# Estimation of Power Amplifier Package Model from Frequency Sweep Measurements

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*Abstract* - In this paper we present a method for estimating power amplifier package model from spectrum analyser frequency sweep measurements. Assumed power amplifier package model is physical and it includes parasitic capacitances and bondwire inductance. Packaged model parameters can be estimated from frequency sweep measurements. Estimated package model was used to design the matching network for 2.14 GHz band, and the correctness of the proposed method and assumed model was confirmed by comparing expected results obtained by simulation with measurements.

*Keywords* – Power amplifier, package model, optimization.

## I. INTRODUCTION

Software defined radio is disrupting RF system design in the same way as FPGA did for digital system design. The need to cover many standards and reconfigurability is driving the expansion of software defined radio even in the markets which have been dominated by few big companies, such as telecommunication infrastructure.

Modern software defined radios operate in very wide frequency range spanning from few MHz well into GHz range. For maximum flexibility external matching circuit, usually consisting of inductors, capacitors and baluns is used to enable operation in such extreme frequency span. Matching network is designed to optimize the performance for a given application, e.g. wideband frequency response, maximum output power etc.

Designing a matching network for a given application is not a trivial task since it consists of fixed on-chip part, i.e. parasitic capacitance, bond-wire inductance etc., and external components. On-chip parasitics must be taken into account, especially in the GHz range, but it is difficult to simulate or measure them.

One of the ways to characterize on-chip parasitics is to run an electromagnetic simulation. However, the accuracy of results depends on the accuracy of electromagnetic models. It is difficult to construct an accurate model since the knowledge of packaging geometry and material properties are not known or incomplete. For example, exact bonding profile (geometry) is not always known so the accuracy of simulated bond-wire inductance is questionable. Material properties, such as molding plastic permittivity and loss tangent, are either completely unknown or specified at low frequency. All of these issues complicate the design of electromagnetic models and lower the confidence in simulation results. Analytic models, such as [1-5] can aso be used, but unknown bondwire geometry and material properties limit the accuracy of results.

Package parasitics can in principle be measured by a vector network analyser. Success of determining package parasitics from packaged chip measurements depends on the impedance of on-chip circuit. In the case of on-chip power amplifier the output impedance is almost purely capacitive, and the chip is a highly reflective load which is difficult to accurately measure. Two-port measurements, where one port is on-chip and the other on PCB, would solve the problem of bondwire measurement, but would require on-wafer probing and fabrication of test chip, which is very expensive.

In this paper we present a method for estimating the package model of software defined radio power amplifier by using only a spectrum analyser frequency sweep measurements. Method and its assumptions are described in Sec. II. Simulation and experimental validation is presented in Sec. III, while concluding remarks are given in Sec. IV.

## II. PACKAGED POWER AMPLIFIER MODEL

Software defined radio should operate in very wide frequency range and is usually designed as direct conversion transceiver to avoid the use of tunable filters. Block diagram of software defined radio direct conversion transmit chain – Fig. 1 – consists of I and Q baseband paths, followed by quadrature mixer and a power amplifier. This architecture does not require an image rejection filter, but must have very good amplitude and phase balance to provide sufficient image rejection and preserve RF signal fidelity. Depending on the chosen modulation, standard CMOS processes may provide sufficient amplitude and phase matching to satisfy required image rejection, while in other cases some kind of calibration must be performed to satisfy system requirements.

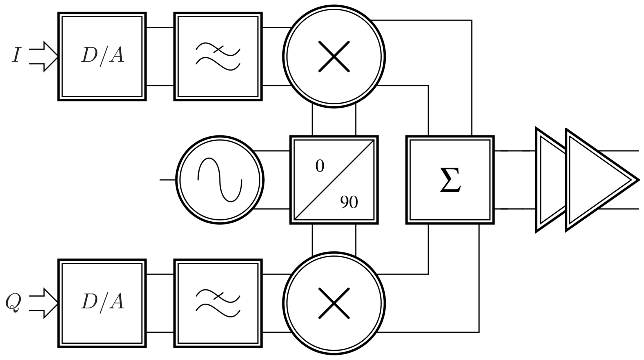


Fig. 1. Software defined radio RF transmit chain block diagram

For a single sideband excitation, generated by a proper choice of $I$ and $Q$ digital baseband signals, the whole

