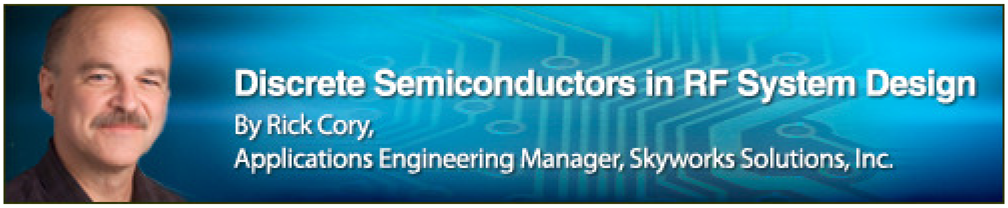
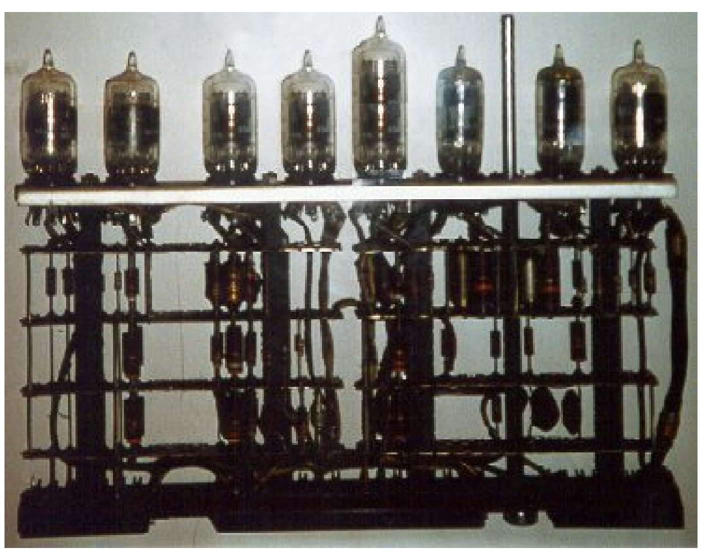


Is Smaller Better?

By Rick Cory, Skyworks Solutions, Inc.

RF/microwave design can be challenging, to say the least. Even with the impressive advances in computer aided design (CAD) software of the past three decades, the fact remains that CAD simulations are only just that: They are simulations and not absolutely accurate predictions of actual performance. As William Camden said in *Remaines of a Greater Worke Concerning Britaine*, “The proof of a pudding is in the eating.” What was true in 1605 is still true today — in order to accurately assess a circuit or a system design, it still must be built and its performance must be measured.

Engineers commonly refer to the initial prototype of a design as a “breadboard.” In the days of vacuum tubes, axial lead, and radial lead components, breadboards were built using metal boxes as foundations. Components were hardwired to each other with most of the passive components mechanically suspended by their leads. Circuit performance could be assessed quickly and design changes were just as fast; pick up a soldering iron, sweat some solder joints to remove a component, and make new solder joints to add another. No microscopes or tweezers were required — needle-nosed pliers and diagonal side cutters ruled the day!



A vacuum tube circuit

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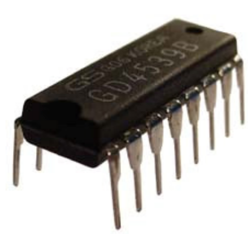
Discrete transistors, while being a truly disruptive technology, initially did not cause any major changes in breadboarding techniques. Parts that were packaged in TO-3, TO-5, and even TO-92 packages were still large enough to be seen with the naked eye and handled with fingertips (before electrostatic discharge became recognized as potentially lethal to semiconductors, of course).

The venerable TO-5 transistor package

Integrated circuits (ICs) produced major changes in the prototyping process. ICs packed more circuit function into ever-smaller volumes. They also brought a method known as “dead bug” breadboarding to the fore. ICs in dual-in-line packages (DIPs) would be placed upside down on a piece of raw circuit board material (typically epoxy-fiberglass dielectric material, fully clad on both sides with copper), with their leads pointing skywards resembling insects that had gone to meet their maker. The external components in the remainder of the circuit would be soldered directly to these leads and to the circuit board, which would typically serve as the circuit ground plane as well as the “platter” that supported the circuit. Changing components, even changing circuit design, was still easily done, although the familiar needle-nosed pliers were supplanted with tweezers. In their final form, these circuits would be built on dedicated printed circuit boards, utilizing through-hole technology — the leads of the components would extend through holes in the printed circuit board to be soldered to interconnecting conductor patterns on the underside of the board.



16-pin DIP integrated circuit package

Consumer products, especially cellular telephones, have driven the trend towards miniaturization. Circuit miniaturization appears to follow a trend similar to Moore's Law, which states that the number of transistors per unit area of an integrated circuit die will double every two years. Miniaturization was a primary benefit as the state-of-the-art of the electronics industry progressed from vacuum tubes to discrete transistors to through-hole packaged ICs, but the rate of miniaturization accelerated wildly when surface-mount assembly techniques and packages became available. Printed circuit layouts were no longer restricted by minimum through-hole diameters. Parts could be mounted much more closely together, and possibly more significant, the underside of a printed circuit board could also be utilized to implement more circuitry and mount even more components.

