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Small-Signal Analysis of Common-Gate Amplifier for RF Applications

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Author's contribution

The author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

The paper presents a study of common-gate amplifier focused in small-signal analysis. Small-signal or frequency response of the amplifier determines the maximum frequency of operation and the effective bandwidth of the circuit. With the analysis, the circuit could be modeled and designed to achieve gain at the desired frequency of operation. Design tradeoffs are inevitable and are carefully considered in the analysis and design, for radio frequency (RF) applications.

Keywords: Amplifier; common-gate; small-signal analysis; voltage gain.

1. INTRODUCTION

Small-signal analysis is essential to study and approximate the behavior of designed circuits containing non-linear devices (i.e. transistors) with linear equations. The analysis is also used to check if the designed amplifier circuit would normally produce gain or attenuation at the desired frequency of operation, through the small-signal analysis, the frequency range of operation of the circuit and the effective bandwidth could be determined.

For this paper, a common-gate amplifier is studied and analyzed using the small-signal analysis. Common-gate amplifier show in Fig. 1

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is one of three basic topologies of single-stage transistor amplifier, typically used as current buffer or voltage amplifier [1-4] for radio frequency (RF) applications. The input signal is fed into the source (*s*) terminal of the transistor. The output is produced at the drain (*d*) terminal, while the gate (*g*) terminal is connected to a bias voltage which will maintain the proper operating conditions.

2. LITERATURE REVIEW

Metal-oxide semiconductor field-effect transistors or popularly known as MOSFETs are capable of offering useful amplification in three different basic topologies [2]. Single-stage transistor composed these three fundamental configurations namely the common-source, common-gate, and common-source configurations. Combinations of these basic circuits are used for particular functions or applications such as the common-gate with common-source active balun and common-source/drain active balun circuit [5-10]. An example an active balun circuit suitable for RF applications due to its high frequency capability is given in Fig. 2 with common-gate and common-source combination.

It is important to analyze the frequency response or small-signal response of the circuit to determine the effective frequency of operation and bandwidth of the designed circuit. The analysis of the active balun in example could be subdivided into the two analysis of single-transistor configurations. As earlier mentioned, the paper is focused on the analysis of the common-gate amplifier.

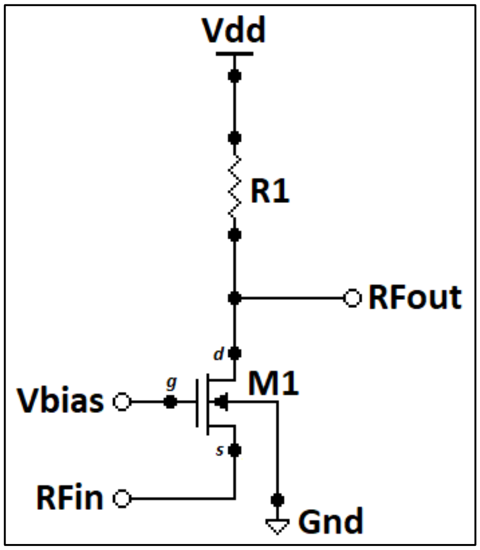

Fig. 1. Schematic diagram of common-gate amplifier

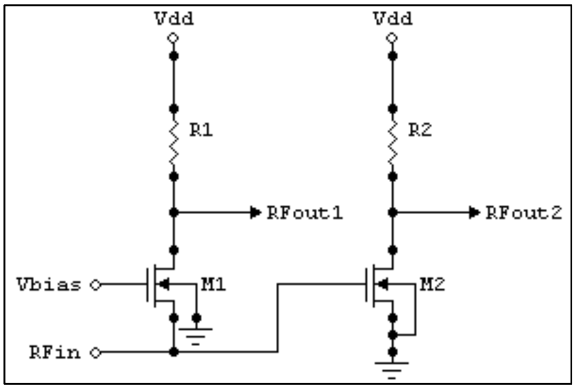

Fig. 2. Schematic diagram of common-gate with common-source active balun

3. CIRCUIT ANALYSIS AND DISCUSSION

To check if the designed common-gate amplifier circuit would normally produce gain or attenuation at the desired frequency of operation, it is necessary to analyze and study the small-signal response of the circuit. Moreover, the frequency range of operation of the circuit and the effective bandwidth could be determined with the analysis. Common-gate topology exhibits no Miller multiplication of capacitances, potentially achieving a wide band [1-4]. Fig. 3 shows the hybrid-π model of the amplifier, and Fig. 4 gives the conversion into the equivalent T-model.

