# Mixed element wideband microwave amplifier design via simplified real frequency technique

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Istanbul University
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# Mixed Element Wideband Microwave Amplifier Design via Simplified Real Frequency Technique

Sedat Kılınç
Electrical-Electronics Eng.
Istanbul University
Istanbul, Turkiye

Ramazan Köprü
Electrical-Electronics Eng.
Işık University
Istanbul, Turkiye

Ahmet Aksen
Electrical-Electronics Eng.
Işık University
Istanbul, Turkiye

B. S. Yarman
Electrical-Electronics Eng.
Istanbul University
Istanbul, Turkiye

***Abstract*—In this study, we illustrate the design and implementation of a wideband microwave small-signal amplifier composed of mixed elements. The design is based on Simplified Real Frequency Technique (SRFT). A design of low power amplifier circuit is completed and its simulations are performed in success. The circuit is designed with lumped elements, however, some of the lumped elements are converted to distributed elements for their convenience in production. In this way, a mixed element wideband microwave amplifier comprised of input/output matching networks with lumped and distributed elements has been formed. Layout work and also post layout simulation is given with satisfying results.**

***Keywords—wideband microwave amplifiers; impedance matching; network synthesis; simplified real frequency technique; optimization; cosimulation, mixed element network.***

## I. INTRODUCTION

In the process of wideband microwave amplifier design, some numerical and computer aided design (CAD) techniques and optimization processes are considerable solutions since there is no well-established analytical solution for amplifier equations which contains many unknown circuit parameters belonging to the input/output matching networks (IMN/OMN) [1-2]. Real Frequency Techniques (RFTs) are one of the numerical techniques offering excellent solutions in many design problems such as matching networks, amplifiers and many more [1-2]. The reflectance based version of these techniques is called as "Simplified Real Frequency Technique (SRFT)" which is known with its simplicity and success in the solutions of many wideband microwave amplifier design problems [1-2]. In the design problems of IMN/OMN (input/output matching networks) encountered in wideband microwave amplifiers, SRFT has been known and become a commonly used technique introduced into the literature with many real-working successful design examples [1-2].

This work is a continuation of a previous work [3], where an amplifier design and implementation is reported which have specs such as 63mW of output power, ~0.8-2.8GHz operating band, ~10.5 dB almost flat gain level along the operating band, with an active device of an HJ-FET NE3509M04 transistor from Renesas Electronics Corp. A narrower band (0.8-1.5GHz) version with similar specs of the amplifier of [3] has also been worked previously in [4].

In this work, we tried to increase the bandwidth further up to 3.9GHz by replacing some of the lumped elements with their distributed equivalents. Moreover, usage of the distributed elements allows also easy implementation of the prototype board in the laboratory environment. Section II presents the details of the lumped to distributed element conversion applied to *all-lumped element amplifier* design mentioned in [3], which we call it as "*reference design (RD)*" from now on. Then, simulation results of this converted *mixed-element amplifier* is shown. Simulation results show that both mixed-element amplifier and all-lumped element amplifier have close performances. Note that the simulation in layout level (ADS) includes realistic lumped models and electromagnetic (EM) effects for microstrip traces on a given commercial FR4 laminate.

## II. DESIGN OF THE AMPLIFIER AND ITS SIMULATION

### A. All-lumped Element Amplifier Design in Matlab

After execution of the amplifier design code in Matlab [3], IMN/OMN circuit schematics, gain and reflectance performances are obtained as seen in Fig. 1 and 2, respectively. Note that, the circuit topologies and element values in these schematics are yielded by the high precision synthesis codes, mentioned in [5, 6], integrated with the amplifier design code.

Using these topology and element values of IMN and OMN, we constructed the overall amplifier schematics as shown in Fig.3. In this figure it can be seen an additional capacitor "C0=47pF" connected to the gate which serves as a DC blocking capacitor, whereas there is no need to add this kind of a capacitor on OMN since its topology has already have such capacitor. The feedback element values are Cf=22pF, Lf=390nH and Rf=390Ohm which were also been determined via the Matlab code. In brief, we have designed a low power wideband amplifier to operate in between 0.8-3.9 GHz band having an average gain of about ~12.5 dB, S11 and S22 lower than ~-8dB along the passband and maximum P1dB output power of 12.6mW. DC operating point is set as VDD=6.3V, VGG=0V, a biasing scheme that makes the transistor work with VDS=3.0V and ID=~30mA [3]. Note that the ADS cosimulation is run using the commercially available realistic models of lumped passives from Murata and Johanson.

