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## The Miller's tale

It is noteworthy that, despite the vast breadth of our industry, its myriad applications, and its diverse technologies, the fundamental building blocks we use in electronic circuits are remarkably consistent and small in number. This observation, pedestrian perhaps at first glance, is eye-opening when you consider that our collective interests span a spectrum from dc to daylight, cover dissipations from flea power to horsepower, and target environments from human-body implants to deep space.

The expectation that a handful of part types should meet such disparate requirements is akin to one that would have paper clips and staples as integral components of trestle bridges: Few things scale to such an extent as do electronic devices. As a result, familiar bipolar and field-effect transistors, a few related active devices, and a whopping three types of passives—resistive, inductive, and capacitive—account for most of our components, no matter if we mount them as discretes on a pc board or construct them in a solid-state fabrication process.

The diversity of our circuits originates not, then, with the number of distinct components at our disposal—each deriving its behavior from unique

physical principles—but rather from topological inventiveness. Historically, this small number of distinct part types has been an advantage: Designers could familiarize themselves with the behavioral nuances native to each type and craft elegant circuits that took best advantage of their constituent elements.

As system complexities and functional densities have grown, however, many designers find themselves engaged in design practices that are, by necessity, far removed from those underlying physical principles and from the behavioral nuances of individual devices. Yet it is those individual devices—by handfuls, hundreds, thousands, or millions—and the interactions imposed by the topology they inhabit

that determine your product's performance. As a result, certain device-centric themes appear in widely varying contexts.

One of these themes is the Miller capacitance—a feedback element implicit to active devices as different in their operating princi-

ples as bipolar-junction and field-effect transistors. The Miller capacitance does not appear explicitly as a parasitic in the active device's small-signal model; you can calculate it from the model and from the electrical conditions that the surrounding circuit imposes as the effective impedance between the internal base node and the collector or between the gate and drain.

Using the bipolar-junction transistor's small-signal model as an example (**Figure 1**), the magnitude of small-signal transconductance,  $g_m$ , derives from the ratio of the collector current and the thermal voltage,  $kT/q$ , where  $k$  is Boltzmann's constant,  $T$  is the temperature in Kelvin, and  $q$  is the electron charge. The base-collector capacitance,  $C_{\mu}$ , results from the base-collector depletion layer and is a nonlinear function of the voltage across that junction.

Assuming a common-emitter configuration, Kirchoff's current law at the output node yields

$$(v_o - v_1)C_{\mu}s + g_m v_1 + \frac{v_o}{R_L} = 0.$$

Because the current through the base-collector capacitance contributes negligibly to the load current, a good approximation of the output is

$$v_o = -v_1 g_m R_L.$$

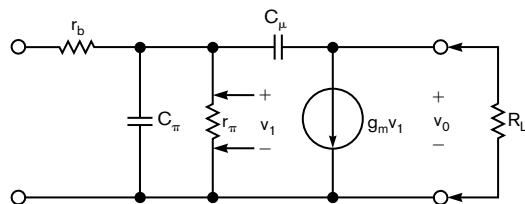
Finally, calculating the impedance between the internal base node and the collector yields the Miller capacitance:

$$\frac{v_1 - v_o}{i_{C_{\mu}}} = \frac{v_1(1 + g_m R_L)}{i_{C_{\mu}}} = \frac{1}{C_{\mu}s}$$

$$C_{\text{MILLER}} = (1 + g_m R_L)C_{\mu}.$$

Though the  $C_{\mu}$  depends on the transistor's physical attributes and dc bias, the small-signal Miller capacitance is larger by a factor of one plus the stage's gain— $g_m R_L$ —the result of the interaction between the device and its electrical surroundings. **EDN**

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**Figure 1** This small-signal bipolar-junction-transistor model includes the output load connection for a common-emitter amplifier configuration.