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TOOL: The universal AC model for FETs presented here provides a mechanism for determining the input resistance, R_{in}, the output resistance, R_{out}, and the AC gain, A_{v}, of a single FET. In many cases, model results may be combined for series or parallel configurations to determine R_{in}, R_{out}, and A_{v}. The universal model allows AC inputs to the gate, source, or drain, and it allows for inputs from more than one of these sources simultaneously.

The universal model assumes that DC conditions have been established by resistors and DC voltage sources, as in the generic circuit shown in Fig. 1.

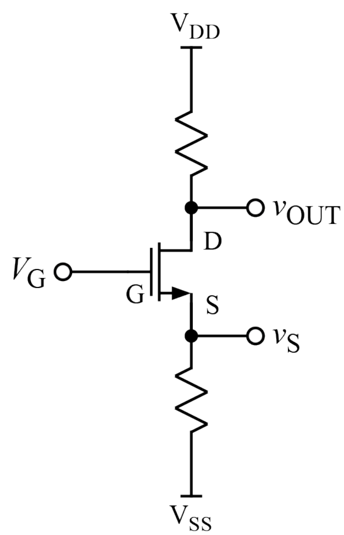

Fig. 1. Generic DC FET circuit.

Without loss of generality, we assume that the combination of DC bias circuitry and AC inputs coupled by capacitors to the gate, source, or drain may be replaced by Thévenin equivalents, as shown in Fig. 2. Note that we assume capacitors are short circuits for AC, and we take source resistor, R_S, and drain resistor, R_D, to be the resistances after taking the Thévenin equivalent of AC inputs to source, or drain. Also, the model is unusual in that it includes AC (not DC!) inputs, v_{ss} and v_{dd}, to the source and drain along with the usual AC input, v_g. to the gate.

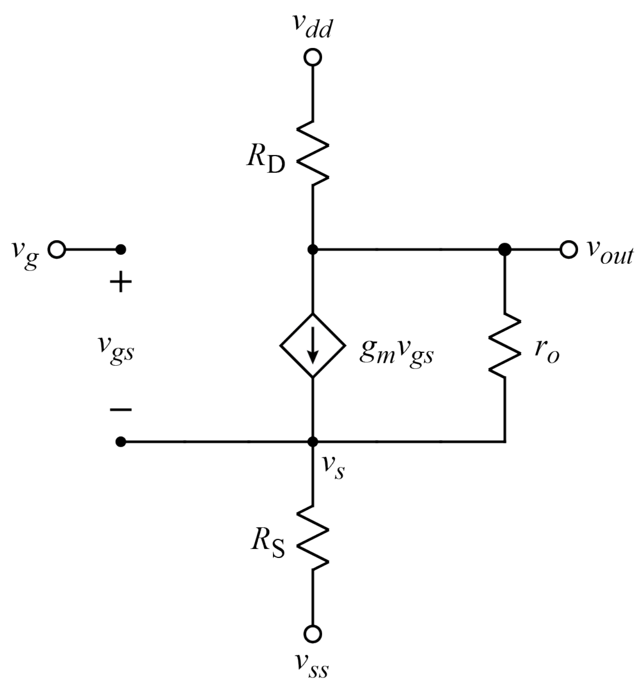

Fig. 2. Universal AC FET model including channel modulation and AC inputs for gate, source, and drain.

To obtain a simple form, we transform the universal model by replacing the Norton equivalent form of the dependent source, $g_m v_{gs}$, and channel modulation resistance, r_o, with a Thévenin equivalent form. Fig. 3 shows the result.

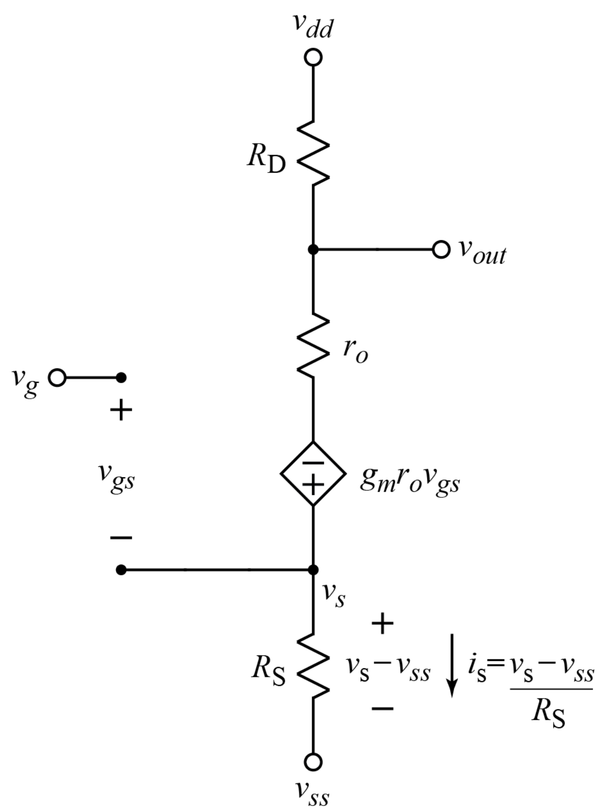

Fig. 3. Transformation of universal AC model with Thévenin equivalent form.

The second step in the transformation of the universal AC model to a simpler form is to expand the dependent voltage source into a sum of dependent voltage sources based on the following expression for v_{gs}:

$$v_{gs} = v_g - (v_s - v_{ss}) - v_{ss}\,. \tag{1}$$

Fig. 4 shows the resulting circuit. Note the polarities of the dependent sources that accounts for the minus signs in (1).

This seemingly odd step in the process produces three desirable outcomes:

1) One dependent source depends only on node voltage v_g instead of a voltage drop in the middle of the circuit, and

2) One dependent source may be transformed into a resistance, as explained below, and

3) One dependent source depends only on the input voltage v_{ss}.

