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Measurement of Load-Pull Performance in the Power Smith Tube Using a Tunable Varactor Matching Network

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***Abstract*—Future radar transmitters will require a fast reconfiguration of their radio-frequency circuitry in order to adapt to changes in operating frequency and spectral output while maintaining high power-added efficiency. In this paper, transistor load-pull measurement results are displayed in the Power Smith Tube using measurements from a tunable-varactor matching network. Measuring load-pull characteristics and plotting them in the Power Smith Tube is a preliminary step toward the implementation of the Power Smith Tube in real-time optimization using the tunable-varactor network. Visualization of the tunable-matching network load-pull results can be used as an aid in designing for optimum power-added efficiency while meeting adjacent-channel power ratio requirements.**

***Index Terms*— power-added efficiency, adjacent-channel power ratio, load-pull, power amplifiers, Smith Chart, optimization, adaptive radar, convex optimization**

I. Introduction

For many future radar systems, the cognitive radar paradigm is being considered in anticipation that participation in dynamic spectrum allocation will be eventually required [1]. This has led to the discussions of designing real-time circuit and waveform optimization to meet increasing demands [2]. The idea of cognitive radar requires radar systems to optimize components in real time according to their surroundings and need [3, 4].

Since the power amplifier is a large consumer of energy in a radar transmitter, power-added efficiency (PAE) is vital in the overall efficiency of a system. In dynamic spectrum allocation, operating frequency and bandwidth are assigned to a user in real time based on surrounding users and available spectrum. The nonlinearities of the transmitter power amplifier and the wide bandwidth necessary for accurate range detection can cause unwanted spreading into neighboring channels. This can be measured using the adjacent-channel power ratio (ACPR). Reconfigurable circuitry will be required to allow a system to quickly optimize to maximize PAE while remaining within ACPR constraints.

The Power Smith Tube is a three-dimensional, cylindrical extension of the Smith Chart [6]. Traditionally, there are many elements that are considered when optimizing a power amplifier with a linearity constraint. When both reflection coefficient Γ_L and input power P_{in} are considered, the process for finding an optimum can be very arduous due to the multiple optimization parameters. Typically, a load pull will be performed and a Γ_L will be selected that has the best PAE while meeting ACPR constraints. Then a power sweep might be taken at the location of the optimum Γ_L in order to find the best P_{in}. These two steps are often repeated until the user believes that acceptable PAE within the power range that also meets the ACPR constraint has been achieved. Figure 1 shows the Power Smith Tube. Additional types of Smith Tubes have also been discussed, including the Bandwidth Smith Tube and Bias Smith Tube [7, 8].

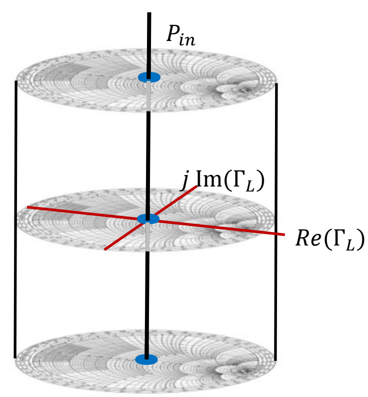


Fig. 1. The Power Smith Tube. The vertical axis represents input power, and the horizontal cross section is a conventional Smith chart (reprinted from [6] for convenience).

A paper previously published by our group demonstrates fast, simultaneous optimization of power-amplifier input power and load reflection coefficient to achieve maximum constrained PAE in the Power Smith Tube, using a gradient-based convex optimization [9]. We have also recently demonstrated implementation of a varactor load tuning network for an adaptive amplifier [10].

In the present writing, we attempt to build the framework for use of the Power Smith Tube in optimization with a tunable-varactor matching network in real-time. As such, our first exploration (presented here) is to plot the three-dimensional equal-PAE and equal-ACPR surfaces in the Smith Tube. Figure 2 shows the measurement setup used for these experiments. The tunable-varactor network serves as a variable load impedance-matching network for the transistor under test. As such, the power output from the transistor is input to the tunable-varactor matching network.

