Testing EMI Shielding Materials with Square Waves

GEORGE TRENKLER and RICHARD DELAGI
Texas Instruments

Engineers in the audio industry fondly recall the test procedures used to determine the real performance of a newly introduced component. At the equipment manufacturer's specified power rating, the equipment was scanned with a sine wave input in a specific frequency range. Generally, it was a spectrum of frequencies between 20 Hz and 20 kHz. No comment on the validity of the results is needed!

Later, the same philosophy was applied to EMI shielding materials; that is, testing shielding performance with sine waves in specific frequency ranges. It is interesting to note that a field strength requirement was not specified. Of course, this type of testing does not reflect the "real world" very well.

With respect to field strength, the use of nonmagnetic metals for shielding is not problematic; all metals have enough electrons to avoid current saturation caused by a decrease of conductance. The situation changes, however, if materials with distributed gap, or materials in which electrical conductivity is produced or enhanced by dopants are used. Moreover, other rules apply to thin film materials whose thickness is less than the theoretical depth of penetration in the given bulk material.

The problem of field strength will arise if the EMI shielding is produced by ferromagnetic materials: all of them have a distinct magnetic saturation level. (Here, the reader is referred to the many tables available in the technical literature, listing physical properties of a multitude of different ferromagnetic materials.) It is actually most interesting to look at composite EMI shielding materials which combine high electrical conductivity with ferromagnetic properties like nickel, cobalt, and high-conductivity iron alloys.

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An important question is, "How closely does sine wave testing approach real-world conditions?" Recent articles address various sources of EMI,[1] but very few sources exhibit sinusoidal wave forms.

The real wave pattern of EM polluters can take virtually any shape, but almost all of them display periodicity. This means they can be introduced as a sum of a fundamental wave and its harmonics and result in the ability to express almost any shape of interference wave with a predictable mathematical expression. All this suggests that the EMI shielding performance of a material will be recognized and evaluated more precisely if testing is done with the EM waves having a multitude of frequencies. The most convenient shape is probably a square wave, if it is easy to produce and it has a large number of harmonics. In the spring of 1992, tests were conducted using a square wave drive. Later, in the fall of 1992, additional testing was conducted, broadening the choice of materials by using not only single layers, but also multiple layers of the shielding materials. The experiment was set up using a tabletop near-field tester.[2] A modification to the tester was made: in order to permit testing of materials of significant thickness compared to the 1.0-cm gap, the gap was increased to 2.0 cm. Thus, when the results are converted to other testing procedures, a coil separation distance of 2.0 cm must be used.

Before testing began, the assumption was made that the fields were not strong enough to saturate the ferromagnetic materials selected for test. This time, the "built-in" amplifier for the receiving coil was omitted. Considering that square wave excitation was needed, the tester was driven from an HP function generator. The output from the tester was fed to the spectrum analyzer system (HP 141-T, with HP 8556-A front-end, and HP 8552-B IF section). Horizontal and vertical outputs from the setup were connected to a HP 7044 plotter, connected in the "X" and "Y" mode. The frequency scan was displayed on the "X" axis, and the signal strength (in dB) on the "Y" axis. Outputs were scaled to coincide with the parameters of the recorder. The overall frequency response is de-