D. Grujić is with School of Electrical Engineering, University of Belgrade and Lime Microsystems. P. Jovanović and M. Savić are with Lime Microsystems. E-mail: {d.grujic, p.jovanovic, m.savic}@limemicro.com transmit chain can be simplified as power amplifier driven by a voltage source, as shown in Fig. 2. This simplification has an underlying assumption that the quadrature mixer-power amplifier interface is frequency independent, which is true for a well designed chip. Furthermore, CMOS power amplifier can be represented as a voltage constrained current source [6-8] with a shunt capacitance. Current source voltage constraints originate from physical limitations of MOS transistors – entering a triode region where they do not operate as current sources and breakdown voltage. Shunt capacitance is the sum of cascade transistor drain junction, drain-gate and drain-source parasitic capacitances.

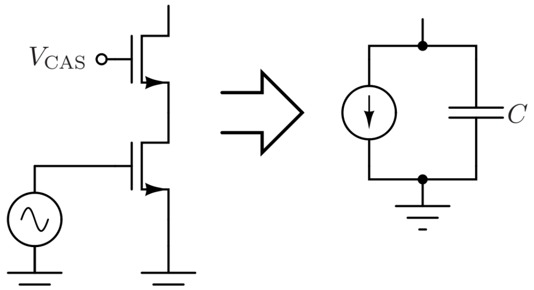


Fig. 2. Power amplifier equivalent model

Integrated power amplifiers are usually designed as differential circuits to boost the output power and to suppress the second order harmonic. Packaged differential amplifier equivalent model, shown in Fig. 3, consists of equivalent voltage constrained current source, parasitic transistor shunt capacitance, series bondwire inductance and resistance, and package parasitic capacitance. In order to design a matching circuit, the values of these parasitic elements should be estimated.

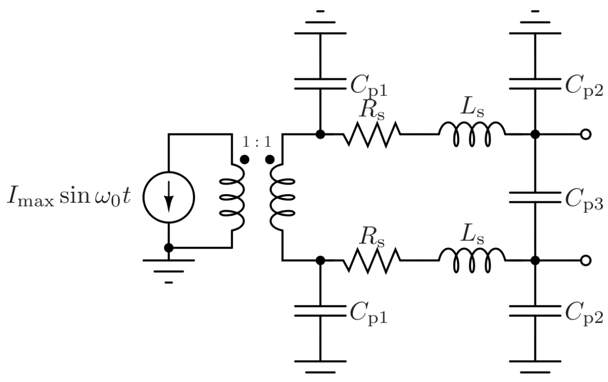


Fig. 3. Packaged differential power amplifier model

Assumed packaged differential amplifier model has six unknowns – driving current amplitude $I_{max}$, parasitic capacitances $C_{p1}$, $C_{p2}$ and $C_{p3}$, series resistance $R_s$ and inductance $L_s$. Determination of assumed power amplifier model parameters is discussed in the following section.

## III. Model parameter extraction and experimental validation

Assumed equivalent power amplifier model has six independent parameters, and it requires a system of at least six equations to solve. Parameters of assumed equivalent power amplifier model can be obtained from frequency sweep measurements, where the number of frequencies is at least six – preferably more, and by optimizing the parameters to fit the measurement data. However, the packaged power amplifier is mounted on printed circuit board, has bias inductors, DC block capacitors and a balun to facilitate spectrum analyser measurements, as shown in Fig. 4. Since the printed circuit board geometry and element values are known, it is possible to determine the values of equivalent packaged power amplifier model from measured output power at different frequencies by performing a frequency sweep and measuring the output power.

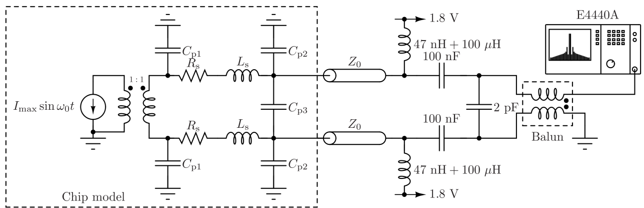


Fig. 4. Setup for frequency sweep measurement

The results of frequency sweep measurements and optimized packaged power amplifier model simulation are shown in Fig. 5. Assumed packaged power amplifier model is in good agreement with measurement results, so it is expected that model parameters correspond to physical reality.

