*Original Research Article*

# RF Matching Networks Using S-Parameters

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## ABSTRACT

The paper presents a design and study of impedance matching for radio frequency (RF) circuit application of common-source amplifier topology. Matching networks for input and output sides of the amplifier were determined from the S-parameters given for the transistor, and ensuring unconditional stability. Impedance matching is necessary in RF circuit design to provide maximum possible power transfer between the source and the load. Complex tradeoffs among technology specifications and design parameters are inevitable, therefore should be carefully handled in designing the impedance matching networks, to optimize the performance of the common-source amplifier.

*Keywords: Impedance matching, S-parameters; common-source amplifier; reactance.*

## 1. INTRODUCTION

Impedance matching plays vital role in optimizing the performance of the radio frequency (RF) integrated circuit design. Matching provides maximum power transfer between the input or source and the output or the load, thus allowing the RF circuit to achieve the desired performance esp. the gain requirements. Passive components such as inductors and capacitors are vital for impedance matching, and are specifically designed such that they would satisfy the gain requirements at a specific frequency or range of operation [1-4]. Design tradeoffs between matching network parameters are inevitable, so it is crucial that inductors and capacitors be designed carefully for the specific requirements of the intended application.

## 2. METHODOLOGY

Actual S-parameters of a common-source amplifier with transistor of width = 300 µm and length = 0.25 µm were initially given for this particular study. Fig. 2 shows the schematic diagram of the a common-source amplifier circuit. Common-source amplifier is one of three basic topologies of single-stage transistor amplifier, exhibiting a relatively high input impedance white providing voltage gain and requiring a minimal voltage headroom [2-5]. Required values of scattering parameters (hereinafter referred to as S-parameters) for a specific frequency of operation could then be determined using linear interpolation. S-parameters of the transistor are given in Table 1 at frequency initially set to 2.6GHz.

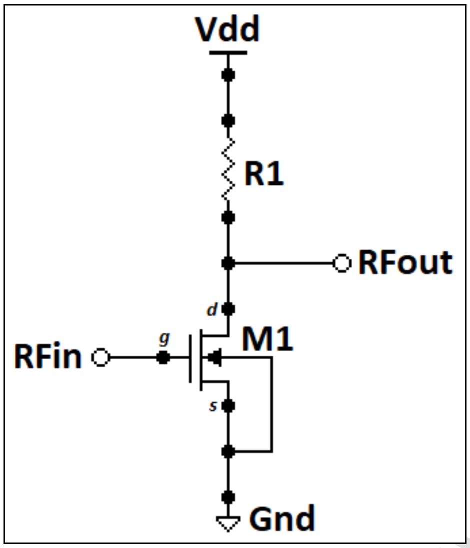

Fig. 1. Schematic diagram of common-source amplifier

Table 1. S-parameters at frequency of 2.6GHz

| S-Parameters | Real part | Imaginary part |
|---|---|---|
| S11 | 0.59986 | -0.53991 |
| S21 | -0.21942 | 1.14183 |
| S12 | 0.06752 | 0.03731 |
| S22 | 0.11658 | -0.40044 |

Stability conditions of the two-port network in terms of S-parameters play an essential role in amplifier designs. Although stability is frequency dependent, we want to ensure that the amplifiers design exhibits unconditional stability esp. at higher frequencies. Expressions of stability constants discussed in [3] could be used to check for the stability of the common-source amplifier design. Computed constants in Table 2 are then used to compute for the source/generator and load reflection coefficients.

Table 2. Computed stability constants

| Stability constants | Values |
|---|---|
| Δ | 0.38253 ∢-103.43° |
| K | 1.78957 |
| B1 | 1.33106 |
| B2 | 0.37628 |
| C1 | 0.65208 ∢-44.98° |
| C2 | 0.13295 ∢-103.49° |

To have unconditional stability, the Rollett stability factor (K) must be greater than unity (1), that is, K > 1, as well as one other condition given in [3-4]. Computations (not shown) observed that all of the conditions are met. With this, the two-port network in terms of S-parameters is unconditionally stable. Importantly, maximum power transfer is achieved when both the generator and load are conjugately matched to the two-port network, as also depicted in Fig. 1 block diagram.

