Analysis of a New Approach for Tunable and Reduced Size Balanced Amplifier using Thin-Film BST Varactors

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***Abstract*— A new approach for tunable balanced power amplifier (PA) using barium-strontium-titanate (BST) varactors is presented and analyzed. Tunable PA utilizes the idea of reduced size tunable branch-line couplers, comprising of BST Varactors. The simulation results indicate the feasibility of balanced amplifier from 1500 to 2500 MHz in terms of gain, reflection coeffecients, and stability. The key features of the presented design are the stability of traditional balanced PA, frequency agility and 50% size reduction due to the use of reduced size branch-line couplers.**

***Index Terms* — Tunable, Reduced size, Balanced Power Amplifier, BST.**

I. INTRODUCTION

Reconfigurability or tunability is a highly demanded trait of an RF front end of any versatile wireless device in the context of upcoming 4G scenario [1]. Tunability promises a reduction in number of components required for separate signal paths dedicated for each band of operation and that would clearly result in decrease in cost, size and energy consumption.

Balanced power amplifiers are important as they have advantages such as good input/output matching, high degree of stability, and a 3-dB higher linearity [2]. But they also suffer from requirement of large coupler sizes, cost of using double devices, and integration problems.

In this paper a very innovative idea to enable tunabilty in balanced amplifier is presented while at the same time reducing the required coupler sizes using ferroelectric varactors.

Section II starts with a brief introduction of balanced amplifier. Section III gives an overview of BST varactors followed by section IV with an introduction of quadrature couplers. Section V explains the idea of voltage reconfigurable balanced amplifier using tunable quadrature coupler. Section VI illustrates results of the tunable PA.

II. BALANCED AMPLIFIER

Balanced power amplifier architecture is very important as it leads to designs which have output performances insensitive to the load mismatch and high degree of stability.

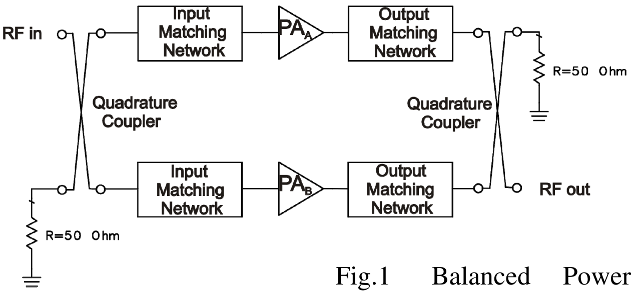


Fig.1 Balanced Power Amplifier Architecture

Fig.1 shows a block diagram of the balanced architecture with two identical amplifiers and quadrature couplers. The quadrature coupler on the left is a power divider and the one on the right is power combiner. It can be demonstrated [2] that in such a scheme the S-parameters can be given as:

$$|S_{11}| = 0.5 \cdot |S_{11A} - S_{11B}| \quad (1)$$

$$|S_{21}| = 0.5 \cdot |S_{21A} + S_{21B}| \quad (2)$$

$$|S_{12}| = 0.5 \cdot |S_{12A} + S_{12B}| \quad (3)$$

$$|S_{22}| = 0.5 \cdot |S_{22A} - S_{22B}| \quad (4)$$

Where S_A and S_B are designated S-parameters of upper and lower PA respectively. The magnitude of S11 and S22 should be zero, if the two individual amplifiers are identical and an excellent stability is expected. The gain of balanced amplifier does not get doubled despite using two devices. Despite lots of advantages, increased cost of PA because of two devices and additional accompanying components is not negligible.

III.BST VARACTOR

BST ($Ba_{1-x}Sr_xTiO_3$) varactors are metal-insulator-metal (MIM) capacitors. They represent an important class of ferroelectric devices with an application in frequency agile tunable microwave circuits. BST varactors are broadly classified as thin and thick film devices which have electric field dependent dielectric permittivity. BST varactor has an excellent tunability, reliability and operating voltage characteristics but suffers from lower quality factors [3]. As derived in [3] the varactor capacitance can be described by the following expression:

$$C_{\mathrm{BST}} = \frac{C_o - C_f}{2\cosh\left(\frac{2}{3}\, ar\sinh\left(\frac{2V}{V_{\frac{1}{2}}}\right)\right) - 1} + C_f \qquad (5)$$

Where C_o is the capacitance at V=0 V less the fringing capacitance C_f, $V_{1/2}$ is the voltage where $C(V_{1/2})=C_o/2$.

