

Fast Amplifier PAE Optimization Using Resonant Frequency Interval Halving with an Evanescent-Mode Cavity Tuner

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Abstract — Fast tuning of a new evanescent-mode cavity tuner is demonstrated to optimize amplifier device power-added efficiency in simulations. The tuning is accomplished by adjusting the two resonant frequencies of the two-element tuner network with a modified interval halving approach. The tuner model is used to adjust the load impedance presented to a power amplifier device. Simulation results show that the tuner is able to quickly converge to provide optimum-efficiency matching to the device from different starting resonant-frequency combinations.

Index Terms — Cognitive radio, impedance tuner, load-pull measurement, power amplifier.

I. INTRODUCTION

High-power matching circuitry with fast tuning algorithms will be needed to implement next-generation cognitive and adaptive radar systems. Tunable matching networks are demonstrated for “on-the-fly” tuning of communication systems by Nemati [1], Qiao [2], and du Plessis [3]. Hays describes fast impedance matching using a tunable-varactor matching network [4] with a gradient-based algorithm. The high-power requirements for radar transmission demand much larger power handling from tunable matching networks than has been traditionally demonstrated. The present paper uses simulation models of a high-power tuner to demonstrate a fast reconfigurable circuit algorithm. The simulation results indicate feasibility for tuning the evanescent-mode cavity tuner in measurement-based testing, and for using this tuner in real-time adaptive radar transmitters.

II. EVANESCENT-MODE CAVITY TUNER

Our simulation focuses on designing a fast tuning algorithm to directly tune the resonant frequencies of a high-power evanescent mode cavity tuner. This tuner changes the load reflection coefficient Γ_L presented to the transistor by tuning the resonant frequencies of the cavity, and the tuning is performed by a turnkey control system with a lookup table and feedback loop. Figure 1 shows the layout of the tuner. For each of the two resonators, the resonant frequency is adjusted by modulating the position of its piezoelectric cover disc.

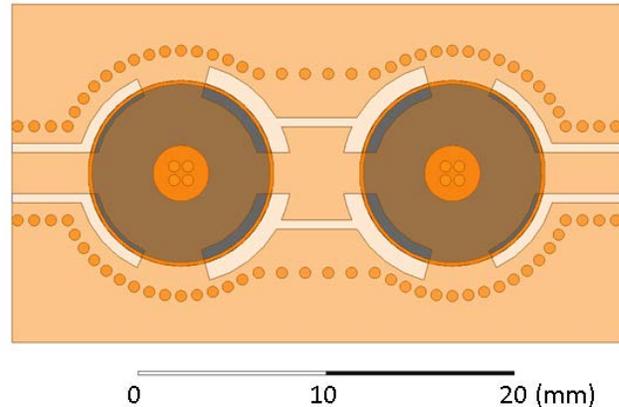


Fig. 1. Layout of the evanescent-mode cavity tuner [5].

We have implemented a simulation using tuner models which was developed in Keysight Technologies’ Advanced Design System (ADS). The simulation adjusts the position of the tuner elements which maps to a change in the resonant frequencies. Figure 2 shows the simulated Smith Chart coverage of the tuner. The extensive coverage provides for a highly reconfigurable circuit. Results of these simulation experiments demonstrate feasibility of implementing this method in both bench-top and field tuning of the cavity resonator.

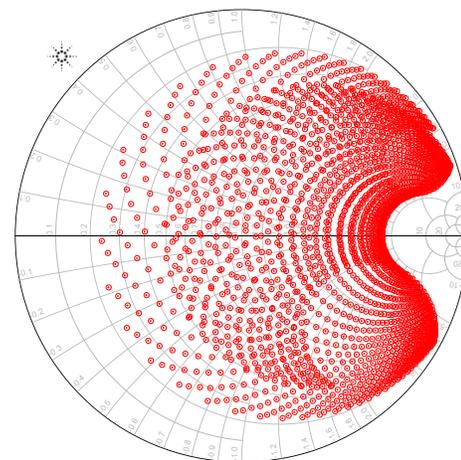


Fig. 2. Simulated Smith chart coverage of S_{11} at the tuner design frequency of 3.3 GHz.

