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515 Schoolhouse Road
Kennett Square, PA 19348

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Abstract This program was to develop and fabricate a low cost composite shielding material (Multishield) that is capable of providing shielding against magnetic fields, including high strength fields. A continuous horizontal web production machine was manufactured and placed in operation. The project demonstrated that the multiple layered shielding material developed was effective at providing attenuation of magnetic fields. Additionally, the continuous electrodeposition system demonstrated that the material could be produced inexpensively in significant quantities. Current emphasis (which will continue via internally generated funds) will focus on improving the mechanical characteristics (i.e. ductility) and verifying the performance of cables using the braided wire.		
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Summary

This program was to develop and fabricate a low cost composite shielding material (Multishield) that is capable of providing shielding against magnetic fields, including high strength fields. A continuous horizontal web production machine was manufactured and placed in operation. This machine was utilized to produce both flat plate and wire shielding material. The project demonstrated that the multiple layered shielding material developed was effective at providing attenuation of magnetic fields. Additionally, the continuous electrodeposition system demonstrated that the material could be produced inexpensively in significant quantities.

The project primarily focused on producing, testing and marketing the Multishield product in the flat plate configuration. These objectives were achieved. A relatively large continuous deposition system was constructed which produces 2 foot wide multilayer sheets with good shielding properties. However, there appears to be a very limited market for this product for this configuration. Market research indicates this is due to several factors. First, flat plate shielding typically is applied in architectural applications (e.g. room shielding). Those applications requiring magnetic shielding, the cost of the room and associated equipment is large compared to any method of installing shielding. In this type of applications, any cost savings from the shielding is insignificant to the overall system cost and makes the use of any cheaper but unproven shielding method impractical. Numerous commercial materials (e.g. thick steel plates) are available; thus, it is believed that Multishield, although effective in these applications, does not provide a significant enough cost or performance advantage for these applications.

A market which appears to be developing slowly is the use of small area magnetic shielding for electronic components, (CPU's, printed cct boards). We are in contact with a number of manufacturing who have received samples and like the product.

An additional application for the flat plate shielding material was felt to be electrical distribution control equipment for protection of the electrical grid against electromagnetic disturbances. However, the current process of deregulating the electric utility industry has resulted in significant reductions in expenditures by these companies. Current emphasis in this industry is on reducing cost and use of capital for mergers and acquisitions. Current research and development efforts in the industry (in both the generation and distribution sectors) are focused on the objective of cost reduction. Because of the defined need for reliability enhancements and the continuing threat of electromagnetic induced disturbances, the future market potential for application of Multishield to address this problem remains. However, it is not expected that any significant efforts to address this issue will be made by utilities until after industry realignment has taken place and / or action is mandated via regulatory mandate.

A potentially more marketable use of Multishield is application as a braided wire shield. The early wires fabricated with this system were too brittle to be braided. Annealing experiments have provided a ductile coating while still maintaining good magnetic properties. Because use of issues concerned with control of annealing conditions (temperature, environment, etc.) when external suppliers we used, a tube furnace was purchased and received in late May. Purchase of this furnace provides the capability to perform controlled annealing experiments in-house. These experiments have not commenced due to problems with procurement of the glass tube (the delivery of the original tube was significantly late due to problems at the manufacturer and once received the tube needed to be returned for repair). Current emphasis (which will continue via internally generated funds) will focus on improving the mechanical characteristics (i.e. ductility) and verifying the performance of cables using the braided wire.

It should be pointed out that the technology developed during this program, plating on wires, appears to open a number of new technologies beyond shielding. The ability to plate a closed magnetic film on a small diameter wires has produced some new devices. This include a new strain sensors as well as current controlled impedance, similar in concept to a variactor. Both of these produces, an offshoot of this technologies, are being actively pursued.

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Project Status

This SBIR Phase II project completed on June 30, 2000. The major technical objectives (i.e. development of an effective low cost magnetic shielding material) were achieved. The project demonstrated the material could be deposited cost effectively onto both flat plate sheets and wire substrates using a continuous deposition process.

Project Results

The purpose of this SBIR program was to develop and fabricate a low cost composite shielding material (Multishield) that is capable of providing shielding against magnetic fields. To achieve this end, there were two primary objectives:

1. Continue with material development and testing to improve performance of the multilayered composite shielding material developed during the Phase I effort.
2. Demonstrate the material could be produced inexpensively.

During the execution of this project, both of these primary objectives were achieved.

Material Composition

The composite material consists of a copper substrate with alternating layers of nickel/iron and copper. The starting substrate typically is a 25 μm (.001") copper foil. To this approximately 12 μm (.5 mils) per side of permalloy is electrodeposited, followed by an additional 12 μm (per side) of copper for a total thickness (film + substrate) of 75 μm (.003"). This process can then be repeated with a final composition of up to 5 layers. Depending on the specific application, the outer film may be left as copper (for soldering) or plated with an additional layer of permalloy for corrosion resistance. During the project, a nominal 12" wide substrate was typically used; however, sheets up to 24" wide were plated using the continuous plating machine described later. The 12" width was selected predominantly to support standardization of material testing.

Continuous Plating System

To achieve the objective of producing the composite shielding material economically, a continuous roll to roll plating system was designed and fabricated. During the design process, it was determined that the required plating tank size was in a region where commercially available plating tanks are not available. Continuous plating systems are usually much narrower (2-3 inches) while larger systems are used for electroless plating (Ni, etc). In addition, all such systems appear to be custom fabricated and are never available off the shelf. Thus, the system was custom designed and fabricated.

The first decision was on the method of feeding the substrate (web) through the machine. Most small systems use a vertical web while larger systems use a horizontal web. The small vertical systems are straight, with the web traveling in a straight line and requiring some type of liquid lock between the various stages. The horizontal web systems have separate tanks and the web is introduced, via rollers, into the tank and removed from the tank at the end. In the initial design, we had wanted to minimize handling of the film. The requirement for multiple rollers appeared to be a weakness so the decision was made to use the vertical web. This design minimizes flexing of the web but requires a liquid lock between the various tanks. Horizontal web systems have separate tanks and the web is introduced, via rollers, into sequential tanks. The problem was the large liquid seal at each tank. The relatively small head (6 inches average) would minimize the design problems with the seals but it was recognized as a problem area and experimental work was started on the web. However, the experiential on the seals were not encouraging. A fluid seal could be designed as a means to minimize the amount of liquid "leaking" though the seal,

such as using narrow gap width and a long length of seal, relying on the an increase in conductance. This approach, which is the most widely used since it avoids contact with the web, requires a cache basis after each seal to reclaim the liquid spilling though the small opening. One of the materials being plated (Fe) plates from Fe^{+2} . One of the problems with this type of plating is the tendency of the Fe^{+2} to change to Fe^{+3} ; the spillage of the liquid increases the surface area and would tend to complicate this problem.

