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Fast, Momentum-Aided Optimization of Transmitter Amplifier Load Impedance and Input Power for Cognitive Radio Using the Power Smith Tube

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***Abstract* — A fast search including momentum is used to quickly and simultaneously optimize power-amplifier load impedance and input power for the highest power-added efficiency while maintaining adjacent-channel power ratio within compliance limits. This search makes use of the recently developed Power Smith Tube, and is expected to be useful in real-time reconfigurable communications and radar transmitters, as well as for fast computer and measurement aided design of power amplifiers. Simulation and measurement results are shown to demonstrate the improved accuracy provided by adding momentum to the search.**

***Index Terms* — Power amplifiers, load-pull, nonlinear measurements, design, cognitive radio.**

I. Introduction

Reconfigurable power amplifiers enable cognitive radio transmission by enabling reconfigurability to multiple frequency bands and operating conditions [1], meeting spectral requirements that may be dynamically varying. An adaptive amplifier using a genetic tuning algorithm is demonstrated by Qiao [2]. Genetic algorithms, however, have been reported to be slower than other algorithms for many applications [3]. Power amplifier performance has been shown to be significantly related to both input power and load impedance [4, 5]. The Power Smith Tube, shown in Fig. 1, provides visualization for simultaneous optimization of input power P_{in} and load reflection coefficient Γ_L in reconfigurable power amplifiers for cognitive radio applications [6]. A recently submitted paper shows an effective algorithm to find the optimum power-added efficiency (PAE) under constraints on adjacent-channel power ratio (ACPR) [7]. In the present paper, this fast search is modified to include momentum, a method that incorporates earlier results in the search progression [8, 9, 10, 11]. The momentum-aided algorithm can reconfigure Γ_L and P_{in} to meet PAE and ACPR goals quickly and accurately.

II. Momentum-Aided Search

The Power Smith Tube search proceeds by adding a three-dimensional search vector $\bar{v}$ to a previous candidate point in the Smith Tube based on PAE and ACPR gradient calculations. This concept is shown in Fig. 2 and the search vector calculations and gradient estimations for the original search are rigorously described in [6]. Adding momentum to the search allows previous candidate points to influence the selection of subsequent candidate points. The momentum-adjusted search vector $\bar{w}_{k+1}$ for the $(k+1)$th point based on the adjusted search vector $\bar{w}_k$ at the kth point and the search vector $\bar{v}_{k+1}$ calculated for the $(k+1)$th point is given as follows:

$$\bar{w}_{k+1} = \alpha\bar{w}_k + (1-\alpha)\bar{v}_{k+1}, \tag{1}$$

where α is the momentum coefficient and is assigned a value between 0 and 1. When α is increased, more momentum is included in the search, and the previous search vector plays a greater role in the choice of the next search vector. For the special case $\alpha = 0$, the search contains no momentum, and $\bar{w}_{k+1} = \bar{v}_{k+1}$. For the special case $\alpha = 1$, $\bar{w}_{k+1} = \bar{w}_k$, and the search vector never changes, but is always equal to its previous value.

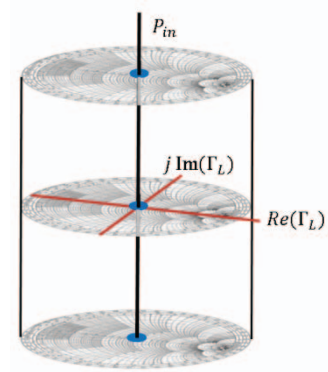


Fig. 1. The Power Smith Tube. The vertical axis represents the input power, while the horizontal cross section of the tube is a conventional Smith chart, reprinted from [1].

III. Measurement Example

The algorithm involving momentum was tested in measurement using a Maury Microwave Automated Tuner System (ATS) load-pull setup, with Keysight Technologies signal generator, power meter, and spectrum analyzer. A Skyworks SKY5017-70LF InGaP packaged amplifier was used as the device under test. The goal of the search is to find the combination of load reflection coefficient Γ_L and input power P_{in} to provide the maximum PAE while maintaining ACPR below a constraint value of -27.5 dBc with a minimum number of (Γ_L, P_{in}) measured points. For comparison with algorithm results, Figure 3 shows the constant-ACPR surface for ACPR = -27.5 dBc, with the constrained optimum included. This plot was constructed from traditional load-pull measurements at multiple values of P_{in}. As P_{in} is increased, the acceptable-ACPR region of the Smith Chart narrows, consistent with the fact that the amplifier operates more nonlinearly at higher values of input power.