III. ALGORITHM DESCRIPTION

The method used in this search is a modified interval halving (binary search) algorithm. As the resonator tuner is comprised of two resonant cavities, the algorithm alternately tunes the resonant frequency of each cavity until the end condition of the search is met. For each of the resonant frequencies f_1 and f_2 , a frequency range is specified to give the bounds of the optimization. The process of a single interval-halving iteration that is performed alternately for each resonant frequency is shown in Fig. 3. The algorithm first simulates the PAE at the midpoint frequency in the f_1 range (f_c) and at a neighboring point of slightly higher frequency ($f_c + f_n$). If the PAE at $f_c + f_n$ is greater than at f_c (Fig. 3(a)), the next candidate f_{next} is chosen at the midpoint between the current candidate and the maximum resonant frequency f_{max} . If instead the PAE at $f_c + f_n$ is lower than the PAE at f_c (Fig. 3(b)), the next candidate f_{next} is chosen between the current candidate and the minimum resonant frequency f_{min} . After one iteration of interval halving is performed in f_1 , interval halving is performed on the other resonant frequency f_2 while holding f_1 constant. The interval halving is performed alternately between f_1 and f_2 until the current candidate point has less than 1% higher PAE than the previous candidate.

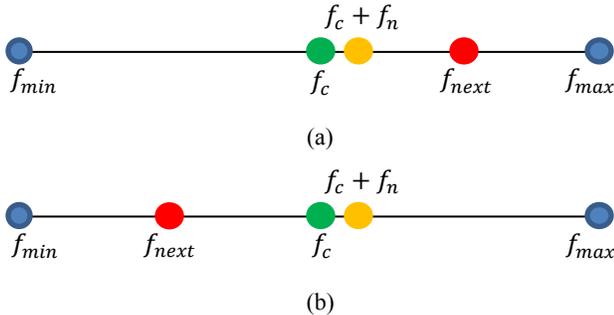


Fig. 3. Modified interval halving search algorithm. The resonant frequency of each tuner is alternately optimized to maximize PAE. Two cases exist: (a) the neighboring point has greater PAE than the starting point, and (b) the neighboring point has lower PAE than the starting point.

IV. SIMULATION RESULTS

The algorithm was tested in simulation with tuner resonant frequency ranges of 3.05-3.57 GHz. A built-in field-effect transistor model was used in ADS to represent the transistor. The search shown in Fig. 4 gives a maximum PAE value of 44.93% at the resonant frequency combination of $f_1 = 3.20$ GHz, $f_2 = 3.47$ GHz. The candidate points of the search are shown in Fig. 5 as impedances on the Smith Chart. Figure 6 shows the traditional load-pull contours. Comparison of Fig. 5 with Fig. 6 shows that the search converges to the optimum location found by traditional load-pull simulations, and the

final PAE values compare well between the search (44.93%) and the traditional load-pull simulation (45.87%).

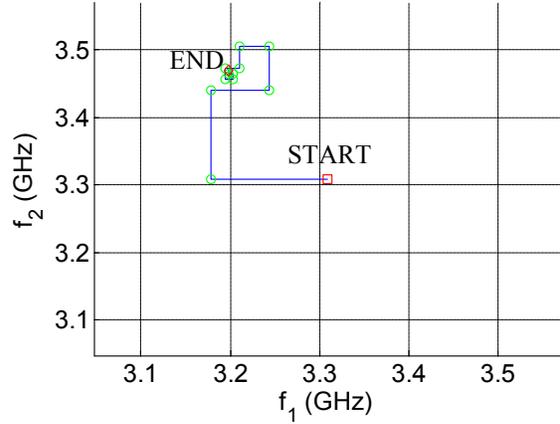


Fig. 4. Resonant frequency search simulation results with starting location $f_1 = 3.31$ GHz and $f_2 = 3.31$ GHz. An optimum PAE = 44.93% was found at $f_1 = 3.42$ GHz and $f_2 = 3.11$ GHz.

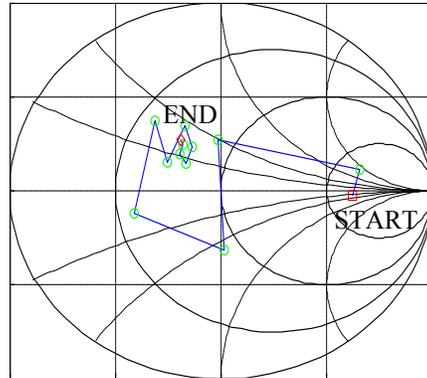


Fig. 5. Smith chart search trajectory for Fig. 4 search with starting location $f_1 = 3.31$ GHz and $f_2 = 3.31$ GHz