Alternately, applying a pressure contact with a material such as Teflon can reduce this leakage significantly but increases the tension required on the web transport system. Both approaches were evaluated and neither was felt to provide a satisfactory solution. Although both approaches could be made to work at 12 inch wide, this is probably the limit on the web size. At the same time, the concern over the rollers was reevaluated. This initial concern with the flexing was based on the strain that occurs in the magnetic layers and was based on plating of a wire, with a total thickness of .020", which means the outer layer of the magnetic film is .01" from the neutral axis. The distance from the neutral axis controls the stress in the outer layer of the film when wrapping around a roller. Although we had no guidelines for the allowable strains, we picked a conservative value and limited the roller to 12" diameter. However, with the decision to plate a flat sheet with a maximum thickness of only .003", the distance from the neutral axis now is only .0015" allowing a much smaller roller (roller diameter of only 1.8 ") for the same strain.

As a result of this analysis, the continuous plating system was redesigned. The basic redesigned system is shown in Figure 1.

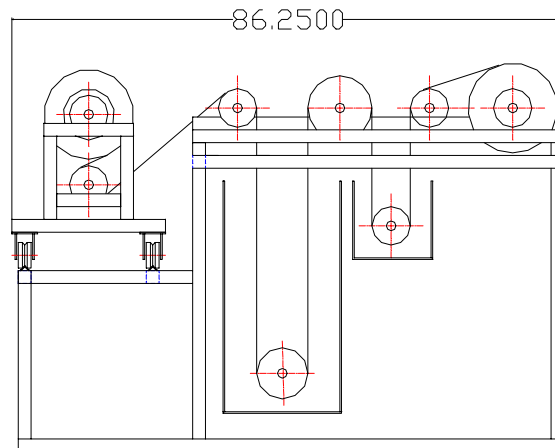


Figure 1: Vertical roll to roll continuous plating system.

The large roller on the left is the feed roller while the large roller on the right is the take up roller. The feed roller runs through an idler roller in to the plating tank, a rinse tank and into the take-up roller. The take-up roller is the system driver (i.e. the web is pulled through the system) while the lateral position of the feed roller is adjusted, via a web guidance system, to control the tracking. Both the drive and take up rollers are copper rollers and are the ground of the substrate while the anodes are driven positive. The anodes can be seen in Figure 2. They consist of two Ti baskets at the outside of the tank and one basket in the center with the plating done on both sides of the web.

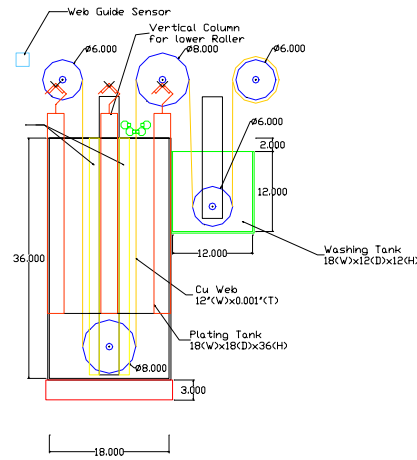


Figure 2: Detailed sketch of plating tank showing the anode assemblies, the web guide sensor and the vertical column. This vertical column, in the center of the tank, is raised to thread the web and then lowered to start plating.

The plating rate of permalloy and copper is about $50 \mu\text{m}$ /hour. For a $12 \mu\text{m}$ layer, this means the film needs to be in the bath for ~ 15 minutes. With a continuous system, the size is related to throughput. This tank has a 4-foot long plating length (2-ft. on both sides of the roller) resulting in a throughput of 16 linear ft./hour.

The advantage of this approach is the ease of scaling. Figure 3 (left hand side) shows the actual system built. This system is capable of plating 1 layer pair /side per pass. The width of the tank, rollers and transport system are capable of handling 24\"

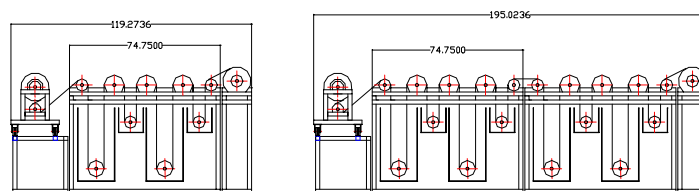


Figure 3: Additional tank to plate two layers per pass (production machine actually constructed) and 4 layers per pass.



Figure 4: Picture of 24 “ wide continuous deposition system.



Figure 5. 24-inch wide roll of shielding foil

After installation of the continuous plating system in June 1999, a large number of engineering obstacles were encountered and overcome to place the machine into operation. Issues such as these are to be expected during initial application of any new production process but they do consume resources to resolve. An example of the issues encountered and their resolution is provided for illustration.

- The Ni/Fe bath was constructed and initial plating occurred.
- To correct plating non-uniformity, the anode baskets were modified to have polypropylene sheaths of ~ 1.5” width on outer ends of bath. Also holes were cut into the inner sides of the anode baskets on June 28 to increase current density in the center of the web.

- The Cu bath was constructed.
- The wiring for the Cu bath supply and return was modified. Shunts were installed and over the next few days a heat dissipation system was fabricated to allow for equal current distribution to each side of the web.
- The rinse systems for both baths were installed. A spray rinse for the Ni/Fe bath also was constructed.
- In order to obtain a more even plating current distribution, the outer anode baskets were replaced on July 27 with 1' wide baskets.

These engineering and production issues serve to illustrate the complexity of placing a new system (such as this) into service. As part of this project, these issues, the alternative solutions considered and the actual resolution were documented to provide a reference to facilitate any potential future scale-up of the process.

Because there has not been any significant market for the Multishield product, production focus was shifted from fabrication of flat plate shielding to deposition of the Multishield material onto wires for production of a braided shield arrangement. A schematic is provided in Figure 6.