This advance in technology is not without a downside. Breadboarding is rapidly approaching the impossible as a result of the reduction in the physical size of electronic components. Many modern components no longer have external leads. Instead, they have electrical terminals spaced so tightly that it is virtually impossible to manually solder a wire to one without bridging to adjacent terminals. These components are so small that they cannot easily be soldered to a circuit board with soldering irons or other such manual tools.

Since consumer demand for further miniaturization shows no signs of abatement, there is continuing pressure to reduce the package size of electronic components. For RF components, this reduction in package size is rapidly approaching its limit, which is effectively the die size of the semiconductor it contains. For example, the SKY13323-378LF is a single-pole double-throw switch die that is packaged in a 1 x 1 x 0.45 mm 6-lead package. The lead pitch of this package is only 350 microns.

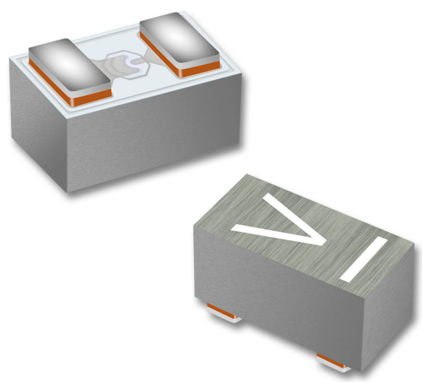
The net effect of this trend to vanishingly small packaged semiconductors is the virtual elimination of an engineer's ability to proceed immediately to the lab to build and test the latest bright idea. Now such circuits must be sufficiently "thought out" to warrant the time and expense of laying out a new printed circuit board, procurement of the board, followed by assembly of the circuit components onto the board, all of which must occur before testing can take place. This process clearly takes time and expends valuable resources.

Circuit simulation has largely taken the place of the "build and test" approach. Circuit simulators enable a designer to evaluate many permutations of a circuit design very rapidly. These simulators all share a common trait: The simulated results that they produce are only as good as the component models that they utilize. For many components, these models have become impressively complex and accurate. On the other hand, comprehensive models for other widely used components simply do not exist or, if they do, are of little value. Anyone who has compared the simulated threshold level (the 1-dB compression point) of a limiter PIN diode to measured performance data, for example, will likely agree that simulation of such a circuit leaves much to be desired. It is the wise circuit designer who keeps in mind that simulations are called "simulations" and not "actual performance data" for a very good reason.

Another challenge of component miniaturization is cooling. The useful life of a semiconductor device is known to be inversely proportional to its temperature. Increasing circuit component density puts semiconductors and passive components that dissipate heat into increasingly close proximity, so the likelihood of mutual heating increases. The reduced physical size of circuit assemblies means there is less surface area from which heat can be removed by radiation or convection. The reduction in the die size of semiconductor elements themselves reduces their cross-sectional area, thereby impeding

conduction heat flow and increasing their thermal resistance. All of these factors combine to increase junction and channel temperatures. It is remarkable that circuit and system designers have produced products with the reliability that they have achieved, but this progress is also not without bound.

The next step to miniaturization is the elimination of the package. Microwave hybrid circuits have been fabricated with packageless dice for decades, so this concept is not new. The advantages of this method of construction are chiefly derived from the absence of semiconductor packages — there are fewer parasitic reactances with which to contend, and circuits can be very compact. In this class of devices, electrical connection is typically made between semiconductor dice and the hybrid circuit's transmission line with bond wires. These bond wires are typically 0.7 to 1.0 mils diameter, so they are very fragile, and in RF/microwave circuits they are generally very pure gold, which is obviously expensive. In many cases, the bond wires must be placed under the direct control of a skilled human operator, so this interconnection technology is not optimal for very-high volume, low-cost consumer products, such as cellular telephones, digital cameras, and so on.



Smaller is better – the 0201 flip chip RF/microwave diode

Flip chip diodes resolve most of these problems. They are packageless semiconductors that have integral solderable terminals by which the devices may be directly connected to the substrate of a multi chip module (MCM) or to a printed circuit board. Their parasitic reactances are very small, due to the absence of a package. Thermal resistance is low, since there are substantial thermal paths from the diode junction to each of its terminals. The diodes shown here fit a 0201 footprint.

Therein lies the rub (apologies to W. Shakespeare): Those who fondly recall the era when impromptu breadboarding was readily possible will not be pleased to see that the 0201 flip chip is so small (0.50 x 0.25 x 0.25 mm). The good news is this — the diminutive size and the virtual absence of parasitic reactances make very accurate models, and thus very accurate circuit simulation, more feasible.

Smaller can be better, indeed.

As seen in the 11/17/09 edition of the RF Globalnet (**www.rfglobalnet.com**) newsletter.

About the Author

Rick Cory is an applications engineering manager for analog products at Skyworks Solutions, Inc. and has over 25 years of experience as an RF/microwave-semiconductor applications engineer. He holds a BSEET from the University of Lowell (now the University of Massachusetts Lowell) and an MBA from the University of Phoenix.