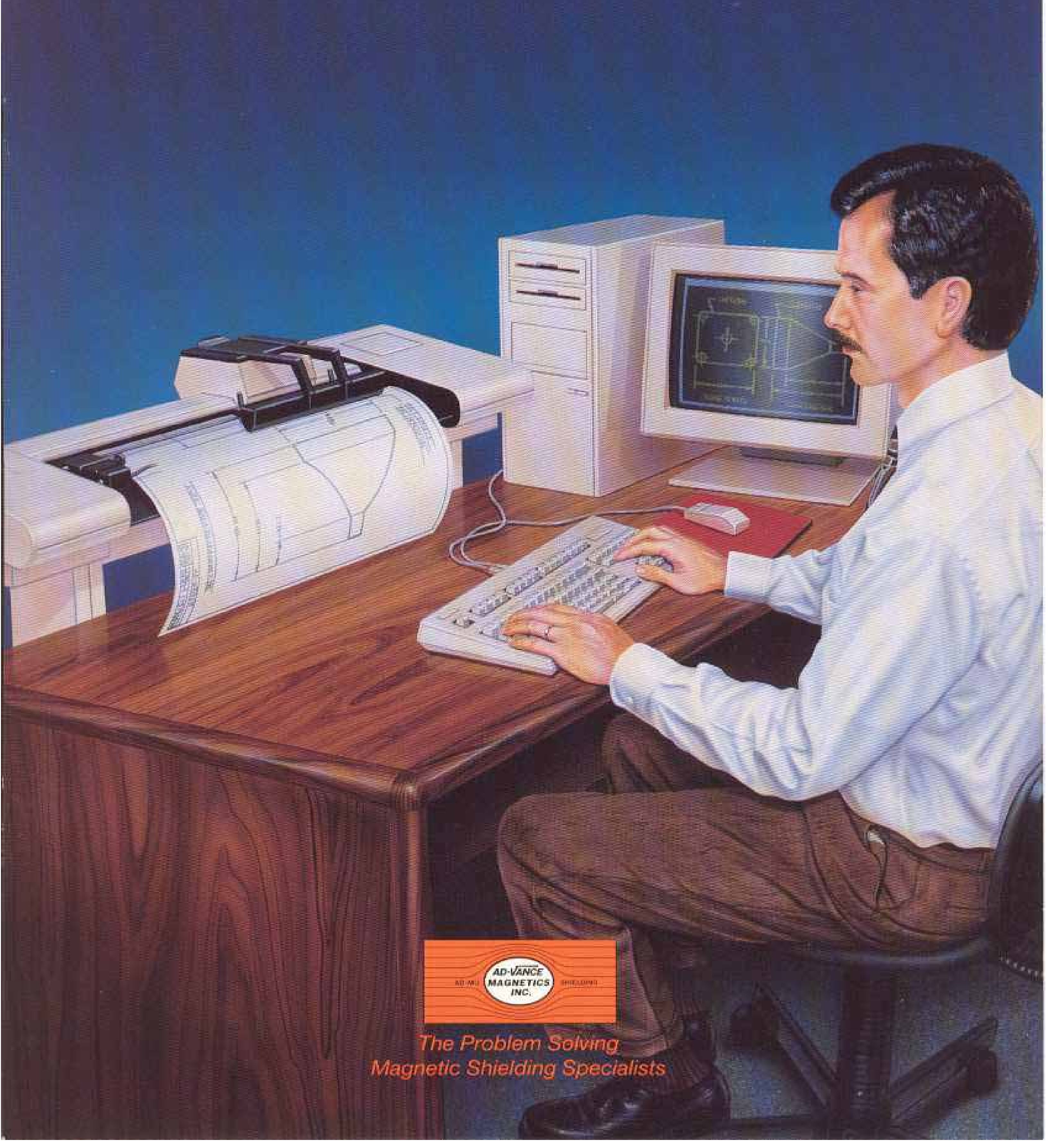
Engineering Catalog

AD-VANCE

MAGNETICS, INC.



AD-MU AD-VANCE MAGNETICS INC. SHIELDING

The Problem Solving
Magnetic Shielding Specialists

High Tech . . .
Space Age Technology. . .
Magnetic Shielding For Today and Tomorrow . . .

Magnetic shields for a 4 inch CRT HUD Display for the F-16 aircraft.

Contents

Engineering Catalog:

Introduction to Technical Article Reprints on Magnetic Shielding From Various Trade Publications

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ENGINEERING SECTION I

25 TYPICAL CASE HISTORIES

Of Engineering Solutions to Magnetic Shielding Problems

by The Engineering Department

AD-VANCE MAGNETICS, INC.

OUR FOURTH DECADE OF MAGNETIC SHIELDING PROBLEM SOLVING

1

PROBLEM

How to prevent scan converter tube degradation with a magnetic shield which also maximizes resistance to vibration and shock.

SOLUTION

Resistance to vibration or shock is maximized by certain construction features. These include four rolled in beads which increase structural rigidity and enhance concentricity, and hydroform construction of the associated sections. All necessary joining parts and seams are heliarc welded. After fabrication, the components are subjected to a proper anhydrous hydrogen anneal to ultimize the magnetic permeability characteristics of AD-MU-80 alloy.

After final anneal, AD-MU-80 exhibits relatively stable permeability characteristics, avoiding the expense and inconvenience of regularly repeated annealings. Furthermore, AD-MU-80 will not saturate when properly used nor suffer excessive loss of permeability from shock. For any alloy of a given permeability, AD-MU-80 displays minimal retentivity.

Single layer high permeability permanently effective AD-MU-80 magnetic shield .031″ thick optimizes scan converter tube performance by diverting external magnetic fields which prevent proper tube functioning.

2

PROBLEM

To design and fabricate a dual purpose magnetic isolation chamber for both low level field research and production testing.

SOLUTION

Provides a low level magnetic field environment wherein magnetically sensitive devices may be placed to observe their characteristics while relatively unaffected by external magnetic fields.

APPLICATIONS are in (a) research and development, both in universities and industrial; and (b) industrial production testing of flux sensitive components or devices. An example consists of magnetometer probes generally operating on a saturation or reluctance principle. Or, any other devices capable of sensing magnetic field perturbations as well as other sensors operating on magnetic principles. Such sensors may be readily calibrated by installing Helmholtz configuration coils. The chamber may also be used with a magnetometer for detecting ferro-magnetic contamination many times found in non-ferrous or non-magnetic alloys.

Construction consists of a series of concentrically positioned shielding cylinders. One end of each cylinder is closed. Removable covers are used at other ends. Holes through covers permit manual access to components under study or test. The attainable attenuation is enhanced by non-magnetic spacing between cylinders. Magnetic isolation requirements are the sole determining factor as to the number of concentric shield systems and types of Ad-Mu alloys used. The entire assembly is mounted horizontally by two aluminum U-channel structures attached to the outermost shield. Possible table marring is eliminated by plastic mounting feet. A design option to incorporate a degaussing coil system is available.

AD-MU Shielding Alloys used are selected to meet user's application. For the inner shield, an alloy displaying maximum mu zero such as AD-MU-80, is generally selected. For the next layer or layers, AD-MU-78 is generally chosen. If the magnetic field environment is abnormally great, the outer shield may be of a medium mu alloy such as AD-MU-48. In extreme cases, the outer shield could be constructed of AD-MU-00.

All seams are TIG welded. After fabrication, the permeable characteristics of each alloy are optimized by a temperature cycled anhydrous hydrogen atmosphere anneal. After assembly, the outside is finished in a baked enamel gray hammertone for a pleasing appearance. All the AD-MU alloys used are relatively inert to any normal environmental attack and do not require further finishing.

Shield Performance can be enhanced by orienting the shield's axis parallel to the earth's plane and then rotating the assembly through 360° to find the minimum field. Fields not exceeding 100 gamma can be readily attained. By proper degaussing of the inner shield structure, a 10 gamma level can be realized. Fields as low as 2 gammas have been attained under favorable environments.

Dimensional Drawing of the pictured assembly is available upon request. Space on the drawing is provided for each user to indicate his specific physical requirement. It is generally no problem to meet specific dimensional requirements.

Model MIC-200 AD-MU magnetic isolation chamber.

3

PROBLEM

How to transport or store Cassette Tape Data without distortion, partial erasure or degradation caused by unexpected exposure to damaging magnetic environments whose very existence may not be known or realized. Also, to prevent physical damage to cassette tapes if dropped during carrying or shipping.

SOLUTION

The dual requirements of physical and magnetic field protection were achieved by using an AD-MU container .050" thick with styrofoam padding. Accordingly, even if dropped to a hard surface during transport, the single cassette tape remains safely inside, unaffected by impact. It is also unaffected by stray magnetic fields from local severe thunderstorms, passing or nearby radiating electronic/electrical gear or equipment, power generating equipment, etc. No periodic annealings are required after dropping, as the anhydrous hydrogen annealing optimizes and stabilizes magnetic shielding characteristics.

Performance Test Data: On pages 20 & 21

Impervious even to rough postal abuse, sturdy .050" thick Model CTDP-25540 AD-MU Protectors with styrofoam padding provide maximum physical as well as magnetic protection for reference data recorded on cassette tapes.

4

PROBLEM

Degradation of high resolution data storage tube performance can be caused by magnetic fields originating in the local environment. The problem was to design and build a magnetic shield to effectively divert such nearby magnetic fields from entering the tube and interfering with the electron beam behavior.

In addition, such a shield was required to: 1) assure maximum resolution of storage tube display capabilities, and 2) provide maximum shielding per unit weight of the structure.

SOLUTION

The final design consisted of a one-piece seamless hydroformed structure. The drawing operation required the entire capability of a 15,000 PSI hydroform machine.

By generating the shield structure from a single piece of AD-MU-80 .050 alloy, a magnetic shielding plane with a minimum of discontinuities was achieved. This realized the first objective—namely maximum resolution of storage tube display capabilities.

The second objective of maximum shielding per unit weight was also attained by the one-piece seamless hydroformed structure of the basic shield body.

The finished structure provides lasting shielding protection. It does not saturate when properly used, will not suffer excessive permeability loss from shock, and displays minimum retentivity. This realized the overall objective of highly effective magnetic shielding designed to last the entire life of the storage tube.

Construction Procedure: Immediately after forming, the unit is stress relief annealed to minimize ovality. Trimming and piercing operations are next, after which a small tubulation is heliarc welded to the viewing screen gun port. The eleven non-magnetic stainless steel threaded studs are precisely positioned and carefully stud welded.

The final unit is then given a complete anhydrous hydrogen atmosphere anneal to assure exceeding the minimum attenuation levels called for in performance testing specifications. Periodic re-annealings are unnecessary because AD-MU exhibits relatively stable permeability characteristics after such final annealing.

Outside surfaces are matt black baked enamel except for the threaded studs. Required lettering and characters are silk screened in white.

Highly Effective Seamless AD-MU Magnetic Shield for Storage Tubes.

5

PROBLEM

To demonstrate the flexibility, convenience and low cost of AD-MU shielding foils to researchers, designers and production managers.

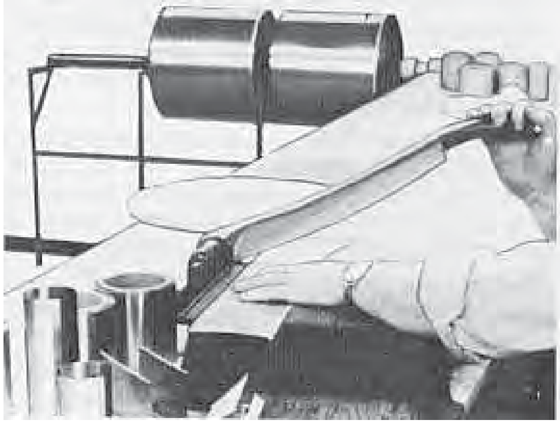
SOLUTION

AD-MU high and low permeability magnetic shielding foils are offered by Ad-Vance Magnetics, Inc. as a fast, convenient, economical method to determine the amount of shielding needed in an application or to solve unanticipated magnetic field problems which adversely affect products being manufactured.

Once the experimental shielding is operating satisfactorily, then the economics are evaluated. The cost of foil shielding for that particular application is compared against the cost of a fabricated shield structure. In larger quantities, a fabricated shield could prove less costly. Quotations can be submitted based on both approaches for final decision.

AD-MU foils have been heat treated and are ready for immediate use. They exhibit useful ductility and can be readily hand trimmed to the desired size on an ordinary cutting board or with shears, then hand formed around the structure or component to be shielded and held in place by simple adhesive tape. They are ideal for use in hard-to-get-at places. They permit placing magnetically reacting components closer to each other, compacting assemblies.

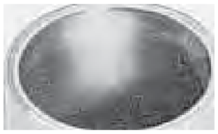
Any length foil may be ordered up to a maximum of 100 feet long per coil and up to 15″ wide. High permeability AD-MU-78 foil is immediately available .002″ thick and 4″ wide, as well as in thicknesses of .004″, .006″ and .010″ either 4″ wide or 15″ wide. Low permeability AD-MU-00 is immediately available .004″ thick in either 4″ or 15″ width. Any in-between width can be furnished on special order.



AD-MU shielding foils are readily trimmed by machine or scissor cutting to size, easily hand shaped to desired contour, eliminating costs of designing and manufacturing pre-fabricated magnetic shields in experimental or production applications.

6 PROBLEM

To assure proper operation of photomultiplier tubes in relatively high magnetic field environments commonly encountered in physics research set-ups and similar applications.



SOLUTION

Model FL-PM was designed with 5-layers to provide maximum flux diversion in such environments. In addition to its adaptability to many experimental applications, variations of this shield design should find use in the production of specialized laboratory equipment.

The outermost of the 5-layers consists of heavy gauge low permeability AD-MU-00 alloy. For mounting convenience, a stainless steel flange is heliarc welded near one end. An interface of .050 non-magnetic stainless steel is next, followed by another shielding layer of heavy gauge low permeability AD-MU-00 and enclosing this, a .020 non-magnetic stainless steel cylinder. The innermost and final shielding cylinder is high permeability .025 AD-MU-78.

Model FL-PM 5-layer AD-MU PM tube shielding enclosure used in physics research set-ups and in specialized laboratory equipment production. Diverts high intensity magnetic flux densities from large electromagnets, permanent magnets, cryogenic magnet set-ups, etc. that might be required in a specific physics experiment.

To maximize shielding effectiveness, the various ferromagnetic layers were individually heat treated. The two AD-MU-00 cylinders were then coated with a rust inhibiting oil to counteract their rather high susceptibility to oxidation in average environments. As the AD-MU-78 cylinder is relatively inert to any normal environmental attack, it was not oil coated.

AD-MU shielding alloys will not saturate when properly used, do not suffer excessive permeability loss from shock, display minimal retentivity, and exhibit relatively stable permeability characteristics after final anneal, avoiding the expense and inconvenience of regularly repeated annealings.

7 PROBLEM

How to design and build a magnetic shield for CRTs that would fulfill these three requirements: 1) shield the neck portion from detrimental local magnetic fields, 2) provide adequate structural support for the tube, and 3) do that at a cost lower than for the usual CRT shield. Cost was an important factor because a large number of shields were involved.

SOLUTION

The final design was based on properly combining magnetic and non-magnetic materials. By experiment, it was determined that a cylindrical structure of .020 AD-MU-78 around the magnetically critical neck area provided all the shielding required for good resolution. The .020 thickness selected provided the needed safety factor against saturation. In addition, the use of AD-MU-78 assured maximum permeability and minimum sensitivity to shock. It was then possible to utilize a lower cost .031 non-magnetic stainless steel to provide the desired structural support for the forward part of the shield.

How the Magnetic & Non-Magnetic Materials Were Successfully Combined: Combining AD-MU-78 with the lower cost non-magnetic stainless steel was accomplished by spin reducing one end of the larger cylinder to mate with the smaller neck cylinder. Structural rigidity was enhanced and fracturing eliminated by incorporating generous radii. A mounting flange was heliarc welded to the outer perimeter of the larger cylinder's open end. The AD-MU cylinder and the spun section were then pressed together and permanently located by a series of spot welds in the overlapping area.

Finishing Operation: To ultimize the cylinder's magnetic shielding characteristics, the assembly was given a complete anhydrous hydrogen atmosphere anneal. Because of AD-MU's relatively stable permeability characteristics, further annealing is not necessary. For the final operation, an attractive glossy baked enamel finish was applied to match the surrounding hardware finish.

Model 200 PS Specially Designed AD-MU Magnetic Shield Combines Low Cost with Required Shielding Capability & Adequate Structural Support.

Performance Data: The neck portion of a group of shields, when subjected to a directed 60 Hz magnetic field normal to the cylinder's axis, showed attenuations ranging between 47 and 55 db (voltage ratio).

Test Procedure: In this test, the radiation source originated from a soft iron pole approx. ⅜″ Dia. x 3″ L located in the center of a solenoid winding of sufficient impedance to prevent overheating during a maximum 5-minute period of excitation. The structure was physically positioned with the pole normal to the shield's axis and approx. ¼″ from the shield cylinder's outer surface and centrally located along the length. Input current was Variac controlled. A thin Hall probe measured the flux density impinging on the shield's surface directly in line with the pole structure. This level was set in the 3 to 5 gauss range. Then the flux within the shield was measured, locating the same probe on the shield's axial center, orienting it for maximum response. The resultant ratio of these two measurements was noted in terms of decibel attenuation.

8 PROBLEM

To prevent resolution deterioration in electron microscopes caused by beam scattering, bending or displacement from normal optimum focus position.

SOLUTION

Model EMS-10 AD-MU shield diverts magnetic fields around the vertical column of an electron microscope, preventing focus interference. By preventing external magnetic disturbances from reacting on the scanning electron beam, the shield assures sharp, clear focus, permitting full magnification.

Construction Features: Constructed of a single layer high permeability AD-MU-78 .050″ thick shielding alloy, Model EMS-10 slips easily over the microscope's vertical column. For maximum effectiveness, the longitudinal butt joint and the perimeter weld on the end are continuous fusion heliarc welded, using the base alloy as a filler media. Necessary perforations in the closed end and the elongated slots in the cylindrical section are positioned to clear all protruding tubulations.

