TELKOMNIKA, Vol.11, No.11, November 2013, pp. 6673~6678
e-ISSN: 2087-278X

Electronically Tunable Impedance-Matching Networks for Intelligent RF Power Amplifiers

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Abstract

This paper presents the simulation and optimization design of the electronically tunable impedance-matching networks for intelligent RF power amplifiers in a cognitive radio system. Reconfigurable elements, such as varactors and RF switches are utilized to achieve the dynamic impedance matching both in the input and output matching circuit, providing coarse and fine tuning of the target impedances with low loss and excellent impedance coverage from 500MHz to 800MHz. The topology of varactor model is illustrated to ensure the precision of simulation. In addition, high-precision bias voltage controlling system is designed to improve the nonlinear problem caused by the varactor. The simulation results demonstrate the excellent performance of the tunable networks, satisfying the requirement of the cognitive radio systems.

Keywords: *cognitive radio systems, varactor, RF switch, impendence-matching network*

1. Introduction

Currently, with the rapid development of wireless communication service, such as wireless local area network (WLAN) and wireless personal area network (WPAN), with an increasing number of people access to the Internet through WLAN, WPAN, the spectrum resources become less and less, bringing the problem of the scarcity of radio electromagnetic spectrum [1]. Cognitive Radio system can monitor the usage of spectrum resources by spectrum sensing and intelligent and systematic learning, adjusting the transmission parameters dynamically to use the spectrum resources efficiently. Cognitive Radio System can make full use of the idle spectrum resources in time and space, so as to solve the problem of spectrum resources tension effectively.

RF power amplifier is the most power consumption and most expensive key component in wireless communication system [2]. As for Cognitive Radio system, RF power amplifier used should be able to be tuned to any operating frequency rapidly among the covering band. Therefore, the research on varactors and RF Switches–tuned electronically impedance matching networks are suitable for this kind of RF power amplifier, having some realistic significance in the construction of Cognitive Radio system.

The main thoughts of this paper focus on introducing reconfigurable elements to achieve the dynamic impedance matching both in the input and output matching circuit of RF power amplifier in Cognitive Radio system [3], the proposed method can greatly reduce the size and circuit complexity of circuit. Along with the maturity of RF tunable components, the covering range of impedance matching network will become wider [4].

This paper is organized as follows: In section II, description is made on the previous works, in addition, both the theory and the structure of our work are given. At the same time, it is necessary to know the characteristics of varactors. A design methodology for tunable impendence matching network is proposed in section III, with the method of designing high-precision bias voltage controlling system which is done to improve the nonlinear problem caused by varactor. Section IV describes the experimental results of electronically tuned impedance matching networks and the high-precision bias voltage supplier. Finally, applications of the design are discussed, following a brief conclusion.

Received May 6, 2013; Revised June 23, 2013; Accepted July 25, 2013

2. The Proposed Method

Traditional broadband RF power amplifier matching techniques can be classified into three categories: The first method is to use the novel transformer-matching networks and active matching to increase the width of PAs' frequency response. With the advantage of solving the problem of large optimal impedance changes, but brings a lower efficiency and output power, and the maximum output power will change according to different frequency [5].

The second way is to design the multi-band matching network for both input and output port, depending on the RF switches to change working states and improve the output power and PAE effectively, with the disadvantage of much more complex circuit [6].

The third idea that used in this paper is to introduce reconfigurable elements to achieve the dynamic impedance matching both in the input and output matching circuit. Although it requires much higher ability of quick tuning (frequency agile) [7], the size and complexity of matching networks are reduced significantly, in addition, the efficiency and output power are both guaranteed.

Usually, π-and т-type structures are utilized to achieve a wide tuning range [8-11], but a certain kind of separate structure has a certain frequency range and bandwidth constraints for the power amplifier in practical applications.

Power amplifiers always work with high power, therefore, DC block capacitor must be used to prevent the DC voltage to impact system. This paper has adopted a combination of π- and т-type structure after many experiments, the main principle is shown in Figure 1.

