A Method of Accurately Measuring Shielding Effectiveness of Materials in Electronic Products

Douglas C. Smith

D. C. Smith Consultants

P. O. Box 1457, Los Gatos, CA 95031

tel: 800-323-3956, fax: 408-358-3799

email: doug@dsmith.org, web: www.dsmith.org

Abstract: A more accurate method to measuring shielding effectiveness of materials used close to circuits in electronic products is presented. In addition to being more accurate for many applications, it is non-destructive and does not require specimen preparation for the test. The test can also be used as a quality control test in a manufacturing environment. Results show clearly which materials perform best within equipment, especially for small products like cell phones.

Introduction

Industry standard tests usually use plane wave, far field, measurements to measure shielding effectiveness. Using plane wave illumination is useful for many applications where the sample of shielding material is in the far field of the source (distance from source to shield is greater than $\lambda/2\pi$ where λ is the wavelength at the frequency of interest). The test yields easily reproducible results.

However, in many electronic products, the source is much closer than $\lambda/2\pi$ to the shield. The result is that the shield is illuminated in the near field of the source and the illumination is not a plane wave. An example of this is a mobile phone where it is desired to shield one area of the circuit board from another. In a case like this, the shield is most likely illuminated by a magnetic field from current loops on the circuit board rather than by plane waves from an antenna at some distance.

When illuminating a shield with a plane wave for test purposes, the electric and magnetic fields are parallel to the plane of the shielding material. A magnetic field from current flowing in a circuit usually illuminates the shield perpendicularly.

As a result of the differences between plane wave and perpendicular magnetic field illumination, shielding materials may give significantly different results depending on the nature of the illuminating field.

Technical Background

Figure 1 shows a diagram of a test setup to measure the shielding performance of a material to a perpendicular magnetic field. One loop is energized by a signal source and the second nearby loop is connected to a receiver to measure the signal induced into the second loop. A spectrum analyzer with a tracking generator output works well for this test.

Some of the magnetic field from the first loop passes though the second loop and generates a voltage in the second loop by Faraday's Law [1]. The direct transmission between the adjacent loops becomes the baseline for a shielding measurement.
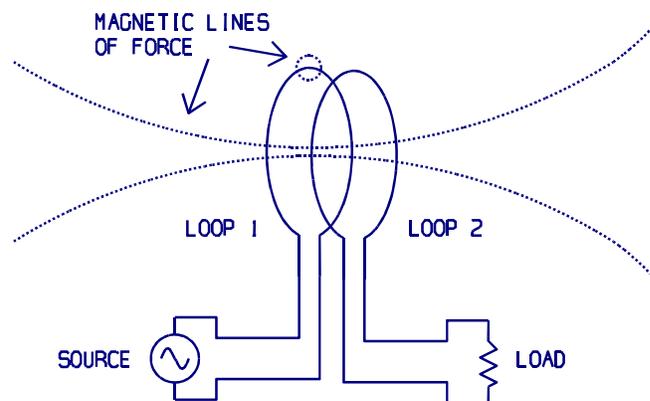

Figure 1: Transmission Between Loops [2]

Figure 2 shows a sample of shielding material placed between the loops. To the extent the material is conductive, it can be considered to consist of an infinite number of conductive loops. The magnetic field from the first loop will induce eddy currents in the shielding material that flow in such a way as to cancel the incident field and the field passing through the second loop is reduced.
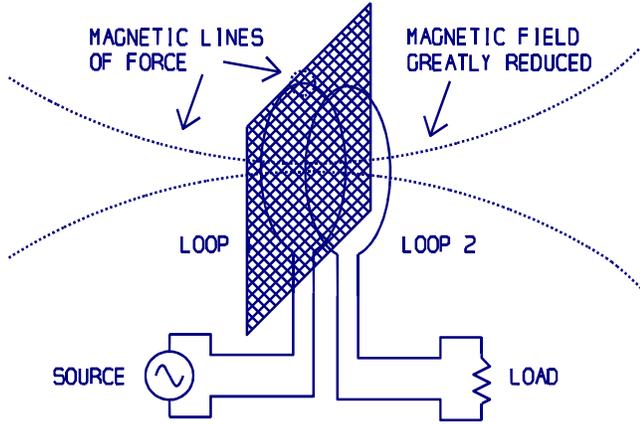

Figure 2: Shielding Material Placed Between the Loops [2]