The simulation was performed at a non-central starting location within the search ranges to test the robustness of the search. In this case, the search still performs interval halving with the endpoint using the same methods, although the intervals on either side of the candidate with the endpoints are not necessarily identical. Figure 7 shows the resonant frequency mapping of a search initiated at $f_1 = 3.18$ GHz and $f_2 = 3.18$ GHz. The search converges to a similar PAE value of 41.14% at $f_1 = 3.42$ GHz and $f_2 = 3.11$ GHz. In this case, the end values for resonant frequencies are almost opposite of those shown in Fig. 4. This shows that different resonant frequency combinations can map to similar values of the load reflection coefficient Γ_L . By comparing Fig. 8 to Fig. 5, however, it is observed that both searches converge to the same Γ_L although the end resonant frequencies differ.

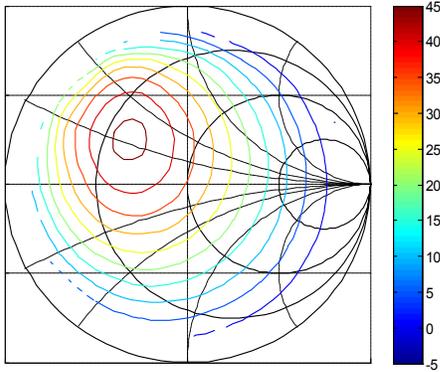


Fig. 6. PAE traditional load-pull results. The maximum PAE is 45.87% at $\Gamma_L = 0.45/150^\circ$.

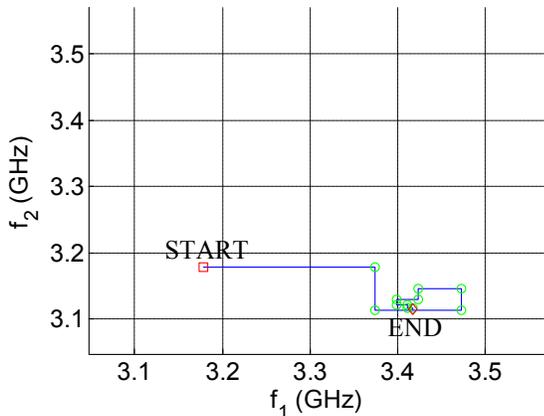


Fig. 7. Simulation results with starting location $f_1 = 3.18$ GHz and $f_2 = 3.18$ GHz. An optimum PAE = 41.14% was found at $f_1 = 3.42$ GHz and $f_2 = 3.11$ GHz.

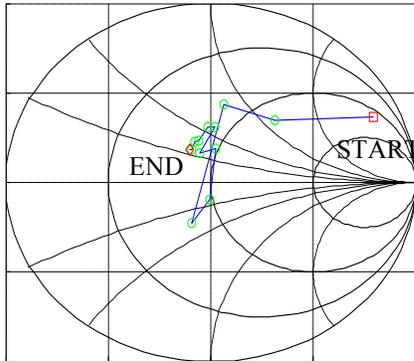


Fig. 8. Smith chart search trajectory of Fig. 7 search with starting location $f_1 = 3.18$ GHz and $f_2 = 3.18$ GHz with end PAE = 41.14%

For the search shown in Figures 7 and 8, the optimum PAE was found to be over 4 percent lower than the traditional load-pull results. An examination of the data shows that the alternating interval-halving approach can often miss an optimum due to the fact that the algorithm

removes half of the remaining part of each frequency range at each step. As such, the optimum may not be reached if the steepest-ascent direction is not aligned along either the f_1 or f_2 axis in the resonant frequency plane. These results prompt the possibility that a gradient search may provide better accuracy and could be examined as a next step in the research process. However, the results obtained will allow the amplifier to operate relatively close to the optimum, and this is expected to occur in most cases.

V. CONCLUSIONS

A fast optimization for tuning the resonant frequencies in a high-power, reconfigurable evanescent mode cavity tuner to maximize power-added efficiency of a transistor has been presented. The results presented in this paper demonstrate the feasibility of this fast optimization for on-the-fly tuning of the reconfigurable network in reconfigurable radar applications. Directly tuning the resonant frequencies avoids the need for a characterization look-up (of the mapping between resonant frequencies and reflection coefficient) during tuning. This approach could amount to a significant reconfiguration time savings in practice.

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