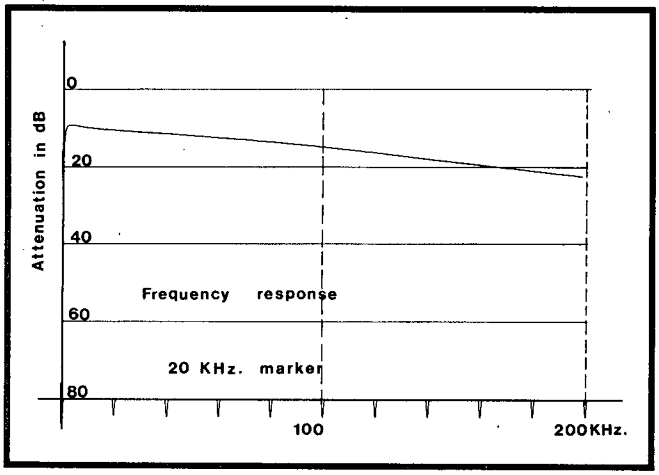

FIGURE 1. *Frequency Response of the Spectrum Analyzer System.*

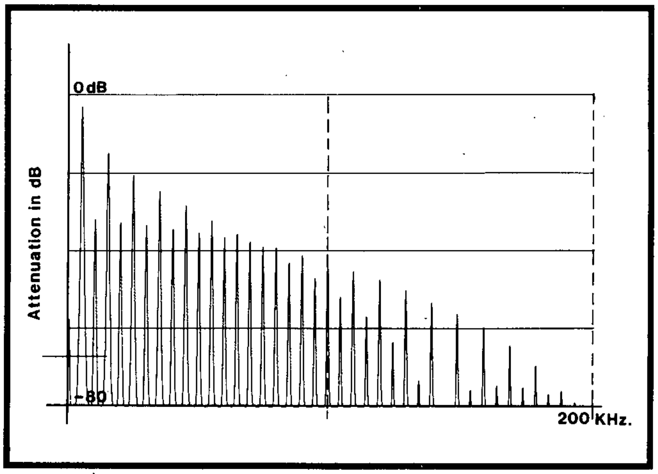

FIGURE 2. *A 5-kHz Square Wave 50-percent Duty Cycle.*

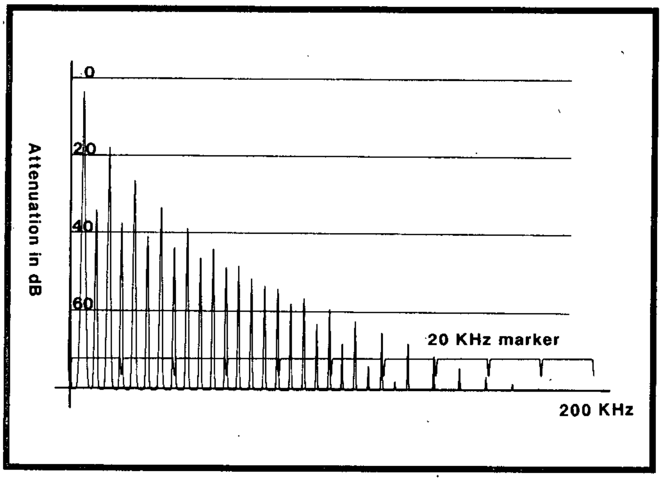

FIGURE 3. *Shielding Performance of 0.013"-thick Phosphor Bronze.*

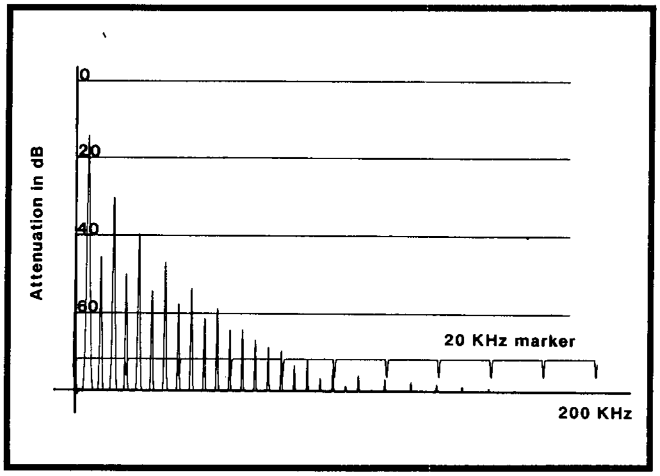

FIGURE 4. *Shielding Performance of 0.025"-thick 1008 Steel, Not Annealed.*

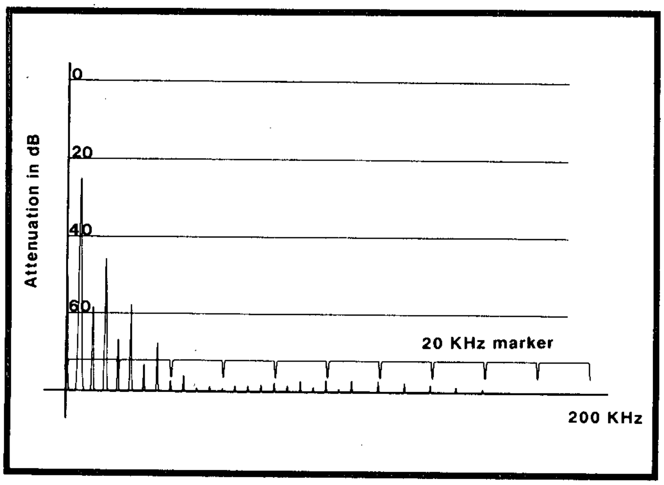

FIGURE 5. *Shielding Performance of 0.025"-thick 1008 Steel, Annealed.*

picted in Figure 1. The oscilloscope connected across the driving coil displayed clean square waves with very little rounding of corners. Figure 2 is an overall scan of the test signal. It is a 5-kHz square wave 50-percent duty cycle. The leading and training edges have a 0.2 volt/μsec tilt. One factor should be noted: a zero level was chosen arbitrarily. The frequency marked on this graph is omitted. The harmonics, being a part of the 5-kHz square wave, are 5 kHz apart. The first spike on the graph is the 5-kHz fundamental of the square wave.

Now the graphs depicting performance of different shielding materials are considered. Figure 3 is the test result of 0.013"-thick phosphor bronze (copper with less than 1 percent phosphorous). The phosphorous addition greatly improves the mechanical