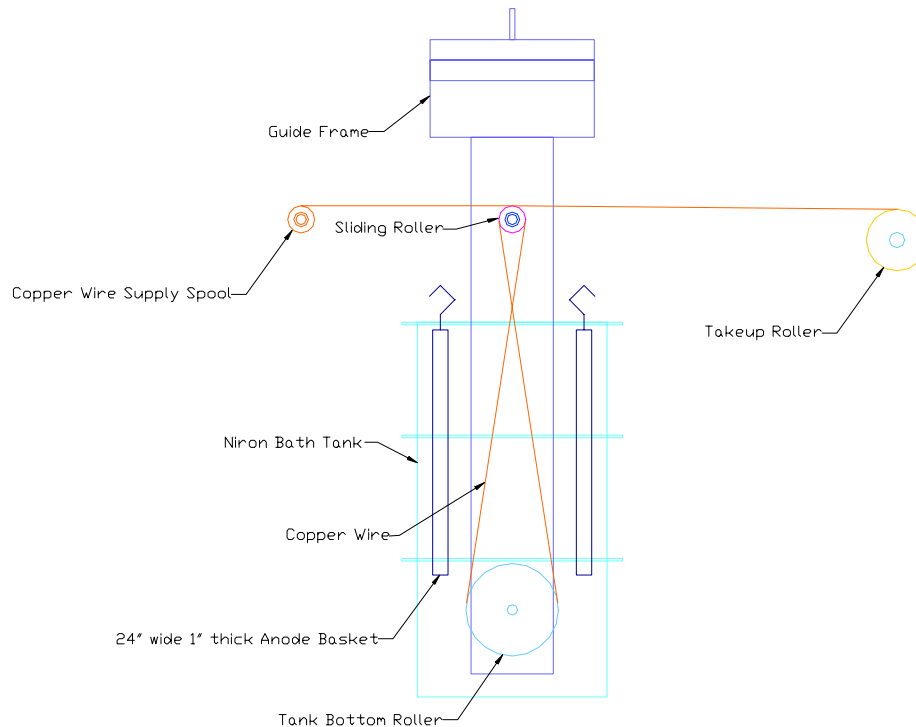


Figure 6: Schematic of wire plating system.

A problem, which was identified early during manufacture of the wire in the production machine, was non-uniform plating based on position within the bath. To understand this issue and investigate potential solutions, a finite element model was developed to evaluate the plating characteristics of the wires. Because a two dimensional modeling program was used, the three dimensional effects of the current distribution near the wire needed to be accounted for. Also, because the modeling program was limited to use of a constant grid spacing, numerical values of relevant model parameters (wire and bath resistivity) needed to be scaled to match the characteristics of the finite element model.

The region near to the wire was modeled as providing a high electrical resistance. This “spreading resistance” was modeled as axiallysymmetric and constant in its respective region. Three separate constant resistance regions out to a radius equal to 10 times the wire radius (r_0) were arbitrarily selected to represent this spreading resistance. The layers modeled extend to $2r_0$, $5r_0$ and $10r_0$ respectively. The second issue was addressed by scaling the model parameters (i.e. resistivity values) to account for these differences. The values of resistivity used in the model are provided in Table 1.

Region	Model Resistivity (Ωm)	Physical Resistivity (Ωm)
Wire	.04	3×10^{-8} (1)
Spreading Resistance Inner Region	.17	
Spreading Resistance Center Region	.07	
Spreading Resistance Outer Region	.03	
Bath	3.9	10 (2)

- (1) CRC Handbook of Chemistry and Physics, 72-nd Ed., p. 12-33.
(2) Reference Sensortex, Inc. Technical Report TR-24.

Table 1: Model Parameters

The model was found to conform closely to the results obtained. Figure 7 shows the current density normal to the wire. This corresponds very well with the observation that the majority of material deposition occurs near the bath exit. Modifications to the model that alter the applied voltages do not substantially change the results. This indicates that the plating is dominated by the local spreading resistance and that the issue is related to the plating geometry. It should be noted that these results do not indicate that the wires produced in the production machine will not be useable as effective shields against magnetic fields; it only indicates that production using this plating geometry is inefficient and introduces problems related to material quality control.

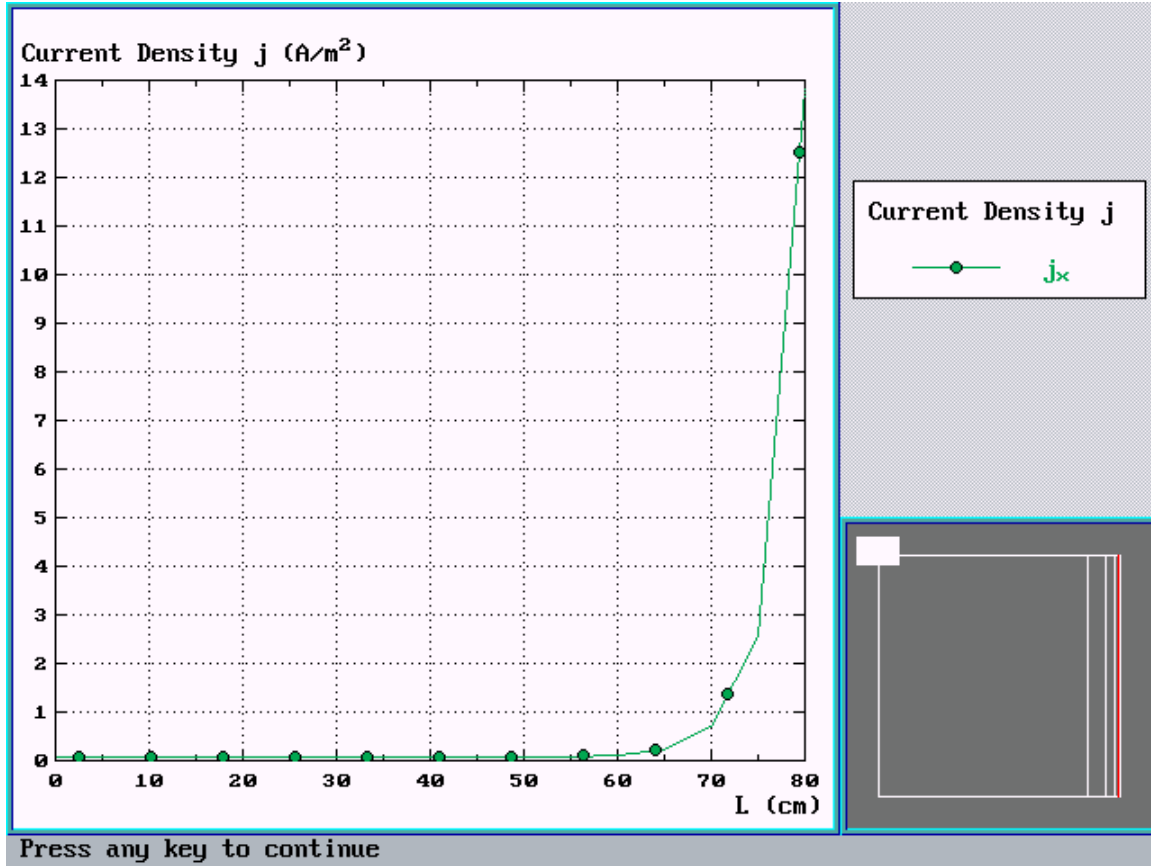


Figure 7: Graph of current density normal to wire for pilot production machine.