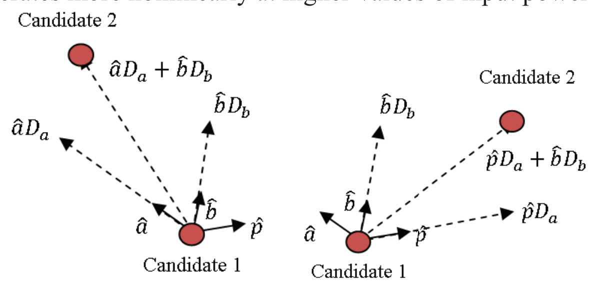


Fig. 2. Search vector calculations when (a) ACPR is outside acceptable limits and (b) ACPR is within acceptable limits, reprinted from [6]

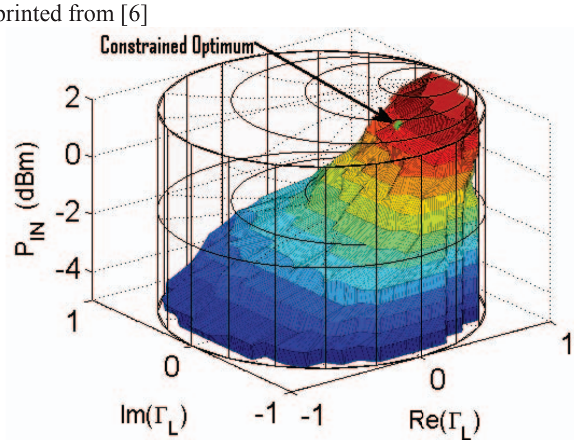
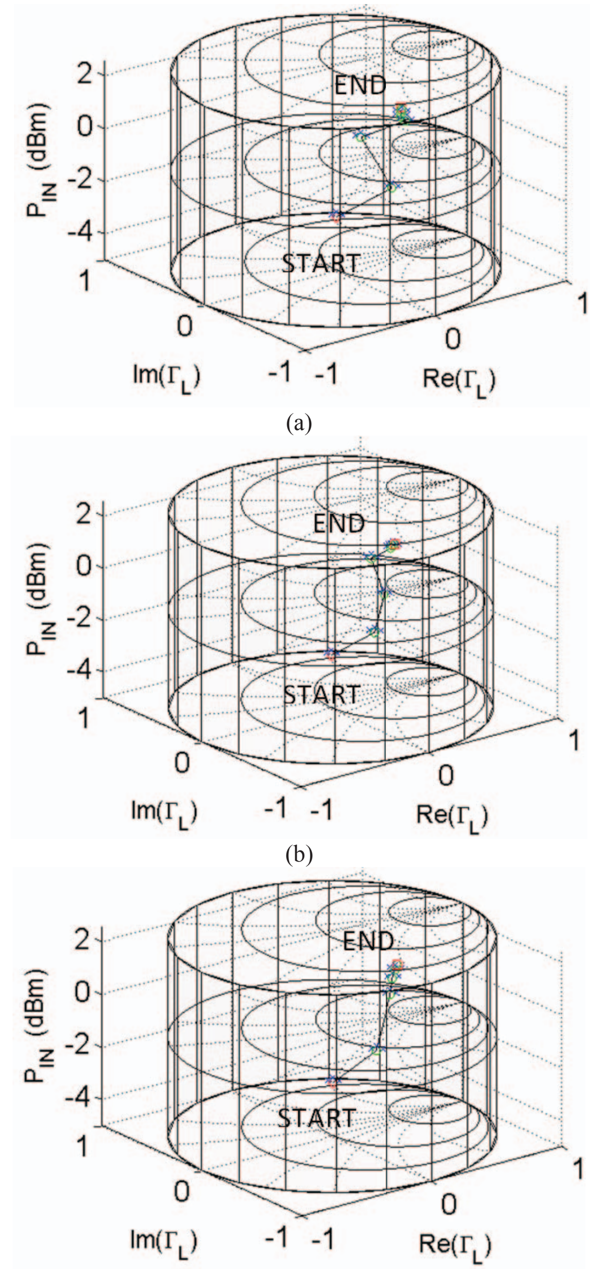