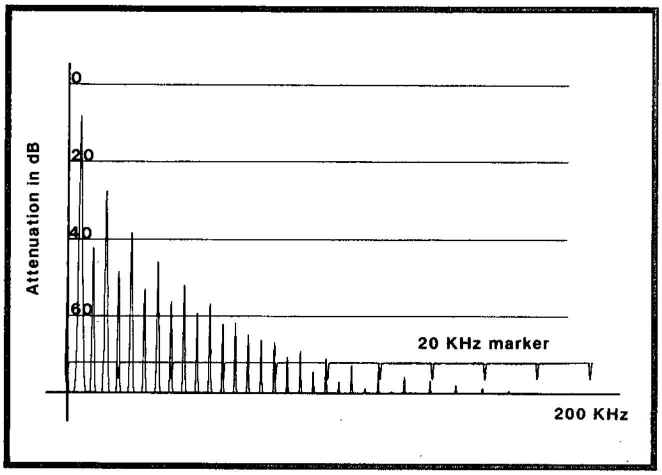

FIGURE 6. *Shielding Performance of Pure Aluminum, 0.01" Thick.*

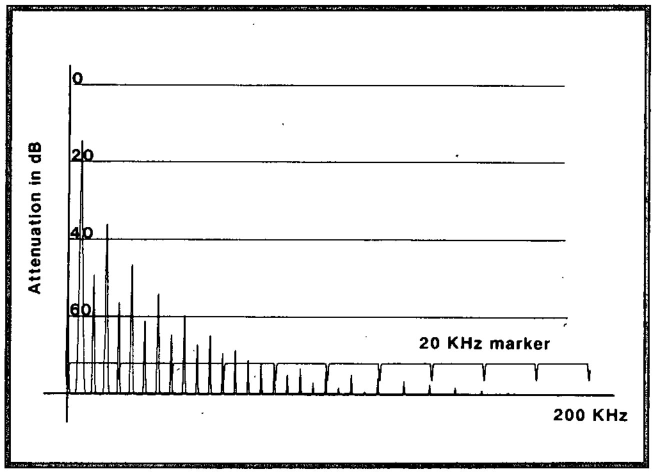

FIGURE 7. *Shielding Performance of Pure Copper, 0.016" Thick.*

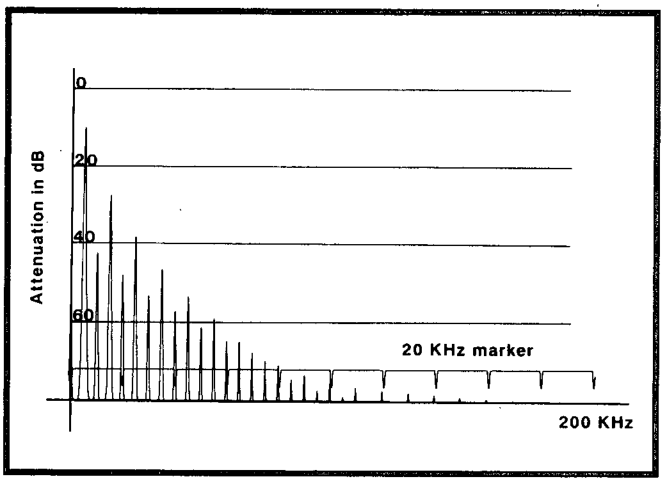

FIGURE 8. *Shielding Performance of Annealed Nickel, 0.009" Thick.*

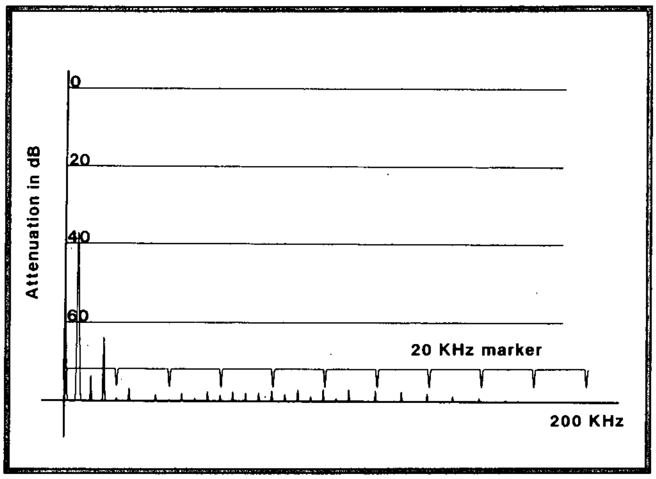

FIGURE 9. *Shielding Performance of Cu-49-Cu, 0.01" Thick.*

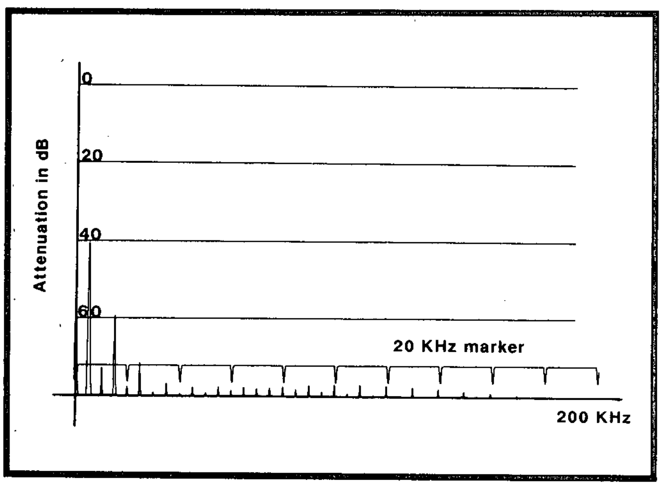

FIGURE 10. *Shielding Performance of 49-80-49 Permalloys, 0.01" Thick.*

properties of copper but reduces the electrical conductivity of the pure copper and its EMI shielding ability.

Figure 4 is standard 1008 steel as received from the manufacturer. The same material, but annealed in "cracked ammonia" (75-percent H_2 and 25-percent N_2) at 900° C for one hour and cooled at a rate of 200° C/hr, is displayed in Figure 5. The difference made by annealing is obvious.

Figure 6 is pure aluminum (more than 99-percent Al) and Figure 7 is pure copper. Both produce good shielding in the high frequency range.

Figure 8 is fully annealed nickel. Figure 9 is a composite material, "Cu-49-Cu." It comprises 20

