Automated Probing of High-Speed Analog/Mixed Boards

In-circuit and functional testers have been limited in their ability to test analog and mixed-signal boards due to the way they interface with boards under test. A new kind of probe promises to overcome these limitations and even change the face of manufacturing and service test.

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In-circuit testers can test boards only at dc or very low ac frequencies (to 10 MHz at best). This is mainly because circuit loading, caused by spring probes in bed-of-nails fixtures and the associated cabling, limits the testers' frequency capability. Functional testers, on the other hand, are designed only to interface to a board at its edge connector. This aspect of their design limits their ability to isolate faults to specific circuits.

Combinational testers, although capable of functionally testing clusters of devices and isolating faults using a bed-of-nails fixture, have the same spring-probe limitations as other bed-of-nails testers. Other testers—prescreeners, manufacturing defects analyzers, and other benchtop test systems—are similarly limited.

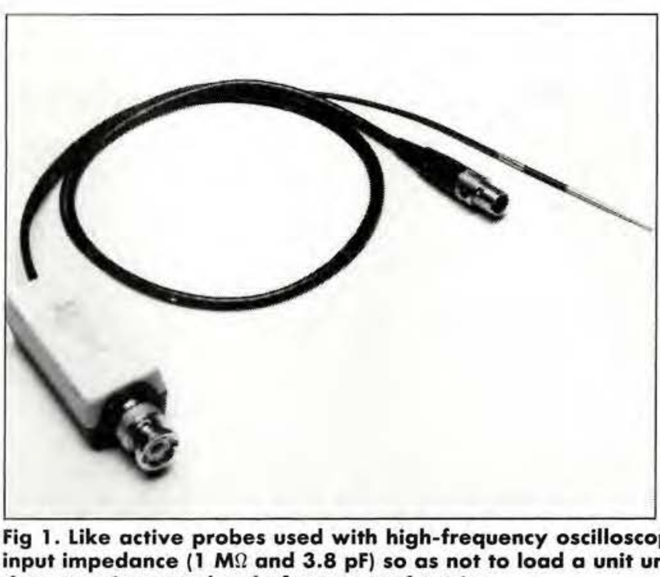
Tektronix, Inc. (Beaverton, OR) has recently developed the P6511 and the P6513 (Fig 1). These spring-probe systems alleviate the test-limiting loading problems encountered with traditional spring-probe/bed-of-nails fixtures. Like ordinary spring probes, these new probes mount in a bed-of-nails fixture, but they have a high impedance (1 MΩ and 3.8 pF) that doesn't significantly load a unit under test. Their flat frequency response (bandwidth) to 300 MHz permits a bed-of-nails fixture to check high-speed signals. (For more information about the construction of these probes, see sidebar, "Probe architecture.")

Probe loading effects

To reduce loading on the circuits, a probe must present a high-input impedance. At higher frequencies, this means that the probe's capacitance, as well as its input resistance, must be controlled. For example, if a probe has a capacitance of 10 pF, at 10 MHz this capacitance creates an effective load of 1,590 Ω. However, a capacitance of 100 pF at 10 MHz presents an effective load of only 159 Ω.

The typical probe in a bed-of-nails fixture connected to the test system with bare wire will have a capacitance of 20 to 50 pF. If the same test probe is connected to the system with coaxial cable, it will typically show 15 to 20 pF; however, terminating the coax in its characteristic impedance creates loading of 50 to 300 Ω.

Purely digital circuits can be tested at low frequencies with low-level loading. These circuits are designed to drive low impedances and are