Fig.3. ACPR = -27.5 dBc. surface from measurement data

Figure 4 shows the trajectory of the search for three different α values from the starting point $\Gamma_L = 0, P_{in} = -3$ dBm. It can be seen that the path is straighter as the value of α is increased (more momentum). In this case for higher α, the number of measured points decreases and the end PAE is higher. For these search parameters, the addition of momentum increases both the speed and accuracy of the search. Table I shows the results for different momentum levels (values of α) from multiple starting points throughout the Power Smith Tube. The results show that adding a moderate level of momentum tends to make the end PAE higher and the ACPR closer to the boundary level (a better result), usually with a decrease in the number of measurements or possibly a very small increase in the number of measurements. For some of the starting points, $\alpha = 0.4$ is too large and often results in less desirable results with more measurements. In most cases $\alpha = 0.2$ or 0.3 seems to be most effective. In general, the measurement results demonstrate that too much momentum can lessen effectiveness.



(c)

Fig. 4. Measurement search algorithm trajectory through the Power Smith Tube with varied momentum values at starting location $\Gamma_L = 0$, $P_{in} = -3$ dBm. Search algorithm trajectory with (a) no momentum included in search (28 measured points), (b) $\alpha = 0.2$ (26 measured points), (c) $\alpha = 0.4$ (24 measured points). The endpoints are shown in Table I.

TABLE I: MEASUREMENT RESULTS WITH VARYING LEVELS OF MOMENTUM

Start Γ_L, P_{in}	α	End Γ_L	End P_{in}, dBm	End ACPR, dBc	End PAE %	# Ms
$0\angle 0°$ $P_{in} = -3$	0.0	$0.40\angle -28.6°$	1.03	-28.06	7.01	28
	0.1	$0.42\angle -30.7°$	1.61	-27.56	7.59	22
	0.2	$0.40\angle -46.0°$	1.38	-27.55	7.37	26
	0.3	$0.41\angle -46.8°$	1.45	-27.53	7.42	23
	0.4	$0.40\angle -32.6°$	1.39	-27.62	7.45	24
$0.8\angle -175°$ $P_{in} = -2$	0.0	$0.39\angle -44.1°$	1.27	-27.70	7.29	30
	0.1	$0.46\angle -36.8°$	1.72	-27.67	7.54	33
	0.2	$0.44\angle -34.2°$	1.81	-27.56	7.73	33
	0.3	$0.42\angle -28.7°$	1.76	-27.53	7.77	36
	0.4	$0.43\angle -33.8°$	1.60	-27.51	7.64	38
$0.25\angle 45°$ $P_{in} = 0$	0.0	$0.36\angle -47.3°$	1.06	-27.58	7.10	40
	0.1	$0.49\angle -35.2°$	1.87	-27.67	7.61	40
	0.2	$0.45\angle -30.5°$	1.86	-27.56	7.73	27
	0.3	$0.45\angle -40.2°$	1.78	-27.52	7.68	30
	0.4	$0.37\angle -33.2°$	1.22	-27.79	7.35	33
$0.5\angle 135°$ $P_{in} = 2$	0.0	$0.45\angle -36.2°$	1.34	-28.31	7.01	34
	0.1	$0.45\angle -30.4°$	1.95	-27.66	7.62	26
	0.2	$0.42\angle -45.2°$	1.63	-27.64	7.42	34
	0.3	$0.43\angle -43.8°$	1.64	-27.62	7.45	30
	0.4	$0.44\angle -37.4°$	1.65	-27.64	7.68	50
$0.75\angle 90°$ $P_{in} = 1$	0.0	$0.39\angle -26.9°$	1.50	-27.78	7.37	31
	0.1	$0.42\angle -31.6°$	1.87	-27.51	7.65	30
	0.2	$0.42\angle -36.7°$	1.79	-27.60	7.64	26
	0.3	$0.45\angle -32.8°$	2.07	-27.52	7.78	42
	0.4	$0.43\angle -43.0$	1.49	-27.70	7.58	34
$0.4\angle -90°$ $P_{in} = -1$	0.0	$0.35\angle -36.7°$	1.16	-27.72	7.10	25
	0.1	$0.44\angle -41.3°$	1.81	-27.59	7.66	28
	0.2	$0.39\angle -37.6$	1.52	-27.64	7.46	19
	0.3	$0.42\angle -36.0°$	1.63	-27.51	7.57	19
	0.4	$0.40\angle -24.2°$	*1.55*	-27.62	7.56	20