The two dependent sources in the hybrid-π model can be combined into one current source assuming that the bulk or substrate connection operates at ac ground. And given that the gate also operates at ac ground, v_{bs} will then be equal to v_{gs}. This combined current source $(g_m+g_{mb})*v_{gs}$ can be replaced by two current sources which are actually equal: One from the source to the gate and one from the gate to the drain. Since the current source flowing from the source to the gate is controlled by v_{sg} itself, applying Ohm's law would result to resistor of value $1/(g_m+g_{mb})$ as depicted in the T-model. This expression is the input resistance (R_{in}) of the common-gate amplifier.

$$R_{in} = \frac{v_i}{i_i} = \frac{v_{sg}}{(g_m+g_{mb})v_{sg}} = \frac{1}{g_m+g_{mb}} \quad (1)$$

Using the T-model and with drain-to-source resistance (r_o) assumed negligible, the small-signal equivalent circuit of the amplifier is shown in Fig. 5 with source resistance (Rs), parasitic capacitances and load resistance (R1). Output capacitance C1 is integrated with the effective capacitance at node *d* (C_d).

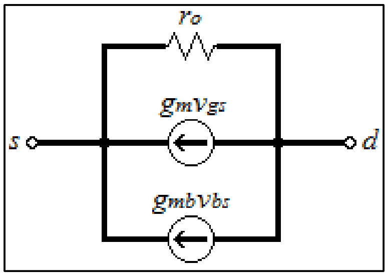

Fig. 3. Common-gate small-signal simplified low frequency hybrid-π model

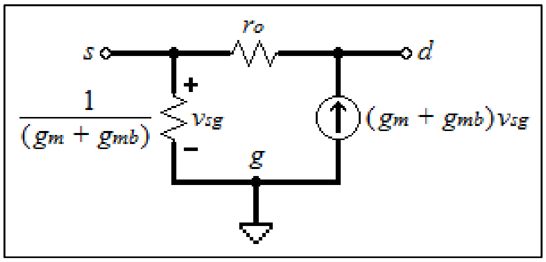

Fig. 4. Equivalent common-gate small-signal T-model

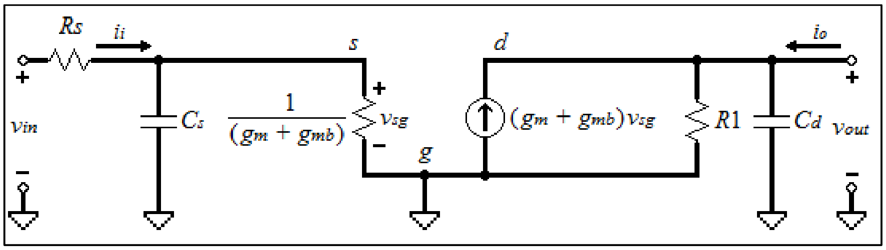

Fig. 5. Common-gate high frequency small-signal model

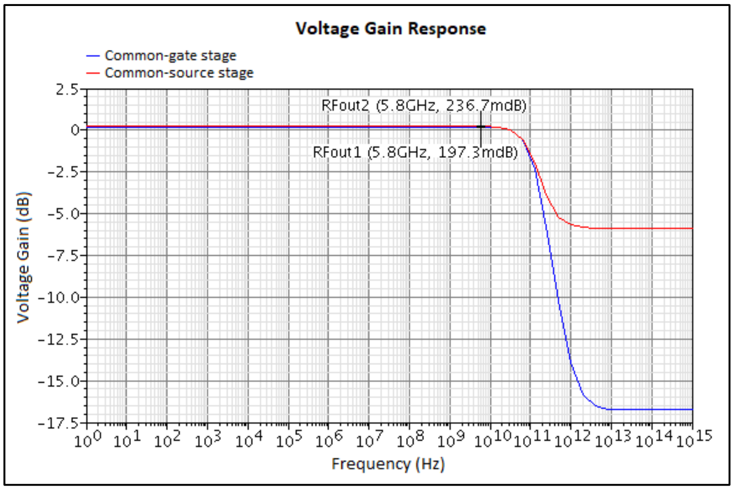

Fig. 6. Voltage gain response over a frequency range

The capacitances contributed by the transistor are connected from the input and output nodes to ground. At node *s*, effective capacitance $C_s = C_{sg} + C_{sb}$, yielding a pole frequency of

$$\omega_{in} = \frac{1}{R_{in,eff} \cdot C_{in,eff}} = \frac{1}{(R_{in}||Rs)C_s} = \frac{g_m + g_{mb} + \frac{1}{Rs}}{C_{sg} + C_{sb}} \tag{2}$$

At node *d*, effective capacitance $C_d = C_{dg} + C_{db} + C1$ would give a pole frequency of

$$\omega_{out} = \frac{1}{R_{out,eff} \cdot C_{out,eff}} = \frac{1}{R1 \cdot C_d} = \frac{1}{R1(C_{dg} + C_{db} + C1)} \tag{3}$$

With drain-to-source resistance (r_o) neglected, input and ouput impedances are isolated or independent from each other. With $g_m + g_{mb} = 17.283$ mS, $C_{dg} = 11.56$ fF, $C_{db} = 0.2122$ fF, load resistance R1 = 58 Ω, and load capacitance C1 = 33.33 fF, the output pole of RFout or the output side could be estimated as

