TECHNICAL NOTE TN10

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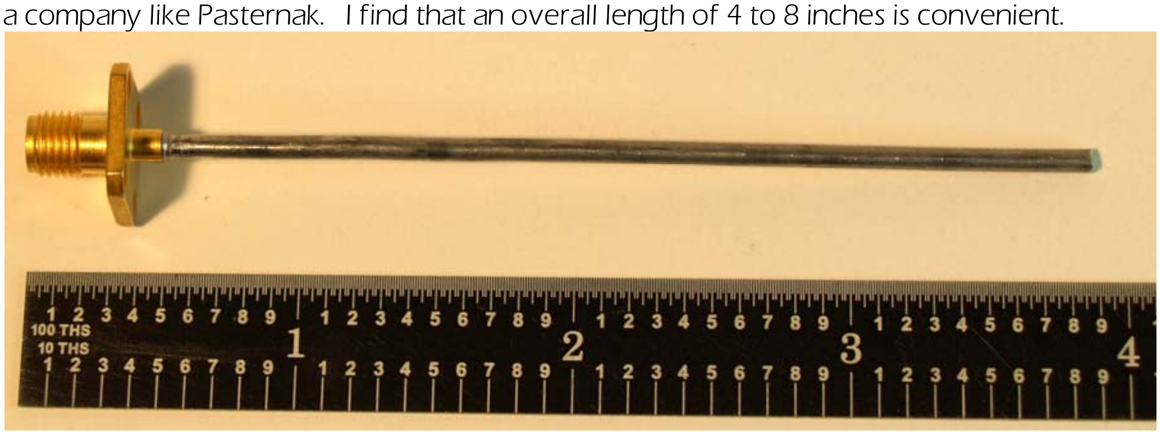
The Simplest EMC Magnetic Field Probe

When working on EMC (Electro-Magnetic Compatibility) issues, the need often arises for a means of measuring or sniffing near magnetic fields to locate sources of unintentional EMI (Electro-Magnetic Interference).

Although probes like the Agilent 11940A and 11941A provide a calibrated response, they are often a bit too large and bulky. Their infrequent use can also make their purchase an impediment, as these probes both run about $2K each.

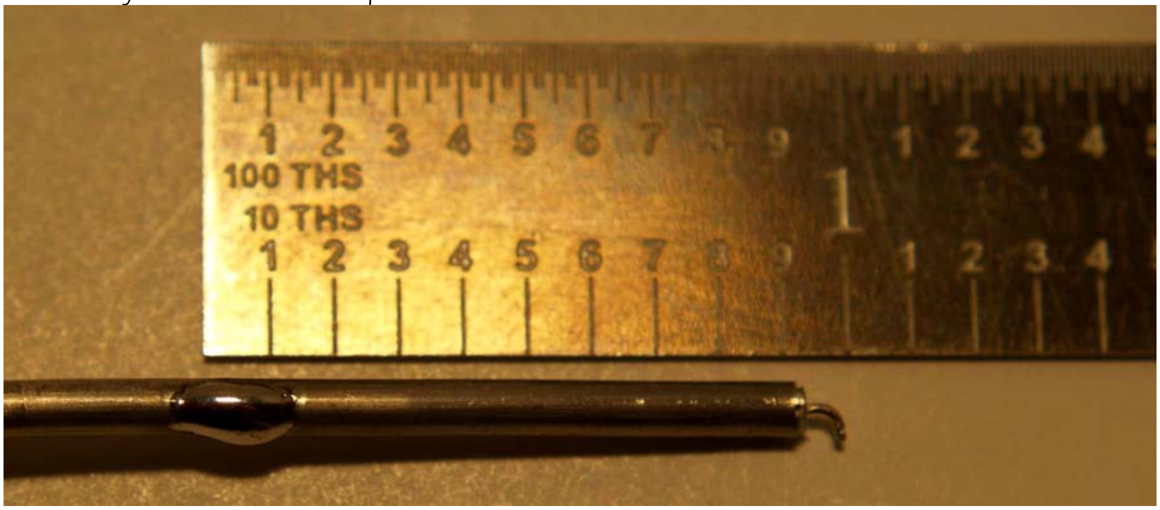
The simple loop probe finds eudemonic utility with either a spectrum analyzer or a digital scope (50 ohm input). This note describes how to construct your own low cost probes for comparative measurements, and also details a very small loop probe for fine spatial resolution.

The probe construction starts with a piece of 0.085" diameter semi-rigid coaxial cable (RG405 type). Attach an SMA connector to one end. If you don't feel like attaching your own connectors, you can purchase coaxial assemblies a company like Pasternak. I find that an overall length of 4 to 8 inches is convenient.