Finishing & Ultimizing Permeability Characteristics: Hand lathe polishing eliminates sharp edges in machined areas. The unit is then subjected to an accurately controlled anhydrous hydrogen high temperature annealing cycle to ultimize permeability characteristics. After installation, shield will not require periodic re-annealing. AD-MU alloys display minimum retentivity. Since AD-MU-78 is relatively inert in laboratory environmental situations, no additional protective finishing is called for. Dimensions: 12¼″ L x 7⅛″ ID.

Model EMS-10 AD-MU Electron Microscope Shield. Intermediate shield of 3-piece assembly

9 PROBLEM

To enclose and shield instrumentation from all external magnetic fields so that mineral samples may be accurately tested.

SOLUTION

Prevents external magnetic fields from distorting precise testing of mineral samples in geo-magnetic investigations. Also can be used in searching for defects and similar applications.

Valuable geophysical information can be gleaned from the interpretation of magnetic data obtained from mineral samples. Such studies cannot be made conveniently unless outside magnetic interference is diverted from the sample and associated sensing equipment. Even the earth's magnetic field must be excluded. Model GMI-300 testing chamber diverts external magnetic fields.

Model GMI-300 is not limited to geophysicist activity. It can be used by any investigator trying to determine if a material contains any small magnetic remanences. These may be present as a defect such as ferromagnetic contaminents present in non-magnetic materials, for example.

Testing procedure begins by supporting the sample at the end of a stable non-magnetic rotating shaft. Sensing coils installed by the investigator are placed around the shaft inside the chamber. Cables pass through the holes in the chamber's covers to connect the sensing coils to the instrumentation used.

Two shielding systems are incorporated into Model GMI-300. First, an inner cylindrical shield of .050 AD-MU-80. The bottom end is heliarc welded shut, and contains a concentrically located hole for entry of the previously described drive shaft. The removable outside fitting cover has a 2″ overlapping flange to minimize magnetic leakage.

A second cylindrical shielding system of .031 AD-MU-78 is 4″ longer and 2″ larger in diameter providing a minimum of 1″ spacing between shields. The outer cylinder is also heliarc welded shut on the bottom and has a removable top mating cover. To minimize magnetic field entry at the bottom, a 2″ long heliarc welded tubulation extends outward from the bottom concentric hole.

The two top covers are made into a single integral assembly to permit simultaneous removal by a convenient external handle. An aluminum disc between the flanges separates and locates the 2 covers.

Spacing between the inner and outer shielding systems is maintained by 3 aluminum spacer bars positioned 120° apart and running parallel to the cylinders' axes. Non-magnetic machine screws attach the cylinders to spacer bars.

As an additional flux diverter of fields emanating from the motor used to rotate the drive shaft, a 15″ circular disc of .031 AD-MU-80 is provided. The disc contains a concentric hole through which the drive shaft passes. The entire assembly is vertically positioned on an aluminum tripod having a circular ring mounting base. After fabrication, all magnetic components are subjected to an anhydrous hydrogen atmosphere anneal to ultimize magnetic shielding capabilities. Dimensions: 16″H x 10″dia.

Model GMI-300 dual construction testing chamber.

10

PROBLEM

Weather radars used in aircraft are subject to some position shift of the display each time the aircraft changes direction or altitude. The display is also subject to distortions caused by electromagnetic interferences generated by electronic devices in its proximity. A shielding enclosure to minimize these effects was necessary. Such an enclosure should also support and position the tube as well as meet aircraft minimum weight requirements.

SOLUTION

All the requirements were incorporated into the final .040 AD-MU-80 shield design to achieve the desired result:

1. It minimizes positioning errors caused by the earth's magnetic field that could occur during aircraft orientation.
2. It diverts electromagnetic interferences generated by electronic devices in the vicinity of the display that could cause detrimental distortion of the display.
3. It provides support and positioning for the tube.
4. Its one-piece hydroformed design and construction offers maximum functional capability for its weight; an important factor in airborne applications.

Performance/Test Data: A conventional attenuation test procedure showed 200 to 300 times attenuation to a nominal field normal to its axis. This measurement was made with the sensing probe located on the approx. axis of the shield. With the probe located inside the shield at least one radii from opposite openings, approx. 100 times (40 db) attenuation were measured.

Construction Features: For maximum effectiveness, the shield is fabricated from a single piece of .040 AD-MU-80, deep drawn using hydroform techniques. The resulting completely seamless enclosure avoids any magnetic discontinuities that might occur in a welded sectionalized shield.

Rigid aluminum mounting or positioning brackets are accurately located on the shield's outer perimeter. For ease of alignment with bolt holes, two floating anchor nuts are used in each bracket. Prior to bracket assembly, the AD-MU shield receives an anhydrous hydrogen anneal which eliminates any necessity for future periodic annealings, as AD-MU's permeability characteristics are relatively stable with time. AD-MU also displays minimum sensitivity to shock and will not saturate when properly used, so provides maximum shielding effectiveness.

Model AWR-150 Efficient Aircraft Weather Radar Display Tube Magnetic Shield.

11

PROBLEM

How to: 1) design optimum magnetic shields that will not fall off when placed around small motors, and 2) manufacture such shields so economically that they can be marketed at a lower price than previously.

SOLUTION

Both major requirements were incorporated successfully into cylindrical shaped shields fabricated from .020″ thick high permeability AD-MU-80 shielding alloy.

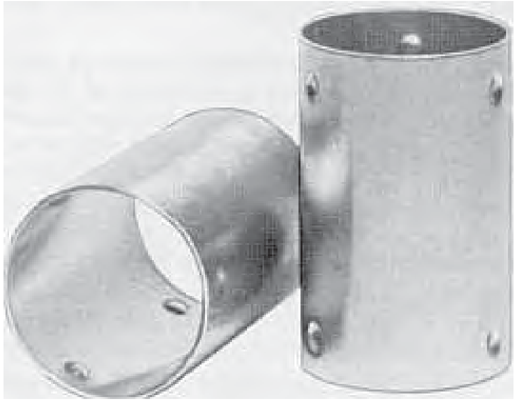
A cylindrical configuration was decided on because it could be slid quickly and easily over the motor. To avoid slippage or falling off, a self-locking feature was devised. This consisted of 3 sets of double dimples, 3 located close to each open end of the shield. The dimples are embossed to a depth of about .015″ and each set is precisely positioned radially 120° apart to assure symmetrical positioning and positive retention.

By eliminating the need for potting or cementing, the self-locking feature also provided an extra cost saving.

Construction: For optimum shielding effectiveness, shields are heliarc welded with the parent material instead of with a welding filler. After fabrication, controlled heat treating procedures assure minimum retentivity and maximum permeability.

Low Cost: The unusually economical shield price is due to simple design and extremely efficient, coordinated, and sophisticated manufacturing techniques.

Radiating Characteristics: To obtain maximum shielding effectiveness, the radiating characteristics must be recognized. Because Type SM-150 is open ended, its cylindrical configuration significantly reduces only the magnetic field radiating from the motor normal to its axis. As the shield is not designed to extend beyond the ends of the motor, radiation in the direction of the axis is not reduced as much. This open ended configuration meets most small motor shielding situations. Complete shielding enclosures can be fabricated to meet more stringent shielding requirements.



Type SM-150 specially designed AD-MU Magnetic Shields slip on instantly, lock firmly into place and are priced 25% to 50% less than comparable shields.

12

PROBLEM

How to effectively shield complex high resolution video recorder head assemblies from a wide range of magnetic field interferences that prevent full operation capability in recording/playback applications in TV studio/mobile, closed circuit, professional home & other video display systems.

SOLUTION

To provide needed shielding and ready access, the final solution required a cover and an unusual 5-sided 2-piece enclosure with a butt mating overlap joint design. High and medium permeability AD-MU alloys were required because they will not saturate when properly used nor suffer excessive degradation of permeability from shock and have stable permeability characteristics after final anneal, avoiding repeated annealings. AD-MU also displays minimal retentivity for an alloy of a given permeability.

Shielding Performance: Effective magnetic shielding was obtained: 1) throughout the entire audio spectrum, and 2) from any interfering flux of varying densities encountered during operation. 3) In addition, electric field shielding is obtained by proper shield grounding.

Three-Layer Construction Throughout: The inner shielding layer of both the cover and the 2-section enclosure is AD-MU-78 high permeability alloy .040" thick, the middle layer interface is non-magnetic stainless steel .030" thick, and the outer layer is AD-MU-48 medium mu higher saturation level magnetic alloy .054" thick. Both AD-MU layers are spot welded to the separating steel layer. Interfering magnetic field penetration between the cover and the 2-piece enclosure is minimized by machining mating surface to assure a good surface contact. The removable flanged cover butt mates to the sloping open end of the enclosure. Two flanges in the cover are milled to generate a slot for the entry and egress of the video tape. Mounting holes, cable entry holes and holes for other mechanical requirements are provided.

Model RH completed assembly with openings in two of the cover's flanges for video tape.

13

PROBLEM

To provide an effective, economical and simple structure for shielding a CRT's deflection yoke and neck, thereby eliminating the need for a larger, more costly and complex magnetic shield covering the entire CRT. Easy, quick access to the yoke assembly was also specified.

SOLUTION

A 2-section shielding structure fabricated from a single layer of AD-MU-78 .025" thick fulfilled all the requirements. Quick, easy access to the yoke assembly is provided by a removable slip-on-and-twist cover. A threaded stud welded to the outside of the cylinder section fits into an "L" shaped slot in the overlapping flange of the cover and is locked by drawing down the nut.

Performance Test Data: Tests made on the shield only in an anticipated low level magnetic field indicated attainable attenuation ranging from 45 to 50 db. No finishing is done after fabrication because the AD-MU-78 alloy offers adequate resistance to the operating environment. Furthermore, AD-MU will not saturate when properly used nor suffer excessive degradation of permeability from shock. In addition, AD-MU displays minimal retentivity for an alloy of a given permeability.

Fabrication Data: The open ended cylinder portion of the 2-piece shield assembly measures 4" L x 3⅝" ID. Inside, the deflection yoke is concentrically located and held in place by epoxy bonding. A rectangular cutout gives additional access when the cover is off. Cable entry is made through an obround notch. Grounding is achieved by two tabs welded to the cylinder near the open front end. In the cover portion of the 2-piece assembly, a concentrically located welded tubulation 3" L completes the shielding of the neck. All seams are heliarc welded for maximum performance.

No Periodic Annealings Needed: After fabrication, the shield is anhydrous hydrogen annealed to optimize magnetic shielding characteristics and provide needed stability to avoid repeated time consuming and costly annealings.

Model L-10 efficient economical CRT yoke/neck magnetic shield with special "L" shaped lock for quick, easy access to yoke assembly.

14

PROBLEM

How to design and build an economical yet adequate magnetic shield for small transformers.

SOLUTION

For economy, an open-ended simplified design was conceived, rectangular in configuration to fit easily over the transformer.

A 3-layer shield was created, consisting of two high permeability AD-MU-78 shielding layers with a copper interface layer between. This combination of ferromagnetic alloy and copper shunt ring enhanced the structure's magnetic shielding effectiveness.

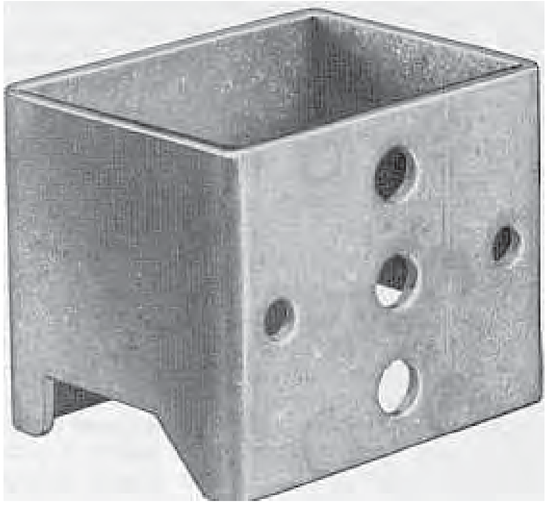
Butting seams were staggered in relation to each other, forming a shunt ring. After die forming, the three layers were permanently positioned by a series of spot brazes. A sizing operation was used to control dimensions.

When properly oriented to the transformer, the open-ended rectangular shielding enclosure acts as an effective shunt ring, restricting and localizing transformer leakage. Thus the copper layer functions both as an effective eddy current shunt ring and as an interface between the two AD-MU shielding layers.

AD-MU shielding alloys provide permanent protection. They will not saturate when properly used, suffer no excessive loss of permeability from shock, exhibit relatively stable permeability characteristics after final anneal (avoiding the expense and inconvenience of repeated re-annealings), and display minimum retentivity.

Summary: The economical simplified design provides the most shielding for the money. Its unique features are:

1. Special 1-piece open-ended integral rectangular construction which (a) localizes transformer leakage, and (b) provides easy assembly with transformer.
2. Dual purpose copper eddy current shunt ring.



AD-MU Shield For Small Transformer.

15

PROBLEM

Due to limited space in small aircraft instrument panels, instruments must be positioned very close to each other. Tachometers with magnetic coupling radiate a rotating magnetic field which significantly distorts the radar tube's performance. Other close magnetically radiating devices further deteriorate the display.

Ad-Vance Engineers were asked to shield the display tube from these magnetic disturbances at the minimum possible cost.

SOLUTION

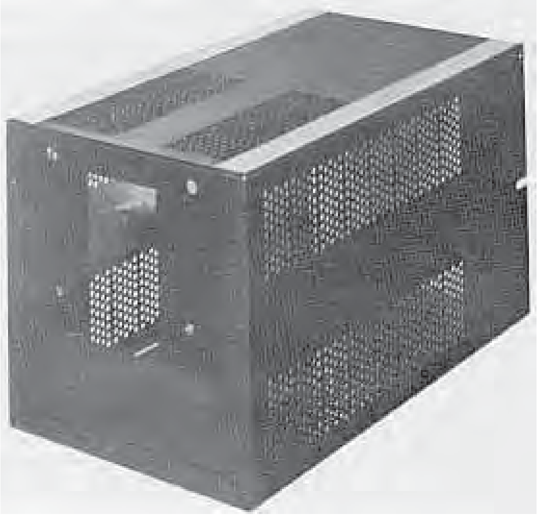
Prevents CRT display distortion, optimizing resolution. Instead of the conventional more costly separate dust cover and magnetic shield, Ad-Vance engineers designed this single unit model which, at lower cost, both encloses and shields the entire weather radar display in small aircraft.

Performance Test Data: Actual performance evaluation in real time operation has firmly established the effectiveness and necessity of such a structure. The tests were conducted by first observing resolution and distortion effects with the old dust cover and then replacing it with the AD-MU cover. Display improvement was obvious.

Construction: The unit consists of a single layer 5-sided rectangular box made entirely of AD-MU-78 high permeability magnetic shielding alloy .031" thick. A rectangular cutout in the back accommodates necessary connectors. The front is completely open. Perforations in the four sides provide vital ventilation. The radar chassis and panel is inserted through the open box front and securely fastened by two bolts.

Two small rectangular slots on the bottom are part of a tie down system. Two parallel unfinished areas on the bottom side (shown up in the picture) assure a good ground return enhancing electrostatic shielding capabilities. For maximum shielding effectiveness, all necessary seams are overlapped and spot welded. The four back holes are part of the fastening system.

Maximizing Magnetic Shielding Properties & Final Finish: After fabrication, the entire unit is subjected to a full anneal to optimize its magnetic shielding effectiveness. The final finish is a durable baked black texture.



Model DCS-15 one-unit dual function AD-MU dust cover/magnetic shield.

16

PROBLEM

To provide, as economically as possible, a repeatable controlled magnetic environment for determining response characteristics, sensitivity, and orientation direction of magnetic sensor devices used for signature recognition, proximity sensing, etc. in a wide variety of industrial, military and commercial security applications. For convenience, mobility also was desired.

SOLUTION

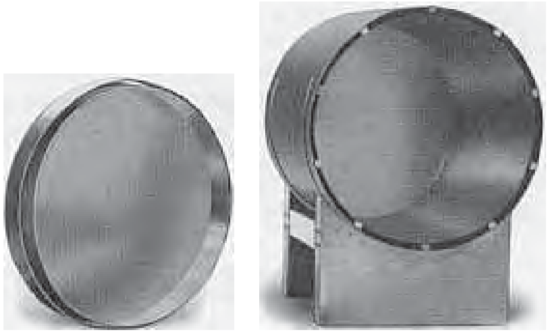
Diverts most of the external fields present. This model's dimensions of 36″ OD & 34″ ID x 40″ L are sufficient to contain a Helmholtz structure of required size without its suffering severe anomaly distortions caused by proximity of the shielding structure. Of course other shields can be constructed to meet any specific dimensional requirement.

This solution also fulfilled the cost and mobility requirements. Cost is far less than for an immobile shielded room. Mobility is achieved by simply using a forklift.

Functioning & Performance: The initial residual field level within the shield is established by incorporating a degaussing winding structure into the shield, located to produce its principal reaction on the inner shield. With the shield's axis parallel to the earth's plane, the degaussing cycle is continued until a minimum residual field of approximately 1 miligauss is reached. The degaussing operation is then terminated. The object is to reach a repeatable level rather than a low minimum. Once the internal ambient level has been normalized, a desired field level generated by the Helmhost system can be established.

Description of Shield Construction: Physically, the shield consists of two concentrically located cylinders of .062″ AD-MU-80 high permeability alloy, each with welded bottom and removable cover top having a 5″ overlap flange minimizing external field entry possibility. Convenient handles on the outside cover simplify manual cover installation and removal.

Ten 1″ x 1″ bar stock aluminum spacers, the length of the cylinders symmetrically spaced, are attached to the inside of the outer cylinder. The two covers are installed simultaneously because they are spaced 1″ apart in all directions and made into an integrated assembly. The entire structure is mounted on a ¼″ thick stock aluminum cradle. The cradle and shield are securely anchored to each other by ¼″ thick aluminum bands welded to the cradle structure and extending around the outer perimeter to a point beyond the shield midline.



Model MEC-125 movable multi-layer controlled magnetic environment chamber.

Mobility: Two parallel 1″ x 4″ aluminum sections are attached to the cradle's front and rear at a height convenient for a forklift to move the entire 800 lb. structure easily.

Optimizing Magnetic Shielding Qualities: Prior to final assembly, the shield and covers were subjected to a proper high temperature anneal. To optimize AD-MU magnetic properties, the vacuum furnace was held at high temperature for an adequate soak time. Cooling rate was carefully controlled to give permeability optimization. Accordingly, AD-MU alloys display stable permeability, will not saturate when properly used, will not suffer excessive permeability degradation from shock, and do not require periodic annealings.