Figure 3 shows a pair of commercial shielded loops with a sample of shielding material between them. Loops incorporating electric field shielding should be used [3].
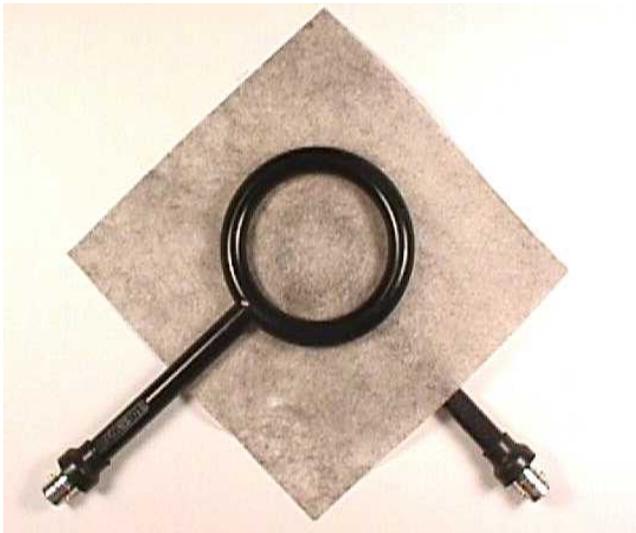

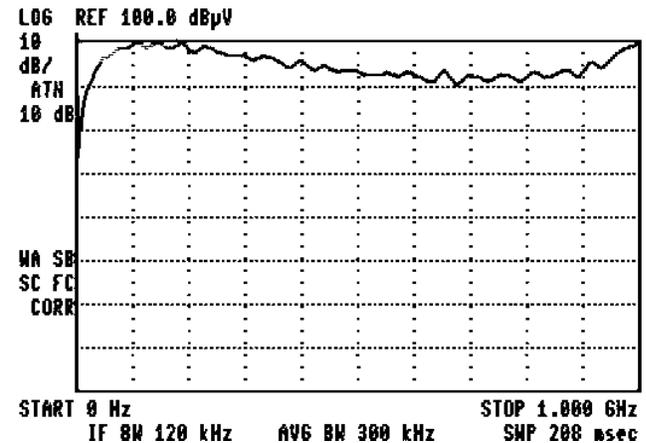**Figure 3:** General Shielding Measurement Setup [2]

Data and Results

Figure 4 shows the positioning of two small shielded loops with a sheet of material separating them. The loops were shielded 2 cm square loops. To measure the shielding effectiveness of several materials, first the loops are separated with non-conductive material,

such as paper, to set the loop spacing about the same as the samples to be measured. The spacing of the loops does not have a large effect if it is below a few mm.
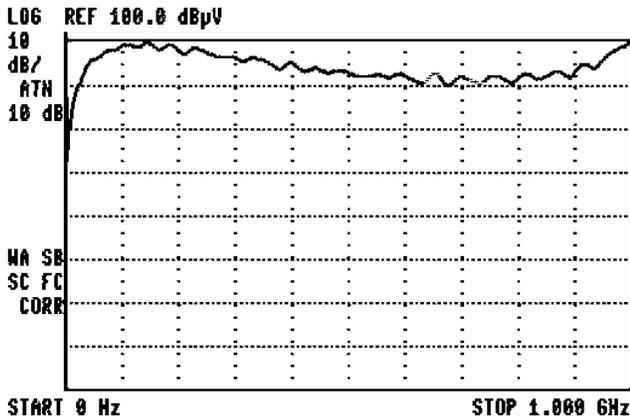

Figure 4: Test Setup for Data [2]

The data plots shown in this paper are the output of the receiving loop for a frequency range from 0 to 1 GHz. Plot 1 shows the transmission between the two loops held directly in contact with each other. The two loop structure is essentially a simple transformer. In Plot 1, one can observe that the frequency response falls off below 50 MHz due to the limited inductance of the loops. The slow drop off in response from the peak at 150 MHz to a low at about 700 MHz is due to flux leakage between the loops, leakage inductance in the "transformer." The rise in response at 1 GHz is due to a resonance in the loops just above 1 GHz. If shielding at higher frequencies is to be measured, smaller loops should be used to raise their self resonant frequency.