Because of the plating results described above, an alternative plating bath configuration has been proposed. This bath would be a long relatively shallow bath. The wire would be plated between a series of anodes with decreasing potentials. These anodes could be either cylindrical (thus completely surrounding the wire circumferentially) or flat plates (with at least 1 anode above and below the wire). The anodes are expected to be “long” in comparison to the distance from the wire to the anode. This ensures that the wire effectively “sees” only the potential of the closest anode.

To investigate the feasibility of this plating configuration, a simplified finite element model was developed. This model consisted of two flat plate anodes, set at different potentials, in series with a small gap between them. Analysis of this plating configuration resulted in a much more uniform material deposition. The model was modified to include a spreading resistance, which resulted in no noticeable difference in either current density or potential distribution. Results of this finite element model are shown in Figures 8 and 9. Based on these results, the long shallow bath with biased anodes is a viable plating approach for efficient production of wire shields.

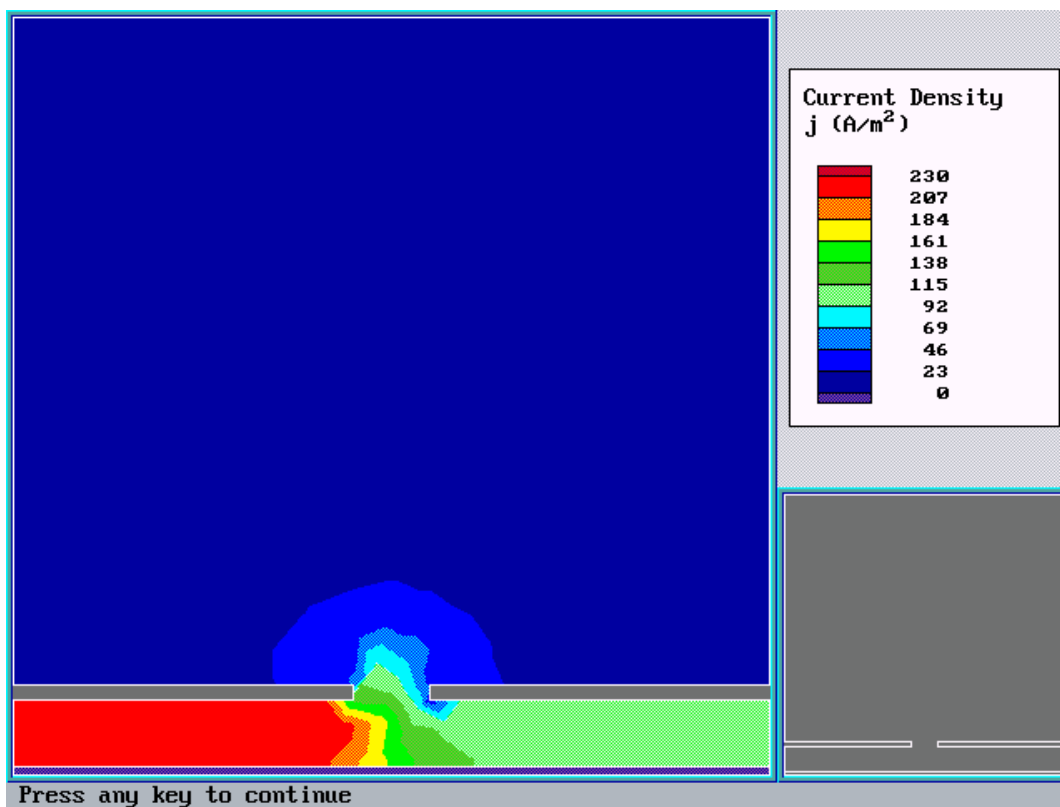


Figure 8: Current density for shallow bath plating of wire 2 anodes set at different potentials.

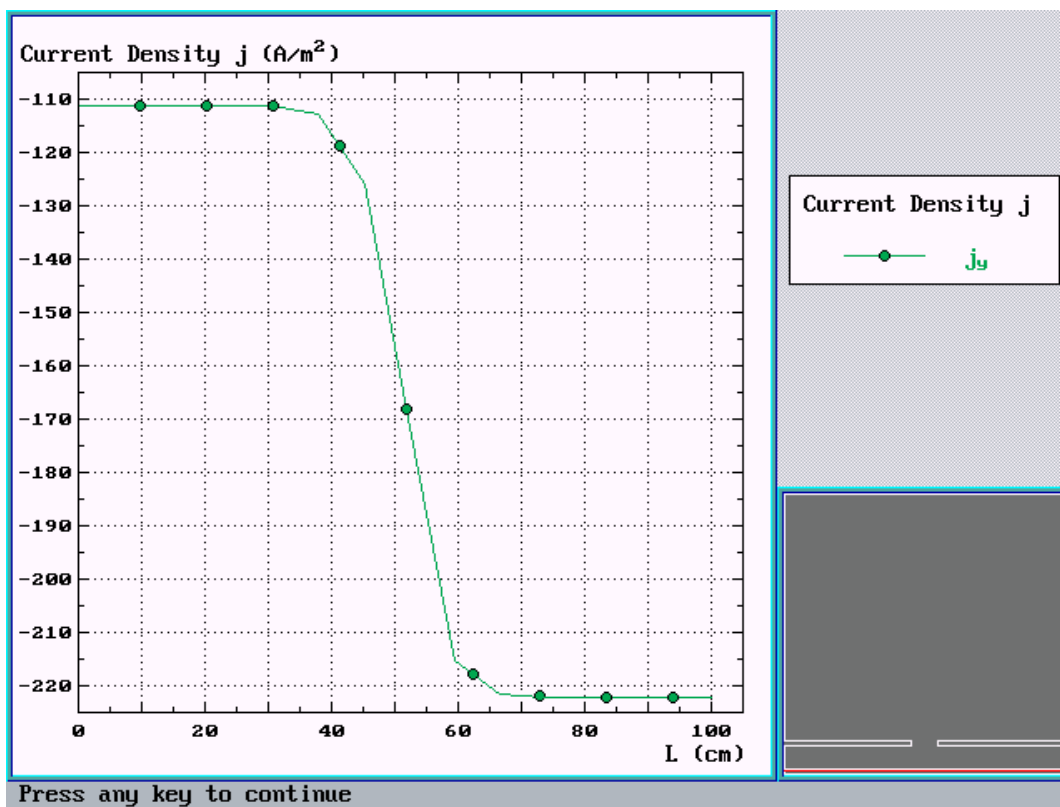


Figure 9: Normal current density for shallow bath plating of wire.