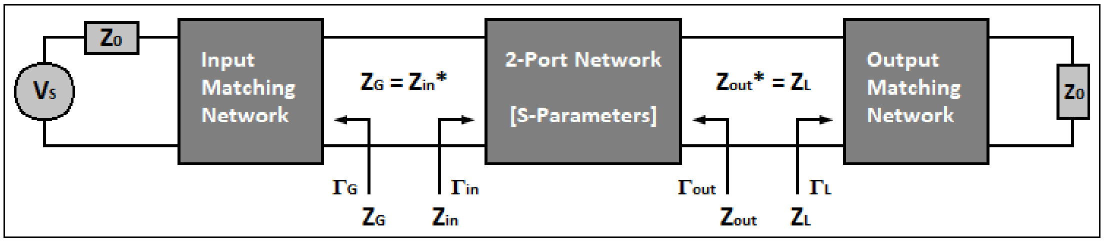

**Fig. 2. Two-port network with matching networks**

Where

$\Gamma_{in}$ = input reflection coefficient of the two-port network
$\Gamma_{out}$ = output reflection coefficient of the two-port network
$\Gamma_G$ = source or generator reflection coefficient
$\Gamma_L$ = load reflection coefficient
$Z_{in}$ = input impedance of the two-port network
$Z_{out}$ = output impedance of the two-port network
$Z_G$ = source or generator impedance
$Z_L$ = load impedance

The generator/source and load reflection coefficients could be derived using the computed stability values earlier discussed.

$$\Gamma_G = \frac{B_1 - \sqrt{B_1^2 - 4\left|C_1\right|^2}}{2C_1} \tag{1}$$

$$\Gamma_L = \frac{B_2 - \sqrt{B_2^2 - 4\left|C_2\right|^2}}{2C_2} \tag{2}$$

With the expressions in (1) and (2), generator and load impedances could now be obtained.

$$Z_G = \left(\frac{1+\Gamma_G}{1-\Gamma_G}\right)Z_0 \tag{3}$$

$$Z_L = \left(\frac{1+\Gamma_L}{1-\Gamma_L}\right)Z_0 \tag{4}$$

Shown in Table 3 are the values of the computed reflection coefficients and impedances, assuming normalized impedance of $Z_0$ = 50 Ω.

**Table 3. Reflection coefficients and impedance values**

| $\Gamma$ and Z | Values |
|---|---|
| $\Gamma_{in}$ | 0.57750 - j0.57717 |

| | |
|---|---|
| $\Gamma_{out}$ | -0.09650 - j0.40242 |
| $\Gamma_G$ | 0.57750 + j0.57717 |
| $\Gamma_L$ | -0.09650 + j0.40242 |
| $Z_{in}$ | 32.57934 - j112.81061 Ω |
| $Z_{out}$ | 30.37350 - j29.49728 Ω |
| $Z_G$ | 32.57934 + j112.81061 Ω |
| $Z_L$ | 30.37350 + j29.49728 Ω |

L-network is used for the input and output matching networks in Figs. 3-4 since it is the simplest and most widely used matching network for lumped elements.

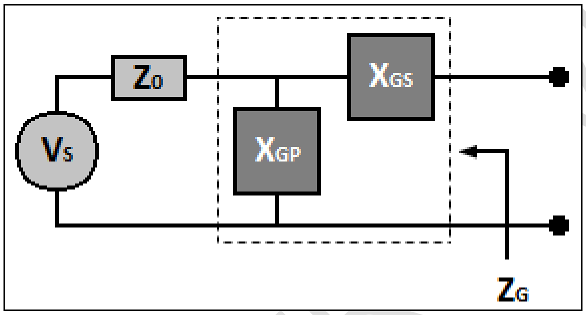

Fig. 3. L-network of the input matching network

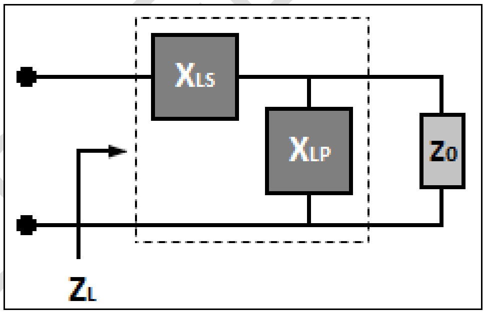

Fig. 4. L-network of the output matching network

Where

$X_{GS}$ = series reactance of the L-network of the input matching network
$X_{GP}$ = parallel reactance of the L-network of the input matching network
$X_{LS}$ = series reactance of the L-network of the output matching network
$X_{LP}$ = parallel reactance of the L-network of the output matching network

The elements of the L-network for both the input and output matching network are arranged in such orientation given that the real components of $Z_G$ and $Z_L$ are smaller than the real component of the normalized impedance which is $Z_0$ = 50 Ω ($R_0$ = 50 Ω) [3-4]. Finally, Table

4 summarizes the computed values obtained for the reactances and the quality-factor ($Q_G$, $Q_L$).