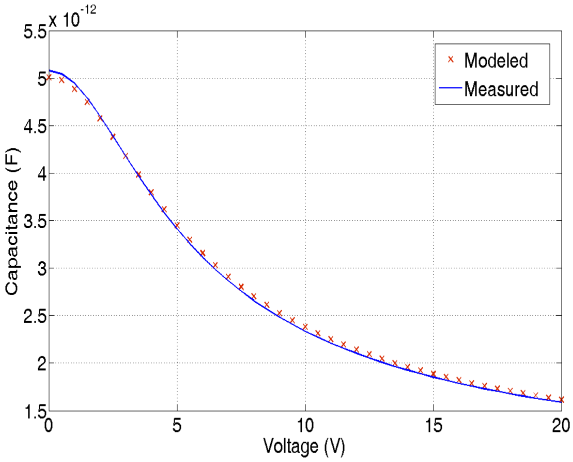


Fig.2. A comparison between modeled and measured capacitance of BST Varactor for different bias voltages.

Fig 2 illustrates voltage dependence of BST Varactor with zero bias capacitance of 5pF for modeled and measured BST Varactors. The capacitance C_{BST}, as well as varactor quality factor Q, extracted from the measured input admittance Y, can be defined as:

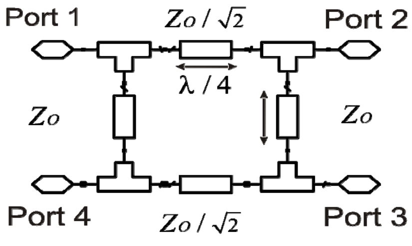
$$C = \frac{\mathrm{Im}\{Y\}}{2\pi f} \qquad (6)$$

$$Q = \frac{\mathrm{Im}\{Y\}}{\mathrm{Re}\{Y\}} \qquad (7)$$

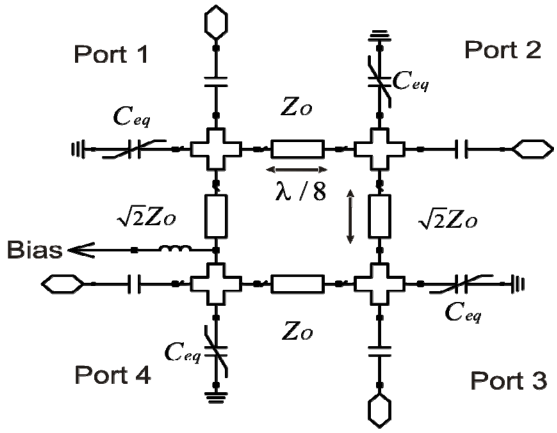
The tunability exceeds 60% at a bias voltage up to 20 volts and quality factor values $Q \approx 30$ have been measured in the frequency region of 2GHz.

IV. TUNABLE BRANCH-LINE COUPLER

Branch-line coupler is a very important component in an RF & microwave realm. The conventional branch-line coupler comprised of four $\lambda/4$ transmission line segments which form the four port network, is shown in Fig. 3a. The inserted power at port 1 is equally divided at the output port 2 and 3 at the $\lambda/4$ frequency.



(a) Branch-line coupler



(b) Reduced size branch-line coupler

Fig.3 (a) Branch-line (b) reduced size tunable branch-line coupler topologies.

The reduced size topology from [4] shown in Fig 3b uses a technique where series $\lambda/4$ branches with $Z_o/\sqrt{2}$ are replaced by Z_o with shunt capacitors $C_1 = 1/(2\pi f Z_o)$ and parallel $\lambda/4$ segments are replaced by $\sqrt{2}Z_o$ with shunt capacitors $C_2 = 1/(2\pi f\sqrt{2}Z_o)$. The complexity is reduced when shunt capacitor at the transmission line ends are combined as

$$C_{eq} = C_1 + C_2 = \frac{1+\sqrt{2}}{2\pi f\sqrt{2}Z_o} \qquad (8)$$

C_{eq} allows far more compact design with reduced complexity and tuning functionality by changing the capacitance enabled by using ferroelectric BST varactors explained in section III.

The reduced sized tunable branch-line coupler using BST varactors are described and implemented in [4] with continues tuning range from 1.7 GHz to 2.1 GHz.

V. TUNABLE BALANCED PA

Balanced amplifier architecture discussed in section II, can be modified by substituting branch-line couplers with the equivalent reduced size tunable branch-line couplers described in section IV. The resulting tunable balanced amplifier is illustrated in Fig. 4.

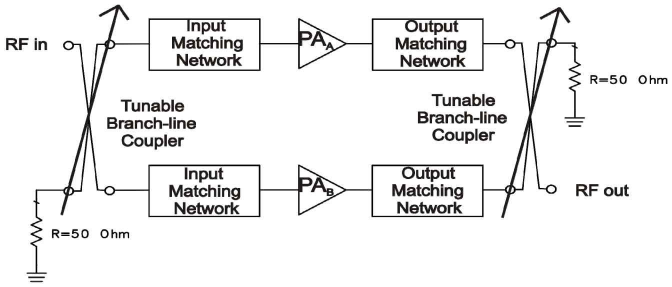


Fig.4 Tunable balanced power amplifier with tunable branch-line couplers.