17

PROBLEM

To design and build a magnetic shield for 16″ CRTs or Memory Type Tubes that can be used in areas subjected to shock and vibration and still deliver top performance shielding.

SOLUTION

Maximum protection against mechanical shock and vibration even in rough sea or mobile ground applications is provided by potting the tube in a resilient material within the shock mounted rugged dual layer shield. Convenient access for periodic yoke adjustments is achieved through four rectangular holes 90° apart cut at the narrow end of the square to round transition. When operational, these holes are shielded by a removable conformally formed cover positioned and secured by tightening two screw clamps.

Performance Test Data: Despite exposure to wide variations in external magnetic environments, control tests determine that 55db minimum attenuation was held with approx. 5 gauss impinging on the shield plane. Operationally, widely varying exposure includes degaussing fields and radiating fields from close by associated electronic equipment, such as power supplies, power carrying service ducts, etc. aboard ship.

Continued on Page 36

Details of Testing Procedure: For QC purposes, a simple point source test of effective attenuation was used. A directional field from a soft iron core solenoid excited by a 60 Hz source was directed normal to the shield's axis. A calibrated AC magnetic field probe was positioned inside the shield and oriented to display maximum pickup from the radiating source. Of course, more elaborate test procedures such as large Helmholtz field generating structures could be used. However, it was determined that a point source test is extremely reliable in establishing that the shielding alloys have responded properly to heat treatment.

Three Element Dual Layer Construction: Illustration shows the main shield on the table, the conformal cover is in the model's right hand and the aluminum bezel in her left hand.

The 3⅝" wide forward section of the basic rectangular shield has an AD-MU-80 inner shielding layer .040" thick and an AD-MU-80 outside overlay .050" thick. This assembly is fusion heliarc welded per MIL-W-8611 to the transition section which terminates cylindrically to mate with the neck section. This section uses AD-MU-80 .062" thick shielding material. The final neck section uses AD-MU-80 .090" thick shielding material.

Four shock mount plates made of U-shaped stainless steel channels are positioned at each radius corner parallel to the shield's axis and vertical to the plane of the open end. These plates are heliarc welded per MIL-W-8611 to the shield itself in addition to using fitted reinforcing gussets mating with the shield's tapered section.

Four flanges formed at right angles extend outward from the shield's open end to facilitate attachment of the aluminum bezel. Bracketry is ⅛" stainless steel. The complete unit was formed over solid aluminum plugs.

Maximizing Magnetic Shielding Properties & Final Assembly: After complete fabrication and fitting, the entire shield, except for the aluminum bezel, was given an anhydrous hydrogen anneal to maximize the high permeability AD-MU-80's magnetic properties. The shield and tube assembly is then mounted inside the console by attaching to the shock mounts.

Model RB customized very large high performance AD-MU magnetic shield for a complex radar system in a series of consoles using either 16" conventional CRT or memory type tubes.

18

PROBLEM

At low cost and without tooling expense, to improve small motor performance with magnetic shielding.

SOLUTION

1. Add db's safely to small motor compatibility performance by diverting interfering magnetic radiation.
2. Provide excellent electrical and thermal conductivity.
3. Save design time and costs.

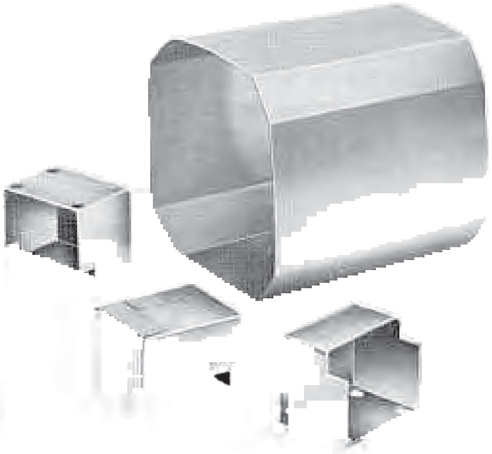
No Tooling Costs: Shields can be furnished in virtually any configuration and size. Tooling costs are eliminated because the ductility of AD-MU foil alloy materials permits cutting with ordinary scissors and manual forming. If desired, the various AD-MU foils themselves may be purchased for contouring easily by hand in your plant to the required outline.

Applications: Tight packaging areas, such as avionic, where sensitive instruments are in close proximity to interference radiating from small motors.

Construction: Construction is high permeability, flexible .010" (0.254mm) AD-MU-78 foil alloy. Model SMS-70F is used both as a self-sufficient shield and as an auxiliary shield over the motor's normal steel case when case shielding alone is inadequate.

Major factors in diverting radiation effectively are a carefully calculated large bend radius and adequate overlaps to handle the magnetic fields.

Should the radiating field be of sufficient strength to saturate the high permeability AD-MU-78 alloy, low permeability AD-MU-00 alloy may be used by itself or in addition to AD-MU-78 alloy.



Model SMS-70F "triple action" flexible magnetic shields.

Performance Test Data: Using 3-layer cylindrical motor shield of .010" AD-MU-78 flexible foil, closed at one end, 3" from motor axis:

1. Without shield, 400 Hz. radiated field, 177m Gauss. With shield, 60 db less.
2. Without shield, 10.K. Hz. radiated field, .64 Gauss. With shield, approx. 85 db less.
3. Spacing Effect: If space permits, an additional approx. 15 db can be obtained by spacing the outer layer to a radius 1.4 × the inner shield radius, (a shield of 2 equal layers).

19

PROBLEM

To make possible rock magnetism studies (paleo magnetism) in an area free of the earth's magnetic field.

SOLUTION

Transports rocks, de-gaussed of present earth's field, safely to a site where the earth's magnetic field is not present. In this protected area, the rocks' initial magnetism can be measured to learn former earth's magnetic fields' history.

Shielding Effectiveness: The required attenuation is approx. 1,000 times (cylinder in field transverse to its axis). The geometric increase in shielding effectiveness of two cylinders vs. a single cylinder is expressed in the following equation:

One cylinder static shield effectiveness, S_1,

given by $S_1 = 1 + \frac{1}{2}\frac{\mu t}{R}$

$\left.\begin{array}{l} t = \text{thickness of cylinder} \\ R = \text{outer radius of cylinder} \end{array}\right\}$ in same units of length

Double cylinder static shield effectiveness, S'

$$S' = 1 + S_1 + S_2 + (S_1)(S_2)\left(1 - \frac{A1}{A2}\right)$$

A1 = Cross section area (normal to flux) of outer surface of first cylinder

A2 = Cross section area (normal to flux) of outer surface of second cylinder

$\left(1 - \frac{A1}{A2}\right) = 0.5$ usually.

Model 090679EM high permeability double cylinder AD-MU-80 magnetic shield.

Construction: Double cylinder construction of .025 AD-MU-80 fabricated alloy provides required strength and shape stability. Aluminum bar spacers separating cylinders have milled reliefs for demagnetizing coils. Outer cylinder radius is $\sqrt{2}$ times inner cylinder radius, with both cylinders having the same thickness.

Large, spun sliding caps fit over the ends of both cylinders, minimizing any attenuation loss due to air gaps. End cap thickness uniformity and fit while using a large radius are the critical quality features in such a shield which determine the uniformity of the residual field inside. Convenient carrying handle is attached with 2 brass screws. Overall length, including end caps, is 12½". OD of outer cylinder is 1⅞". Weight 1¼ lbs.

Lasting Protection: Lasting shielding protection is provided because AD-MU-80 does not saturate when properly used, will not suffer excessive permeability loss from shock and displays minimum retentivity.

Tight Quality Control: Up-to-date equipment for all types of metal forming, heliarc and spotwelding, deep drawing, and processing control of heat treating and finishing is used. In addition, there is complete in-house tool room and conscientious in-house quality control.

Lower Shielding Costs: Reduced shielding costs for many requirements are probable due to Ad-Vance's possession of existing tooling for nearly every type magnetic shield.

Four Decades of Helpful Problem Solving: During the last quarter century, over 90% of past and present magnetic shield designs have been created and fabricated by engineers and personnel with Ad-Vance. Its magnetic shielding is used off-planet in satellites and spacecraft, and world-wide in precision industrial, laboratory, military and consumer applications. The firm is the industry's largest, oldest, most experienced independent firm exclusively manufacturing magnetic shielding.

20

PROBLEM

To produce a small, high permeability pick-off bobbin core which can generate a changing flux in a magnetic circuit.

Model BC-22EC AD-MU-80 High Permeability Pick-Off Coil Magnetic Bobbin/Core Assembly. Note small size.

SOLUTION

Applications: The changing flux in a magnetic circuit generated by Model BC-22EC causes a small AC signal. Applications are: counting frequencies, noting relative positions of moving objects in aircraft instrumentation devices, etc.

Operational Data: Pole pieces can be added to direct the flux through the center of the bobbin. Proper heat treating is vital; otherwise the permeability is affected and output lowered, as the flux rate of change converts directly to AC output.

Precision Construction: Fabrication is made to tight fitting dimensions; in particular, tack weld build-up is controlled to .03" max. radius, most tolerances ±.005" and tolerances on flange diameter ±.0015".

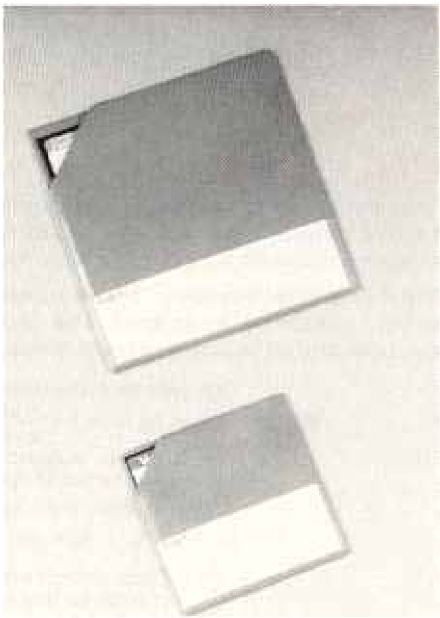
21

PROBLEM

To protect valuable recorded data on flexible disks from distortion, erasure or degradation caused by unforeseen external magnetic fields.

SOLUTION

"Infogard" magnetically shielded enclosures keep recorded data just as clear upon destination arrival as before beginning journey. Also, data so protected is unaffected by X-rays & other airport safety procedures as well as from various hidden hazards during ordinary supposedly safe storage or routine transport. Thus "Infogard" is regarded as inexpensive insurance against such unforeseen hidden hazards. "Infogard" for either 8" and 5¼" flexible disks.



22

PROBLEM

To economically protect valuable cartridge cassette tape data from unexpected magnetic radiation during supposedly safe storage or routine transport.

SOLUTION

Type CTDP 052478-G Protective Case houses up to an unprecedented 36 3M or similar Data Cartridge Type DC100A 3$\frac{9}{16}$" x 2⅝" x ¾" cassette tapes.

Safety and low cost insurance are provided in uncertain environments against distortion, partial erasure, or degradation of irreplaceable data recorded on magnetic tapes. Unexpected hazards include local severe thunderstorms, passing or nearby radiating electronic and electrical gear or equipment, power generating equipment, carelessness by unheeding or uninformed personnel, deliberate vandalism with powerful permanent magnets, and other types of electromagnetic pollution.

Construction: The protective case is constructed of lower permeability AD-MU-00 alloy .050" thick including internal partitions. Up to 36 tapes fit easily into 2 rows, each row with 18 individual compartments.

For ready access, tapes protrude slightly higher than partitions. A ¾" thick foam lining inside the cover compresses to .62" when case is closed, holding tapes firmly in place. For minimal magnetic leakage, there is a ½" cover overlap when unit is closed.

Two padlock type security latches, piano type hinges and a foldover handle for convenient storage are other construction features. ID case dimensions are 16.65" L x 7.42" W x 3.35" H. Finish is per Federal Standard 595 Color No. 25184.

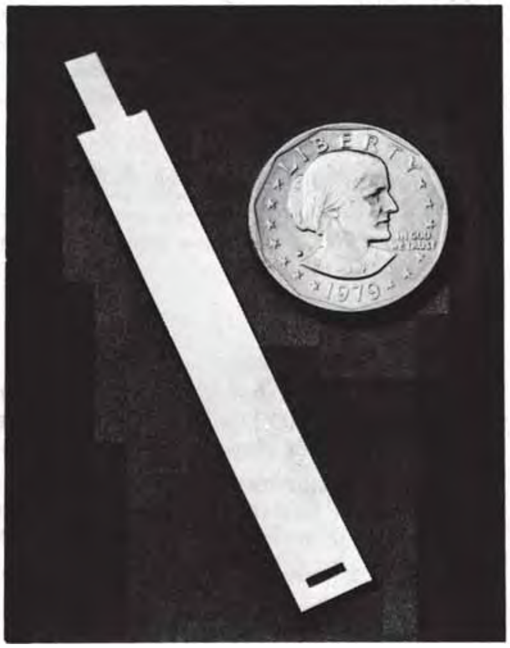
23

PROBLEM

To design and manufacture a simple, small, lightweight wrap-around shield for a pickup coil.

SOLUTION

All three requirements were incorporated into this magnetic shield manufactured in large or small quantity from AD-MU-80. 002" thick foil. The shield orients the magnetic field for the pickup coil, which is a necessary component in a sophisticated Magnetic Proximity Switch. High permeability AD-MU-80 foil optimizes the function of the Magnetic Proximity Switch. This shield represents one of the smallest (both in weight and size) that Ad-Vance Magnetics has produced in large quantity.



24

PROBLEM

To design and produce a shield for the new field of fast processing, where devices such as interferometers and Josephson junctions are used as circuit elements for processing signals at wave lengths of light. Such a shield also must serve to keep cryostatic and room temperature systems in controlled electromagnetic environments.

SOLUTION

Ad-Vance Magnetics' engineers devised a new generation of magnetic shields to protect ultra-high speed VLSI cryostatic memories from magnetic interference. These shields were developed in cooperation with VLSI manufacturers at the forefront of the high technology required of tomorrow's 5th generation computers. For complete data on these "King-sized" shields, please refer to the article reprint on page 80.

25

PROBLEM

The Need For A Shielded Room

Physical location and proximity considerations, as related to EMI, are ofttimes absent at the time of equipment installations; or in some cases even in the initial architecture. (Structural steel electric transmissions lines, neighboring facilities, earth's field, etc.)

Let's look at a couple of over-simplified examples.

Example "A"
Equipment that is very sensitive to EMI may require magnetic shielding for portions of the area, or the total area.

Example "B"
(Inverse of Example "A") Equipment that is emitting a high level of electromagnetic interference may require magnetic shielding to protect adjacent areas.

SOLUTION

Let Ad-Vance Magnetics assist you in determining the best approach to electromagnetic compatibility.

An effective shield room design may include different magnetic shielding alloys and/or different thicknesses of material on the same surface, depending upon the sources and characteristics of the interfering fields.

Our engineering department can provide "on site" testing, thorough evaluation and consultation. Evaluation and design are the key factors in effective results and cost impact.

We do not install shield rooms.

We do prescribe and supply properly selected shielding materials, fabricated to shape and size, fully annealed, and provide detailed installation instructions.

BASIC RELATIONS BETWEEN $\bar{E}$ and $\bar{H}$ VECTORS FOR A PLANE WAVE

Plane wave solutions for Maxwell's equations in a uniform material of dielectric "constant" $k_e = \epsilon/\epsilon_0$ and magnetic permeability $k_m = \mu/\mu_o$ and having conductivity σ are a special case which is widely useful for many approximate calculations of electromagnetic shielding and wave transmission. $\bar{E}$ and $\bar{H}$ vectors satisfy the wave equation and so each of the six components, resolved along the x, y and z axes satisfy the scalar wave equation

$$\nabla^2 u - \frac{\sigma\mu\partial u}{\partial t} - \frac{\epsilon\mu\partial^2 u}{\partial t^2} = 0.$$

For incidence of a plane wave perpendicular to the plane X Y, (i.e., direction of propagation Z, normal to that surface X), each component, u, is a function of the Z coordinate and of time only, being independent of x and y due to the plane wave assumption. Expressing u as an exponential, i.e., $u = u_0\ \epsilon^{jwt-yz}$, leads to convenient expressions and is quite general. In this formula $j = (-1)^{1/2}$, ω is angular frequency, γ is the propagation constant $= \pm\ (\sigma\mu j\omega - \epsilon\mu\omega^2)^{1/2} = \pm\ j\omega\sqrt{(\epsilon - \frac{j\sigma}{\omega})\mu}$. The expression for μ is a solution of the wave equation for these values of γ if it is assumed that the uniform region considered is free from electric charges and currents, except for currents resulting from Ohm's law.

For further generality, γ is put in complex number form: $\gamma = a + j\beta$. For a non-conductive medium this reduces to $\gamma = j\beta$; a being zero. This enables us to rewrite the expression for u in the form $u = u_0\ e^{\pm az}\ e^{j(\omega t \pm \beta z)}$ which may be recognized by circuit designers from oscillator theory. Interpreted, this represents a disturbance with sinusoidally varying value with time and also having sinusoidal variation with z when a = 0. It has wave length $\lambda = \frac{2\pi}{\beta}$ so that, when z varies by a wave length, u reverts to its initial value. Velocity of propagation of a wave crest is given by $v = \frac{\omega}{\beta} = \lambda f$, where is positive in the direction of increase of z for the negative signs in the expression for u and negative for the lower signs. $e^{\mp az}$ describes a reduction of intensity, or damping, in the direction of propagation of the plane wave. The intensity of u falls to $\frac{1}{e}$ of its initial value in a distance $\frac{1}{a}$ into the medium. Thus, the disturbance in a conducting material is a damped plane wave, and, in an insulator medium, it is an undamped plane wave. In the latter case, where = 0, then $B = \omega(\epsilon\mu)^{1/2}$ and the velocity is simply $v = \frac{\omega}{\beta} = \frac{1}{(\epsilon\mu)^{1/2}}$ or, $v = \frac{c}{n}$, where c is the velocity of light in free space (3.00×10^8 m/sec.) and n is the index of refraction in the medium. (Ratio of light vel. in space to its vel. in the medium.) $n = \left(\frac{\epsilon}{\epsilon_0} \times \frac{\mu}{\mu_0}\right)^{1/2}$. For the limiting case of a perfect conductor then $\gamma = \pm j(-j\omega\sigma\mu)^{1/2}$, telling us that the real and imaginary parts are equal in magnitude, i.e., that a wave inside a perfect conductor is damped down to a small fraction of its impinging intensity in a few wave lengths; this distance varies inversely with either frequency or conductivity. The distance of penetration of plane wave into the conductor in which the intensity of $\bar{E}$ or $\bar{H}$ component falls to $\frac{1}{e}$ of its impinging value is referred to as a "skin depth" because it is equal to that quantity used in circuit theory at high frequencies:

$$\text{Skin depth, } \delta = \left(\frac{2}{\omega\sigma\mu}\right)^{1/2}$$

The ratio of $\bar{E}$ to $\bar{H}$ components in a given direction is a most useful quantity having dimensions of Volts/Amps, known as the wave impedance. For the plane wave example, E_z and H_z are zero; so no component of E or H exists in the z direction.

$$\frac{E_x}{H_y} = -\frac{E_y}{H_x} = Z_o = \frac{\mu jw}{\gamma} = \frac{\gamma}{\sigma + \epsilon j\omega}$$

These various forms of the Z_o constant mean that $\bar{E}$ and $\bar{H}$ are at right angles to each other and to the propagation direction. For the useful example of empty space as medium,

$Z_o = \pm\left[\frac{\mu_o}{\epsilon_o}\right]^{1/2} = \pm\ 376.6$ Ohm, a pure resistance, although it has both a reactive and a resistive component in a conductive medium.