**Table 4. L-network elements**

| Q and Z | Values |
|---|---|
| $Q_G$ | 0.73124 |
| $X_{GP1}$ | 68.37681 Ω |
| $X_{GP2}$ | -68.37681 Ω |
| $X_{GS1}$ | 88.98723 Ω |
| $X_{GS2}$ | 136.63400 Ω |
| $Q_L$ | 0.80385 |
| $X_{LP1}$ | 62.20081 Ω |
| $X_{LP2}$ | -62.20081 Ω |
| $X_{LS1}$ | 5.08159 Ω |
| $X_{LS2}$ | 53.91296 Ω |

Passive components particularly capacitors and inductors could be determined from the L-network reactances given the frequency of 2.6GHz. Positive reactance implies an inductive component while a negative reactance denotes a capacitive component.

Two sets of passive component values are used in the design simulation to check if the whole circuit is actually matched at the frequency of operation. Design1 is composed of Lgs1 and Lgp1 for the input matching network and Lls1 and Llp1 for the output matching network. Design2 is comprised of Lgs2 and Cgp2 for the input matching network and Lls2 and Clp2 for the output matching network. Tables 5 shows the actual values computed.

**Table 5. Actual L-network passive components**

| Passive components | Values |
|---|---|
| Lgp1 | 4.186 nH |
| Cgp2 | 0.895 pF |
| Lgs1 | 5.447 nH |
| Lgs2 | 8.364 nH |
| Llp1 | 3.808 nH |
| Clp2 | 0.984 pF |
| Lls1 | 0.311 nH |
| Lls2 | 3.300 nH |

## 3. RESULTS AND DISCUSSIONS

Two designs were studied and simulated using the two sets of values of the input and output matching networks. Figs. 5-6 shows the schematic designs of Design1 and Design2. Figs. 7-10 shows the comparison of the results of the S-parameter plots of the two designs.