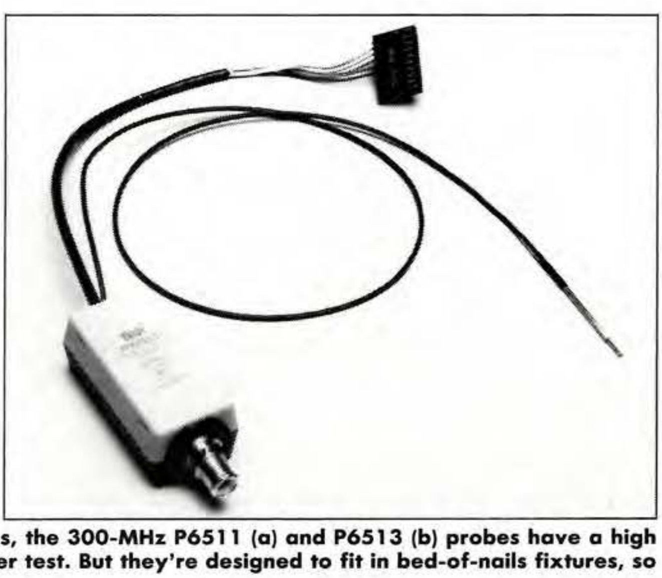


Fig 1. Like active probes used with high-frequency oscilloscopes, the 300-MHz P6511 (a) and P6513 (b) probes have a high input impedance (1 MΩ and 3.8 pF) so as not to load a unit under test. But they're designed to fit in bed-of-nails fixtures, so they permit a new level of automated testing.

therefore more tolerant of loading. High-impedance elements in an analog circuit, such as a phase-locked loop, won't tolerate such loading. Thus, analog boards and boards with a mixture of analog and digital circuitry require high-impedance probes for accurate testing. Fig 2 shows the difference in response between a P65XX-series probe and a conventional spring probe with twisted pair when both are connected to a 1-ns rise time pulse.

The wide bandwidth and low loading of the P65XX-series probes permit true functional and in-circuit testing at high frequencies. The probes can be mounted in a bed-of-nails fixture like those commonly used for in-circuit testing, the board under test can be powered up, and the test system can perform ac functional tests directly at critical, in-circuit nodes.

Since these probes have just been introduced, it is necessary to use a hypothetical example to illustrate their potential uses. A good example for our purposes is a board from a distance-measuring equipment (DME) set used in civilian aviation (Fig 3) since it combines digital and RF elements.

An advantage of using a DME board as an example is that avionics equipment is generally manufactured with a high degree of serviceability. Consequently, the underlying test-design work is already done, and most boards will have adequate test points and good service manuals.

Test philosophy

Measurements of the DME board's analog characteristics, such as local oscillator frequency, pulse width and timing, and signal amplitudes, can be easily automated using analog test equipment interconnected by a GPIB or an RS-232C interface.

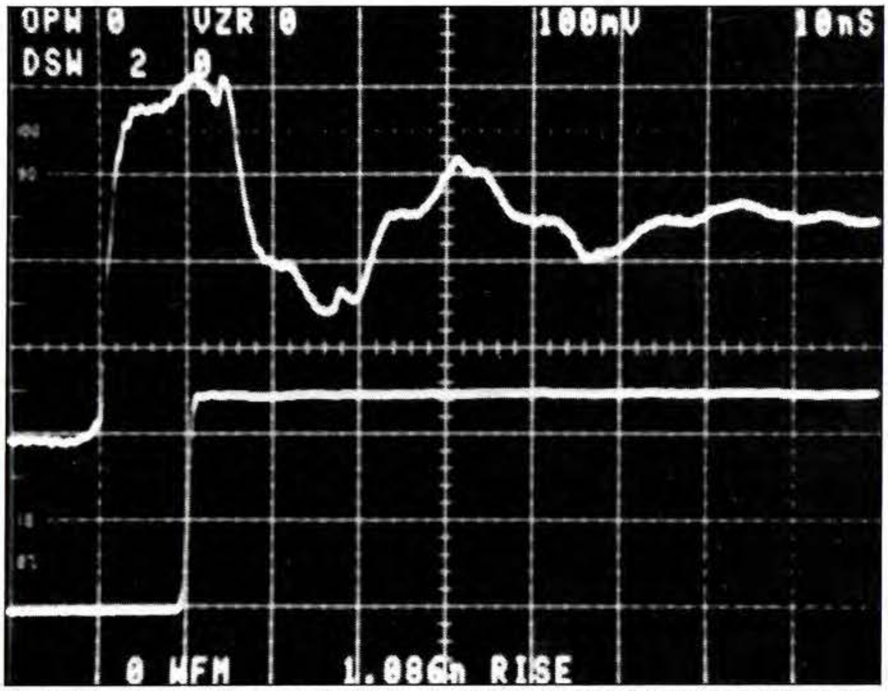


Fig 2. This scope trace photo illustrates the difference in performance between an ordinary spring-contact probe (top) and the P65xx-series probes (bottom). With a 1-ns rise-time signal, the distortion created by an ordinary probe is sufficient to invalidate any measurement.