### B. Layout Design and Cosimulation

Based on the circuit synthesized at phase A, we have constructed a layout and performed EM simulations with realistic element models in this phase. To do this, first we run a re-optimization to make the terminations 50 Ohm both on the generator and load side. Re-optimized gain and reflectance performances using ADS (of Agilent, Inc.) are shown in Fig. 4.

Upon completion of the re-optimization process, we begin to design the layout of the re-optimized circuit. In this step, we planned to convert serial lumped inductors (L6 and L8 on IMN; L5 and L7 on OMN) to transmission lines and parallel lumped capacitors (C5 and C7 on IMN; C6 and C8 on OMN)

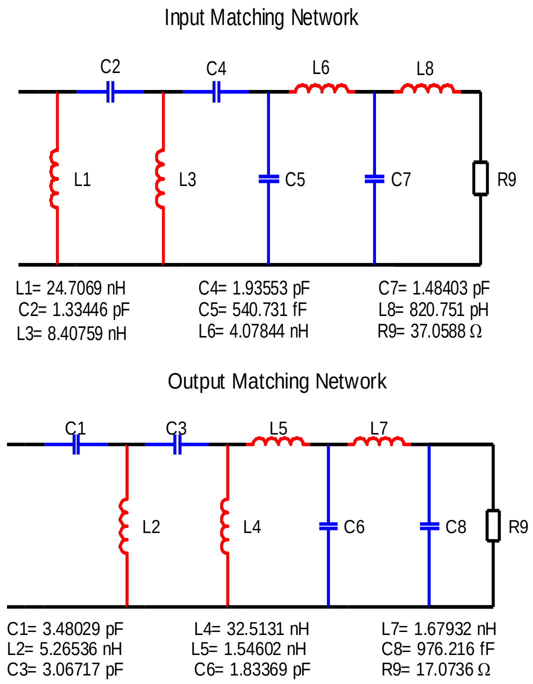

Fig. 1. Synthesized input and output matching networks.

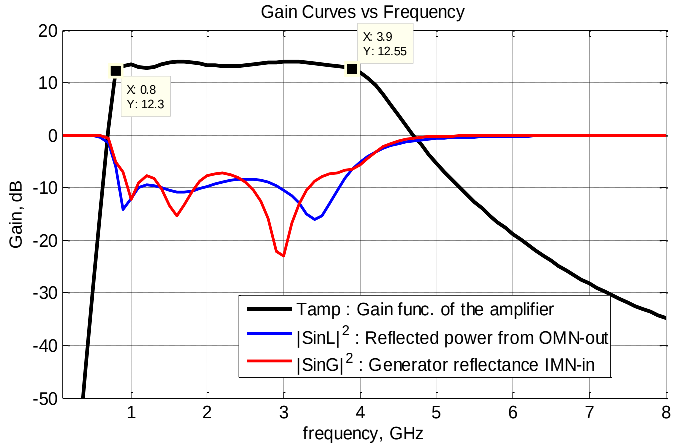

Fig. 2. Gain performance of the synthesized Circuit.

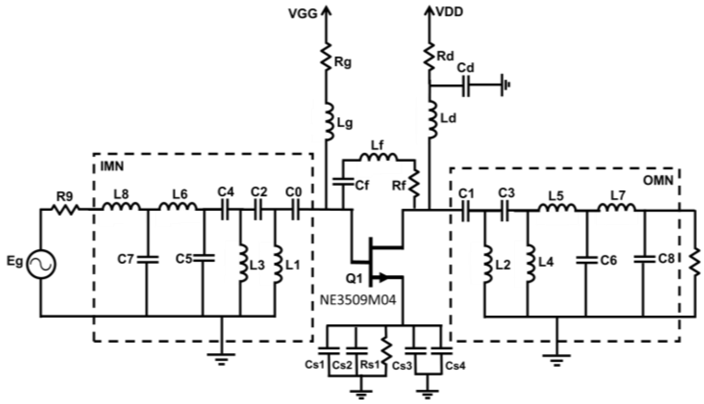

Fig. 3. Circuit schematic with ideal lumped elements.

to open-stubs, so except for these elements, we have generated the layout for the rest of the circuit to simulate EM behavior which is inevitable from a successful prototyping point of view. We used an FR4 laminate as a dielectric material, with the specs of relative permittivity = 4.4, dielectric thickness $h$ =1mm, conductor thickness = 43µm, loss tangent = 0.02. We only converted $L_f$ = 3.9nH from lumped to distributed element at this step in the feedback path. Then using this layout part, we performed the cosimulation on the schematic window. Fig. 5 shows the circuit with layout and ideal circuit elements.