- ▷ Clean off the outside shield with some fine sandpaper. Slip two to four Ferrite beads onto the coax to aid in reducing the outside shield current. The Ferrite beads are Steward HFB075024-000, available from DigiKey, part number 240-2146-ND. You may want to use a small bit of Super Glue to hold the beads in place, just to make handling easier.

▷ Strip back the outside shield by 0.1" Install a small bend on the center conductor. Tin the outside sheath approximately 1" back from the open end.



▷ Form the loop around a 0.25" diameter mandrel. I find the 0.25" diameter a convenient compromise between sensitivity, spatial resolution, and ease of probing. It provides a predictable response to ~1GHz.

▷ Solder the center conductor to the outside shield.

▷ Degrease the assembly with a little Isopropyl Alcohol.

▷ Dip in Plasti-Dip for a protective non-conductive plastic coating. Plasti-Dip is available from your local hardware store, and also on Amazon.com. A 14oz. can is about $8 and provides enough coating for at least 20 probes.
CAUTION: Do not use this probe around hazardous voltages (for example: AC power mains).

The probe is not perfect; it does not have a flat response with frequency, and it can also pick up E fields. It will certainly be far more sensitive at high frequencies, as it is a simple loop probe whose output voltage is given by Faraday's law. Faraday's law of induction (for a sine wave):

$$V = 2 \bullet \pi \bullet f \bullet B \bullet A$$

where: f is the frequency in Hz
B is the magnetic flux density in Wb/m^2 (T Tesla)
(the *old nomenclature is Webers/ m^2, supplanted by the Tesla*)
A is the area of the loop in m^2
and V is the voltage produced by the loop

To get the magnetizing force H in Ampere-turns per meter, we can use the well known relation that in free space (or in open air, close enough).

$$B = \mu_0 \bullet H \qquad \mu_0 = 4\pi \bullet 10^{-7} \;\; in \;\; WB / A \bullet m$$

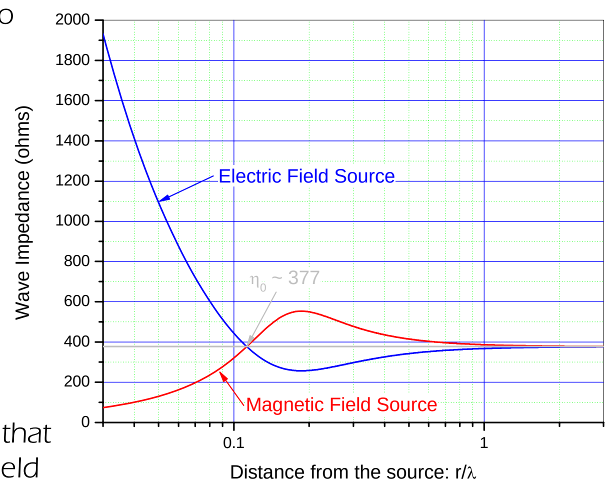
And solving for H, we obtain:

$$H = \frac{V \bullet 10^7}{8 \bullet \pi^2 \bullet f \bullet A}$$

These simple probes are handy, and very easy to make, but because they are not differentially sensed and have incomplete shielding, they will pick up E fields as well. If you are a bit fuzzy on magnetic field measurements, I can recommend [1] for an entertaining and educational overview.

You may find the use of a broadband amplifier to be helpful, I recommend a unit like the Agilent 8447D for 100KHz to 1000MHz. Calibrating your sensor is straightforward using a small length of microstrip with a VNA (Vector Network Analyzer) or spectrum analyzer with tracking generator.