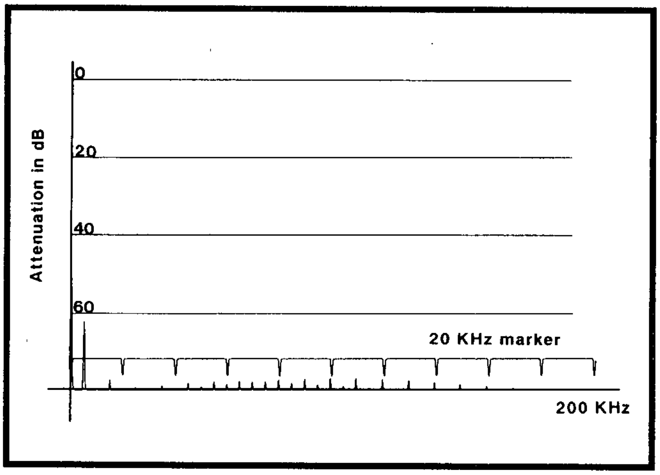

FIGURE 11. *Shielding Performance of 80 Permalloy, 0.008" Thick.*

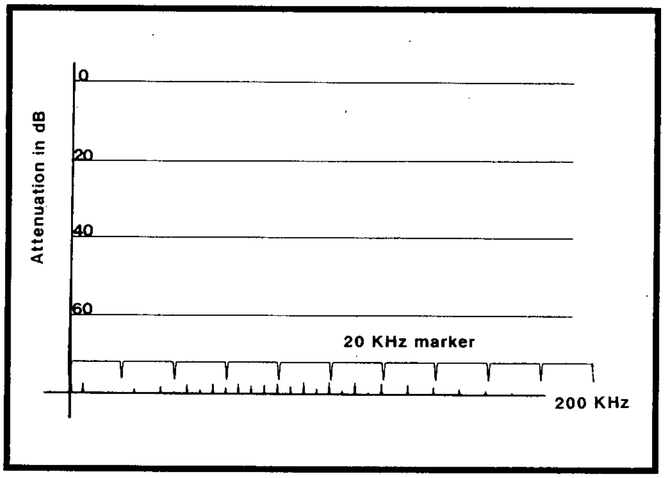

FIGURE 12. *Shielding Performance of Mu-Metal, 0.0135" Thick.*

percent-60 percent-20 percent thickness layers. It is a metallurgically bonded combination of copper, 49 percent permalloy and copper respectively, subsequently heated with a proprietary treatment.

Figure 10 represents a laboratory development for high-density magnetic flux shielding material at low frequency. It is a 3-layer material comprised of 20 percent-60 percent-20 percent thickness ratios of "49","80" and "49" permalloys. It was the prototype for development of a graded material for high dynamic range magnetic field densities.

Figure 11 is "80" permalloy (16 to 20 percent Fe, 80 percent Ni, and up to 4 percent Mo). It provides great attenuation of low frequency, leaving some "hash" around 60 to 120 kHz. Due to the exceptional purity of the materials used for this alloy, the price of this shielding material is high.

Finally, Figure 12 shows the test result of the "mu-metal." The material is similar to "Permalloy 80" but includes an additional few percent copper.

It should be noted that the last two materials have the best shielding properties in the low frequency range. However, both are useful only for low density magnetic flux fields since they are easily saturated. On the other hand, additions of Mo and Cu produce very narrow hysteresis loops and high "M" (in the range up to 500,000), reducing the magnetic saturation values to 8.5 kG and 7.0 kG, respectively.

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3. McBride, Lyle E., *EMC Technology*, May-June 1987 and Jan.-Feb. 1989.

GEORGE (YURY) TRENKLER *was a member of the Technical Staff, Advanced Development, Texas Instruments. He was born and educated in the U.S.S.R. Yury worked for TI from 1965 until his retirement in January, 1990, and his last responsibilities included the development of expanded clad metals, composite EMI shielding materials, electronic testing systems, and work in the design of reinforced metals. He holds 30 U.S. patents and currently is involved in consulting work with TI in the areas of magnetics, metallurgy, and electronics. (401) 434-7787.*

RICHARD DELAGI *received his B.A. and M.E. degrees in Metallurgy and Mechanical Engineering from Columbia University. He joined Texas Instruments in 1954 and has done extensive work to develop processes for the manufacture of multilayer metallurgically bonded metals and alloys. Dick pioneered the development and application of diffusion bonded metals in the industrial sector. Much of his early work was applied to fuel reactor core fabrication for the U.S. Navy's nuclear submarine program. His work in applied materials science has also included the areas of electrochemistry, electronics, electro-optics, magnetics and electromagnetic radiation. Mr. Delagi has served on committees of the Department of Energy and the National Science Foundation. In 1985, he was elected a Fellow of Texas Instruments. He holds over 30 U.S. and foreign patents. (508) 699-3218.*