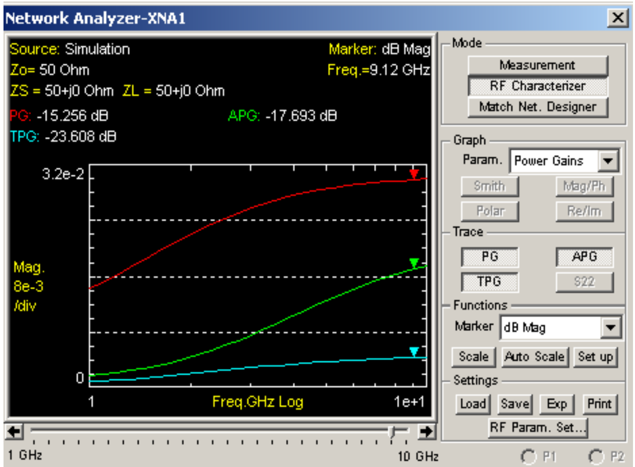

Fig. 7 The output of simulated HPA gain signal

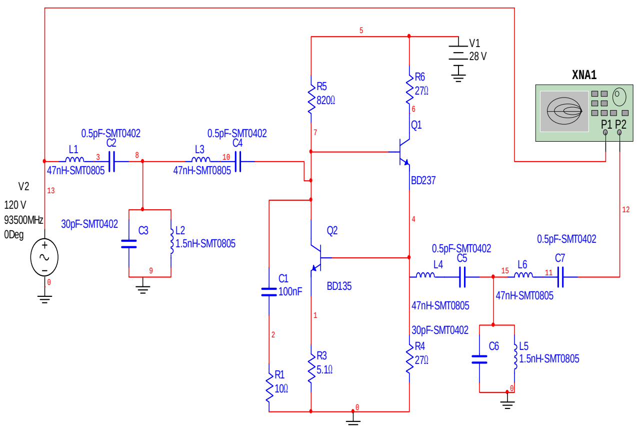

Fig. 8 Simulation circuit of output voltage signal

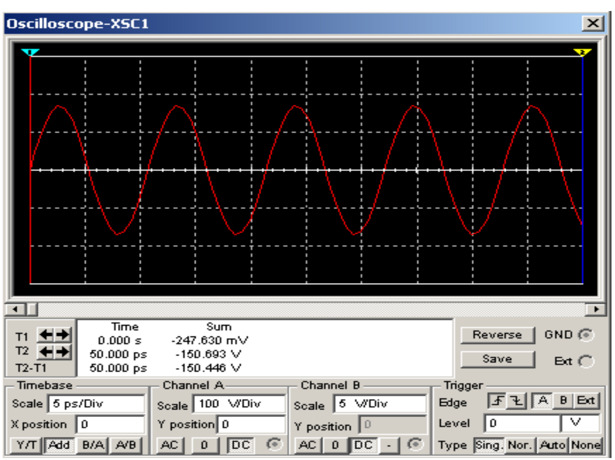

Fig. 9 The output result of simulated HPA with 9.35 GHz signal

Fig. 7 is shown output power gain of HPA with 9.35 GHz signal simulated with software. Fig. 8 is measured the output result of power gain with oscilloscope. Fig. 9 is the output result of simulated HPA with 9.35GHz signal.

VI. Conclusions

In designing the high power amplifier (HPA), the main goal is to be stable unconditionally for the complete range of frequencies where the device has a substantial gain. It was found that the designed HPA biasing circuit has a result of unconditionally stable with K value of 1.264. Then, the input and output matching network is carried out and the complete network is yielded in order to simulate Electronics Workbench Multisim8 software. The equivalent transistors BD135 and BD237 are chosen to run the 9.35GHz HPA simulation. The simulation results are based on the measurement of high stability and power gain are reached 15.256 dB, 15.5dB, respectively. The input, output reflection and isolation coefficient are indicating good impedance matching.

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