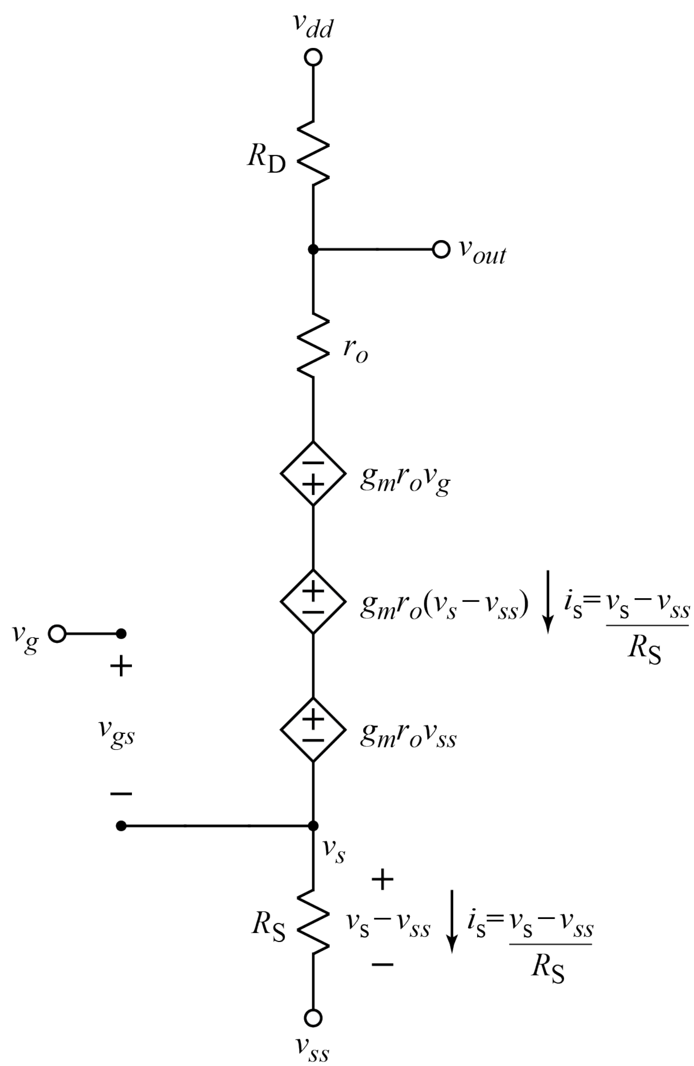

Fig. 4. Universal AC model with dependent voltage source split into three sources.

We keep the top and bottom dependent sources as is, since they depend on particular AC input voltages, v_g and v_{ss}, whose values may remain symbolic or will have known values. Note also that, in a practical circuit, one of those two AC input voltages, v_g or v_{ss}, is almost certain to be zero, (i.e., reference).

For the dependent source in the middle, the voltage and the current are both a multiple of the voltage drop across R_S, which is $v_S - v_{SS}$. In such cases, a dependent source may be replaced with a resistance determined by Ohm's law.

$$R_{\text{eq}} = \frac{v}{i} = \frac{g_m r_o (v_s - v_{ss})}{\dfrac{v_s - v_{ss}}{R_{\text{S}}}} = g_m r_o R_{\text{S}}$$

Fig. 5 shows our final model, which is a voltage divider.

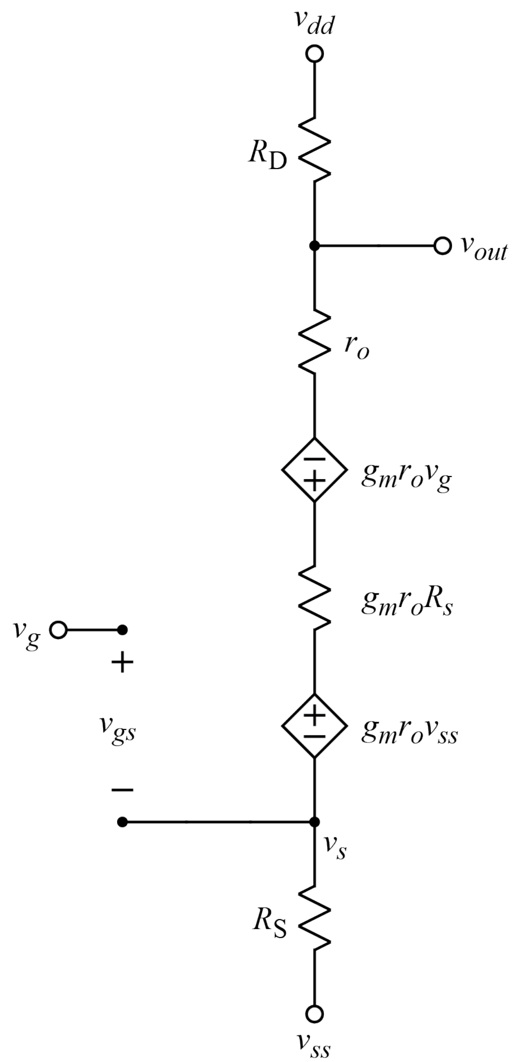

Fig. 5. Universal AC model for FET circuit.

We use the universal model to find input resistance, R_{in}, output resistance, R_{out}, and gain, A_{v}. In the case where channel modulation, r_o, is absent, we obtain correct formulas by taking the limit as r_o approaches infinity.

REF: Behzad Razavi, *Fundamentals of Microelectronics with Robotics and Bioengineering Applications, 3rd Ed., Enhanced eText,* New York, NY: Wiley, 2021. ISBN: 9781119694397