IV. CONCLUSIONS

A search algorithm with momentum designed for the real-time optimization of power amplifier load impedance and input power in cognitive radio applications has been demonstrated. In general, measurement results show that moderate amounts of momentum assist the search's accuracy and, in many cases, speed in finding the constrained optimum in a sample two-parameter search. With appropriate momentum, the trajectory of the search in the Smith Tube is observed to straighten and be less sensitive to measurement-based gradient estimation noise. Momentum shows promise for decreasing circuit reconfiguration time and increasing optimization accuracy for cognitive and reconfigurable radio applications.

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REFERENCES

[1] A.M.M. Mohamed, S. Boumaiza, and R.R. Mansour, "Novel Reconfigurable Fundamental/Harmonic Matching Network for Enhancing the Efficiency of Power Amplifiers," 2010 European Microwave Conference, Paris, France, September 2010, pp. 1122-1125.

[2] D. Qiao, R. Molfino, S. Lardizabal, B. Pillans, P. Asbeck, and G. Jerinic, "An Intelligently Controlled RF Power Amplifier with a Reconfigrable MEMS-Varactor Tuner," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 53, No. 3, Part 2, March 2005, pp. 1089-1095.

[3] W. du Plessis and P. Abrie, "Lumped Impedance Matching Using a Hybrid Genetic Algorithm," *Microwave and Optical Technology Letters*, Vol. 37, No. 3, pp. 210-212, May 2003.

[4] D.M. Snider, "A Theoretical Analysis and Experimental Confirmation of the Optimally Loaded and Overdriven RF Power Amplifier," *IEEE Transactions on Electron Devices*, Vol. ED-14, No. 12, December 1967, pp. 851-857.

[5] H.M. Nemati, C. Fager, U. Gustavson, R. Jos, and H. Zirath, "Design of Varactor-Based Tunable Matching Networks for Dynamic Load Modulation of High Power Amplifiers," *IEEE Transactions on Microwave Theory and Techniques,* Vol. 57, No. 5, May 2009, pp. 1110-1118.

[6] J. Barkate, J. Barlow, M. Fellows, C. Baylis, L. Cohen, and R.J. Marks II, "The Power Smith Tube: Joint Optimization of Power Amplifier Input Power and Load Impedance for Power-Added Efficiency and Adjacent-Channel Power Ratio," 2015 IEEE Wireless and Microwave Technology Conference, Cocoa Beach, Florida, April 2015.

[7] J. Barkate, M. Flachsbart, Z. Hays, M. Fellows, J. Barlow, C. Baylis, L. Cohen, and R.J. Marks II, "Fast, Simultaneous Optimization of Power Amplifier Input Power and Load Impedance for Power-Added Efficiency and Adjacent-Channel Power Ratio Using the Power Smith Tube," submitted to *IEEE Transactions on Aerospace and Electronic Systems*, May 2015, in correspondence.

[8] D.E. Rumelhart, G.E. Hinton, and R.J. Williams, "Learning Representation by Back-Propagating Errors," *Nature*, Vol. 323, No. 9, October 1986, pp. 533-536.

[9] G. Qiu, M.R. Varley, and T.J. Terrell, "Accelerated Training of Backpropagation Networks by Using Adaptive Momentum Step," *IEE Electronics Letters*, Vol. 28, No. 4, February 1992, pp. 377-379.

[10] P.Arabshahi, J.J.Choi, R.J.Marks II and T.P. Caudell "Fuzzy Control of Backpropagation," Proc. First IEEE International Conference on Fuzzy Systems, (FUZZ-IEEE 1992) San Diego, pp. 967-972, March 1992.

[11] R.D.Reed and R.J.Marks II, *Neural Smithing*, MIT Press, 1999.