A problem, which was identified early during the manufacturing of the wire, has been the poor ductility of plated wire. This has limited the capability to weave the wires into a braid to provide shielding. To address this issue, use of annealing has been investigated to improve the ductility. During the report period, samples of plated wires were sent out for annealing. These samples were found to have the expected improved ductility. However, the annealing process resulted in a decrease in the magnetic properties of the wires (initial samples provided no magnetic properties at all). However, by varying the annealing process conditions (e.g. temperature, time, furnace environment (air, vacuum, and nitrogen blanket) cool-down process, etc.), ductile samples with acceptable magnetic properties were obtained. Though repeatable results are possible, an optimized process has not been identified.

A problem which was encountered during annealing was the inability to obtain satisfactory results from external sources. To address this problem, Sensortex purchased a tube furnace. This furnace (Lindberg model 54S-MK8028-22 / 1200 deg C / 16600 W output) was delivered in late May. A tube was purchased from a commercial supplier, but significant delivery delays were experienced. Additionally, when the tube arrived in August, the end cap cracked during initial use. This required sending the end cap out for repair. These repairs are scheduled to take until late September to complete. At this time, annealing experiments and testing (using internally generated funds) will commence.

Material Testing

Flat Plate Shielding

Standard shielding measurements require a large sample (~ 30" square) and a large shielded room with special attention to seams. With only a 12" wide sample not enclosed in a shielded room, leakage around the edges sets the lower limit on the transmission. Two small test systems were setup to provide information on the magnetic performance as a function or process control parameters.

The first system constructed utilized a cylindrical geometry. The system consists of a Helmholtz coil for excitation and a pickup coil in the center of the cylindrical shield to measure low frequency performance. This system has the advantage that a closed form solution for the shielding effectiveness can be obtained. However, there were two significant issues with respect to this test setup. First, there was an observed large decrease in shielding effectiveness from 100 – 600 Hz. This problem was eliminated by maintaining the input current at a constant value. An example of this effect is provided in Figure 10, which shows measurements from test run #Ni-157.

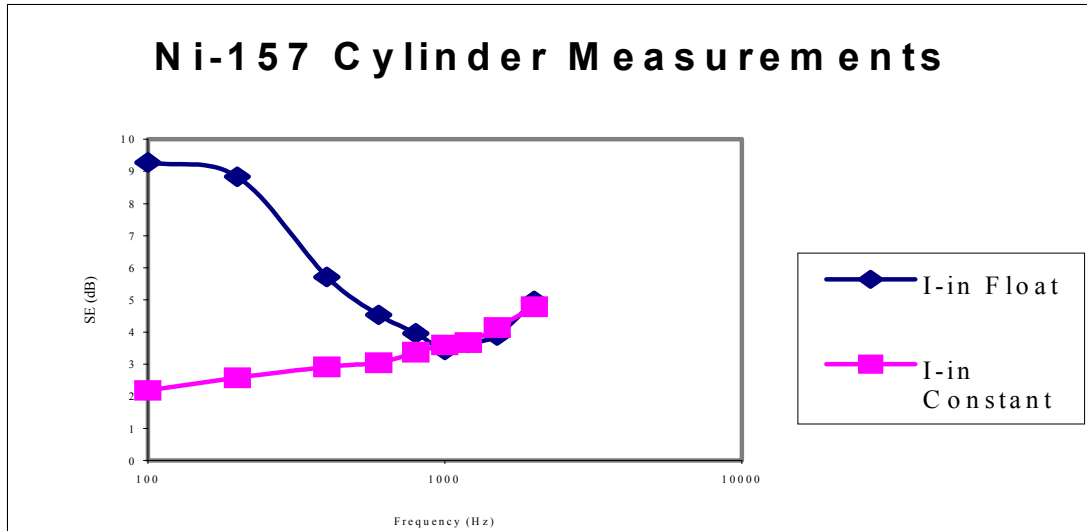


Figure 10: Cylinder shielding effectiveness versus frequency.

The second major problem with the use of the cylindrical testing method was a difficulty in achieving reproducible measurements. This was due to the fact that very small changes in sensor orientation (brought on by the act of placing and removing the test film) caused changes in the measured output, and thus in the calculated shielding effectiveness. To address this deficiency, a flat plate testing arrangement was constructed. The only drawback to this approach is that there is no closed form theoretical solution to the flat plate geometry against which test results can be compared. All calculations of permeability from flat plate measurements are derived from curves generated from a finite element analysis. To facilitate consistency in performing the permeability calculations for tests conducted using the flat plate geometry, a MATHCAD program was developed. This program uses a third order polynomial fit to the theoretical points calculated by the finite element shielding program. The correlation is given by

$$\mu t = 10^{-13}SE^3 - 10^{-8}SE^2 - .0006SE$$

where μt is the permeability – thickness product and SE is the measured shielding effectiveness. The program was successfully used to calculate the plated Ni thickness and relative material permeability from the measured change in mass of the test sample due to Ni plating and the measured magnetic field (with and without the plated shield present) input by the user. Using the flat plate test method, repeatable test results were readily achieved; thus this test method was adopted as the standard.

Plating of permalloy onto a Cu substrate is an electrochemical process. This process for plating onto flat sheet geometry has been modeled via a finite element program. The finite element program then calculates the resultant current distribution from which the amount of permalloy plated onto the substrate can be inferred. Thus, it was important to test the assumptions of the model. An important parameter in the calculated solution of the current distribution is the conductivity of the bath solution. To obtain the Ni/Fe bath resistance, the center anode assembly of the pilot production machine was removed. The system was then electrically configured such that one of the outer anodes was connected to the output of a DC power supply. The other outer anode was then reconfigured to ground via the return path to the power supply (so that this set of Ni baskets serves as the bath cathode). Power was supplied at various levels to provide selected constant current. The results of these measurements are provided in Figure 11.

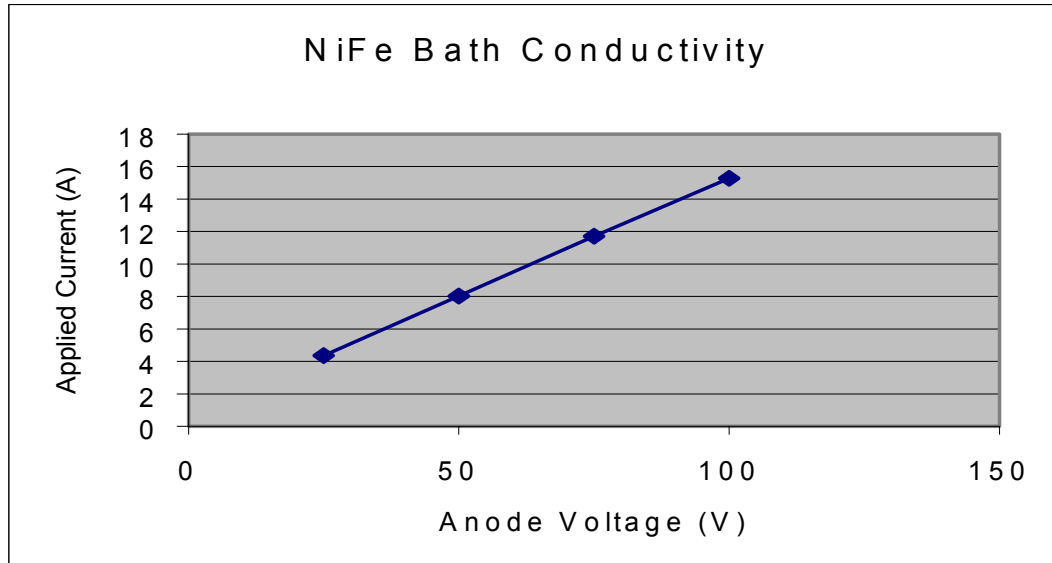


Figure 11: Plot of Ni /Fe bath current vs. voltage measured at anode and cathode bars.