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The equipment needed to make an automated analog measurement with these probes would include a Tektronix 11300 or 11400 Series oscilloscope, a TSI 8150 test system interface, and a TSA 8140 test system adapter. Fig 4 shows a test system in which a scope automatically measures the interval between pulse pairs put out by the DME even though the pulse pair has a low repetition rate.

Probe architecture

Conventional active oscilloscope probes have an input attenuator and amplifier mounted as close to the tip of the probe as possible to reduce input capacitance. But this is impossible with the P6511 and P6513 due to their necessarily small size (they are mounted on 100-mil centers) and their use of standard, inexpensive spring tips.

Instead, a new approach is used with these probes, one for which a patent has been applied: a passive hybrid attenuator is mounted in the probe receptacle. The input end of this hybrid connects to the spring tip by means of an elastomer, and the output of the hybrid connects to a coaxial cable by means of another elastomer. The hybrid is an attenuator that, from the standpoint of the probe tip, effectively divides by 10 the capacitance of the cable and the input capacitance of the amplifier. This is what produces the low 3.8-pF input capacitance.

The end of the coaxial cable opposite the spring probe feeds an FET amplifier, whose output will drive 50 Ω. The FET amplifier is a wide-bandwidth amplifier that provides the path between the 1 MΩ at the probe tip and the 50 Ω needed to drive the 50-Ω input of any test equipment.

The two probes differ primarily in their connectors. The P6511 has a twist-on BNC connector as a signal output connector and a power connector that will connect to the Tektronix 1102 power supply. The P6513 has a slide-on BNC and Berg pins for the power supply connection. The P6513 connectors are designed for easy use in the Tektronix TSI 8150 test system interface.

The test system adapter serves as the direct point of interface between the test system and the test fixture and houses various driver, scanner, and power cards.

The test system interface is a 50-Ω switcher used to switch the probes among various analog instrument inputs in this system. It can switch up to 900 probe channels at high bandwidths with minimal signal degradation. It provides power, timing, and control for a variety of driver, scanner, and switching cards housed in the test system adapter. In addition, the test system interface is able to communicate with various external programmable instruments, such as signal generators, over an IEEE-488 interface.

The test system adapter serves as the direct point of interface between the test system and the test fixture and houses various driver, scanner, and power cards. To increase the number of cards at the test system adapter, auxiliary card racks can be mounted in either a vertically or horizontally configured adapter. Versions of the auxiliary card rack can house up to 12 low-frequency scanner and power switch cards, or six high-frequency RF and microwave scanner cards.

The tester is used to uncover such special analog phenomena as high-frequency signal aberrations and cross talk, which can have an adverse effect on system operation. The circuit nodes at which such phenomena could occur are identified, and the test methodology follows a conventional signal-tracing approach, from input to output.

Fixturing considerations

Since the DME boards are designed with manufacturing and service test points, a logical approach would be to design a fixture with probes that access the bottom side of the board at each point where such manufacturing or service test pads exist. At first, it may sound like an expensive proposition to create a bed-of-nails fixture with active probes because they are more expensive than conventional spring probes. However, there are a number of factors involved that can significantly reduce fixture costs.

For one, it must be remembered that while the probes were designed for use in a bed-of-nails fixture, the number of probes required will be greatly reduced. With the signal-tracing test approach outlined above, only functional or critical points on the board will need to have probes, rather than every node on the board.

This test fixturing approach offers the added advantage of reducing contact problems, for two reasons: first, since fewer probes are needed, the number of contact problems are reduced statistically. Second, contact resistance of 10, or even a few hundred, ohms has a negligible effect on the measurement because the probes have a 1-MΩ input resistance.