$$f_p = \frac{\omega_{out}}{2\pi} = \frac{1}{2\pi} \cdot \frac{1}{(58\,\Omega)(45.1022\,fF)} = 60.84\ GHz \tag{4}$$

The overall transfer function for the voltage (A_v) is thus given by the succeeding equation. The first fraction in A_v represents the low-frequency gain of the common-gate amplifier. Resistance r_o is again assumed to be negligible. Note that if r_o is not omitted, the input and output nodes interact thus making it difficult to calculate for the poles [1-4].

$$A_v = \frac{v_{out}}{v_{in}}(s) = \frac{(g_m + g_{mb})R1}{1 + (g_m + g_{mb})Rs} \cdot \frac{1}{\left(1 + \frac{s}{\omega_{in}}\right)\left(1 + \frac{s}{\omega_{out}}\right)} \tag{5}$$

$$A_v = \frac{(g_m + g_{mb})R1}{1 + (g_m + g_{mb})Rs} \cdot \left(\frac{1}{1 + \frac{C_{sg} + C_{sb}}{g_m + g_{mb} + \frac{1}{Rs}} s} \right) \cdot \left[\frac{1}{1 + R1(C_{dg} + C_{db} + C1)s} \right]$$

Input resistance of the common-gate amplifier is affected by the value of the load resistor (R1).

Increasing R1 would increase the voltage gain. But with the power consumption requirement, there will be a limit in the effectiveness of increasing R1. A voltage gain response of an active balun with common-gate amplifier stage is shown in Fig. 6.

It is necessary to analyze the frequency response or small-signal response of the circuit to determine maximum frequency of operation and the effective bandwidth of the application. This would guarantee that the designed circuit would normally produce gain or attenuation at the desired frequency of operation, as measured in Fig. 6 at 5.8 GHz which is a typical value for RF applications.

4. CONCLUSION

Discussion on the small-signal analysis is presented for the common-gate amplifier. It is essentially important to study and analyze the small-signal response or frequency of the amplifier to determine the frequency of operation, the desired gain or attenuation, and its effective bandwidth. Design tradeoffs are inevitable; hence, they are carefully considered in the design of the common-gate amplifier circuit. Through the analysis, it could be checked if the circuit is capable for RF applications by determining the effective frequency of operation and other required response such as the voltage gain.

DISCLAIMER

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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COMPETING INTERESTS

Author has declared that no competing interests exist.

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