The resistance is most accurately obtained from the slope obtained. However, because the results obtained from measurements are constant, simply taking the ratio of applied voltage (as measured directly at the anode and cathode bars) to measured current provides an accurate estimate of the bath resistance.

To obtain the bath conductivity from this result, the system is modeled as a parallelepiped with dimensions given by the effective anode/cathode area and the distance between them. The effective cathode area as measured to be $\sim 312 \text{ in}^2$ (2013 cm^2) and the distance between the anode and cathode baskets $12\frac{1}{4}$ inches (31 cm). The conductivity is then obtained from

$$I = \sigma A(V/\ell).$$

Substituting for the resistance from Ohm's law, the conductivity is thus obtained from

$$\sigma = \ell/AR.$$

From the measured values, the bath conductivity was calculated to be

$$\sigma = .1 \Omega^{-1} \text{ cm}^{-1}$$

Since the resistivity is simply the reciprocal of the conductivity, a value of $\rho = 10 \Omega \text{ cm}$ is obtained for the bath resistivity.

Braided Wire Shield

The major problems encountered with accurately measuring the shielding effectiveness directly were (1) difficulty in eliminating the azimuthal leakage around the braided cable shield and (2) the strong dependence of the results on the details of the testing configuration. These problems resulted in difficulty with the accuracy and repeatability in the measurements. From a literature search, which was conducted to identify appropriate testing configurations, the surface transfer impedance of the cable was found to be an effective method of determining the shielding characteristics associated with cabling [1, 2]. The surface transfer impedance (Z_T) has been found to be a useful measures of the intrinsic shielding capabilities for cable shields primarily because it is not dependent upon the test setup. In April, a test configuration (described briefly below) will be assembled to measure the surface transfer impedance of the braided cable shields.

The testing method replicates the surface currents and charges induced on the shield via externally applied fields. This is achieved by using an external coaxial conductor through which current is applied. The method relies on the uniqueness theorem concerning the electric and magnetic fields, i.e. the potentials in some region of space are uniquely determined (to within an additive constant) if the charge and current densities are specified throughout the region and the potentials (or fields) at the boundaries are specified [3]. (note that this is the same theorem that allows use of the method of images to solve some types of electrostatic problems). The basic test circuit schematic is shown in Figure 12 below. The test setup is constructed such that the diameter of the outer shield material (D_1) is much less than the length of the shield/coaxial cable test assembly, i.e. $D_1 \ll \ell$. For this configuration, the shield transfer impedance is then determined from

$$Z_T (\Omega / m) = -U_2 / I_1 \ell.$$

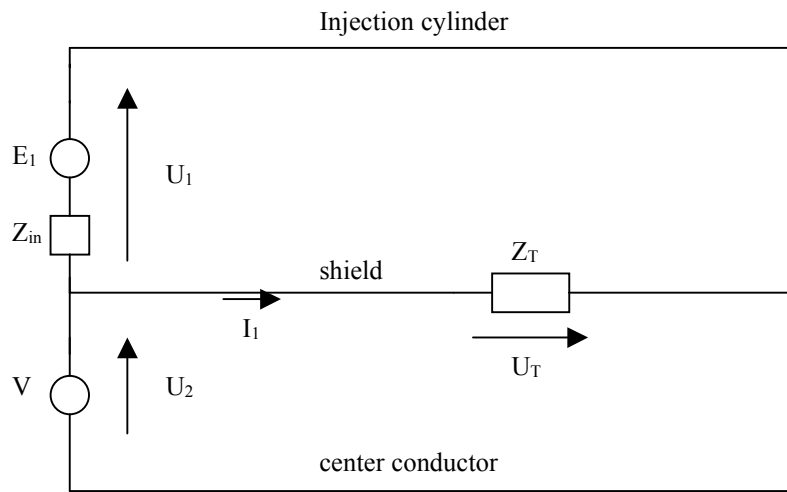


Figure 12: Basic shield transfer impedance test configuration schematic.

As discussed previously, experiments to test the shielding properties of braided cables have not commenced due to problems with procurement of the glass tube (the delivery of the original tube was significantly late due to problems at the manufacturer and once received the tube had to be returned for repair). Currently, the tube end cap is being repaired with completion scheduled for late September. Once repairs are complete, wire samples will be annealed. These annealed samples will then be sent to an external supplier for braiding. These samples then will be tested using the approach discussed previously. These activities will be performed using internally generated funds.

Production Issues

One of the issues with respect to production of large amounts of flat sheet shielding material is the ability to adequately control Fe^{2+} concentration to obtain good quality film. To provide for adequate quality control, experiments were conducted to determine a control range for this parameter.

For these tests the chemical composition of the bath was controlled. The bath pH was maintained between 3.5 and 3.9 for all test runs. Fe^{2+} concentration was then measured and controlled. Initial test runs were conducted with a low Fe^{2+} concentration of 2.0 g/l with at least two runs conducted at each Fe^{2+} concentration; typically one with bath agitation and one without. Fe^{2+} concentration was increased in approximately .5 g/l increments. Flat plate shielding effectiveness measurements were then taken from both the front and back sections of the web for frequencies of 100 Hz to 2 kHz and the material

permeability calculated at 400 Hz. This process was repeated over Fe^{2+} concentrations from 2 to slightly more than 6 g/l.