The simplified assumption that wave impedance is uniform along the path of propagation is not often realizable in practice. Any practical shield or enclosure is definitely not uniform, but may be composed of sections of uniform shielding containing discontinuities such as seams, joints, access openings, etc. Wave impedance is uniform only when considering plane wave, i.e., those independent of the distance from the source. For high and low impedance waves it is not uniform but depends on the distance from the source.

These considerations (may) account in part for the discrepancies between calculations based on theory and experimental results. Modifications of the transmission theory (using the wave impedance concept and taking account of its variation) result in closer agreement between theory and experiment for low impedance fields in the frequency range below 200 K Hz. According to this reasoning, the shielding effectiveness of an enclosure should be measured at three different levels of wave impedance:

(1) low impedance magnetic field or E/H much less than 120π Ohms.
(2) high impedance electric field or E/H much greater than 120π Ohms.
(3) plane wave impedance or E/H = 120π Ohms.

r is the distance from the dipole source to the point of interest

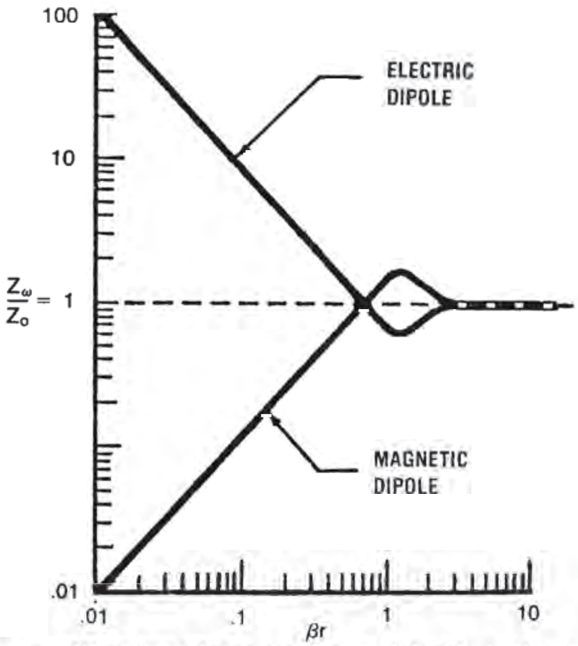


Fig. 1. Wave impedance versus βr (electric and magnetic dipoles)

Low-impedance magnetic field

A low-impedance wave may be obtained in the near field of a magnetic dipole (loop). Here, the wave impedance is expressed by

$$\frac{Z_\omega}{Z_0} = \left[1 + (\beta r)^2\right]\left[\frac{(\beta r)^2}{(\beta r)^6 + 1}\right]^{1/2}$$

Fig. 1 shows Z_w/η_0 for a magnetic dipole as a function of βr. Hence Z_w is very small compared with η_0 when $\beta r << 1$, and we may also assume that $r \leqq 0.005$ for Z_w to be considered a low-impedance wave.

In a manner similar to that in the preceding section, it can be shown that the upper frequency limit for a magnetic dipole to generate a low-impedance wave at 0.3 meter from the source is 5 MHz.

The use of a Helmholtz coil to generate a uniform, high-intensity low-impedance field below 200 kHz has resulted in good agreement between experimental measurements and theory.

COMPARISON OF MEASUREMENT TECHNIQUES

Magnetic Field Measurement

1) Small Transmitting Loop to Small Detecting Loop Method: Figs. 2 and 3. (Example: MIL-STD 285.)

2) Large Transmitting Loop to Small Detecting Loop Method: A single-turn transmitting loop is used which surrounds the room. The loop plane is tilted so that it includes a diagonal of the enclosure (11) (Figs. 4 and 5).

Advantages

a) Since the large loop causes currents to flow across all seams of a shielded enclosure, one measurement is sufficient to obtain an indication of the shielding effectiveness at a given frequency. Thus time and costs may be reduced.

b) The field generated is more uniform than for a smaller loop.

c) Measurement repeatability is improved over that of the small loop to loop method, since the position of the transmitting loop with respect to the enclosure remains fixed.

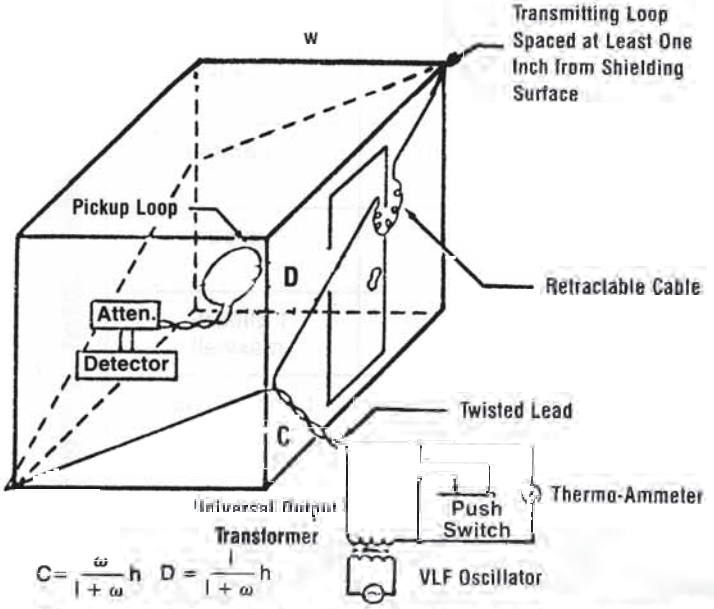


Fig. 4. Large loop test setup. Pickup loop is in plane of large loop or center enclosure.

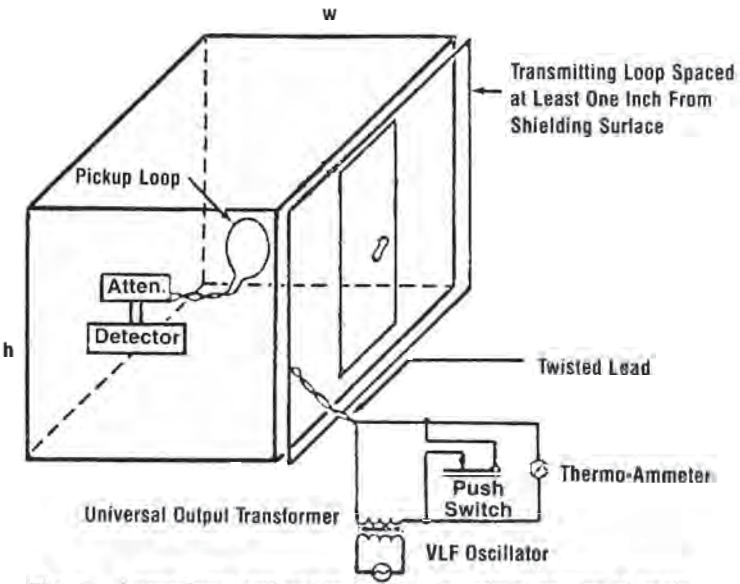


Fig. 5. Large loop test setup. Pickup loop is at center of enclosure and parallel to large loop.

Disadvantages

a) A complex test setup is required, and it is difficult to implement for different sizes and shapes of enclosures.

b) Frequency range is limited, and a high current is difficult to maintain since at higher frequencies the loop impedance becomes quite high; thus it is difficult to maintain low impedance matching with the signal generator.

c) Orientation of the tilted loop does not allow a strong field penetration through the floor and ceiling joints.

3) Helmholtz Coil with Small Loop Detection Method: [1] The coil completely surrounds the shield enclosure.

Advantages

a) The field generated is very uniform over a wide area.

b) Intensity of the generated field is reasonably strong; hence dynamic range is good.

c) Since the field generated is uniform, any variation of shielding effectiveness at a constant distance from the transmitting loop may be an indication of a shield anomaly (seam, discontinuity, metallic inclusion, etc.).

d) It provides a convenient way to detect joint and seam defects.

e) Measurement time and cost are relatively low.

f) Measurement repeatability is high.

g) The most uniform field is generated when the coil separation *D* is nearly equal to mean half-side length. Hence a uniform field can be generated for room size enclosure measurements.

Disadvantages

a) The test setup is quite complex, especially when one test enclosure adjoins another.

b) Uniformity of the field as frequency increases can only be maintained by a reduction of the Helmholtz coil dimension, thus limiting the sample size.

c) Leaky joints of the enclosure that are parallel to the direction of the current flow in the large loop are not detectable. Thus to detect the effect of all possible seams and discontinuities of a rectangular enclosure, three sets of measurements should be performed corresponding to the three possible orientations of the leaky joints.[10]

References

(1) "Survey of Techniques for Measuring R. F. Shielding Enclosures" SY O'Young Reuben Goldman and Lars Jorgensen in I.E.E.E. Trans. on EMC, Vol. EMC-10, No. 1, March, 1968.

(2) "Ferromagnetic Shielding Related to the Physical Properties of Iron", by F. J. Young; 1968 I.E.E.E. EMC Symposium Record, pp 88 to 95 (I.E.E.E. Pub. No. IEEE 68 C12-EMC.)

(3) "The Shielding of Electromagnetic Pulses by Use of Magnetic Materials", by R. R. Ferber, IEEE Electromagnetic Compatibility Symposium Record 1969, pp 73 to 78 inclusive. (IEEE Publication 69CS-EMC).

THE PRINCIPAL ELECTRICAL AND MAGNETIC UNITS

Quantity	Practical (English)	Giorgi MKS	C.G.S. Electrostatic	C.G.S. Electromagnetic
Length	1 foot, 1 inch	1 metre	1 centimetre	1 centimetre
Mass	1 pound	1 kilogram	1 gram	1 gram
Force	1 pound weight	1 dyne-five = 1 newton	1 dyne	1 dyne
Time	1 second		1 second	1 second
Work, Energy	1 joule		1 erg	1 erg
Power	1 watt		1 erg/second	1 erg/second
Charge	1 coulomb		1 statcoulomb	1 abcoulomb
Current	1 ampere		1 statampere	1 abampere
Electromotive force	1 volt		1 statvolt	1 abvolt
Resistance Resistivity	1 ohm 1 ohm/cm cube or 1 ohm-centimetre		1 statohm	1 abohm
Conductance Conductivity	1 siemens = 1 mho 1 mho/cm cube		1 statmho	1 abmho
Capacitance	1 farad		1 statfarad	1 abfarad
Inductance	1 henry		1 stathenry	1 abhenry
		MKS unrationalized	**MKS rationalized**	
Flux (∅)	1 line = 1 maxwell	1 weber	1 weber	1 line = 1 maxwell
Flux density (B)	1 line/sq in	1 weber/sq metre	1 weber/sq metre	1 gauss
Magnetizing force (H)	1 ampere-turn /in	1 praoersted	1 ampere-turn /metre	1 oersted
Magnetomotive force ($\mathcal{F}$)	1 ampere-turn	1 pragilbert	1 ampere-turn	1 gilbert
Reluctance $\mathcal{R}$		1 pragilbert/ weber	1 ampere-turn/ weber	1 gilbert/ maxwell
Permeability of free space (μ_0)		10^{-7} henry/ metre (or 10^{-7} weber/sq metre/praoersted)	henry/metre	1 abhenry/cm (or 1 gauss/ oersted)
Permittivity of free space (Σ_0)		8.85×10^{-12} Farad/Metre		

ELECTRICAL AND MAGNETIC UNITS

RELATIONSHIPS BETWEEN UNITS	
1 metre = 100 centimetres	1 centimetre = 1/100 metre
1 kilogram = 1000 grams	1 gram = 1/1000 kilogram
1 newton = 10^5 dynes	1 dyne = 10^{-5} newton
1 joule = 10^7 ergs	1 erg = 10^{-7} joule
1 watt = 10^7 ergs/second	1 erg/second = 10^{-7} watt
1 coulomb = 3×10^9 statcoulombs = 0.1 abcoulomb 1 statcoulomb = 3.33×10^{-11} abcoulomb	1 abcoulomb = 3×10^{10} statcoulombs
1 ampere = 3×10^9 statamperes = 0.1 abampere 1 statampere = 3.33×10^{-11} abampere	1 abampere = 3×10^{10} statamperes
1 volt = 3.33×10^{-3} statvolt = 10^8 abvolts 1 statvolt = 3×10^{10} abvolts = 300 volts	1 abvolt = 3.33×10^{-11} statvolt
1 ohm = 1.11×10^{-12} statohm = 10^9 abohms 1 statohm = 9×10^{20} abohms	1 abohm = 1.11×10^{-21} statohm
1 mho = 9×10^{11} statmhos = 10^{-9} abmho 1 statmho = 1.11×10^{-21} abmho	1 abmho = 9×10^{20} statmhos
1 farad = 9×10^{11} statfarads = 10^{-9} abfarad 1 statfarad = 1.11×10^{-21} abfarad	1 abfarad = 9×10^{20} statfarads*
1 henry = 1.11×10^{-12} stathenry = 10^9 abhenrys 1 stathenry = 9×10^{20} abhenrys	1 abhenry = 1.11×10^{-21} stathenrys
1 weber = 10^8 maxwells = 10^8 lines	1 maxwell = 10^{-8} weber
1 weber/sq metre = 10^4 gauss	1 gauss = 10^{-4} weber/sq metre
1 praoersted = 10^{-3} oersted 1 ampere-turn/inch = 0.495 oersted = 495 praoersteds 1 ampere-turn/metre = 0.01257 oersted = 12.57 praoersteds	1 oersted = 10^3 praoersted
1 ampere-turn = 1.257 gilberts 1 pragilbert = 0.1 gilbert 1 ampere-turn = 12.57 pragilberts	1 gilbert = 0.796 ampere-turn 1 gilbert = 10 pragilberts 1 pragilbert = 0.0796 ampere-turn
1 pragilbert/weber = 10^{-8} gilbert/maxwell = 0.0796 ampere-turn/weber 1 ampere-turn/weber = 1.257×10^{-8} gilbert/maxwell	

* = 1.11×10^{-12} farad

1 μμF = 0.9 statfarad

ELECTRICAL AND MAGNETIC UNITS

There are several systems of units in common use, but they may be divided into three clearly distinguished groups:

1 Unrationalized systems, including
  (a) Absolute* c.g.s.** electrostatic system.
  (b) Absolute* c.g.s.** electromagnetic system.
  (c) Absolute* m.k.s. (metre-kilogram-second) system. Otherwise known as the Giorgi system.

2 Rationalized systems including
  (a) Rationalized m.k.s. system (Giorgi).

3 Practical systems
The common pactical system includes the volt, ampere, coulomb, ohm, farad, henry and watt.

All fundamental physical relationships are normally worked out in one of the unrationalized systems, and the final result may be converted into practical units for general use.

Rationalized systems have been developed to simplify certain calculations. They may be used as alternatives to unrationalized systems.

The m.k.s. system is increasing in popularity because neither the c.g.s. electrostatic system nor the c.g.s. electromagnetic system is convenient for use with all problems, and the combined use of the two systems has been generally adopted in the past. Another reason for its popularity is that it includes many of the practical units, the second, joule, watt, coulomb, ampere, volt, ohm, mho, farad and henry. The rationalized m.k.s. system has been standardized by the American I.R.E. (January 1948). (I.R.E. now is IEEE).

The Giorgi m.k.s. system absolute system was adopted by the International Electrotechnical Commission (I.E.C.) in Bruxelles, June 1935 (see Proceedings of National Academy of Sciences Vol. 21 No. 10 pp. 579-583, October 1935; reprinted by Harvard University, Publications from the Graduate School of Engineering 1935-36 No. 167). See also A. E. Kennelly "I.E.C. adopts MKS System of Units," Electrical Engineering 54.12 (Dec. 1935) 1373. See also References below.

In any one sequence of calculations it is essential to retain the same system throughout. The final result may then, if desired, be converted to any other system. The Basic Magnetic Relations Table on page 36 should enable any engineer to do this.

REFERENCES TO MKS SYSTEM

Carr, H.L.A. "The M.K.S. or Giorgi system of units—the case for its adoption" Proc. I.E.E. Part I 97.107 (Sept. 1950) 235.

Rawcliffe, G. H. "The rationalization of electrical units and its effect on the M.K.S. System" Proc. I.E.E. Part I 97.107 (Sept. 1950) 241.

Marriott, H., and A. L. Cullen "The rationalization of electrical theory and units" Proc. I.E.E. Part I 97.107 (Sept. 1950) 245.

Bradshaw, E. "Rationalized M.K.S. units in electrical engineering education" Proc. I.E.E. Part I 97.107 (Sept. 1950) 252.

A brief description of all systems including the m.k.s. is given in "Applied Electronics" (Massachusetts Institute of Technology; John Wiley & Sons Inc. New York; Chapman & Hall Ltd., London, 1943) Appendix B.

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*An absolute system is one which includes length, mass and time in its fundamental dimensions.
**c.g.s.—centimetre-gramme-second.