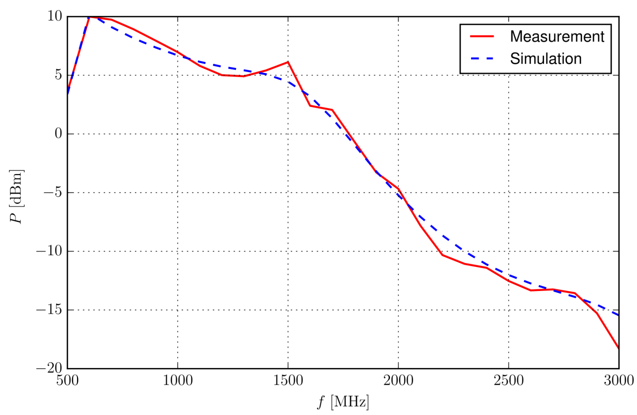


Fig. 5. Measured and simulated frequency sweep. Simulation was performed with optimized package model.

Optimized model parameters can be used to predict performance in the desired frequency band. In our case, the desired frequency band was centered around 2.14 GHz, and the goal was to design a matching circuit which would optimize the output power. Matching circuit was designed by using the optimized packaged power amplifer model and changing the printed circuit board components. Model obtained by optimization is shown in Fig. 6.

If the assumed packaged power amplifier model is correct, then it is expected that the optimized matching network simulation results should be in good agreement with measurement results. Experimental validation was performed by changing the printed circuit board components to the ones obtained by optimization and frequency sweep power measurements. Comparison of simulation and measurement results are shown in Fig. 7.

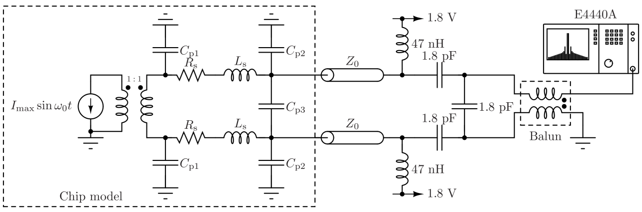


Fig. 6. Setup for measuring the optimized matching circuit for 2.14 GHz band

From Fig. 7 it can be seen that simulation and measurement results are in reasonable agreement, and that the optimized component values can be used as a good starting point for fine tuning of matching network. It also shows that the assumed package model and estimated model parameters are correct.

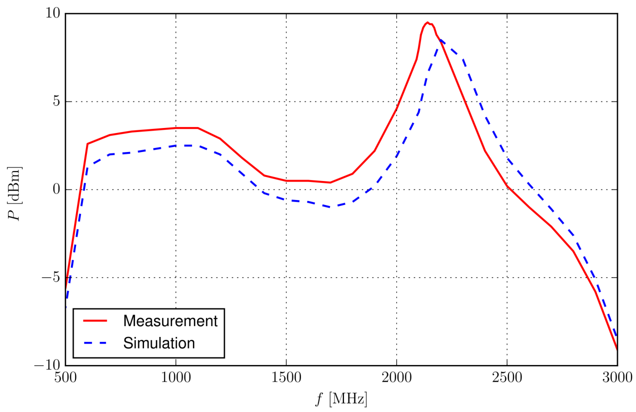


Fig. 7. Comparison of expected and measured output power with matching circuit for 2.14 GHz band

## IV. Conclusion

In this paper we have shown a method of estimating power amplifier package model from frequency sweep measurements. Measurement of frequency dependent software defined radio output power was used to fit the parameters of physical power amplifier package model. The model includes parasitic capacitance and bondwire inductance. Estimated model was used to design a matching network for 2.14 GHz band, and was verified by measurement. The proposed method may be used to estimate the package model without the need for network analyser measurements or test chip if assumptions are satisfied.

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