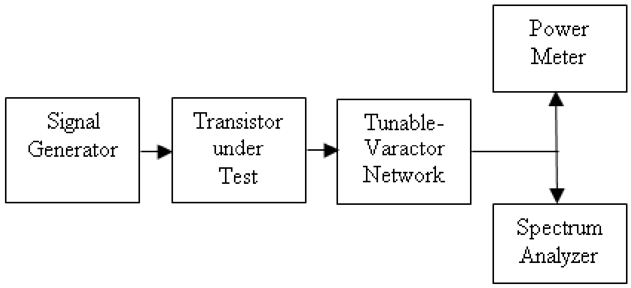
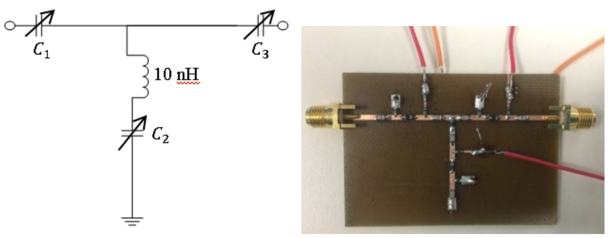


Fig. 2. Measurement test setup.

Figure 3 shows the topology and layout of the tunable-varactor matching network, designed for use at 1.3 GHz based on the approach of Fu [11]. Figure 4 shows the characterized states at an input power of 0 dBm of the matching network for the load reflection coefficient Γ_L, whose complex plane is the Smith Chart.

A power-dependent characterization is required for the varactor matching network due to its nonlinear behavior with input power, which is the device output power. This characterization is thoroughly described in a recently submitted journal paper [12], and is employed in this work.



(a) (b)

Fig. 3. (a) Design of 1.3 GHz tunable matching network, based on Fu [11], (b) implemented tunable-varactor matching network, reprinted from [10] for convenience

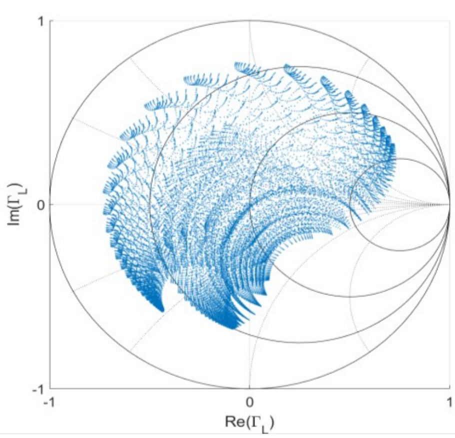


Fig. 4. Characterized load reflection coefficient states for the tunable varactor matching network, reprinted from [10] for convenience

II. Measurement Results

Load-pull measurements were performed on a Microwave Technologies MWT-173 field-effect transistor (FET) at different power levels to construct PAE and ACPR contours within the Power Smith Tube. The operating frequency was 1.3 GHz. The transistor was biased to a V_{GS} = -1 V, V_{DS} = 2. At this bias point, significant nonlinearity exists, providing spectral spreading. A modified linear up chirp was generated using an Agilent N5182A signal generator. Agilent E3647A power supplies were used to supply voltage to the transistor and varactors. An Agilent N1911A power meter was used to measure power out and an Agilent N9010A signal analyzer was used to measure ACPR. Each point on the Smith chart took approximately 4 seconds to measure. The load-pull measurements were performed from -9 dBm to 5 dBm of input power in 1 dBm increments. A constraint of ACPR ≤ -30 dBc was imposed on the design. The maximum PAE satisfying this ACPR constraint was found to be 17.5% at located at Γ_L =.41/-13.34° and P_{in} = 1 dBm. Figure 5 shows the Power Smith Tube plot for this constraint. This figure was obtained with Matlab by concatenating all the separate load-pull data and then creating an isosurface using built-in matlab commands. The blue surface is the ACPR = -30 dBc surface, representing the constraint. The red surface represents the equal-PAE surface for the maximum constraint PAE of 17.5%. The point at which these two surfaces intersect is the constrained optimum point. Note that the PAE surface was chosen to be shown instead of gain or output power because this is the parameter that is going to be used in optimization. Figure 6 shows the top view of the Smith Tube which reveals that edges of the ACPR = -30 dBc surface are also the edges of the region accessible by the tunable varactor matching network shown in Fig. 4. This is an additional visualization issue that typically occurs when the Smith Chart coverage of the matching network is limited. Therefore, it can be concluded that the boundaries of the ACPR = -30 dBc surface would simply be the edges of the tuner accessible region and the bottom of the cylinder.