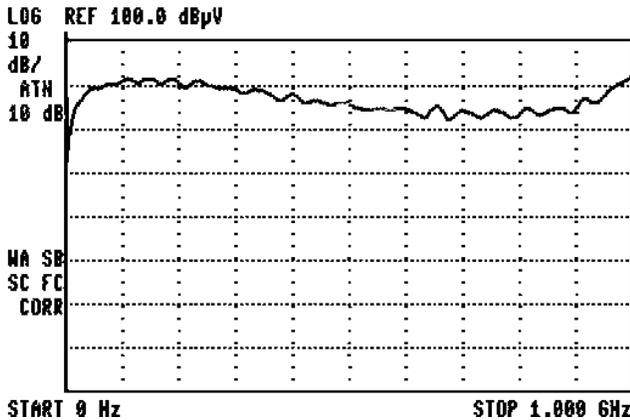**Plot 1:** Direct Transmission Between Loops

Plot 2 shows the result when the loops were separated with a sheet of PVC plastic of about the same

thickness as the shielding samples tested. As expected, there is very little difference between the two plots.

Plot 2: PVC sheet

Plot 3 shows the result for a piece of "shielding cloth" that was advertised to have as much as 100 dB shielding effectiveness. The sample looked like a fabric that could be made into clothing. As can be seen from the data, for this test there was only about 10 dB of shielding present. Such material should not be used in systems close to circuits for internal shielding.

Plot 3: Shielding Cloth

Plot 4 shows the shielding for a sample of aluminum foil. As can be seen, the received signal was below the noise floor of the spectrum analyzer except for frequencies lower than 300 MHz. The signal in the receiving loop starts increasing below 300 MHz because of skin depth.

Skin depth is the distance into a conducting material where the current density of a current flowing on the surface is reduced to about 37% (1/e) of its density on the surface. Skin depth for a metal is given by:

$$\delta = \frac{2}{\sqrt{2\pi f \mu \sigma}} = \frac{6.6}{\sqrt{f \mu_r \sigma_r}} \ cm$$
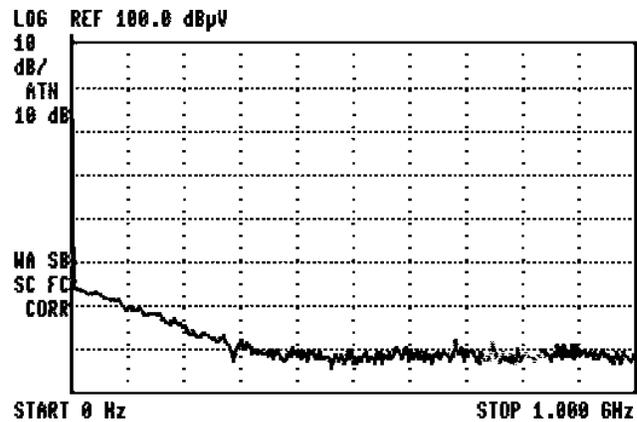
<div align="center">General Formula   For Copper</div>

Formula 1: Skin Depth

where: f is the frequency
μ is the permeability of the material
σ is the conductivity of the material

If values for copper are used, the formula on the right results where μ_r and σ_r are the permeability and conductivity relative to copper and are unity for copper. At 10 MHz for copper, the skin depth is about 0.002 cm! Very little thickness is required to get good shielding effectiveness.
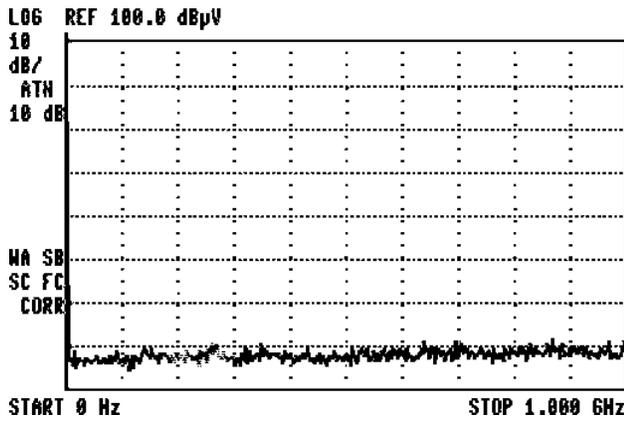