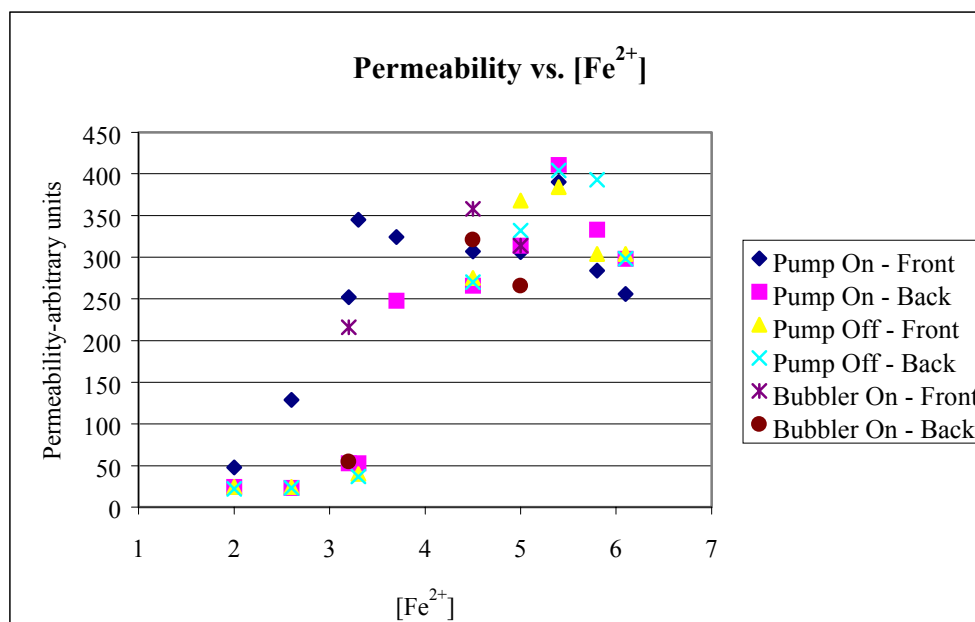


Figure 13: Material permeability vs. Fe^{2+} concentration

The results of these tests are shown in Figure 13 where material permeability is plotted against Fe^{2+} concentration. At low concentrations of Fe^{2+} , film shielding effectiveness and permeabilities were poor. As Fe^{2+} concentration was increased, both shielding effectiveness and permeability improved in agreement with expectations. Film permeability reached a plateau at approximately 4 g/l Fe^{2+} concentration with a maximum observed at approximately 5.4 g/l. Permeability then began to decrease slowly. From the data obtained, these experiments indicate a control range of 4 – 6 g/l Fe^{2+} will result in relatively consistent films with maximal permeability. It should be noted that this system is giving permeability in arbitrary units. Small changes (2x-3x) between same size samples will track actual relative permeability, which can be measured in different configurations of the sample.

A second major problem which required resolution was the visually observed corrosion/oxidation of the plated foil from the time it leaves the Cu plating bath and reaches its respective rinse tank. There is a long path length from the time the web leaves the plating bath until it enters the rinse. It is observed that significant oxidation occurs by the time the web reaches the Cu plating bath exit roller. This is a significant issue with respect to the materials marketability in terms of visual appearance. An experiment was conducted to determine if this oxidation/corrosion also had any deleterious effect on the materials shielding performance. The results of this experiment indicate there is no measurable decrease in SE due to the oxide layer which is in agreement with the expectation that at the low frequencies of the measurements (100 - 2000 Hz), the SE should be entirely dependent upon the thickness of the Ni/Fe layer deposited).

The most promising solution to this problem was the use of an air knife system to blow the Cu bath solution residue off of the web. Preliminary testing using nozzles fabricated in-house indicated that the process would sufficiently clean the web and prevent the observed oxidation/corrosion provided that a sufficiently large air flow was provided. Several vendors were solicited to provide quotations for providing air knife systems. These were in the range of \$2000 - \$5000 per bath. Due to the high cost of these commercially supplied systems, it was decided the most cost-effective approach would be to design a system in-house. To facilitate this effort, a single air knife was purchased mounted on the center roller assembly of the Cu bath. Results using the single air knife confirmed (visually) the ability to prevent the

oxidation/corrosion process. However, because the market for the large flat plate shield material has not materialized, the decision was made not to spend capital investment on a detailed system design, material acquisition and system installation at this point in time.

Product Marketing

During the Phase II effort, significant efforts were made to identify potential target markets for the Multishield product. These efforts focused on trade show displays and aggressive follow-up of potential leads. Additionally, product literature was developed and the product was prominently featured on the corporate web site (www.sensortex.com). Because the flat plate configuration was the most advanced, it was the configuration most prominently featured. Particularly, the material was displayed at the IEEE EMC Symposium in Seattle, WA during August 1999 and the NASA Tech East Conference / Trade Show held in Miami Beach, FL during October 1999. These efforts have been disappointing and indicate that no significant market exists for this configuration. Research indicates this is due to several factors. First, flat plate shielding typically is applied in architectural applications (e.g. room shielding). In these applications, the predominant concern is shielding against the **E** component of the electromagnetic field (versus the **B** component which is where Multishield provides superior performance). Numerous commercial materials are available at low cost to achieve this objective; thus, it is not believed that Multishield, although effective in these applications, provides a significant enough cost or performance advantage for these applications. An additional application for the flat plate shielding material was felt to be electrical distribution control equipment for protection of the electrical grid against electromagnetic disturbances. However, the current process of deregulating the electric utility industry has resulted in significant reductions in expenditures by these companies. Current emphasis in this industry is on reducing cost and use of capital for mergers and acquisitions. Current research and development efforts in the industry (in both the generation and distribution sectors) are focused on the objective of cost reduction. Because of the defined need for reliability enhancements and the continuing threat of electromagnetic induced disturbances, the future market potential for application of Multishield to address this problem remains. However, it is not expected that any significant efforts to address this issue will be made by utilities until after industry realignment due to deregulation has taken place and / or action is mandated via regulatory mandate.

As a result of the trade shows, several potential contacts were made which were pursued. One outcome of these efforts was an agreement to be available as a supplier to EuroMC. This company is a distributor of EMC equipment throughout Europe. Additional discussions were held with other potential partners and customers. A notable example was discussions with Stork Group NV (a leading Dutch aerospace and engineering firm). These discussions have centered on potential partnering efforts. However, because of an ongoing corporate restructuring, the discussions are progressing very slowly. As a second example, a small quantity of Multishield was purchased by Intelligent Systems Design (ISD), Inc. of Miami, FL. ISD is a manufacturer of electronic components. They are investigating the suitability of Multishield™ to shield printed circuit boards from crosstalk. Their boards operate at different frequencies and are physically close. Based on the primary goals to shield at 215 kHz, a single layer material of ~ 2 mils thickness was sent. Based on testing performed, this configuration should provide more than 100 dB shielding effectiveness at the intended application frequency. Initial test results are encouraging; however, because the test group lead engineer has temporarily been assigned in Europe, further testing is on hold until he returns.