Moving from the general to more specific considerations, the probe-tip receptacles are mounted in a fixture in the same way as ordinary receptacles (Fig 5a). The receptacles can be mounted on 0.100-in. centers, accept conventional replaceable spring-probe tips, and provide 0.250-in. travel. A variety of standard spring probe tips can be used: crown tips for solder joints and cone tips for plated throughholes, for example. The P65XX series of probes have a low output impedance and can drive a 50-Ω line, so there can be several feet of coaxial cable between the fixture and the test equipment.

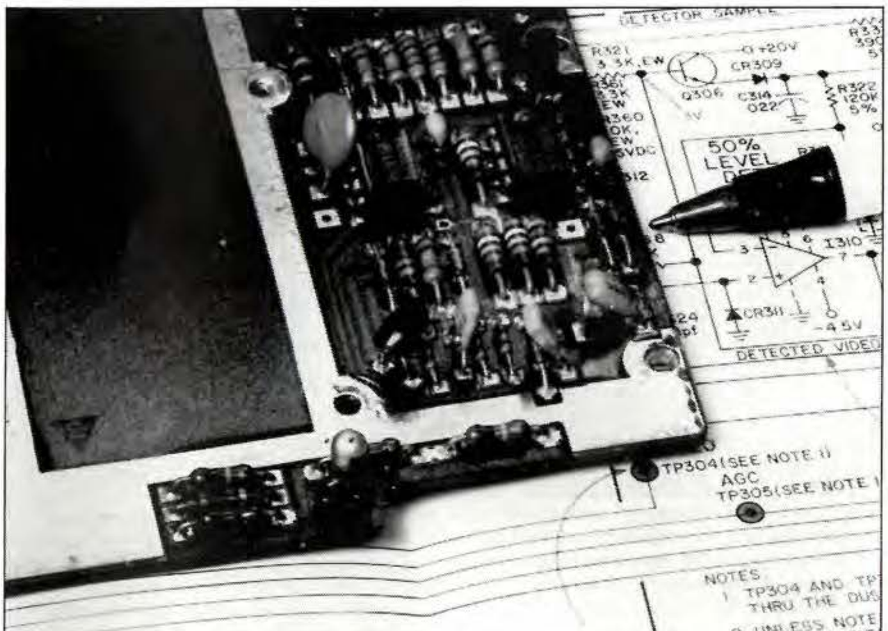

Fig 3. The board shown here is from a DME set used in commercial avionics. A digital/RF board, it is a good candidate for testing with P65xx probes due to its existing service points, ideal for probing. The scope trace shows a measurement of pulse timing made automatically at that point.

Grounding is important with active probes because the probe's input capacitance is essentially charged through the inductance in its ground lead.

Grounding

Unlike conventional bed-of-nails fixtures, grounding is an important consideration when creating fixtures with these probes (as it is with all active, high-performance probes). With these probes, a second spring probe must be installed close to the signal-measuring probe to provide a ground contact to the board.

Grounding is important with active probes because the probe's input capacitance is essentially charged through the inductance in its ground lead. In effect, the ground lead and probe form an LC filter circuit. Since the inductance of the ground lead is determined by its length, the ground lead directly affects the bandwidth of the probe system. Thus, the ground lead can significantly affect the probe's performance, particularly during the process of measuring high-speed aberrations and transient response.

The ground lead for these probes should therefore be as short as the board layout permits. If board layout dictates that the ground lead's length must be relatively long (over 1 in.) and its length affects performance, multiple parallel ground leads should be used to reduce the overall inductance (Fig 5b).

Fig 4. The test system seen here has a TDI 11400 scope, a TSA 8140 test system adapter (the apron) with a high-speed bed-of-nails fixture, and a TSI 8150 test system interface to control driver and scanner cards in the TSA. The system is controlled over a GPIB interface; here, desktop computer at left provides control.

A global impact

The availability of these probes may have a widespread effect on how testing is done in the future. Consider this potential impact in relation to the way testing is conducted today and the demands of just-in-time (JIT) manufacturing.