Using the schematic shown in Fig. 5, except for the elements we want to convert to distributed ones, we replace the ideal models with their realistic ones one by one compensating their changes on gain via re-optimization.

As realistic models, we used Murata GJM15 series capacitors and Johanson 402 series inductors from the installed ADS library. Then we eliminate C5 and L6 on the IMN side because they have negligibly small element values (on the order of pH and fF). Once the realistic models are attached on the ideal elements, and determining the values of ideal matching elements, we make the lumped to distributed conversion for the elements C7 and L8 on IMN; L5, C6, L7 and C8 on OMN which have exact distributed equivalents regarding to conversions shown in Fig. 6 [7].

In Figure 6, X expresses the reactance in terms of angular frequency ω, capacitance C or inductance L; $Z_0$ and θ express the characteristic impedance and electrical length of the line, respectively. In these conversion formulae, selection of $Z_0$ value is important, for example a very high impedance can be realized with very thin transmission line and it is hard to print it precisely, on the other hand a low impedance corresponds to a wide line which may cover more space on pcb and also can cause radiation and loss.

Therefore, $Z_0$ value should be chosen between a predetermined range that is suitable for practical manufacturing. After determining a suitable $Z_0$ value, one can easily find the θ by equating the reactance of the lumped element to the reactance of its distributed equivalent. For example, from the equations in Fig. 6, electrical length of a shunt capacitor $\theta_c$ and electrical length of a serial inductor $\theta_l$ can be found as:

$$\begin{aligned} \theta_c &= \cot^{-1}\left(\frac{1}{\omega C Z_0}\right) \\ \theta_l &= \sin^{-1}\left(\frac{\omega L}{Z_0}\right) \end{aligned} \tag{1}$$

After making conversions, the serial inductors (L8 on IMN and L5, L7 on OMN) take the form of serial transmission line, and shunt capacitor C8 on OMN takes the form of an open-

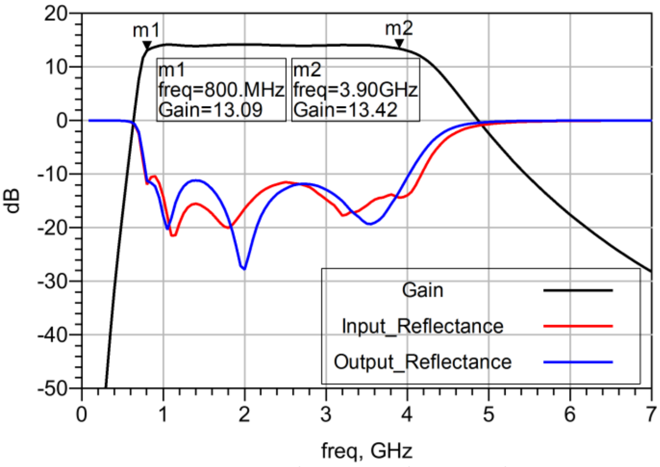

Fig. 4. Gain and input/output reflectance performance of the re-optimized circuit.

circuited stub. But we converted C5 on IMN and C6 on OMN into symmetrical radial stubs because their size could be an issue as intersecting other elements or covering more spaces on the PCB. Thus, in order to reduce their size on the PCB, C5 on IMN and C6 on OMN are converted to distributed elements as radial stubs and we find the appropriate parameters of these radials via tuning on the ADS co-simulation since they have no exact equivalent. Finally we achieved the circuit seen at Fig. 7 with the gain and reflectance performance shown at Fig. 8. As seen in Fig. 8. However, there is a distortion around 3GHz caused by the self-resonant frequencies of the realistic lumped element models and conductor traces, which may be eliminated using passives having much higher self-resonance frequencies. The gain is about 11dB in 0.8-3.8GHz frequency band. Therefore, it can be said that a successful design has been completed.