Plot 4: Aluminum Foil

A given thickness of metal represents fewer skin depths at lower frequencies. In Plot 4, below 300 MHz, the foil is fewer skin depths thick as compared to higher frequencies and some signal is leaking through. However, the shielding effectiveness is still about 60 dB at 100 MHz so the foil is still many skin depths thick and is a good shield.
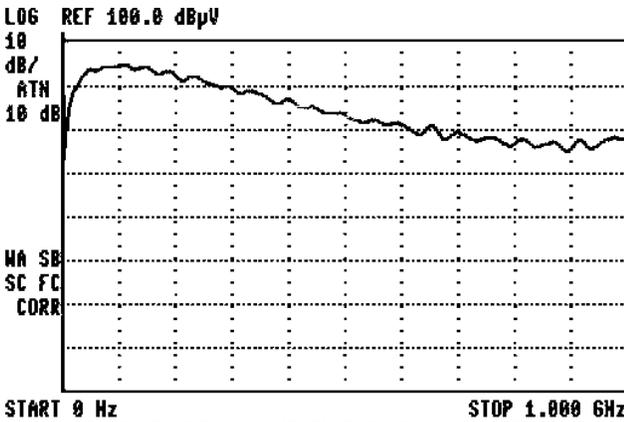
Above 300 MHz in Plot 4, the signal was below the noise floor of the spectrum analyzer. Plot 5 shows the result when the loops are held far apart. In this plot, the noise floor can be seen for the entire frequency range. At 100 MHz, the signal leaking though the aluminum foil was about 10 dB above the noise floor.

Plot 6 shows the result for another commercial shielding material, a flexible cloth-like material with imbedded tiny wires that can be seen upon close inspection. The material was similar to Figure 3's.
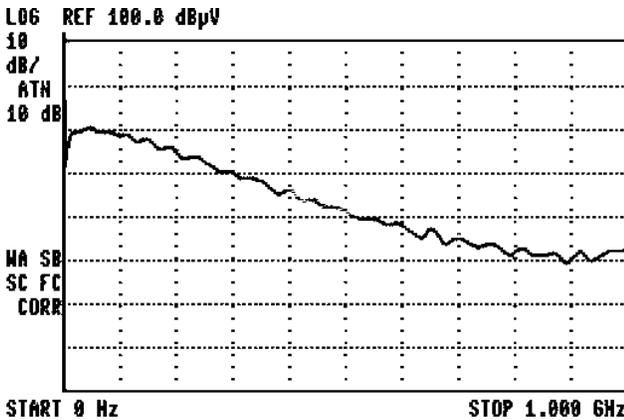
LOG   REF 100.0 dBµV
10
dB/
ATN
10 dB

WA SB
SC FC
CORR

START 0 Hz   STOP 1.000 GHz

Plot 5: Null Experiment

The shielding was only about 5 dB at 100 MHz and about 10 dB in the 700-1000 MHz range. This is another example of a material that would not make a good shield close to circuits.

LOG   REF 100.0 dBµV
10
dB/
ATN
10 dB

WA SB
SC FC
CORR

START 0 Hz   STOP 1.000 GHz
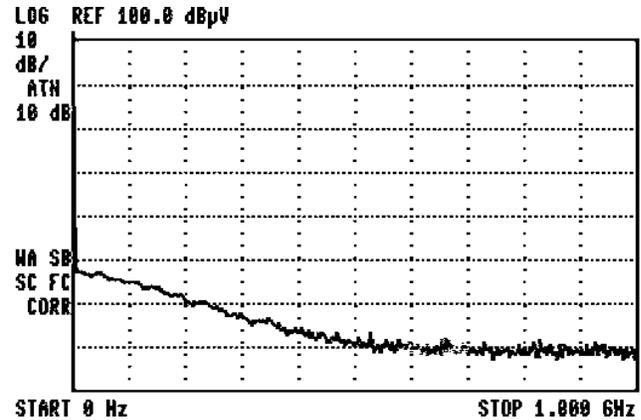
Plot 6: Cloth with Wire Material

Plot 7 resulted from an ESD shielding bag. The shielding effectiveness varies from 20 dB to about 40 dB. Although the metallized layer is very thin, it still represents many skin depths at 900 MHz and thus has 40 dB of shielding effectiveness there.