CALCULATION ASSISTS IN SHIELD DESIGN

Design:

1

(g) = Attenuation

Ho = Field intensity outside } Measured in oersteds
Hin = Field intensity inside }

Where $g = \frac{Ho}{Hin}$

2

S.E. = Shielding efficiency in dBs
$S.E. = 20 \text{ Log}_{10}\, g$

3

$\% \text{ Shielding} = (1 - \frac{1}{g})\ 100$

4

Definitions:

Field:

Strength (H), in oersteds (lines/cm² in Air)
Flux Density (B), in gauss flux density in material (lines/cm²)

Shield Material:

Permeability (μ), a ratio measure of material's capability to conduct magnetic lines of force or flux mu = B/H

Magnetic Saturation Level The flux level at which the material can no longer conduct any additional lines of force.

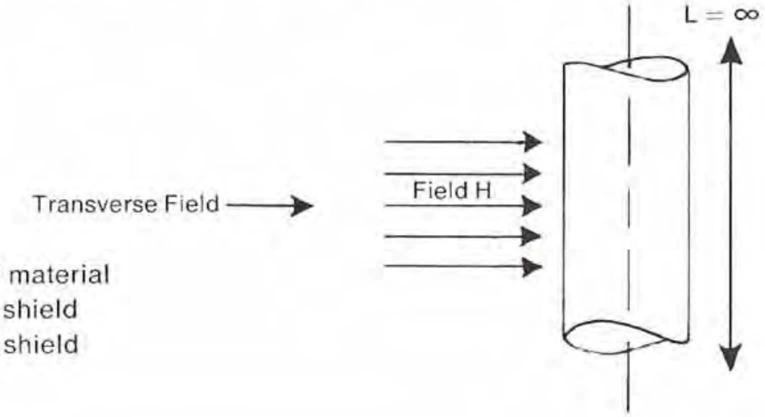
Reluctance (R), measure of material's resistance to the passage of magnetic flux.

$R = \frac{1}{\mu A}$ 1 = flux path length (CM)
A = cross sectional area (CM²)

5

Design Calculations
(A) Uniform DC field

$$g = \left(\frac{\mu}{4}\right)\ \left(1 - \frac{a^2}{b^2}\right)$$



Where: μ = permeability of material
a = inner radius of shield
b = outer radius of shield

CALCULATION ASSISTS IN SHIELD DESIGN

Substituting (b − T) for a (where T = material thickness) and simplify, we obtain

$$g = \left(\frac{\mu}{4}\right) \left(\frac{T}{b}\right) \left(2 - \frac{T}{b}\right) \approx \frac{\mu T}{2b}$$

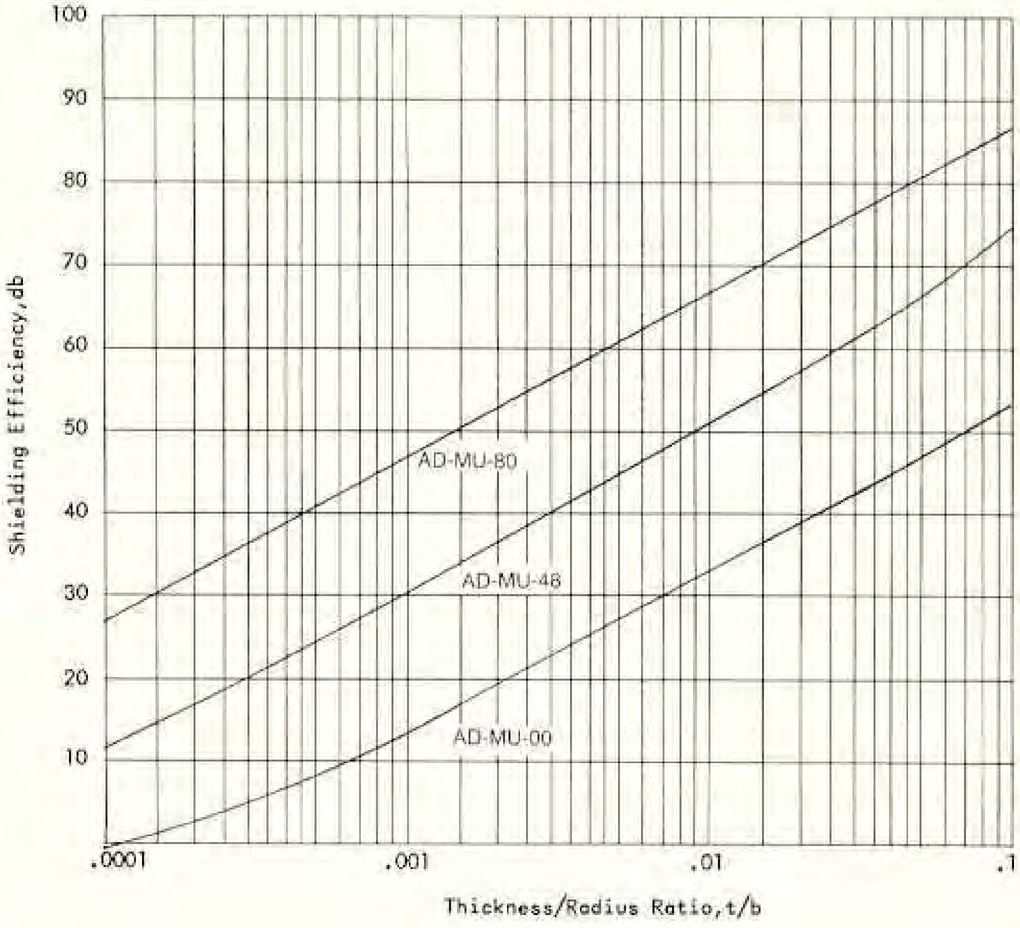
Shielding effectiveness depends only on the permeability of the material and the ratio of wall thickness to outer radius. The above holds true for cylinders with a length to diameter ratio of 4 or more.

(B) AC Field

Designing for a DC field provides a maximized shield in AC fields of equal density (AC peak).

(C) Shield Geometry

Multiple Layer Shields should have an air gap of approximately .020 to .030″ or material thickness whichever is the greater.



Electrical Characteristics

Typical DC Magnetic Properties for AD-MU Shielding Alloys

	Material	Initial Permeability at 40 gauss	Permeability at 100-200 gauss	Maximum Permeability	Saturation Induction gauss	Coercive Force oersteds
High Permeability	AD-MU-80	75,000	100,000	300,000	8,000	0.015
	AD-MU-78	60,000	43,000	250,000	7,600	0.01
Med. Permeability	AD-MU-48	11,500	20,000	130,000	15,500	0.05
Low Permeability	AD-MU-00	*300	1,300	3,000	22,000	1.00

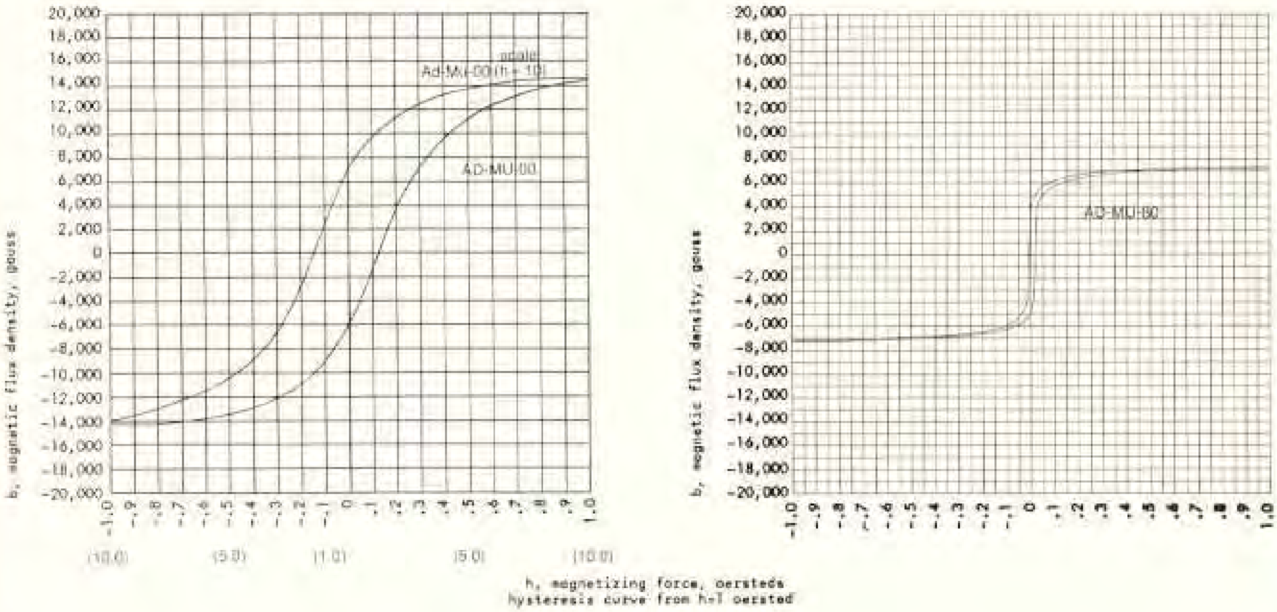
*Unannealed State

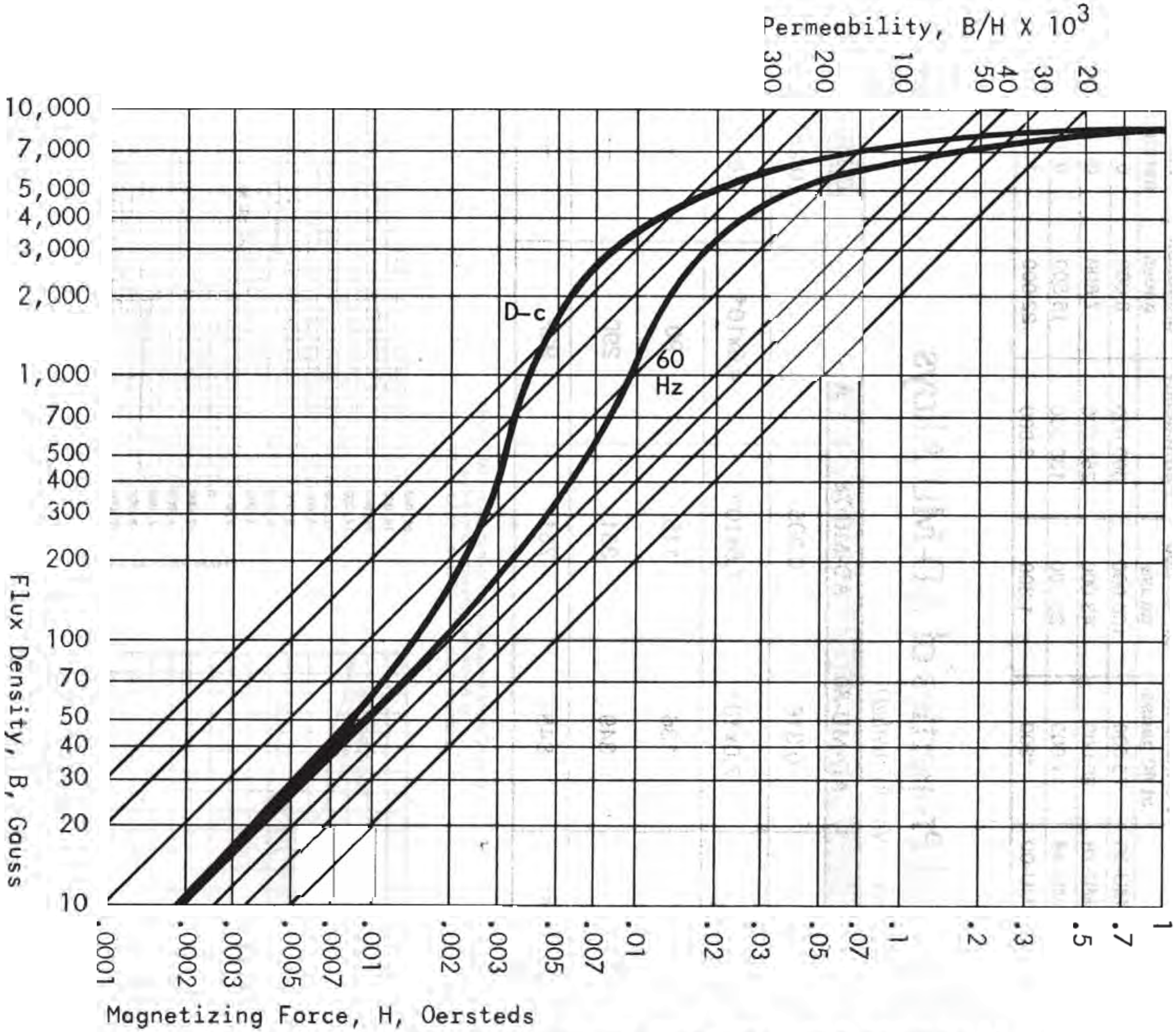
Typical Physical Properties of AD-MU Alloys

(Forming Temper – Not Annealed)

	AD-MU-80	AD-MU-78	AD-MU-48	AD-MU-00
Density (lb/in^3)	0.316	0.305	0.294	0.283
Thermal Expansion Coefficient/ °F(68°-212°F)	7.0x10^{-6}	7.5x10^{-6}	4.6x10^{-6}	7.6x10^{-6}
Thermal Conductivity (BTU/in/ft^2/hr/°F)	136	115	90	—
Electrical Resistivity (ohm-cir mil/ft)	349	331	290	—
Curie Temperature (°F)	845	761	932	—

Direct Current hysteresis loops for h (max) = 1.00 Oersted
for Ad-Vance high permeability alloys
and for h (max) = 10.0 Oersted for Ad- Mu 00





Typical magnetization curves of AD-MU-80 (.014 thickness).

IN-HOUSE HELMHOLTZ COIL TESTING CAPABILITY ASSURES MEASUREMENT CONSISTENCY IN SHIELDING ENCLOSURES

Uniform field testing is widely regarded as one of the most consistent, simple and effective methods of testing magnetic shielding materials and enclosures at audio and power frequencies. Its value is in good measurement repeatability and excellent field uniformity.

EQUIPMENT AND OPERATION

1. Source of Uniform Field: (a) Two 30" ID coils spaced at 18" apart. Each coil contains 120 turns of #12 ga. solid, insulated wire. The Helmholtz coils are driven with approx. 57VAC to achieve a 5 Gauss field when using a variac-power supply. (b) Regulated power supplies 0-300VAC, 0-250VDC (two, including current and voltage metering). (c) Construction: entirely wood, including wooden dowels. No ferromagnetic materials are used.

2. Small Detector Probes (placed inside the enclosure under test with accurate position control): (a) Small diameter calibrated multi-turn copper wire coils enclosed in slotted copper cans for shielding out electric field component. Ballantine VTVMs Model 310A, including 0.10 Ohm current sampling resistor. (b) Hall Effect AC/DC Gauss meter Dyna-Empire Model 800.

3. Measurement Standards: (a) Two standard magnets for calibrating Hall Effect probes—90 Gauss and 1K. Gauss. (b) Classical Flux Calibrator (provides a known change of flux linkage). (c) Skin-effect magnetometer, using one of the Ballantine 310A's as a detector. (d) A set of calibrated attenuators.

HELMHOLTZ TESTING AND THEORY

The two equal Helmholtz coils are placed with coinciding axes at a distance from each other equal to their common radius to provide a homogeneous magnetic field extending to approx. 1/10th the radius around the center point. To illus-


For optimum operation, Ad-Vance Magnetics' in-house Helmholtz testing equipment is built entirely with wood. Even the dowels are wood. There is no metal whatsoever in the frame to distort test results.


CRT shield testing: The shielding enclosure being tested is entirely contained within the two Helmholtz coils.

trate this theory quantitatively, plot on graph paper the field intensity values due to each coil at various points along the axis:

For one coil, $H = \frac{2\pi a^2 nI}{(a^2 + x^2)^{3/2}}$, where a = mean radius (cm) of Helmholtz coil, x = axial distance from center (cm), I = current (C.G.S. unit), n = number of turns, H = field intensity (Oersted or Gauss).

Adding together the intensities due to the two separate coils provides the resultant intensity: $H = \frac{4\pi a^2 nI}{\left(a^2 + \frac{a^2}{4}\right)^{3/2}} = \frac{4\pi nI}{\frac{5}{4}^{3/2} \times a} = \frac{4\pi nI \times 4^{3/2}}{5^{3/2} \times a} = \frac{6.4\pi nI}{a\sqrt{5}}$ (at the center). (Two coils with currents in the same direction.)

Dynamic range is good because the generated field's intensity is reasonably strong. Larger shields, relative to the Helmholtz coil diameter than 1/5th diameter may be subjected to uniform field test if nearly symmetrical; e.g., cube shaped boxes, cylinders, or other shapes that are very rough approximations to the sphere.

Possible shield abnormalities or shielding deviations caused by seams, discontinuities, etc. are indicated by variations in shield attenuation (at a constant distance from the Helmholtz source). With short measurement times and low costs facilitating production testing and locating possible faults, rejects are prevented.

ENHANCED SKIN EFFECT

High Permeability Thin Shields Also Perform Better Than Any Other Shield at Sufficiently High Frequencies, Especially When E-M Pulses Are to be Shielded Out.

A shielding mechanism known by the name "enhanced skin effect" comes into play at radio frequencies where copper has usually been used alone, or aluminum cans, for example. Design information for this type of super-shielding was not widely available until the "electromagnetic pulse" problem associated with nuclear weapons had been tackled, although the mathematical formulation of the effect as seen from the point of view of an engineer designing a communications transmission coaxial cable had been published in 1918.(1) Design data comparing the effectiveness of copper and ferromagnetic materials for pulse shielding at widely ranging intensities of applied fields has been greatly augmented in recent years by research in this "EMP" problem area and renewal of interest in the mechanism arises in data transmission at high rates via cables and in microwave reflectometry. These results are brought out, along with a few references to applications, so that users may quickly calculate which kind of shielding material should be chosen for the frequency range and field intensities that they must protect against by way of shielding, or filtering out conducted or induced pulse. (The most effective filters make use of high permeability surrounding a conductor and are effectively miniature lossy coaxial cables.)(2)

The skin effect, which results in the measured ac resistance of a conductor being much higher than its dc resistance, increasing with frequency, is enhanced, compared with copper alone, in the sense that the time taken for the electric and magnetic fields (assumed tangential to impinging surface) to diffuse through the permeable layer is greater than for the same depth of copper in the ratio $\frac{C_f \beta_s}{4\ C_c\ B_0}$, where $\beta_0 \pm \mu_0 H_0$, C_f is conductivity of the ferromagnetic, C_c is conductivity of copper, B_s is the saturation magnetic induction in the ferromagnetic and H_0 is the impinging magnetic field in air.