Because traditional board testers can be very expensive (some cost over $1 million), board manufacturers need to use them at or close to their maximum capacity. While this is possible in operations where a high volume of one type of board is being tested, many manufacturers have to cope with a wide variety of board types.

When there are numerous types of boards, manufacturers that use traditional board testers are forced to queue up boards so that they can be tested in an economical fashion. Boards are held in staging areas, and, when a sufficient number of boards has accumulated, fixturing can be changed and new test programs can be loaded without dramatically affecting throughput.

Unfortunately, this approach is inconsistent with the JIT manufacturing practices that many companies wish to institute. For JIT, many manufacturers want the average price of a test system to come down to about $100,000 so that they can have a dedicated tester waiting to test a board whenever it comes down the line.

It does not seem desirable to adapt in-circuit testers for this environment since they can do little more than basic dc tests. On the other hand, it will be extremely difficult for vendors of traditional functional testers to reduce their prices significantly.

Viewed in this environment, the new spring probes may spur a trend toward more economical testers for assembly and service. Such testers could come from companies involved with low-cost controllers, test interfaces, and easy-to-use test languages. Until now, a practical interface to the board under test that could handle ac measurements was missing, a gap filled by the new probes.

JIT may well force the growth of ad hoc, modular test stations, despite traditional objections to rack-and-stack test systems. While user-configured testers carry a configuration overhead that turnkey testers do not, JIT makes manufacturing procedures required by expensive testers unnecessary. Less expensive test stations may be the key to quality on the JIT production line. ET

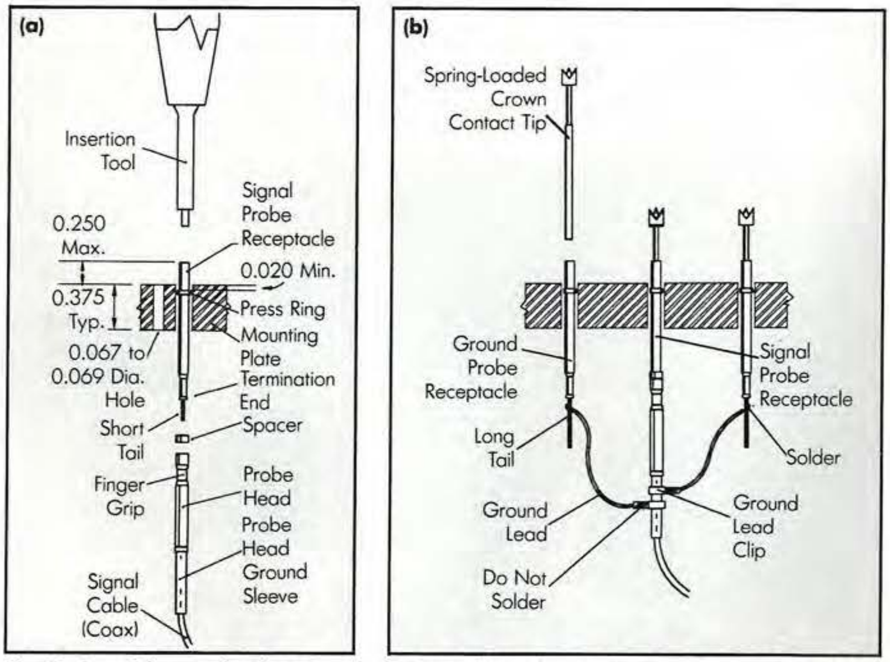

Fig 5. As with standard spring-contact probes, the probe-tip receptacles of the P65xx probes are placed in a bed-of-nails fixture (a) with ordinary insertion tools in accordance with the dimensions shown. The receptacle has a shorter "tail" than ordinary receptacles to control probe impedance. It is necessary to provide careful grounding with these probes (b) so that they will maintain their high bandwidth. When board layout dictates that ground lead lengths exceed 1 in., parallel grounding with ½-in. leads can be used to reduce ground-lead inductance. Ordinary probes are used for grounding.