The tunable balanced PA design benefits tremendously from reduced size branch-line couplers as passive coupler structure dimensions are reduced by 50% by replacing $\lambda/4$ transmission line segments with $\lambda/8$ segments.

The only additional price to be paid for enabled tunability and size reduction is the requirement of bias voltage V_b with tuning voltage generator for branch-line couplers by using any suitable method such as described in [5].

VI. SIMULATION RESULTS

Reduced size branch-line coupler described in section IV, comprising of BST varactor model [3], are designed and simulated using Agilent ADS simulation tool.

The low quality factor of BST varactor and resulting losses are taken in to consideration in analysis. Fig. 5 and Fig. 6 shows the transmission coefficient and phase difference of the tunable branch-line coupler. As the bias voltage V_b is altered from 0 to 15 volts, the coupler is continuously tunable from 1.5 to 2.5 GHz. The implemented reduced branch-line coupler is utilized in co-simulation along with TQM676021 GaAs HBT PA models from Triquint Semiconductors in order to analyze the performance of resulting tunable balanced power amplifier in terms of gain, input and output matching as well as stability.

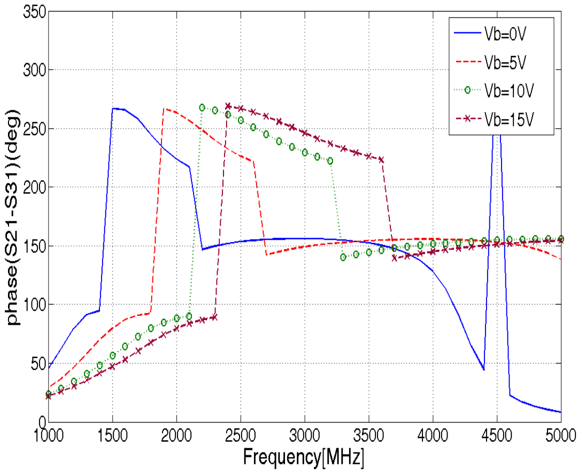


Fig.5 Phase difference of tunable branch line coupler.

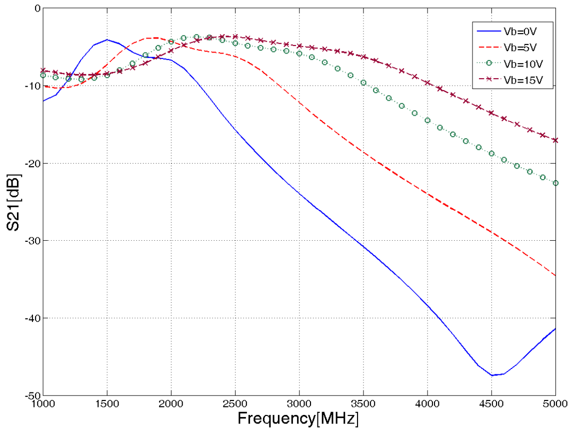


Fig.6 Transmission scattering parameter of tunable branch-line coupler at different bias voltages.

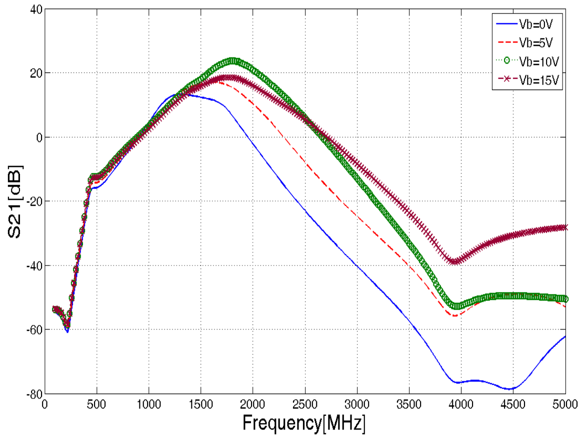


Fig.7 Transmission scattering parameter for tunable balanced power amplifier.

