

Multi-Conductor Transmission Line Probe

FIELD OF THE INVENTION

This invention relates to vertical probes for making
5 temporary electrical contact to a device under test.

BACKGROUND

Electrical devices and circuits are commonly tested
using probe arrays configured to make temporary electrical
10 contact to the device under test. As technology evolves,
there is an increasing demand for probing of high frequency
(e.g., 10 GHz or more) devices under test. Currently, high
bandwidth probe cards (>10GHz) either use very short
probes, such as a membrane probe card, or a combination of
15 separate signal probes and ground probes.

A membrane probe card has very little flexure since it
is very short and stiff. This limits probe overtravel and
produces very high contact forces. In cases where the
signal probe is a separate structure from the ground probe,
20 signal and ground probes do not flex together as a
monolithic unit. As a result of this, there can be
undesirable changes in impedance as devices are tested.
Also, mechanical constraints from separated signal and
ground probes limit how well the impedance can be matched
25 to ideal. Accordingly, it would be an advance in the art
to provide improved high frequency probes.

SUMMARY

This work provides vertical transmission line (e.g., ground-signal-ground) probes having alternating capacitive and inductive sections. These alternating sections can be designed to provide a desired transmission line impedance (e.g., between 10 and 100 Ohms, preferably 50 Ohms). Probe flexure in operation is mainly in the inductive sections, advantageously reducing flexure stresses on the dielectrics in the capacitive sections.

The lengths of these sections are preferably significantly smaller than the probe length (for example, less than $1/10^{\text{th}}$ the overall length of the probe), such that the resulting alternating capacitive and inductive impedances provide the desired RF transmission line impedance with sufficient accuracy.

This allows for a multiconductor probe where individual conductors are separated by dielectrics to achieve a transmission line effect. The better impedance match improves frequency bandwidth of the overall probe structure. The mixed capacitive and inductive regions improve mechanical integrity of the structure, where the mechanical integrity is predominantly in the capacitive regions of the probe where flexure is low.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A shows an exemplary embodiment of the invention.

FIG. 1B shows an exemplary overall probe configuration.

FIG. 2 is a close up view of an exemplary embodiment.

FIGs. 3A-C are images of fabricated probes at various magnifications.

FIGs. 4A-B show images of a probe at two points in an exemplary fabrication sequence.

5 FIGs. 5A-C schematically show exemplary probe design variations.

FIG. 6 shows an exemplary probe array according to an embodiment of the invention.

10 FIG. 7 shows return loss results for conventional and new probes.

FIG. 8 shows insertion loss results for conventional and new probes.

15 FIG. 9 shows terminal impedance time domain reflectometry (TDR) results for conventional and new probes.

DETAILED DESCRIPTION

FIG. 1A schematically shows an exemplary embodiment of the invention. This example is a vertical probe 112 for testing electrical devices. It includes an alternating sequence of capacitive sections (102a, 102b, 102c, 102d) and inductive sections (104a, 104b, 104c) along the length of probe 112. Here 102 shows a cross section through any of 102a, 102b, 102c, 102d, and 104 shows a cross section through any of 104a, 104b, 104c. Probe 112 includes a signal conductor 106 and one or more ground conductors (108a, 108b) insulated from the signal conductor.

The capacitive sections (e.g., 102a, 102b, 102c, 102d) include a dielectric material 110 configured to hold the signal conductor 106 at fixed separations from the one or

more ground conductors 108a, 108b by occupying space between the signal conductor 106 and the one or more ground conductors 108a, 108b, as shown in cross section view 102. The inductive sections (e.g., 104a, 104b, 104c) are air bridge structures having the signal conductor 106 separated from the one or more ground conductors 108a, 108b by air gaps, as shown in cross section view 104. Here posts 108c connect ground conductors 108a and 108b to each other in the capacitive sections, as described below in more detail in connection with FIG. 2.

Impedances of the capacitive sections and impedances of the inductive sections effectively provide a uniform transmission line impedance of the probe. This is possible according to the known approximate equivalence of a periodic LC structure with a transmission line. So in some embodiments it is preferred that the alternating sequence of capacitive sections and inductive sections be periodic along the length of the probe. Preferably, the uniform transmission line impedance of the probe is substantially 50 Ohms (i.e., 45-55 Ohms). The lengths of these capacitive and inductive sections are preferably significantly smaller than the probe length (for example, less than $1/10^{\text{th}}$ the overall length of the probe), such that the resulting alternating capacitive and inductive impedances provide the desired RF transmission line impedance with sufficient accuracy.

FIG. 1B shows an exemplary overall probe configuration. This is a somewhat more realistic view of the overall probe configuration than shown on FIG. 1A.

FIG. 2 is a close up view of an exemplary embodiment. This example relates to a preferred embodiment where the vertical probe has a ground-signal-ground configuration. This ground-signal-ground configuration is also shown (more

schematically) in views 102 and 104 on FIG. 1A.