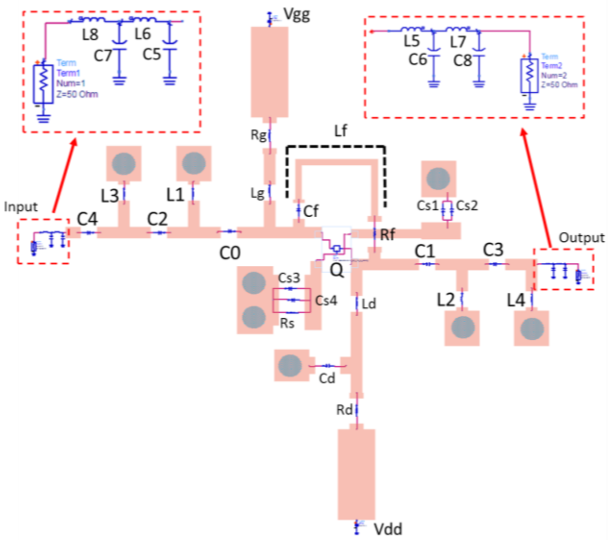

Fig. 5. Cosimulation of the circuit with its traces on lumped part.

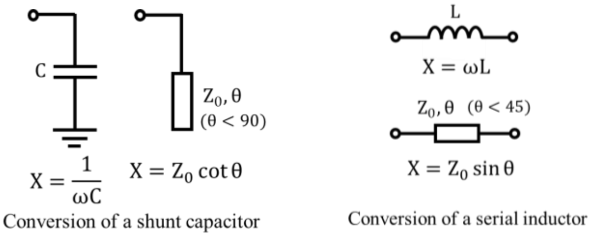

Fig. 6. Lumped to distributed conversion.

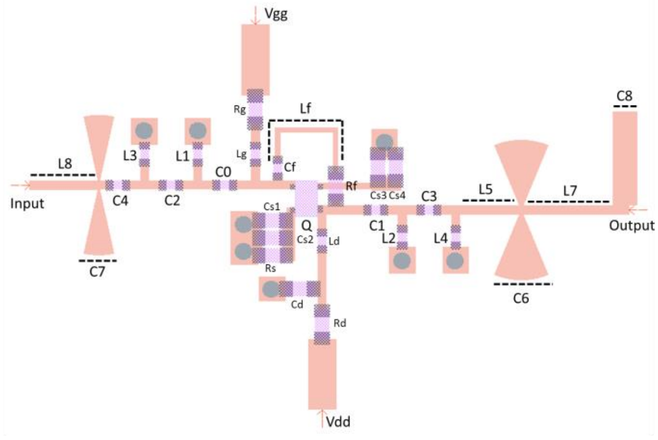

Fig. 7. Final circuit.

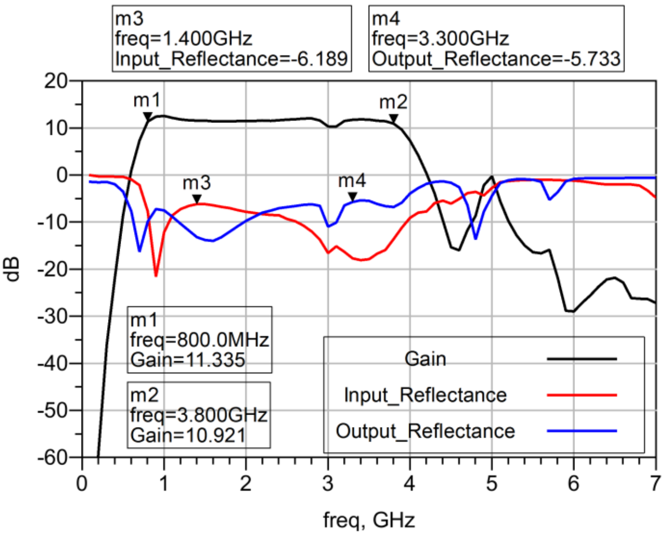

Fig. 8. Performance of the final circuit.

## III. CONSLUSION

Design of a low power mixed element amplifier circuit is presented. The circuit is designed with lumped elements, but some of the lumped elements are converted to distributed elements for their convenience in production. Post layout simulations give very promising results which shows the efficacy and usability of the design approach.

## ACKNOWLEDGMENT

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