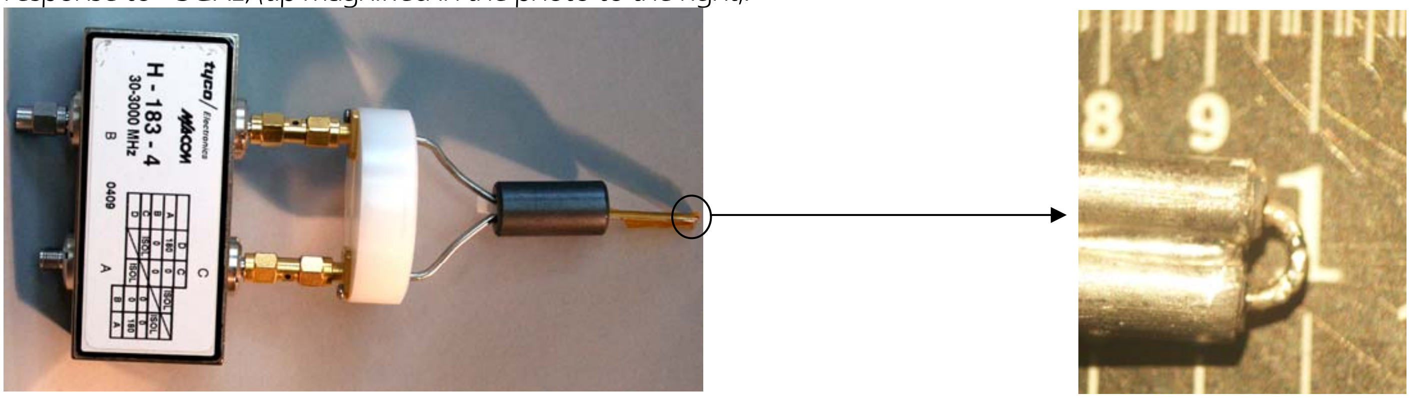
In many cases, the sources of EMI problems usually boil down to either 1: Common-mode voltage sources exciting interconnect cables, or 2: H field sources. For the purpose of this tech note, we are restricting our attention H field sources. So why do we usually care about the H (magnetic) field more than the E (Electric) field? Because the E field is so much easier to stop than the H field, simply use a thin conductive plate to shield. Recall from basic shielding theory, that the shielding effectiveness is proportional to the ratio of the wave impedance to the shield impedance. The near field wave impedance for an E field source is very high, but the near field impedance of an H field source is very low [2], [3]. There is a Mathcad worksheet on the Technical Info page of my website that shows the wave impedance versus distance for E field and H field sources (the plot is shown at right).



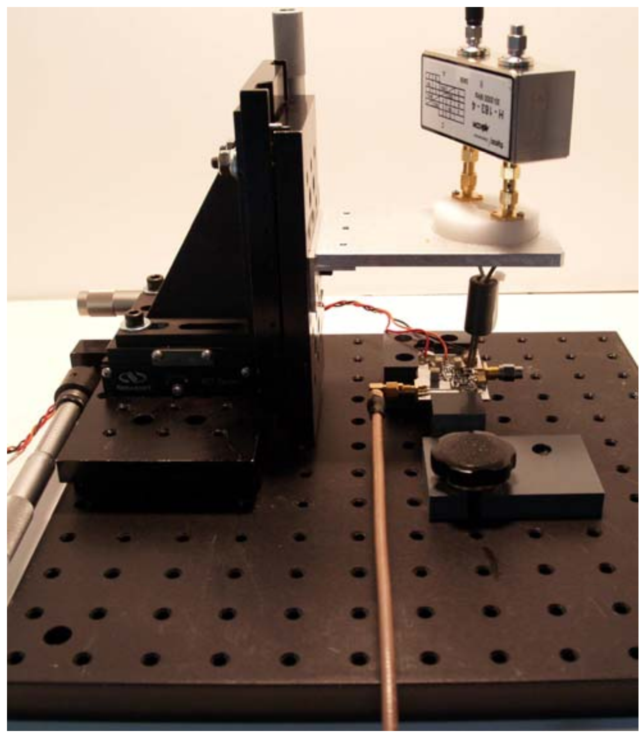
For SMT circuits, a smaller probe is required for careful sniffing to a particular pin or fine trace.

This approach makes use of a very unique device, the MACOM H-183-4 180 degree hybrid. The MACOM H-183-4 is used as a 180 deg wideband balun to reject the coupled E field, by connection of the two semi-rigid coax cables to the 180 degree out of phase inputs (port C and D).

For very fine position magnetic field location/sniffing, only a small loop will suffice, and it provides a predictable response to ~3GHz, (tip magnified in the photo to the right):



A simple XYZ holder arrangement can be helpful in careful positioning/probing:



References:
[1]. Herbert Arthur Klein, *The Science of Measurement, A Historical Survey* , Mineola, NY: Dover Publications, 1988. Although a little dated in some areas, this book is a most readable and entertaining overview of all measurements: electrical, optical, nuclear, physical, thermal … Although the title sounds a bit dry, I find the book to be continued good reading, and the first place I turn to for clarification of fuzzy measurement unit knowledge (and as an excuse for work avoidance).
[2] David A.Weston, Electromagnetic Compatibility, 2nd Edition. New York, NY: Marcel Dekker, Inc. , 2001.
[3] Clayton R. Paul, Introduction to Electromagnetic Compatibility, 2nd Edition. Hoboken, NJ: John Wiley & Sons, 2006.