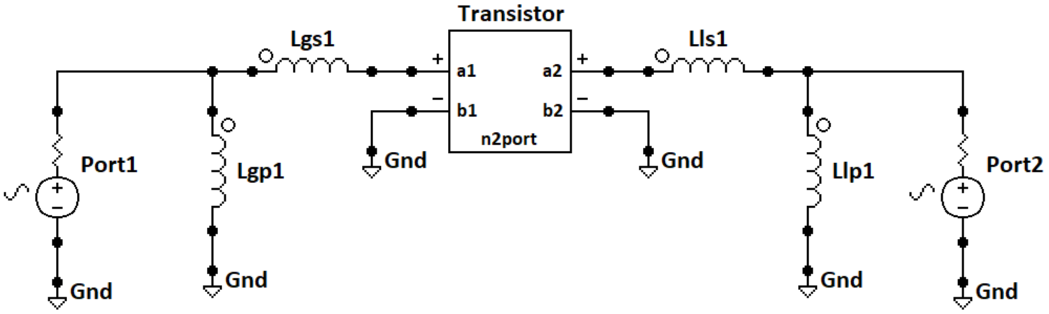

Fig. 5. Design1 schematic diagram

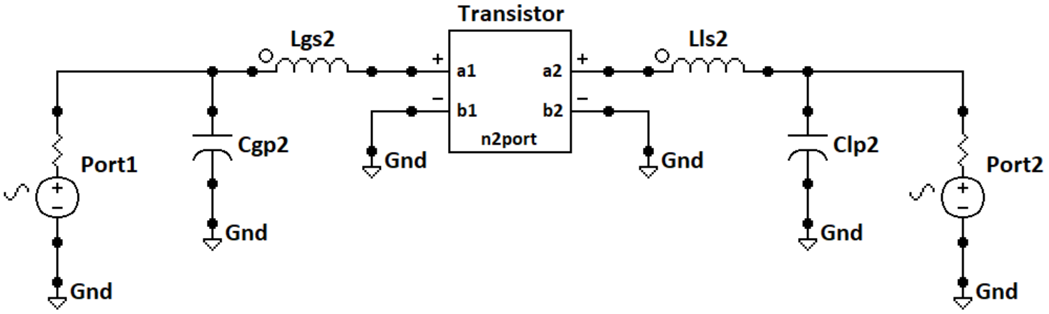

Fig. 6. Design2 schematic diagram

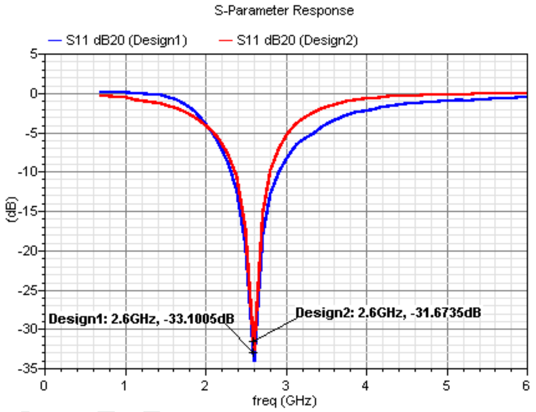

Fig. 7. S11 response in dB vs. frequency

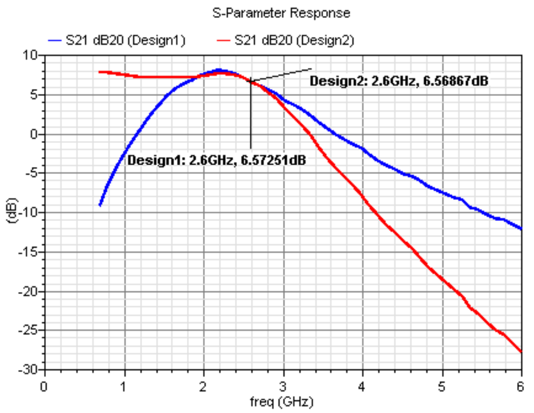

Fig. 8. S21 response in dB vs. frequency

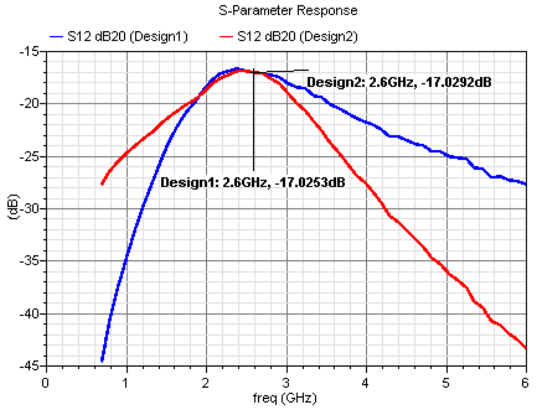

Fig. 9. S12 response in dB vs. frequency

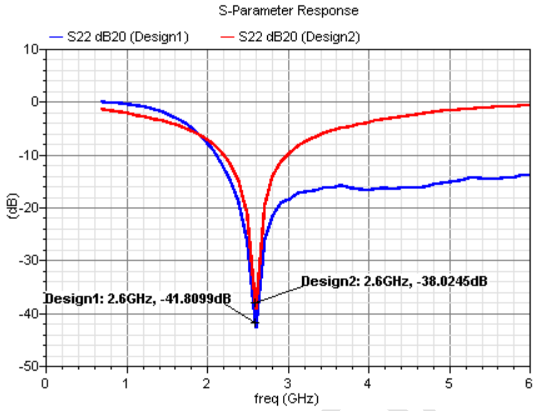

Fig. 10. S22 response in dB vs. frequency

The plots showed that the two designs are somehow matched at 2.6GHz frequency, with values comparable and relatively close to each other. However, it can be observed that the S-parameter plots of Design2 are smoother than the plots of Design1 at frequencies greater than 2.6GHz. The difference is evident esp. in the S22 plot in Fig. 10. This signifies that Design2, which is consist of inductor-capacitor combination in the L-matching networks, exhibits a stable behavior for higher frequencies than the Design1 which is an all-inductor design. Furthermore, the S11 and S22 plots of Design2 are more symmetric in reference to 2.6GHz compared to the Design1. Table 6 summarizes the values of S-parameters at the frequency of operation.

**Table 6. S-parameters response at 2.6GHz**

| S-Parameters | Design1 | Design2 |
|---|---|---|
| S11 | -33.101 dB | -31.674 dB |
| S21 | 6.573 dB | 6.569 dB |
| S12 | -17.025 dB | -17.029 dB |
| S22 | -41.810 dB | -38.025 dB |

The gain of the transistor or the common-source amplifier is indicated by the S21 plot. At 2.6GHz, the gain is 6.573dB and 6.569dB for Design1 and Design2, respectively. It can be observed in the S21 plots that as the frequency increases in the higher frequencies esp. beyond the frequency of operation, the gain decreases. If the gain-bandwidth product is to be remained constant, then as the bandwidth or the frequency increases, the gain should compensate, thus decreasing the gain.

## 4. CONCLUSION

Impedance matching is necessary in RF circuit design to provide maximum possible power transfer between the generator or source and the output load. Matching networks for input and output sides of the common-source amplifier were determined based on the S-parameters given for the transistor. , Ensuring unconditional stability of the matching networks, two designs were modeled and analyzed. Design2 which comprised of an inductor-capacitor combination in the input and output matching networks resulted to a smoother response or a more stable behavior for higher frequencies than the Design1 with all inductors in the matching networks. To optimize the performance of the RF circuit particularly the common-source amplifier, complex tradeoffs among technology specifications and design parameters should be carefully considered and analyzed in designing the impedance matching networks.

## COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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