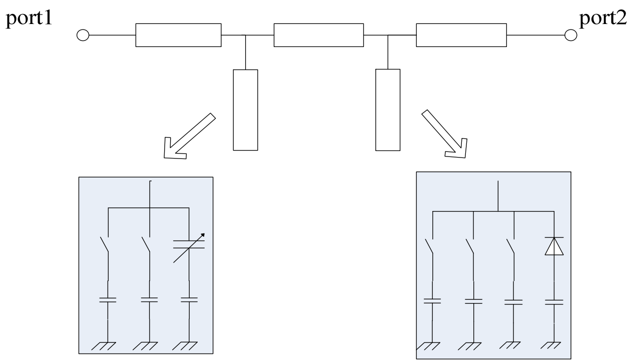

Figure 1. Structure of Tunable Impendence Matching Network

The junction capacitance of varactor is determined by the bias voltage provided, when the reverse bias on the PN junction is changed, the capacitance of it will be influenced. The higher reverse bias, the less junction capacitance, the relationship between the reverse bias and junction capacitance is nonlinear. Therefore, attention should be paid to the accuracy of reverse bias loaded on the varactor when using it. As a result, the accurate varactor model must be made according to the appropriate indicators and parameters in the ADS2008 [12], through model building, the relationship between bias voltage and the corresponding capacitance value could be achieved, and the target value can be reached by adding precision bias voltage finally.

3. Research Method

3.1. High-Precision Bias Voltage Controlling System

A high-precision bias voltage controlling system is designed by using the high-precision 10-bit digital potentiometer. First, the input voltage is converted to the tuning voltage range (0-30V) of varactor through the DC-DC converter (LM2576). In the circuit, several filter circuits are utilized to reduce noises and ripples of the output voltage, ensuring the stability and reliability of output voltage. Then ARM7 chip (ADuC7026) utilized helps to control the access resistance dynamically through the SPI interface protocol adjusting the output voltage. At the output port, the emitter follower circuit is used to cut down noises and ripples of the output voltage. Of which the emitter follower is achieved by the high-precision operational amplifier introducing feedback to the inverting input port form the output port. A 4×4 keyboard and corresponding indicators are designed to improve human-computer interoperability of this system, ensuring a better performance in the case of independent operation.

The AD5292 is a single-channel, 1024-position digital potentiometers that combines industry leading variable resistor performance with low resistor tolerance error feature simplifies open-loop applications as well as precision calibration and tolerance matching applications. These devices are capable of operating across a wide voltage range, supporting both dual supply operation at ±10.5 V to ±16.5 V and single supply operation at +21 V to +33 V, while ensuring less than 1% end-to-end resistor tolerance error and offering 20-time programmable (20-TP) memory. The AD5292 device wiper settings are controllable through the SPI digital interface.

3.2. Varactor Model

The varactors in the matching network are NXP BB179 varactor diodes. Since NXP does not provide an ADS model [10], the diode model was used in ADS together with the model parameters of the spice model NXP provided. Therefore, the first step is to design the varactor model. Figure 2 shows the topology of varactor model. The simulation of the model in the ADS matches the data sheet from NXP fairly very well.