For a material with nearly rectangular B-H loop, at the inner edge of the outer skin saturated region the magnetic field is H_c, the coercive force, no matter how large is the field magnitude impinging. As long as the incident magnetic field is large enough to saturate the outer skin depth(s), the saturated region will increase in depth. When the impinging surface field has dropped below H_c, the inward diffusion of the saturated region will reverse direction and the field in the shield will continue to decay, following the major hysteresis curve down to B_r, the retentivity point. Fields in the inner, previously unsaturated regions, will decay towards zero, unless another pulse arrives greater than H_c.

References

1) Transient Wavefronts on Lossy Transmission Lines —Effect of Source Resistance by P. C. Magnusson. (Biblio). IEEE Transactions on Circuit Theory, Volume CT-15, Number 3.
2) Compatible EMI Filters by H. M. Schlicke, H. Weidmann. (Biblio). IEEE Spectrum Volume 4, Number 10

Editors of technical magazines welcome state-of-the-art magnetic shielding articles from the innovative problem solving engineers at Ad-Vance Magnetics, Inc.

Reprints of Technical Articles
on Magnetic Shielding from Various Trade Publications
are presented in the following pages.

Prepared by The Engineering Staff
of Ad-Vance Magnetics, Inc.

Articles have been updated from original printing
for maximum present day usefulness.

Magnetic Shielding In a Cryogenic Environment

by Robert F. Arentz and Mark H. Johnson, Ball Aerospace Systems Division, Boulder, CO, and Lester Dant, Ad-Vance Magnetics, Inc., Rochester, IN (219) 223-3158

A report on the changes in the magnetic shielding efficiency of a commercially available, high permeability material as a function of fabrication, annealing process, temperature, field intensity and frequency is presented. Data are presented for the same alloy treated by two different processes. Data were taken at 300°, 77°, 4° and 1.91°K, with sinusoidal excitation field strengths of 5 and 50 gauss. One of the samples remained stable above 1 kHz and, in fact, showed an improvement in its shielding efficiency at 4°K over that at 300°K. The other sample showed significant shielding degradation at 4°K at these high frequencies. Because of the relatively stable behavior of both materials as a function of temperature at low frequencies, they would, therefore, be useful for localized, cryogenically cooled magnetic shielding in such systems as SQUIDs, satellite-borne magnetometers and particle detectors.

Our involvement with cryogenically cooled magnetic shielding began with a need to design a shield for a spaceborne, superfluid-cooled SQUID-based, magnetometer system known as the Stanford Relativity Experiment or GP-B.

At that time, useful and cryogenically stable shielding materials were completely unknown to us. A material called Cryoperm-10[1] was called to our attention by the Electromagnetic Technology Division of the National Bureau of Standards. This material has been measured at 4.4°K to have an initial permeability of 8.81 x 10^{-2}H.m (70,000 μ), and a maximum permeability of 3.14 x 10^{-1} (250,000 μ). Even though this material has good magnetic properties, it was eventually dropped from consideration for several reasons having to do, in part, with the difficulties involved with purchasing, MIL-Spec certification and a maximum strip width.

Our search produced only five references dealing directly with the measurements of the shielding factor or permeability characteristics of ferromagnetic alloys at low field strengths (.6 x 10^{-4}T), low temperatures (1.9° to 4°K) and low frequencies (.01 to 10 kHz); and one reference dealing with all of these for pure iron.

We agree completely with Suzuki et al., "that the performance of ferromagnetic shields immersed directly in liquid helium has rarely been reported."

In the five references cited, one finds a regular beastiary of materials identified only by their trade names; but few references for alloy composition or sources. Furthermore, a property such as permeability is often quoted only as a ratio between two temperatures, but the absolute permeability is left unstated. Also data are not usually taken over a broad range of frequencies.

As will be seen in our data curves, large differences do occur over a relatively short frequency span, particularly in the decade between 100 and 1 kHz. In addition, each reference cites at least one anecdotal contribution to unusual magnetic characteristics such as strain, annealing at high temperatures, cooling and annealing profiles below 100°K, applied field strengths and alloy purity. To compound the confusion, some works measure properties that are temperature independent, such as saturation induction (B_s). Some measure initial permeability, some measure maximum permeability which are nearly impossible to compare and a few measure the actual B-H curve.

There is a multitude of magnetic shielding alloys available in today's marketplace, each alloy having its own individual distinct characteristics. There are various formulations ranging from industry standards to exotic concoctions, each having its own magnetic properties, physical properties and shielding effectiveness sensitive to frequency, temperature and magnetic environment.

Identification of a specific alloy may be revealed by a military specification, a manufacturer's published specification or a fabricator's-seller's trade name.

Optimum magnetic shielding for a specific application is a result of many factors, including:

- The proper selection of alloy chemistry.
- Good metallurgical mill practice.
- Thickness of material.
- Physical size and configuration.
- Technique of fabrication.
- Final annealing process.

Nearly all magnetic measurements are difficult to make, let alone when added to the problems of a cryogenic magnetics measurement. We, therefore, chose to measure the shielding factor of an enclosed, right circular cylinder, that was 17.8 cm high, 7.62 cm wide (OD) and with a wall thickness of 1 mm. The material we tested is an alloy called AD-MU-78.

AD-MU-78 is a high permeability, ferromagnetically soft alloy with a nominal composition by weight percentage of Ni (75-77), Fe (12-15), Cu (4-6) and a maximum content of Cr (3), Mg (1.8), Si (0.5), Ph (0.02), S (0.02) and C (0.05). We received two cans with end caps for study. Although the two specimens were made from the same ingot of material, they had undergone separate and distinct processes. Can No. 1 (henceforth called AD-MU-78) underwent a standard processing used by the manufacturer. Can No. 2 (henceforth called CP-EXP-1184) underwent a proprietary processing. Both cans were formed by a heliarced, butt-weld seam along their longitudinal axis and by a welded plate for the bottom. The end caps slipped tightly over the outer walls of the cylinder with a 2 cm overlap. In the center of each cap, there was a .64 cm dia hole through which leads for the pickup coil could be routed, and cryogenic fluids could fill the interior volume.

All in all, we found the alloy to be very tractable from all points of view. It forms and welds easily. It can be purchased in sheets up to 40.6 cm wide and in lengths up to 3 meters long. It comes in a variety of thicknesses. Its alloy composition is well documented and can be purchased to a MIL-Spec (MIL-N-14411, Composition 2). It is made in the U.S. and interacting with the manufacturer is very easy. Its price is competitive, and its magnetic properties are quite good.

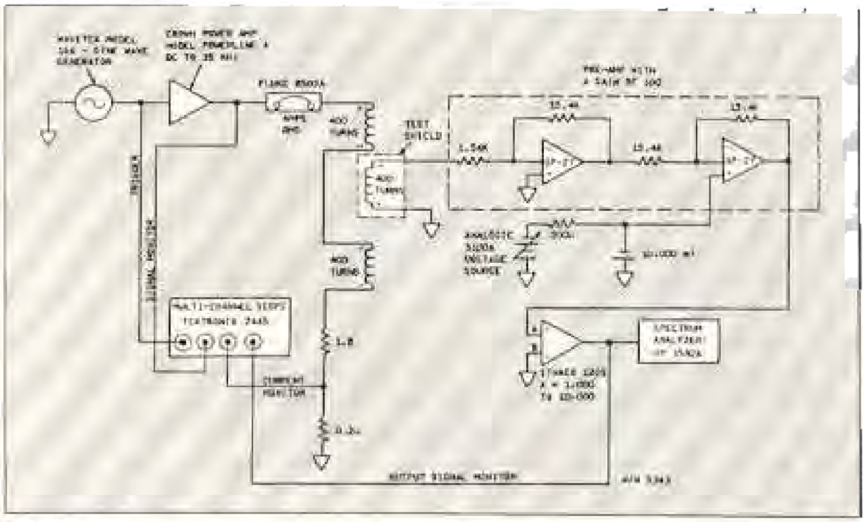


Figure 1.

Experimental Procedure

Our setup was quite simple and standard. We drove a controlled, sinusoidal current into a pair of coils hooked in series-aiding and measured the induced, open-circuit output voltages of a third coil located between them.

The geometry of the three coils was always fixed and the coupling between the coils was measured first without, and then with the can inserted between the coils.

The shielding factor is then simply the ratio of the two signal levels. We varied the drive frequency continuously over the range of .008 Hz to 12 kHz, and selected two rms drive currents of 20 mA and 160 mA. These currents gave us fields which maximum rms values were 4 and 50 gauss at the contact interface between a drive coil and the wall of the can. These field levels were measured with a calibrated, thin Hall-effect sensor probe carefully inserted between the coil and the surface.

Due to our selection of available instrumentation, we chose to monitor the input rms current on a calibrated John Fluke 850LA meter; and to measure the output voltage signal on a calibrated Hewlett-Packard 3582A spectrum analyzer. Our exact set-up is depicted in **Figure 1.** Note that the entire system is dc coupled.

Since our test configuration converted an input rms current into an output rms voltage, our transfer function is dimensionally that of transconductance. Since we can't think very clearly in mhos, we have chosen to invert our numbers to ohms by dividing the output voltage by the input current.

Having the input coil inside the can reduced our 60 Hz pickup to virtually nothing. We added a hand-built, two-stage preamp in the pick-up line directly at the output from the dewar. This gave us a dc offset control to compensate for thermal drifts in the Ithaco instrumentation amplifier which was run at fixed and measured gains between 1,000 and 10,000. The two-stage preamp was built up from Precision Monolithic's OP-27 OP-amps and 170 metal film resistors.

The noise floor of the system was carefully checked with the spectrum analyzer and was just 6.75 nV/Hz which is equal to the quadrature sum of the two OP-27s at 3.8 nV/Hz and the Ithaco at 4.1 nV/Hz.

The end-to-end electronics gain of the two stages was measured by the transfer function capability of the 3582A spectrum analyzer and was tweaked where necessary to be within 1 percent of the gains stated on the front panel. All the data has been referred to the input through division by the gain numbers.

The worst-case signal-to-noise ratio occurs when the cans were present at 20 mA of drive current, T = 300k and f = .008 Hz. At that limit, the SNR was 2-2. In all other cases, the SNR was greater than 10 and frequently greater than 1,000.

The coils were hand-wound on a cardboard tube, 400 turns per coil and each coil was wound with standard No. 31 AWG insulated copper magnet wire.

The coils all had IDs of 4.5 cm and ODs of 5.5 cm. The internal pickup coil was left on its cardboard mandrel, and the mandrel was cut and shaped to provide a tight slip-fit transversely across the inside of the can. The outer two drive coils were removed from their mandrels and then tied into compressed circular coils with a winding thickness of .068 cm, while leaving the loop's ID and OD unchanged. The drive coils were connected in series-aiding and were aligned to be on axis with the pickup coil.

Due to an overall diameter limitation set by the ID of the dewar neck (10.16 cm), the compressed outer coils were strapped hard against the outer wall of the can. They, in fact, were bent slightly to conform to the can's radius of curvature. Once the coils were in place on the cardboard model, each coil was adjusted by the removal of the few turns of wire to be 11 mH ±10 percent as measured in realtime on an HP LCRZ impedance meter. When added to the dewar cabling, the drive coils had a low Q resonance created by the stray capacitances associated with the coil winding and the cabling at 32 kHz.

The coupling between the coils was measured with the coils mounted on a close tolerance cardboard model of the cans. This kept the geometry of the three coils very closely the same both with and without the cans being present. The coils were mounted in the bottom third of the can to get as far away as possible from any field leaking out of the hole in the top or fringing from the small gap between the lid and the body.

Both sets of coils were connected to the 300k electronics through No. 28 AWG twisted shielded-pair cable, and the shields were all connected to a single-point ground. All ground loops were assiduously tracked down and dispatched.

The cans were supported by a very thin walled stainless steel tube being pushed through the hole in the lid. Just below the lid, we placed a small chip on the tube to prevent it from being extracted from the can. The can-coil assembly was positioned and held in place by tape.

The two sets of twisted shielded cables came down the inside of the tube. One cable went into the inside of the can and connected to the pickup coil. The other cable split out from the tube through a small notch cut in the side of the tube about 2 cm above the lid. The notch also let cryogenic fluids into, and vapor out of, the inside of the can.

Both cables came out of the top end of the tube and the top 5 cm of the tube was sealed with an epoxy plug. This not only locked the cables in place at the top, but also sealed the tube so that the suspended unit would be pumped to superfluid pressures.

Data were taken on three runs, first on the cardboard model to get the baseline coupling data. All the data were taken inside the aluminum-walled, fiberglass necked dewar. Data at 300°K were taken first. Data were next taken at 77°, 4° and then 1.91°K. The temperature was taken from the saturated vapor pressure curves for LHe and pressure was monitored on a calibrated MKS Baratron head and readout. To lower the temperature from 4° to 1.91°K, the dewar volume was pumped through an auxiliary port with a 30 CFN rotary vane roughing pump. All low-temperature measurements were taken with the coils and then the coils with the can submerged in liquid; the liquid also filled the inside of the can.

At all times, the coils were 11.5 cm from the nearest conductive wall, which we believe to preclude any eddy current effects in the dewar from affecting the data. We were also suspicious enough of the deep cusp at f = 1 kHz to check the coils and cans with the unit suspended in a large styrofoam cooler which we then filled with liquid nitrogen. During these tests, all extraneous conductive materials were at least 11.5 cm from the coils. The cusp remained unchanged during these retests.

Discussion of Results

The results of our study will not be discussed in great detail, this report being primarily a presentation of data. Arguments based on skin effects and domain wall motion can be made, however, allowing for a first-order understanding of the observed behavior. For a more comprehensive explanation

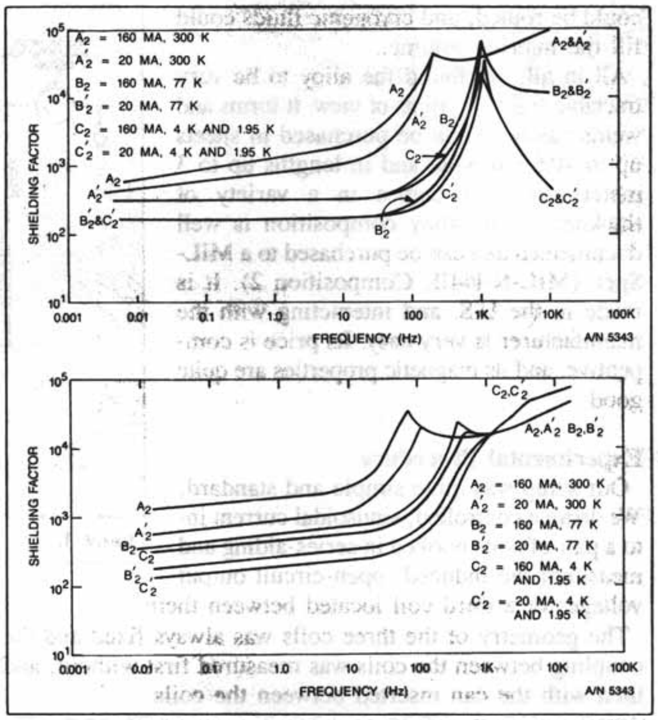
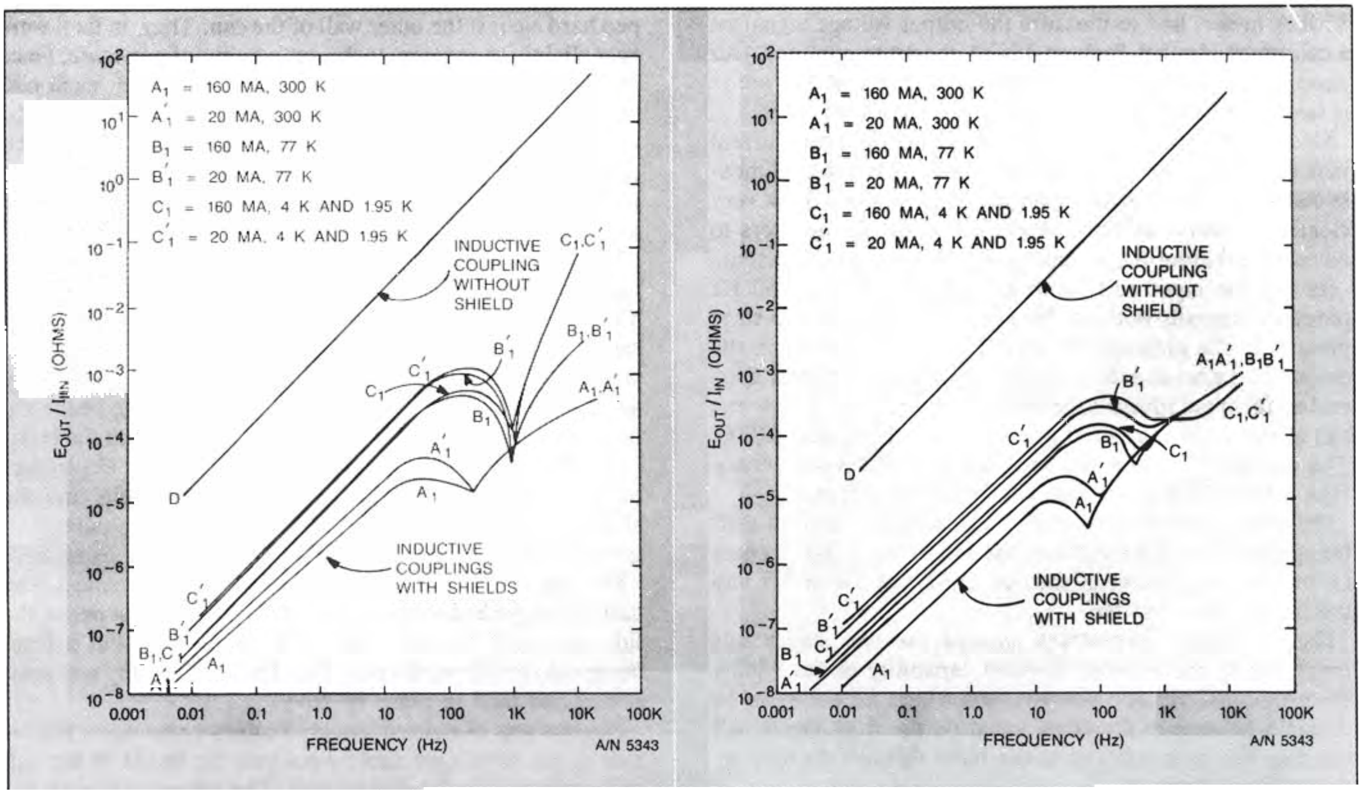
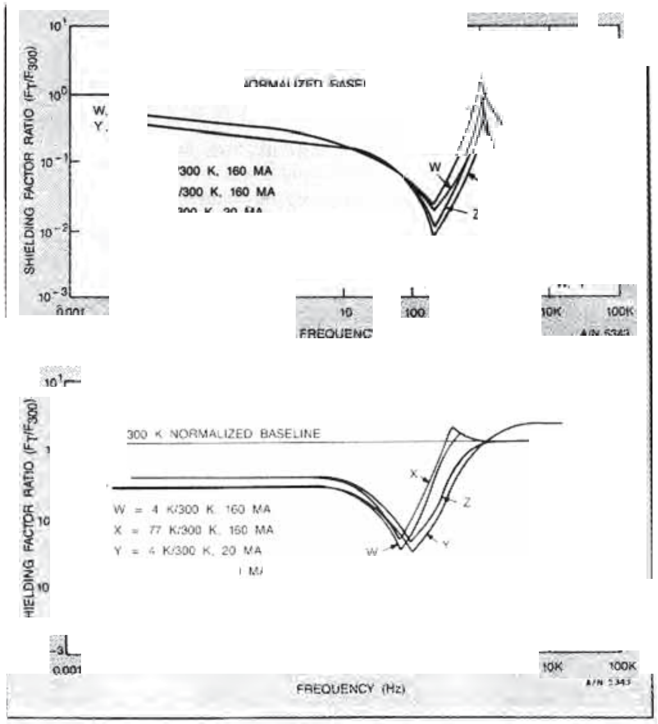


Figure 4 CPEXP-1184 Shielding Factor vs. Frequency, Temperature and Field

Figures 4 and 5. Figures 4 and 5 are plots of the shielding factor as a function of frequency. Curves A_2 through C_2' were obtained by dividing curve D in Figures 2 and 3 by the raw data curves A_1 through C_1'. The resulting set of curves represents the ratio of the inductive coupling between the input and output coils without shielding to the inductive coupling between the coils with shielding as a function of frequency, temperature and excitation field strength.