Additionally, results of research conducted under this project were presented at a SBIR Conference in Huntsville, AL. A copy of the material used during this presentation is provided in Appendix A. The presentation was well received and as a result Sensortex worked with Ormet Corporation of Carlsbad, CA to deposit Multishield™ onto electrical circuit boards prepared using Ormet's spray deposited shielding material. The intent was to prove the potential for Multishield™ to provide additional shielding beyond that which could be obtained using Ormet's process individually. This would expand the marketability for Ormet's product into applications that require a greater degree of

shielding effectiveness. Both single and multiple layer applications of Multishield™ were produced. Measurements indicated that the addition of Multishield™ did provide an increased level of shielding (thus proving the concept). However, some technical issues were encountered which could limit the utility of this approach. There were significant difficulties obtaining quality films (qualitatively measured by visual appearance and adhesion) when Multishield™ was deposited onto the Ormet prepared boards. Another difficulty was that although the application of Multishield™ resulted in an increase in shielding, this was only marginal compared to depositing an equal thickness of Multishield™ onto a “clean” circuit board, (i.e. the SE was reduced when depositing Multishield™ on top of boards prepared with Ormet’s process). Sensortex and Ormet are discussing these issues and determining how to proceed.

References:

- [1] B. Szentkuti; “Shielding Quality of Cables and Connectors: Some Basics for Better Understanding of Test Methods”; Proceedings of the 1992 IEEE International EMC Symposium.
- [2] J. S. Hofstra, M. A. Dinallo and L. O. Hoeft; “Measured Transfer Impedance of Zbraid and Convolute Shields”; Proceedings of the 1982 IEEE International EMC Symposium.
- [3] D. J. Griffiths; “Introduction to Electrodynamics”, Second Edition; 1989 Prentice Hall, Inc.; Upper Saddle River, NJ

Appendix A: Huntsville SBIR Conference Presentation Material

Slide 1 & 2

Sensortex, Inc.



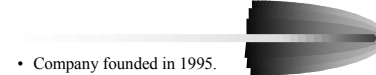
EMP Shielding Using Multilayer Film

Managed by US Army SMDC
Advanced Technology Directorate - Mr. Mark Brown

Dr. William Biter	Phone: (610) 444-2382
Sensortex, Inc.	Fax: (610) 444-6193
515 Schoolhouse Road	e-mail: wbiters@sensortex.com
Kennett Square, PA 19348	http://www.sensortex.com

Distribution Statement C. Distribution Authorized to U.S. Government agencies and their contractors. Critical Technology, 3 August 1999.
Other requests for this document shall be referred to SMDC-TC-AC, POB 1500, Huntsville, AL 35897

Company Background



- Company founded in 1995.
- Focus is on developing high technology materials and processes for defense, aerospace, utility, and process industries.
- Provides extensive R&D capabilities.
- In-house manufacturing of multi-layered shield material for reduction of magnetic field interference and emissions.
- Key personnel hold DoD Secret or Top Secret Clearances.

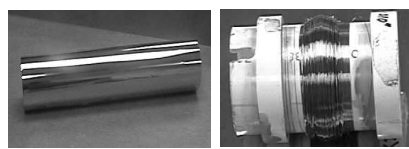
Slide 3 & 4

Magnetic Shielding - The Need



- Defense - interference to command and control systems and asset detection from electromagnetic detection systems and countermeasures.
- Commercial Aviation, Communications, and Utilities - electromagnetic interference of critical control equipment resulting in process upsets and system failures.

The Solution - Multishield™



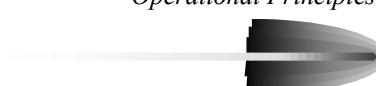
Slide 5 & 6

Multishield™ Advantages



- Capable of shielding against both low and high frequency magnetic fields.
- Capable of shielding against both low and high intensity fields.
- Low cost.
- Light weight.
- Capable of supporting multiple application geometries.

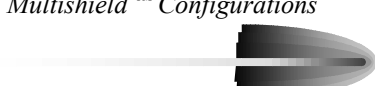
Operational Principles



- Advanced composite composed of alternating magnetic and conductive layers.
- Strong mutual interaction between layers, results in waves shedding energy between magnetic and conducting layers.
- Provides improved shielding in high field applications where saturation limits the effectiveness of conventional materials.

Slide 7 & 8

Multishield™ Configurations



- Continuous sheets up to 24" wide. Supports shielding of rooms and large structures. Can be cut and fit to shield smaller enclosed components (e.g. process instrument racks).
- Cylindrical sleeving from 15 mils to 10" diameter. Supports shielding of power and signal cables.
- Can be electroformed onto composites for custom and lightweight applications.

Multishield™ Performance



Cylindrical Shielding - Magnetic Field

Flat Plate Shielding - Magnetic Field

Slide 9 & 10

Production Process



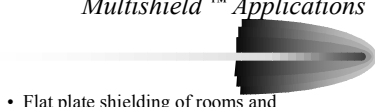
- Industry unique continuous processing capability up to 60 sq. ft per hour. Ensures material consistency and quality.
- Standard material configurations and performance or custom design to support specific applications.

Continuous Production Process



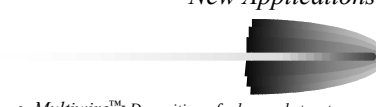

Slide 11 & 12

Multishield™ Applications



- Flat plate shielding of rooms and enclosures.
- Cylindrical sleeved shields for process signal cables.
- Braided wire shields for power line shielding.
- Electroformed plated shielding for unique applications.

New Applications

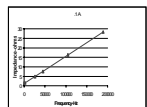


- **Multiwire™**- Deposition of advanced structure on small wires results in new device-
 - Inductive wire -can replace ferrite beads for power applications
 - Current Limiting- Inductive load increases with current above threshold

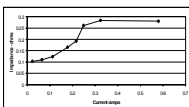
Slide 13 & 14

Multiwire



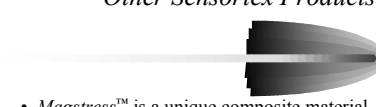


Inductance vs Frequency for 10 cm. Inductive Load - 25 microhenry.



Inductance vs Current for 400 wires at 1 kHz.

Other Sensortex Products



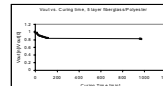
- **Magstress™** is a unique composite material that uses a piezoelectric magnetostrictive film to provide the capability of measuring stress on load bearing structures.
- **Emiswitch™** is an advanced electrically controlled film that is capable of controlling visible and infrared emissivity for thermal control.

Slide 15

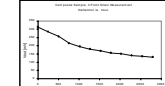
Magstress™

Low Cost Monitoring of Stress/Strain Changes





Strain vs Curing Time for 10 cm. Strain - 0.001.



Strain vs Temperature for 10 cm. Strain - 0.001.

- Monitoring of Composite Curing Process
- Monitoring of Composite Structure with Permanently Embedded Sensing Elements