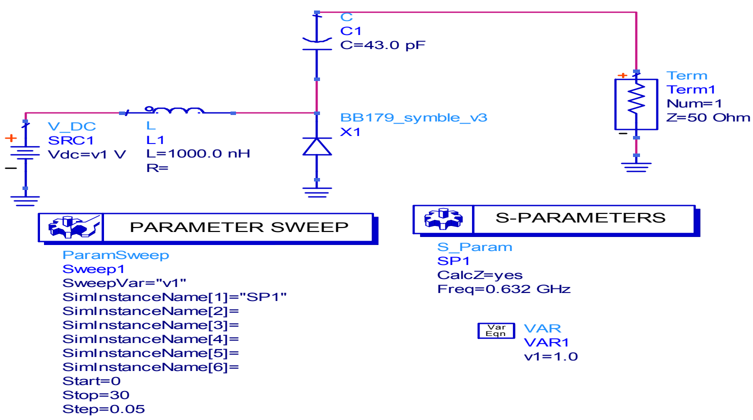

Figure 2. The Topology of Varactor Model

3.3. Tunable Impendence Matching Network Design

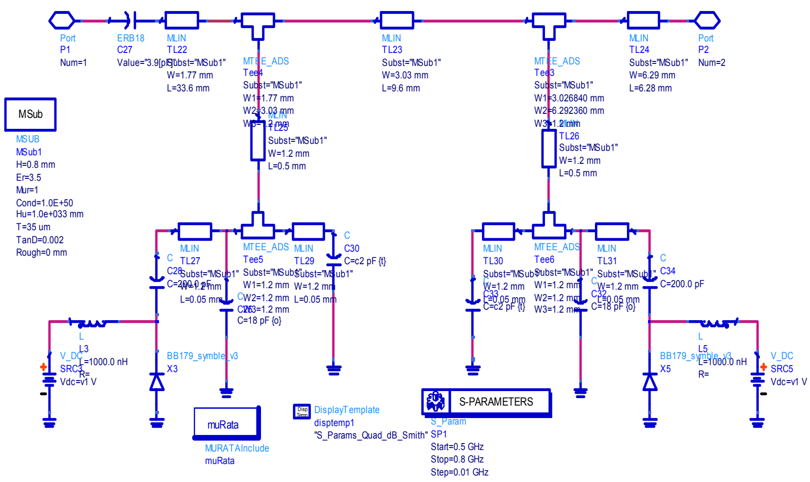

Figure 3. Circuit of the Tunable Impendence Matching Network

The tunable impendence matching network proposed is firstly designed in the ADS2008, The load-pull and source-pull simulations are done firstly to obtain the optimal input and output impedances at different center frequency, corresponding the maximum output power and PAE, using the Freescale' devices MRF9060 of 60W-PEP LDMOSFET. After that the matching networks are obtained according to Smith chart tool in ADS2008, utilizing microstrip lines, varactors, RF switches and capacitances. Attention should be paid that series capacitance must be used to avoid the influence of DC current. Optimization design must be done to obtain the optimum length of microstrip lines corresponding different center frequencies, the values of capacitances and voltage could be tuned by the tools of ADS2008. Figure 3 shows the circuit obtained when using real-models, MTEEs and MuRata capacitances to replace the ideal DC block and transmission lines.

4. Results and Discussion

4.1. Computer Simulation and Analysis

The simulation test of the varactors and RF Switches–tuned electronically Impedance-matching networks was performed on the ADS2008. At first, the band is divided into 6 parts, the center frequencies are 500MHz, 550MHz, 600MHz, 630MHz, 700MHz, 750MHz, 800MHz. it is important to simulate the network at different center frequency, leaving the length of microstrip lines fixed, the states of switches being on or off and values for bias voltage adjustable. After this work, the conditions of the varactors, RF switches and capacitances are all determined according to the requirement.

The tuning range is performed in Figure 4, as shown in the results, it could reach wide range impedances, corresponding frequency from 500-800MHz. As a result of fixed length of microstrip lines, there are still some impedances which the matching network could not reach. But for the RFPA applications, the impedances are relatively concentrated, and it is enough to meet the requirement.

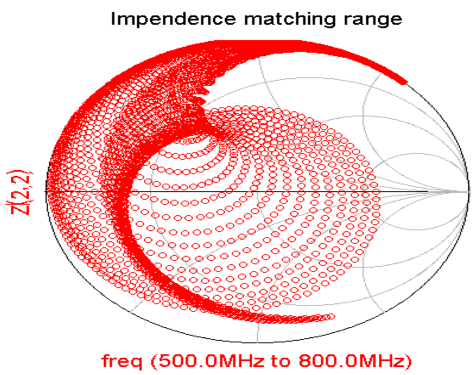

Figure 4. Smith Charts for Matched Impendence Coverage from 500M to 800M Hz

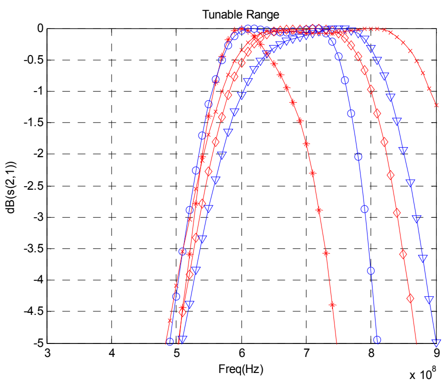

Figure 5. Insertion Loss (S21) of Matching Network

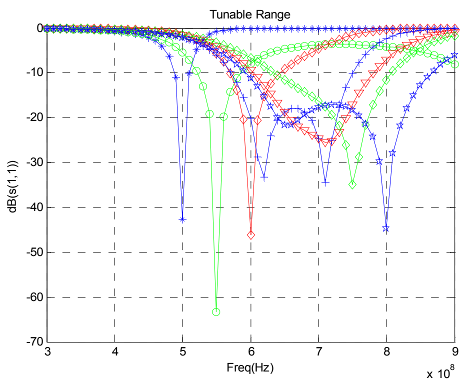

Figure 6. Return Loss (S11) of Matching Network

In addition, Figure 5 shows the results of insertion loss (S21) of the matching network which is well above -0.5dB at 500-800MHz, by tuning the varactors and turning the RF switches on or off, the controlling signals are given by the ARM7(ADuC7026), in addition, the bias voltage of varactors is obtained by the high-precision bias voltage controlling system. S-parameters had a good performance from 500MHz to 800MHz. From Figure 5, it is clear to obtain that the width of the stability of in-band frequency response becomes wider by the increasing frequency.