LOG   REF 100.0 dBµV
10
dB/
ATN
10 dB

WA SB
SC FC
CORR

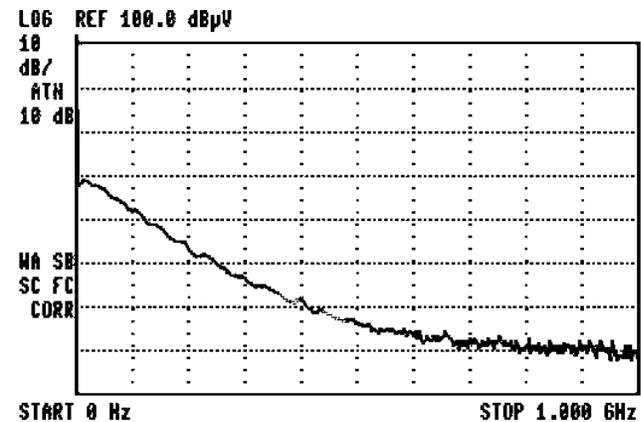**START 0 Hz   STOP 1.000 GHz**

Plot 7: Shielding Bag

Most ESD shielding bags do not have this much shielding effectiveness.

Plot 7 shows the shielding effectiveness for a heavily metalized (internal layer) bag). The metalization is thick enough that the bag was opaque. As a result it had more shielding effectiveness than the bag of Plot 6.

LOG   REF 100.0 dBµV
10
dB/
ATN
10 dB

WA SB
SC FC
CORR

START 0 Hz   STOP 1.000 GHz

Plot 7: Aluminum Shielding Bag

Plot 8 shows the measured result for a sample of shielding material that was vacuum metalized on both sides using a process proprietary to Shielding for Electronics [4]. The sample was metallized on both sides of the substrate material.
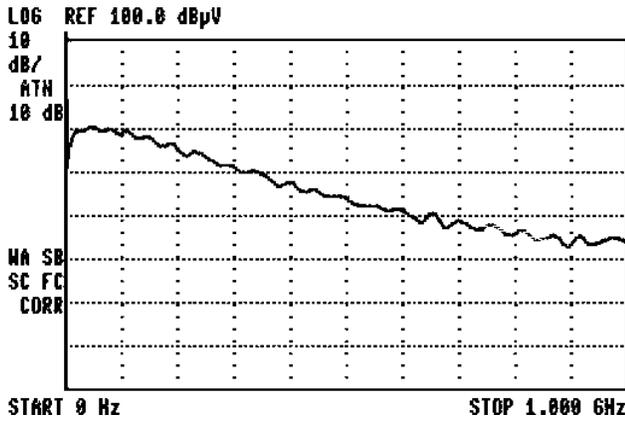
LOG   REF 100.0 dBµV
10
dB/
ATN
10 dB

WA SB
SC FC
CORR

START 0 Hz   STOP 1.000 GHz
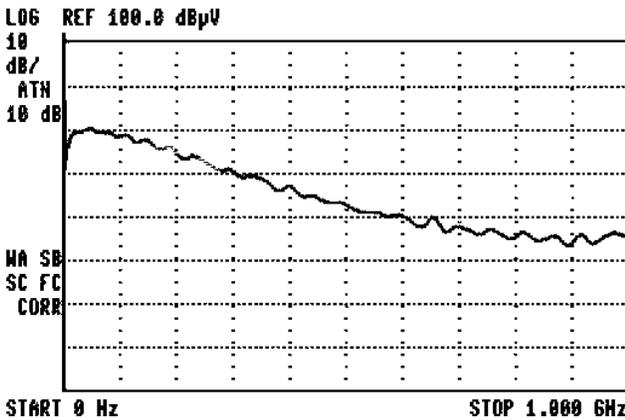
Plot 8: Shielding for Electronics Sample "A"

The sample shows 60 dB of shielding above 500 MHz and almost 40 dB at 100 MHz.

Plot 9 shows another sample from Shielding for Electronics where only one side of the sample was metallized. As one would expect, the shielding effectiveness is less, but would be adequate for many applications.

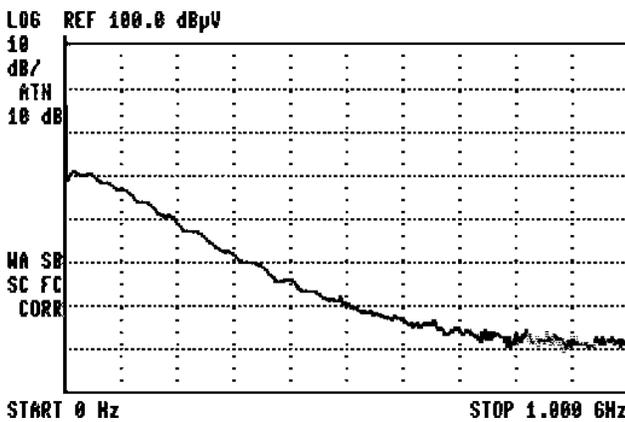Plot 10 shows a similar sample. The shielding effectiveness can be see to be consistent from sample to sample.