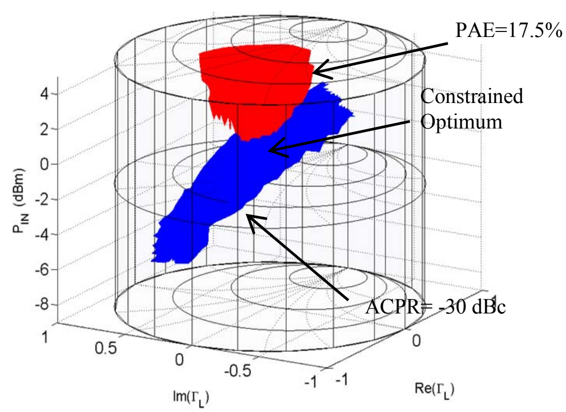


Fig. 5. Measurement Surfaces for ACPR = -30 dBc and PAE=17.5% in the Power Smith Tube. The ACPR-constrained

optimum solution occurs where the two surfaces intersect; the surfaces are collinear at this point. The maximum PAE satisfying the constraint was found to be 17.5%, located at Γ_L =.41/-13.34° and P_{in} = 1 dBm.

Figure 5 demonstrates how the point where the ACPR constraint surface and constrained-optimum PAE surface meet is where the optimum solution occurs. This figure also reveals that the shapes of these two regions are nearly convex, which is ideal and suitable for our previously presented gradient optimization technique [9]. Note that these shapes do not have to be perfectly convex since some non-convexity is inevitable because of noise. As long as the general shape of these regions are convex, the algorithm should have no problems converging.

Figure 7 shows the graphical design for a different constraint: ACPR ≤ -38 dBc. The constrained optimum PAE is 10.89%, located at Γ_L = 0.42/-14.65° and P_{in}=-2 dBm. The PAE = 10.89% surface for this figure is much larger since the PAE constrained optimum value is smaller. The ACPR acceptable region is also smaller which is due to the ACPR constraint being stricter. However, despite these changes, this limit still proves to be suitable for optimization since the PAE and ACPR surfaces are nearly convex. This also demonstrates that an intelligent fast algorithm could be feasibly implemented in the Power Smith Tube for constrained optimization on this device.

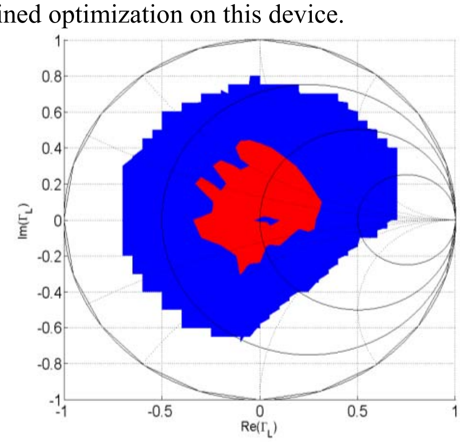


Fig. 6. The top view of the Power Smith Tube shown in Figure 5. It can be observed that the ACPR = -30 dBc surface edges correspond to the points accessible by the tunable varactor network shown in Figure 4.

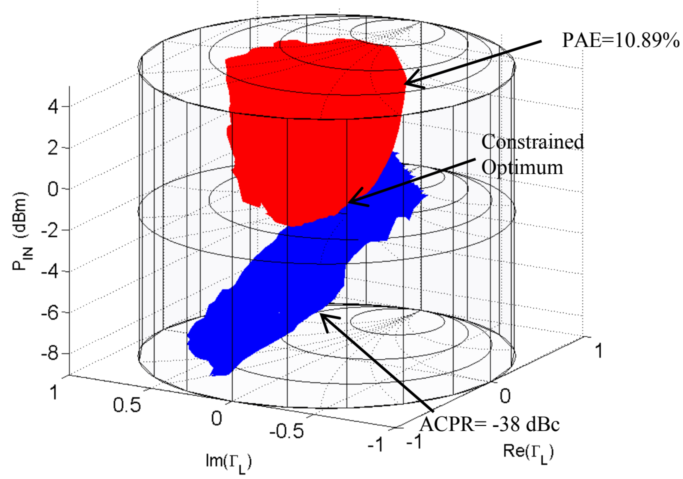


Fig. 7. ACPR isosurface for ACPR= -38 dBc and PAE=10.89%. The ACPR-constrained optimum solution occurs where the two surface intersects; the surfaces are collinear at this point. The maximum PAE satisfying this constraint was found to be 10.89%, located at Γ_L = 0.42/-14.65° and P_{in}=-2 dBm.

III. Conclusions

The Power Smith Tube is demonstrated for input power and load reflection coefficient optimization, using load-pull measurements performed with a tunable-varactor matching network. The results show that the combination of reflection coefficient and input power providing the maximum PAE given an ACPR constraint can be simply found. The surfaces for PAE and ACPR appear to be shaped in a way that will allow fast optimization using a modified gradient search. This will be a topic of continued research in this area, with a goal of developing a real-time, simultaneous optimization of reflection coefficient and input power for an adaptive power amplifier using this tunable-varactor matching network.

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