Figures 2 and 3. Curves A_1 through C_1' are raw data plots of Eout/Iin as a function of frequency with excitation currents and temperatures as shown in Figure 2. Curve D is the inductive coupling between the input and output coils as a function of frequency with no shielding between them. Curve D is identical for all currents and temperatures within the domain of interest.



Figures 6 and 7. Figures 6 and 7 represent the effect of temperature on the shielding factor ratio as a function of frequency, normalized to a 300°K baseline.

of ferromagnetic behavior, the reader is referred to the list of references at the end of the paper. Details of the annealing process, being one of a proprietary nature, are not discussed. Any differences in the shielding factor characteristics of the two specimens are assumed to be a function of the fabrication and annealing processes.

The behavior of the two cans as a function of temperature, frequency and excitation field strength is nearly identical below 1 kHz. The shielding factor of both materials is relatively constant as a function of frequency between .01 Hz and 10 Hz and increases by nearly two orders of magnitude between 1 Hz and 1 kHz. Divergent behavior in the shielding factor is observed in the AD-MU-78 sample above 1 kHz, with its 4°K shielding factor falling off by two orders of magnitude and its 300°K shielding factor improving slightly.

The CP-EXP-1184 can shows convergent behavior above 1 kHz with a marked improvement in the 4°K shielding over that at 300°K.

A slight field strength dependence is evidenced in both materials. Below 100 Hz, CP-EXP-1184 exhibits a field strength dependence throughout the entire temperature domain, whereas AD-MU-78 shows a field strength dependence only at 300°K. Between 100 Hz and 1 kHz, the primed and unprimed CP-EXP-1184 data curves converge, indicating a dramatic falloff in the field strength dependence of the shielding factor within this frequency band. A temperature-dependent translation of the point of convergence is observed with this point translated to higher frequencies at lower temperatures. All of the CP-EXP-1184 data curves intersect at 1 kHz with the 300°K and 77°K curves converging thereafter. The 77°K and 4°K shielding factors of AD-MU-78 are identical below 100 Hz. A slight temperature dependence within this temperature domain is evidenced between 100 Hz and 1 kHz, with a dramatic increase in the temperature dependence above 1 kHz.

The shielding factor curves show a crisp-like behavior between 100 Hz and 1 kHz, again attributed to skin effects, with a temperature dependent translation in the maximum shielding factor to higher frequencies. At frequencies above this critical value, the shielding factor is no longer dependent on the applied field strength.

Between 10 Hz and 100 Hz, both samples show an order of magnitude degradation in their shielding factor ratios. A minimum occurs at ~ 100 Hz for the CP-EXP-1184 sample and at ~ 200 Hz for AD-MU-78. Between 100 Hz and 1 kHz, an increase in the shielding factor ratio of almost two orders of magnitude was observed for both samples. Although the shielding factor ratio degrades between 10 Hz and 100 Hz, the shielding at all temperatures, for both samples, increases within this frequency band. It should be noted that, although both samples exhibit relatively stable shielding as a function of frequency between .01 Hz and 10 Hz, there is virtually no frequency dependence of the shielding factor ratio of the CP-EXP-1184 sample within this frequency range, although a slight linear decrease in the shielding factor ratio of AD-MU-78 is observed.

Summary

Many high permeable soft ferromagnetic materials can be bought commercially, however, very few are commercially available which exhibit effective shielding at cryogenic temperatures down to 4°K. AD-MU-78 and CP-EXP-1184 are of the same material composition, however, they have undergone separate and distinct processes. Although both sample materials exhibit similar behavior below 1 kHz, their behavior becomes quite divergent at frequencies above 1 kHz. Whereas AD-MU-78 degrades significantly in going from 300°K to 4°K at these high frequencies, the CP-EXP-1184 sample shows a marked improvement in its 4°K shielding factor over its shielding factor at 300°K.

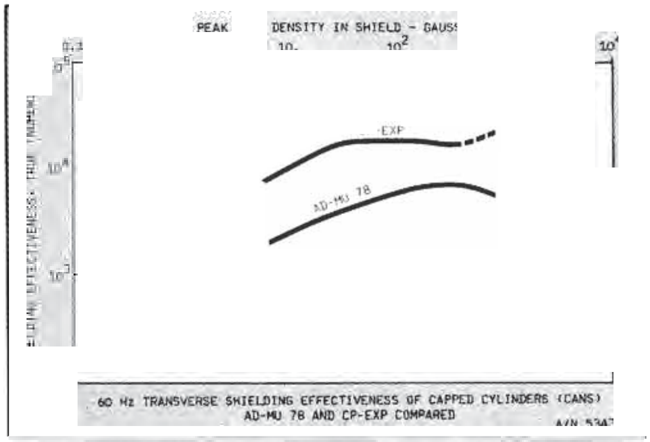


Figure 8. 60 Hz Transverse Shielding Effectiveness of Capped Cylinders (cans), AD-MV 78 and CP-EXP Compared.

It can be concluded that for shielding at low frequencies, both AD-MU-78 and CP-EXP-1184 exhibit effective and stable behavior as a function of temperature, however, for shielding at frequencies above 1 kHz, CP-EXP-1184 is a much better shield at cryogenic temperatures. Because of their shielding effectiveness at low temperatures, they would, therefore, be useful for localized cryogenically cooled magnetic shielding for such devices as sensitive magnetometers. **EE**

Magnetic Shielding

Many magnetic shielding problems can be solved with a pair of scissors and a sheet of magnetic foil. The thickness of the shield and the number of layers required are determined first by simple formulas. The foil is then hand-trimmed to the required outline and fitted around the structure to be shielded. Measurements then tell whether refinements are needed. If you have only a few shields to worry about, the job is done. If you have thousands to make, this is still a good initial design procedure.

Satisfactory ductile foil material ranging from 0.002 to 0.01-in. thick, is available in a variety of permeabilities. It may be best to start with 0.004 or 0.006-in. thickness. Adhesive tape can hold the shield in place. Low-permeability foils are usually 0.004-in. thick, and high-permeability foils can be obtained as thin as 0.002 in. Several widths are available.

Mathematical approach

The best materials to use, the most efficient geometries and the degree of shielding attainable can be found out by trial and error, but that's time-consuming and imprecise. On the other hand, a purely mathematical approach can be very complex, and because of the many simplifications and assumptions that must be generally made to simplify calculations, the results can be unreliable unless the engineer makes some measurements. An approach that combines the insights of a mathematical analysis and practical trial and error, produces the best results.

The mathematical analysis of magnetic shielding is an ancient subject.[1] One of the first conclusions drawn by investigators was that multiple, concentric shields are more effective than increased thicknesses of a single magnetic material shell. Beyond a certain thickness, it has been found, much greater shielding can be obtained if the shell is divided into several layers of alternate magnetic and nonmagnetic material. For a sphere or long cylinder, when the radii of the layers are large compared with their thickness, best results are obtained when the alternate magnetic-nonmagnetic layers are approximately equally thick.

The general equations for calculating the degree of shielding in multilayer shells are complex; a calculator or computer is usually required to obtain solutions. But for a single-layer enclosure, an approximate solution is:

$$g_1 = H_o/H_i = \frac{\text{field intensity outside the shield}}{\text{field intensity inside the shield}}$$

$$\begin{aligned} &= (\mu/4)\,(1 - r_i^2/r_o^2) \\ &= (\mu/4)\,[(t^2/r_o^2) - (2t/r_o)] \\ &\cong \mu t/2r_o\ (t \ll r_o),\ \text{when } (r_o - t) \text{ is substituted for } r_i. \end{aligned} \tag{1}$$

where,

μ = permeability of the magnetic material,
r_i = inner radius of the shield,
r_o = outer radius of the shield,
t = thickness of magnetic material.

These equations are valid for spherical shields or for cylindrical when the length-to-diameter ratio is 4 or more. For multilayer shields, each additional magnetic-material layer around the first layer multiplies the attenuation by roughly

$$g_{ij} = \mu t^2/r_o^2 \tag{2}$$

As an example, assume that a shield is in the form of a long cylinder with an OD of 2 in. and wall thickness of 0.02 in. and that the shield material has $\mu = 10^5$. Then the shield can produce attenuation of $0.02 \times 10^5/2 \times 1 = 1000$. Doubling the thickness of the material would only double the attenuation. But if a second 0.02-in.-thick magnetic layer, about 0.02-in. away, surrounds the first, the attenuation is 40 times greater, or 40,000. The space between the two magnetic layers must be occupied by nonmagnetic material, such as copper, aluminum or any dielectric material.

Magnetic saturation

Equations 1 and 2 are approximations; but, even with use of a fully expanded equation,[2] the results are still approximate. This is because all mathematical analyses assume that the magnetic material behaves linearly–flux density is directly proportional to magnetomotive force–and that, thus, μ is a constant. This is not true, especially with the high-permeability materials that are used for shielding. In addition to nonlinearity, magnetic materials saturate. At saturation the permeability is very low, and the material has little shielding ability.

Experience indicates, therefore, that the thickness of shield material should be selected to keep the flux density in the material in the range of 2500 to 3500 gauss, because generally the permeability is maximum in this region of flux density. When the flux densities become larger than can be handled by a single sheet of foil material, multiple layers can be used. Or heavier-gauge sheets, to about 0.05 in., can be bent, stamped or drawn into the desired shape with shop tools. However, unlike foil, heavier-gauge material requires heat treatments after fabrication.

Obviously, it is desirable to use shield material with the highest possible μ. However, as the magnetic material table shows, high-permeability materials saturate at lower flux levels. Thus when multiple-layer shields are designed to provide high levels of attenuation, the outer layer (which is exposed to the highest intensity of flux density) should be selected from high-saturation-level, albeit lower-μ, material. Shielding materials are classed as having low, medium or high permeability. Low-permeability materials, though, have high saturation levels–18,000 to 20,000 gauss. Medium-permeability materials saturate at somewhat lower levels–roughly 15,000 G. And the high-permeability materials saturate in the 7500-to-9000-G. range. Also, retentivity is related to permeability. Minimum retentivity may be an important requirement for assemblies that are sensitive to low dc magnetic fields. High-permeability materials have the lowest retentivities.

An example where theory can be misleading because of saturation occurs in the often-quoted criterion[2] for optimum shield thickness.

$$t = 3r_i/2\mu$$

In this case it is better to use multilayered construction. In the previous example, with $r_i \simeq 1$ in. and $\mu = 10^5$, $t = 1.5 \times 10^{-5}$ in. However, most magnetic materials, when this thin, quickly saturate in a field of any reasonable intensity. Moreover the material would be too fragile to fabricate.

The need for magnetic shielding

It is often hard to determine whether a problem is caused by magnetic fields. Many sources, including the earth, generate magnetic fields. Other system components, such as CRTs, photomultipliers, every coil and magnetic memories and tapes, can be affected by these fields. The effect can be a simple positioning error in a dc field. If the field is time-varying, it can cause hum or degradation of a CRT's resolution.

It used to be difficult to measure a magnetic field accurately. A small coil, excited with a distinctive ac signal, could serve as a source to determine if the circuit was susceptible to magnetic interference. The small coil could also be used as a pickup probe to detect ac fields. Though crude, these improvisations were often very effective, but they provided little in the way of accurate measurement of the field strengths that were present. Today, gaussmeters accurately cover the range from 0.02 to 50,000 G for frequencies from dc to 20 kHz and higher, and provide direct readings as easily as a voltmeter. The probes to detect the magnetic field are usually Hall-effect, InAs elements. For calibration, the National Bureau of Standards will certify the flux value of a simple permanent-magnet reference. A well-stocked electronic laboratory should have a gaussmeter, and its probe can be used to hunt and measure interfering magnetic fields with ease.

After the offending field is detected and mapped, the accessibility and component layout in the region of the field will determine whether it is better to enclose the source or the pick-up device, or perhaps both. A first-trial shield can be put together with the foil-and-scissors technique, and the results can be checked with a gaussmeter probe. Several adjacent foil layers can be applied to provide a simple, thick shield. Or a spirally wound foil, sandwiched with copper or aluminum foil, can produce a multilayer shield for greater shielding.

When the shape, thickness, number of layers and material types have been established by rough mathematics and measurements, more permanent designs can be undertaken, and companies that specialize in magnetic-shield fabrications can be called in. Now you can talk intelligently, with known facts and figures. Often a manufacturer may have a stock shield to suit your problem, or he may be able to modify one of his shields economically.

Electrostatics

Since ferromagnetic shielding alloys are reasonably conductive, proper grounding of an electromagnetic shield can usually provide an adequate electric-field shield at low frequencies. Grounding is not necessary to obtain magnetic shielding, but it's good practice. At increased frequencies, skin effect becomes a dominant factor, and the conductivity of the shield material should be greater than that of permeable alloys. For good conductivity, materials like aluminum or copper are needed. One way of combining magnetic and electrostatic capabilities in a single-layer shield is to copperplate the magnetic shield with sufficient copper to satisfy skin-effect requirements.

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1. Giovanni Battista della Porta, Magiae naturalis, sive de miraculis rerum naturalium . . . *Libri VII (1589).*

2. Wadey, W. G., "Magnetic Shielding with Multiple Cylindrical Shells." *The Review of Scientific Instruments*, Nov., 1956, pp. 910-916.

3. Kraichman, M. B., "Handbook of Electromagnetic Propagation in Conducting Media," NAVMATP-2302, available from Supt. of Documents, Gov't Printing Office, Washington, D.C. 20402.

The above article was prepared by Richard D. Vance, President, Ad-Vance Magnetics, Inc., Rochester, Ind. ITEM

BASIC MAGNETIC PARAMETERS

Magnetic Property	Symbol	Defining Equation	MKS Unit	CGS Unit
Magnetomotive Force	$\mathcal{F}$	$\mathcal{F} = NI$	ampere-turn	1 gilbert = 10/4π or 0-79577 ampere turn
Flux	ϕ	$EMF = -N d\phi/dt$	weber[1]	1 maxwell (line) = 10^{-8} weber (1 weber = 10^{8} maxwells)
Reluctance (Magnetic Resistance)	$\mathcal{R}$	$= \frac{\mathcal{F}}{\phi}$	$\frac{\text{ampere-turn}}{\text{weber}}$	$\frac{\text{gilbert}}{\text{maxwell}} = \text{magnetic ohm}$
Reluctivity	ν	Reluctance/unit length		
Magnetizing Field (inducing magnetic field)	H	$H = d\mathcal{F}/dl$	$\frac{\text{ampere-turn}}{\text{meter}}$	1 oersted = $10^{3}/4\pi$ or 79.577 amp-turn/m
Flux Density (resulting induced magnetic Induction Field)	B	$B = \mu H$ $\phi = \iint B\,dA$ (Flux = B × Area)	tesla = weber/m² $= \frac{\text{newton}}{\text{amp-m}}$	gauss = 10^{-4} tesla (1 tesla = 10^{4} gausses)
Permeability	μ	$\mu = B/H$; inverse of reluctivity	$\frac{\text{weber}}{\text{m}^2} \Big/ \frac{\text{amp-turns}}{\text{m}}$ $= \frac{\text{weber}}{\text{m-apere-turns}}$	$\frac{\text{gauss}}{\text{oersted}}$
Permeance	$\mathcal{P}$	Inverse of reluctance		
Inductance	L		henry = inductance that produces counter-EMF of 1V when current changes at a rate of 1 amp/second	
Intensity of Magnetization	$\mathcal{J}$	$B = \mu_0 (H_\mu + \mathcal{J})$; $\mathcal{J} = xH$	amp-turn/meter	oersted
Susceptibility	x	$\mathcal{J}/H$	dimensionless	dimensionless

[1] Weber = joule/amp = volt-sec

[2] Permeability of free space (μ_0) $= 4\pi \times 10^{-7} \frac{\text{joule}}{\text{amp}^2\text{-meter}} = 4\pi \times 10^{-7} \frac{\text{weber}}{\text{amp-meter}} = 4\pi \times 10^{-7} \frac{\text{henry}}{\text{meter}}$

[3] Permittivity of free space (ϵ_0) $= \left[\frac{1}{4\pi \times (2.998)^2 \times 10^9}\right] = 8.85 \times 10^{-12}$ Farad/meter

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Shape foil into a magnetic shield

with scissors. Permeability, thickness and the layers needed are determined by simple formulas and measurements.