Plot 9: Shielding for Electronics Sample "B"

Plot 10: Shielding for Electronics Sample "C"

Plot 11 shows a product from another manufacturer that is comparable to the material in Plot 8. One can see that the material in Plot 8 yields about 5 dB more shielding effectiveness at all frequencies where the signal is above the noise of the spectrum analyzer.
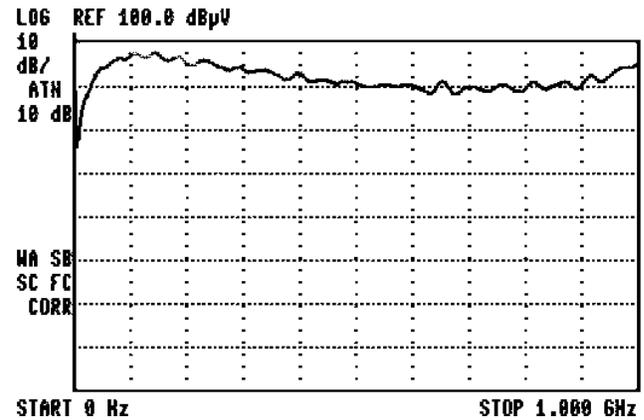
From Plots 8 and 11 one can see that this measurement method provides a quick and accurate way to compare different shielding materials.
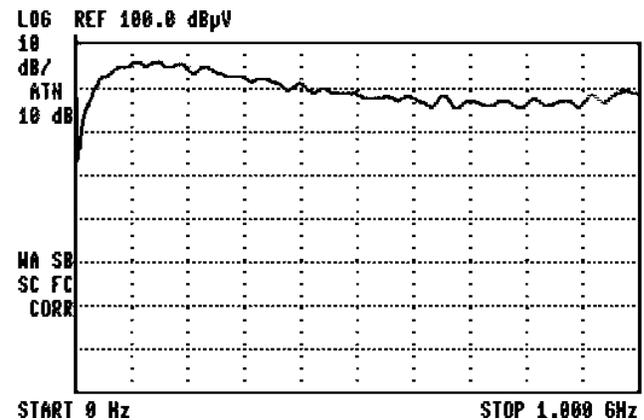

Plot 11: Seiren Fabric

Plot 12 shows the shielding effectiveness of a sample of ferrite sheet of the type that is placed on IC devices to reduce emissions from the device. As can be seen, it would not prevent radiation into nearby circuits. The shielding effectiveness is so low it is barely measurable by this test.

Plot 12: EMI Absorber Sheet (1.25"x2")

Plot 13 shows the transmission between the two loops when they are separated by about 3 mm (1/8 inch). The signal loss is about 5 dB up to 900 MHz and about 10 dB at 1 GHz. The samples tested were much thinner than 3 mm so slight variations in thickness of the samples would not introduce much error in the measurements.

Plot 13: Loops Separated by 3 mm (1/8 Inch) Air

Other Possibilities

The data provided by this test can be used to calculate the thickness of the shielding material or coating as well as providing a quick comparison test between materials.

With smaller loops and higher frequencies, the test can be used to detect defects in shielding material such as small voids and scratches. The test is fast and not destructive of the shielding material and so could be used in a manufacturing environment for quality control.

Summary and Conclusions

A new test was described that correlates more closely to the way many shielding materials are used, especially on circuit boards. Data was presented to show how the test can be used to compare materials and show if a particular material would perform well in an application.

The test is non-destructive and can be used in real time in a manufacturing environment.

Notes and References

[1] Faraday's law states that the voltage induced in a loop is proportional to the amount of time changing magnetic flux passing through the loop.

[2] Figure from seminar notes, High Frequency Measurements and Noise in Electronic Circuits, D. C. Smith © 2002, and the website http://emcesd.com. Used with permission.

[3] "Signal and Noise Measurement Techniques Using Magnetic Field Probes," IEEE 1999 EMC Symposium Proceedings. pp. 559-563. Available for download from: http:/emcesd.com/pdf/emc99-w.pdf.

[4] Shielding for Electronics, Inc., 232 E. Caribbean Drive, Sunnyvale, CA 94089, Tel: 408.745.0561, http://www.shieldingforelectronics.com.