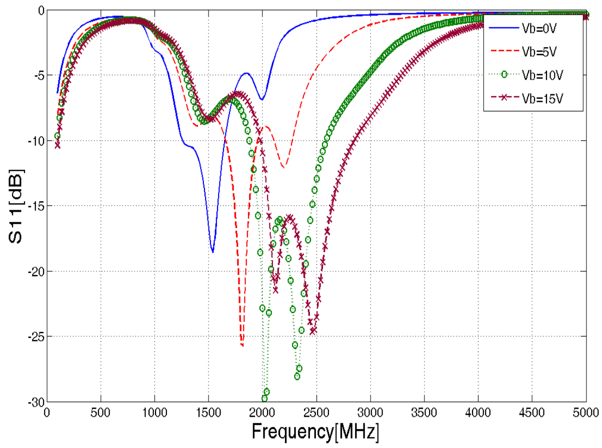


Fig.8 S11 for tunable balanced power amplifier at different bias voltages

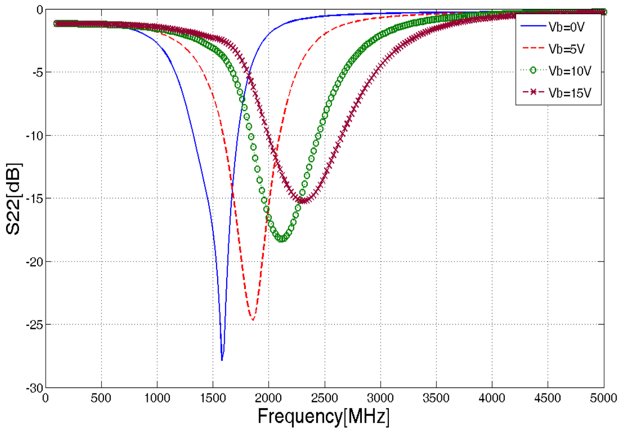


Fig.9 S22 for tunable balanced power amplifier at different bias voltages.

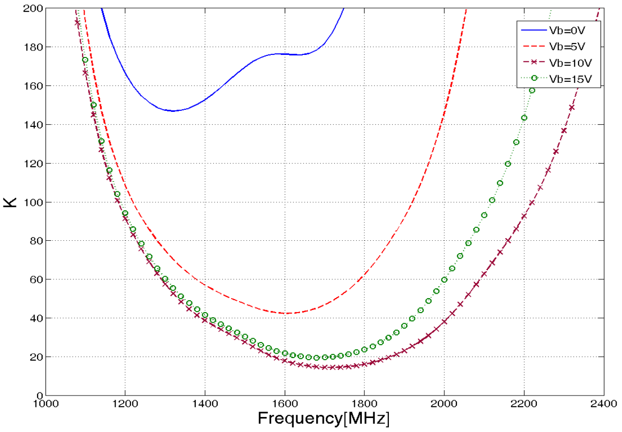


Fig.10 Stability factor K for tunable balanced power amplifier

The simulated gain of balanced amplifier without coupler is 18 dB at 1.8 GHz, while Fig 7. shows the tunable gain of balanced amplifier along with coupler. Fig 8-10 illustrate the input, output reflection coefficients and stability factor K of a tunable balanced amplifier comprising of BST varactors, when the bias voltage is swept from 0 to 15 volts. An interesting point that should be mentioned for the response of the tunable balanced PA is its low pass characteristic for the transmission parameter S21. The roll-off in the S21 curve at higher frequencies is caused by the equivalent low-pass segments used for the reduced size branch-line couplers. As a result, harmonics at the PA output are significantly attenuated which is highly desirable for a PA circuit.

VII. CONCLUSION

Analyses of a tunable balanced PA envisage a very stable broadband device whose operation can be reconfigured at continuous frequency range of 1500 to 2500 MHz. BST varactors enable an excellent tuning range but low quality factor is a major cause of losses. While requirements of two amplifiers and additional components for any traditional balanced PA remains intact, increased frequency agility along with an expected 50% size reduction due to reduced size coupler is a major advantage in the presented tunable balanced power amplifier.

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REFERENCES

[1] J. Cranincks, S. Donnay,“ 4G Terminals: How are we going to design them?’’, Proc. 2003 IEEE Design Automation Conf. June 2003, pp79-84.

[2] R.S. Engelbrecht, K.Kurokawa,“ A wide-band low noise L.band balanced transistor amplifier’’,Proc.IEEE vol.53,no.3,pp.237-247, March 1965 .

[3] M. Schmidt, E. Lourandakis, R. Weigel, A. Leidl, S. Seitz “A Thin-Film Varactor Model for Linear and Non Linear Circuit Simulation for Mobile Communication Systems”, Applications of Ferroelectrics, ISAF’06.IEEE International Symposium on the, pp.372-375,2006.

[4] E. Lourandakis, M. Schmidt, S. Seitz, R. Weigel, “Reduced Size Frequency Agile Microwave Circuits Using Ferroelectric Thin-Film Varactors”, IEEE MTT Transactions Vol.56, No.12, Dec.2008.

[5] J. Dickson, “On-chip high voltage generation in NMOS integrated circuits using an improved voltage multiplier technique”, IEEE Journal of Solid State Circuits, Vol.11, No.3, pp.374-378, 1976.