S11 are displayed in Figure 6, corresponding values are mainly under -20 dB in the whole band. With increases of operating frequency, bandwidth below -20 dB is about 6 times wider than that designed in lower frequency as a result of the optimum microstrip lines.

4.2. Hardware Implementation of Bias Voltage Controlling System

The photo of high-precision bias voltage controlling system is shown in Figure 7, verifying the reliability and effectiveness of the method proposed in this paper, 8 high-precision 10-bit digital potentiometers are used for the hardware implementation, the controlling device utilized in the system is ADuC7026, experiment platform is built according to digital multimeter (UT58E) and oscilloscope (Agilent 54622D).

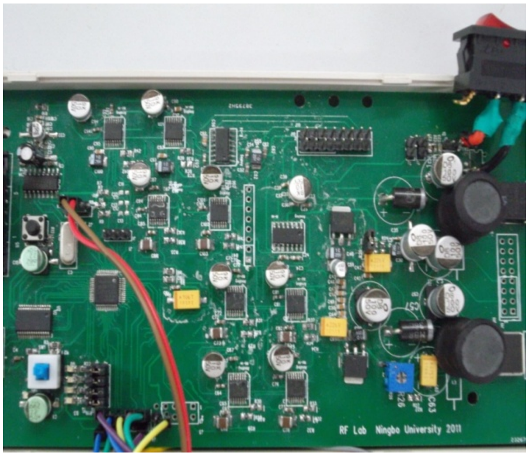

Figure 7. Hardware Implementation of High-precision Bias Voltage Controlling System for Varactor

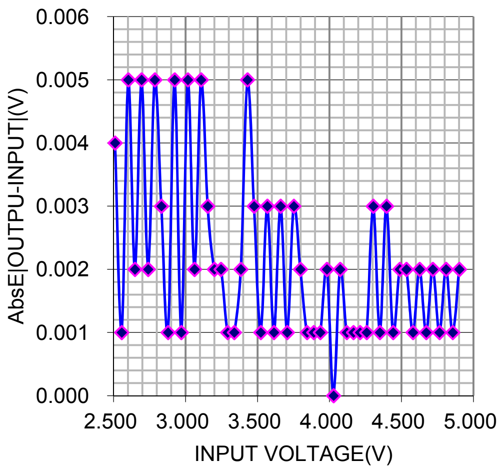

Figure 8. The Graph of the Absolute Error (AbsE) of the Measured Voltage Result at the Range of 2.5V~5V

Finally, this paper gives the key testing data of the controlling system. As shown in Figure 8, absolute error measured is less than 5mV, greater than or equal to 1mV for the fine-tuning needs. The analysis of the testing results shows the feasibility of the controlling system and meeting the actual requirement.

5. Conclusion

This paper has introduced a new structure for a tunable impedance-matching network for intelligent RF Front-Ends of power amplifiers which are applied in broadband Cognitive Radio systems. The tunable impedance matching network consists of varactors, RF switches and microstrip lines utilized both individually and combined from 500M to 800M Hz that has variable characteristic impedances. In addition, in order to improve the nonlinear problem caused by varactor, a high-precision bias voltage supplier is designed.

Through simulations and measurements, it is shown that the design could be used to realize a tunable matching network for Cognitive Radio applications, with the S11 mainly under -20dB and S21 well above -0.5dB for the network. High-precision bias voltage controlling system is demonstrated together with absolute error mostly closing to 1mV.

Acknowledgements

This work was partially supported by the National Science and Technology Major Project of China (2010ZX03007-003-04), the National Natural Science Foundation of China(61171040), the Key Project of International Cooperation of the Provincial Science Technology Major Projects of Zhejiang (2010C14007), the Provincial Natural Science Foundation of Zhejiang (Y1101270), the Natural Science Foundation of Ningbo (2011A610188) and the Scientific Research Foundation of Graduate School of Ningbo University(G12JA019).

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