Preferably, the grounds 108a, 108b of the ground-signal-ground configuration are electrically connected within the vertical probe. A preferred way to provide this connection
5 is shown on FIG. 2. In this example, the capacitive sections are configured as layered posts including:

a conductive core 108c connecting a bottom ground layer 108a to a top ground layer 108b;

an insulating shell 110 disposed around the conductive
10 core 108c; and

a signal conductor 106 disposed around the insulating shell 110.

Here the signal conductor 106 is separated from the conductive core 108c by the insulating shell 110. The
15 insulating shell 110 defines a bottom separation between the signal conductor 106 and the bottom ground layer 108a. The insulating shell 110 also defines a top separation between the signal conductor 106 and the top ground layer 108b. Insulating shell 110 can have different lateral
20 thicknesses in different layers to aid in defining the bottom and/or top separations.

FIGs. 3A-C are images of fabricated probes at various magnifications. Here the inductive and capacitive sections of the probes as described above are clearly visible in the
25 fabricated structures.

Probes as described above can be fabricated via MEMS (microelectromechanical systems) fabrication technology. Preferably, the insulators as described above are organic dielectric materials which are protected from damage by
30 plasma or chemical processes by metallic encapsulation. The organic dielectrics are revealed at the end of the process by selective etching of the metal protecting the

dielectric. For example, Copper and other probe materials can shield the dielectric during fabrication processes that can damage the dielectric, such as plasma processes.

FIGs. 4A-B shows scanning electron microscope (SEM) images of the same region during fabrication. The dielectric is on the inside of the metal formations when appropriate. The images show before (FIGs. 4A) and after (FIG. 4B) removal of the protective metal, and formation of the resultant air bridges.

FIGs. 5A-C schematically show exemplary probe design variations. The example of FIG. 5A shows a periodic probe having identical capacitances C_0 in the capacitive sections and with each inductive section 502 having the same conductor width. In the example of FIG. 5B, lengths and/or widths of one or more of the inductive sections are modulated along the length of the probe to determine a mechanical resilience of the probe. Here inductive sections 504, 506, 508 have different widths, as shown. In the example of FIG. 5C, capacitances of one or more of the capacitive sections are modulated along the length of the probe. Here different capacitances C_1 , C_2 , C_3 , C_4 for the capacitive sections are shown. One way to modulate capacitance this way is to alter the distance between signal conductor 106 and conductive core 108c on FIG. 2 to have a different value in each capacitive section.

FIG. 6 shows an exemplary probe array according to an embodiment of the invention. Here a probe array 602 includes two or more of the vertical probes as described above (probes 602a, 602c, 602e) and is affixed to a space transformer 604, where the resulting probe head assembly is configured to make temporary electrical contact to contacts 608 on a device under test 606, as schematically indicated by arrow 610. In cases where guide plates are used to

define the positions of probes in the probe array,
electrical contact between metal (or metallized) guide
plates and the ground conductors of ground-signal-ground
probes as described above can be used to improve electrical
5 grounding. This is analogous to prior work on multipath
probes having outer ground conductors in combination with
metal or metalized guide plates. The number and
arrangement of the transmission line probes in the array is
not critical for practicing the invention. The
10 configuration of the device under test usually dictates the
number and arrangement of the probes.

It is often preferred in practice for probe array 602
to further include one or more other vertical probes (602b,
602d) which can have any conventional vertical probe
15 design. These other probes can be used for connections
where the improved electrical performance of transmission
line probes isn't needed, and cost reduction and/or
improving current carrying capacity are more relevant
issues. Thus a preferred probe head concept uses
20 transmission line probes only for those electrical
connections that require the improved electrical
performance as described below. The rest of the
connections to the device under test can be made with
conventional vertical probes.

25 The resulting probes have demonstrated good electrical
performance. In one example, return loss for transmission
line probes was better (i.e., below) -15dB for frequencies
up to 60 GHz, which is markedly better than conventional
probe designs which exceeded -15dB return loss for
30 frequencies over 15 GHz (FIG. 7). Variability of return
loss with probe spacing and positions was also less for
transmission line probes than for conventional probes.

In another example, insertion loss for transmission line probes was better (i.e., below) 1 dB for frequencies up to 60 GHz, which is markedly better than conventional probe designs which exceeded 6 dB insertion loss for
5 frequencies up to 60 GHz (FIG. 8). Variability of insertion loss with probe spacing and positions was also less for transmission line probes than for conventional probes.

In a final example, impedance time domain
10 reflectometry (TDR) for transmission line probes shows substantially less ringing than for conventional probes. (FIG. 9). Variability of impedance time domain reflectometry with probe spacing and positions was also less for transmission line probes than for conventional
15 probes.