Many magnetic shielding problems can be solved with a pair of scissors and a sheet of magnetic foil. The thickness of the shield and the number of layers required are determined first by simple formulas. The foil is then hand-trimmed to the required outline and fitted around the structure to be shielded (Fig. 1). Measurements then tell whether refinements are needed.

If you have only a few shields to worry about, the job is done. If you have thousands to make, this is still a good initial design procedure.

Satisfactory ductile foil material, ranging from 0.002 to 0.01-in. thick, is available in a variety of permeabilities. It may be best to start with 0.004 or 0.006-in. thickness. Adhesive tape can hold the shield in place.

Low-permeability foils are usually 0.004-in. thick, and high-permeability foils can be obtained as thin as 0.002 in. Several widths are available.

Mathematical approach provides insights

What are the best materials to use, the most efficient geometries and the degree of shielding attainable? You can find out by trial and error, but that's time-consuming and imprecise. On the other hand, a purely mathematical approach can be very complex, and because of the many simplifications and assumptions that must be generally made to simplify calculations, the results can be unreliable unless the engineer makes some measurements. An approach that combines the insights of a mathematical analysis and practical trial and error, produces the best results.

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1. **A pair of scissors and a roll or two of foil magnetic-alloy material** are all you need to fabricate a practical magnetic shield.

The general equations for calculating the degree of shielding in multilayer shells are complex; a calculator or computer is usually required to obtain solutions. But for a single-layer enclosure, an approximate solution is:

$$g_1 = H_o/H_i = \frac{\text{field intensity outside the shield}}{\text{field intensity inside the shield}}$$
$$= (\mu/4)\ (1 - r_i^2/r_o^2)$$
$$= (\mu/4)\ [(t^2/r_o^2) - (2t/r_o)] \qquad (1)$$
$$\cong \mu t/2r_o (t << r_o), \text{ when } (r_o - t) \text{ is substituted for } r_i.$$

In these equations,

u = permeability of the magnetic material,
r_i = inner radius of the shield,
r_o = outer radius of the shield,
t = thickness of magnetic material.

Richard D. Vance, President, Ad-Vance Magnetics, Inc., Rochester, Ind. 46975.

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These equations are valid for spherical shields or for cylindrical when the length-to-diameter ratio is 4 or more.

For multilayer shields, each additional magnetic-material layer around the first layer multiplies the attenuation by roughly

$$g_{ij} = \mu t^2/r_o^2. \qquad (2)$$

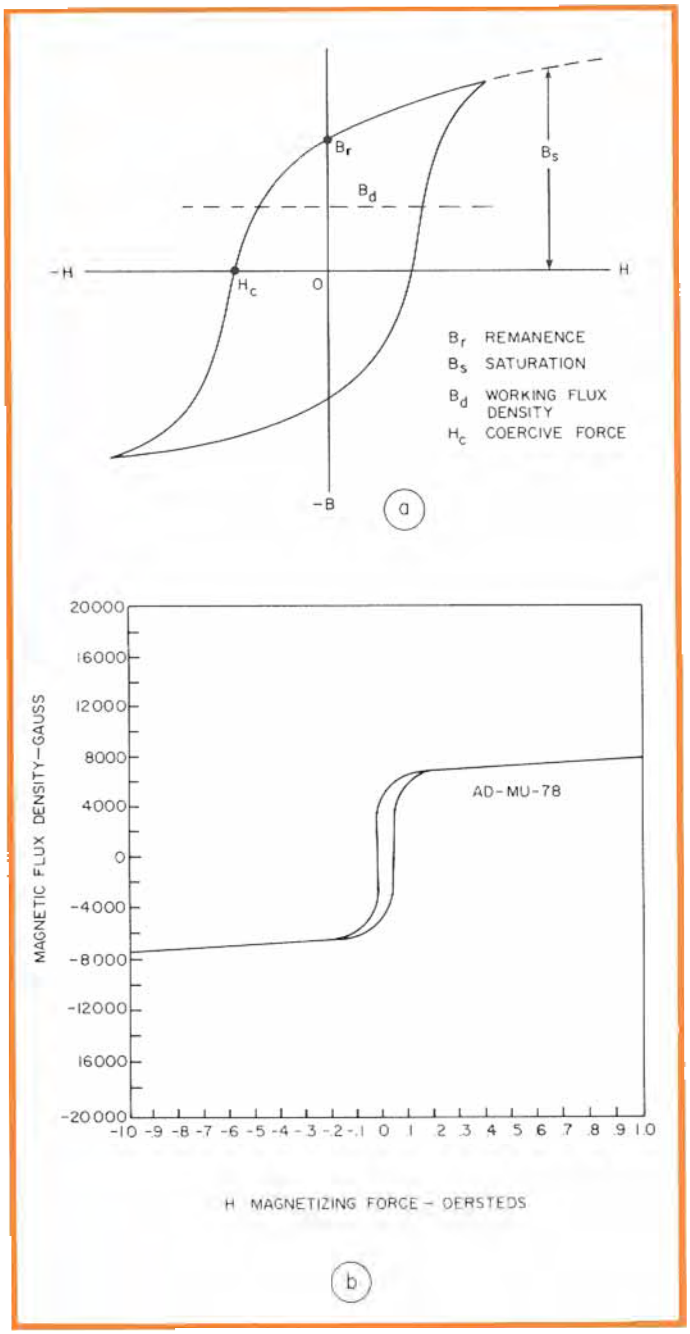
As an example, assume that a shield is in the form of a long cylinder with an OD of 2 in and wall thickness of 0.02 in. and that the shield material has $\mu = 10^5$. Then the shield can produce attenuation of $0.02 \times 10^5/2 \times 1 = 1000$. Doubling the thickness of the material would only double the attenuation. But if a second 0.02-in.-thick magnetic layer, about 0.02-in. away, surrounds the first, the attenuation is 40 times greater, or 40,000. The space between the two magnetic layers must be occupied by nonmagnetic material, such as copper, aluminum or any dielectric material.

Magnetic materials saturate

Eqs. 1 and 2 are approximations. But even with use of a fully expanded equation,[2] the results are still approximate. This is because all mathematical analyses assume that the magnetic material behaves linearly—flux density is directly proportional to magnetomotive force—and that, thus, μ is a constant. This is far from true, especially with the high-permeability materials that are used for shielding (Fig. 2). In addition to nonlinearity, magnetic materials saturate. At saturation the permeability is very low, and the material has little shielding ability (see table).

Experience indicates therefore that the thickness of shield material should be selected to keep the flux density in the material in the range of 2500 to 3500 gauss, because generally the permeability is maximum in this region of flux density.

When the flux densities become larger than can be handled by a single sheet of foil material, multiple layers can be used. Or heavier-gauge sheets, to about 0.05 in., can be bent, stamped or drawn into the desired shape with shop tools. However, unlike foil, heavier-gauge material re-



2. **Permeability—the slope of a BH curve (a)—is not constant,** contrary to the assumption in most mathematical analyses of magnetic systems. The BH curve of AD-MU-78, a high-permeability-alloy, is very steep, and it has an almost rectangular saturation point.

quires heat treatments after fabrication.

Obviously, it is desirable to use shield material with the highest possible μ. However, as the magnetic material table shows, high-permeability materials saturate at lower flux levels. Thus when multiple-layer shields are designed to provide high levels of attenuation, the outer layer—which is exposed to the highest intensity of flux density—should be selected from high-saturation-level, albeit lower-μ, material.

Shielding materials are classed as having low, medium or high permeability. Low-permeability materials, though, have high saturation levels—18,000 to 20,000 gauss. Medium-permeability materials saturate at somewhat lower levels—roughly 15,000 G. And the high-permeability materials saturate in the 7500-to-9000-G range.

Also, retentivity is related to permeability. Minimum retentivity may be an important requirement for assemblies that are sensitive to low dc magnetic fields. High-permeability materials have the lowest retentivities.

An example where theory can be misleading because of saturation occurs in the often-quoted criterion[2] for optimum shield thickness.

$$t = 3r_i/2\mu.$$

In this case it is better to use multilayered construction. In the previous example, with $r_i \simeq 1$ in. and $\mu = 10^5$, $t = 1.5 \times 10^{-5}$ in.

However, most magnetic materials, when this thin, quickly saturate in a field of any reasonable intensity. Moreover the material would be too fragile to fabricate.

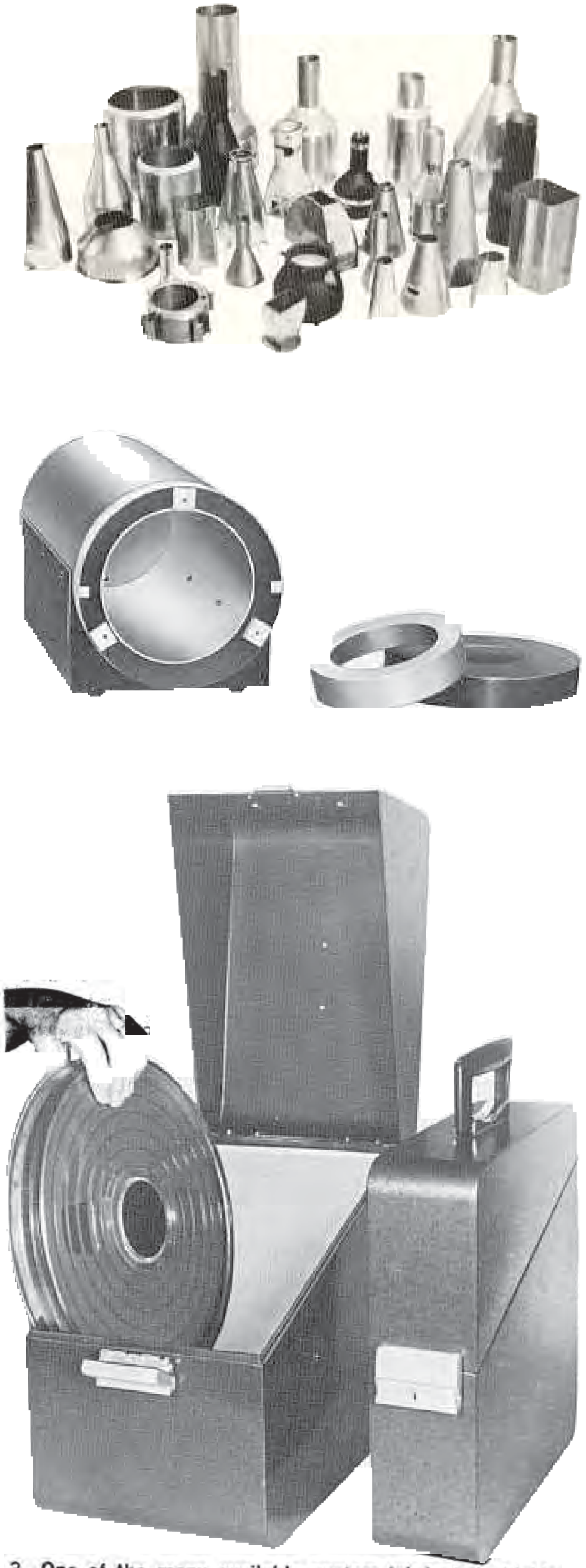
When do you need magnetic shielding?

Often it's hard to determine whether a problem is caused by magnetic fields. Many sources, including the earth, generate magnetic fields. Many other system components such as CRTs, photomultipliers, every coil and magnetic memories and tapes, can be affected by these fields. The effect can be a simple positioning error in a dc field. Or if the field is time-varying, it can cause hum or degradation of a CRT's resolution.

It used to be difficult to measure a magnetic field accurately. A small coil, excited with a distinctive ac signal, could serve as a source to determine if the circuit was susceptible to magnetic interference. Or the small coil could be used as a pickup probe to detect ac fields.

Though crude, these improvisations were often very effective, but they provided little in the way of accurate measurement of the field strengths that were present.

Today gaussmeters accurately cover the range from 0.02 to 50,000 G for frequencies from dc to 20 kHz and higher. They provide direct readings—as easily as a voltmeter does. The probes to detect the magnetic field are usually Hall-effect,



3. **One of the many available custom-fabricated shields (a),** or magnetic-isolation chambers (b), or perhaps a standard package such as a special protective case for magnetic tapes (c), might fill your need for shielding.

Typical dc magnetic properties for shielding alloys

	Material	Initial permeability at 40 gauss	Permeability at 100-200 gauss	Maximum permeability	Saturation induction gauss	Coercive force oersteds
High permeability	Ad-Vance AD-MU-80	35,000	45,000	350,000	8200	0.015
	Ad-Vance AD-MU-78	20,000	30,000	800,000	7500	0.015
Med. permeability	Ad-Vance AD-MU-48	11,000	27,000	100,000	15,200	0.03
Low permeability	Ad-Vance AD-MU-00	300	500	3000	22,000	1.0

SEE NEW CHART IN ENGINEERING SECTION II.

InAs elements. And for calibration of the meters, the National Bureau of Standards will certify the flux value of a simple permanent-magnet reference.

A well-stocked electronic laboratory should have a gaussmeter, and its probe can be used to hunt and measure interfering magnetic fields with ease.

After the offending field is detected and mapped, the accessibility and component layout in the region of the field will determine whether it is better to enclose the source or the pickup device, or perhaps both. A first-trial shield can be put together with the foil-and-scissors technique, and the results can be checked with a gaussmeter probe. Several adjacent foil layers can be applied to provide a simple, thick shield. Or a spirally wound foil, sandwiched with copper or aluminum foil, can produce a multilayer shield for greater shielding.

When the shape, thickness, number of layers and material types have been established by rough mathematics and measurements, more permanent designs can be undertaken, and companies that specialize in magnetic-shield fabrications can be called in. Now you can talk intelligently, with known facts and figures. Often a manufacturer may have a stock shield to suit your problem, or he may be able to modify one of his shields economically.

Note: The magnetic properties in the table are valid only if the material is properly annealed, especially after it has been stressed during fabrication of the shield. Even dropping or jarring the shield can, with some materials, substantially affect permeability. Thus it is wise to order by specifying permeability and saturation—the vendor's material number is not enough.

The annealing process generally is not simply a heating process with slow cooling. It must be done under the proper atmosphere — preferably in a vacuum — and with careful control of cooling rate at predetermined temperature levels.

And, of course, the shield material may require protective finishes, such as cadmium plating or painting.

Shields can also handle electrostatics

Since ferromagnetic shielding alloys are reasonably conductive, proper grounding of an electromagnetic shield can usually provide an adequate electric-field shield at low frequencies. Grounding is not necessary to obtain magnetic shielding, but it's good practice.

At increased frequencies, skin effect becomes a dominant factor, and the conductivity of the shield material should be greater than that of permeable alloys. For good conductivity, materials like aluminum or copper are needed. One way of combining magnetic and electrostatic capabilities in a single-layer shield is to copper-plate the magnetic shield with sufficient copper to satisfy skin-effect requirements. ■■

References

1. Giovanni Battista della Porta, Magiae naturalis, sive de miraculis rerum naturalium . . . *Libri VIII* (1589).

2. Wadey, W. G., "Magnetic Shielding with Multiple Cylindrical Shells," *The Review of Scientific Instruments*, Nov., 1956, pp. 910-916.

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Shielding Materials—When and How to Use Them

When electronic equipment intended to handle certain precise levels of input, whether logic or continuous signal, picks up undesired inputs at the operating, triggering or higher levels, a disfunction occurs. The sources of EMI/RFI include conducted interference via wire, cable, and/or induced voltage and current attributable to electromagnetic fields that couple energy into the calibrated circuits. Sometimes the undesired source is obvious and can be subjected to line filtering or shielding suitable to the frequency and intensity encountered. However, unexpected and unpredicted sources and combinations may not be analyzed so easily.

The earth's magnetic field, of course, is pervasive but not always taken into consideration. Other unwanted fields including electromagnetic pulses of wide dynamic range can be caused by local severe thunderstorms and improperly grounded power cable systems acting as antennas for switching transients on the power lines, or for the low-frequency power currents. In aircraft, for example, instruments are closely packaged due to limited space. The radar tube's performance can be visibly distorted by nearby tachometers which may radiate a rotating magnetic field. The radar display is subject to some position shift each time the aircraft changes direction or attitude relative to the earth's field. A magnetic (*i.e.* permeable) shield enclosure minimizes these effects as well as supporting and positioning the tube.

Clear, sharp CRT readouts are vital in many applications. Yet, without magnetic shielding at the tube neck, this cannot be optimally achieved. In electron microscopes, a magnetic shield around the vertical column prevents resolution deterioration caused by beam scattering, bending or displacement from normal optimum focus position. A sharp, clear focus is thus achieved, permitting full magnification.

Magnetic shielding is indispensable for providing an economical, repeatable controlled magnetic environment for determining response characteristics, sensitivity and orientation direction of magnetic sensor devices used for signature recognition, proximity sensing, etc. in a wide variety of industrial, military and commercial security applications.

Complex, high resolution video recorded head assemblies must be shielded from a wide range of magnetic field interferences that may prevent full operational capability in recording/playback applications in TV studio/mobile, closed circuit, professional home and other video display systems.

Some comparatively new hazards to optimum electronic equipment functioning are still largely unrecognized, such as the low ceilings in modern concrete structures reinforced with steel beams. The metal in the ceilings is much closer to sensitive equipment than was the case in older, higher-ceilinged buildings. The resulting magnetic disturbance is substantially greater than 150 Gamma/cm, a typical magnetic field gradient in older reinforced concrete industrial buildings.

There are also hazards when analogue or digitized data on magnetic tape or cassettes is stored or transported. The fidelity of vital recorded information may be distorted or even partially erased by unforeseen external magnetic fields, or by carelessness of unheeding or uninformed personnel, or by deliberate vandalism with powerful permanent magnets. Tape data protectors provide needed shielding against such hazards. The protectors are used by all branches of the armed forces, NASA, other governmental organizations and many private firms.

Once the offending field source is identified, one practical approach in determining needed shielding is to order a small quantity of heat treated ready-to-use magnetic shielding foil from a shielding manufacturer. It is available for immediate delivery in various convenient widths, lengths and shielding strengths for high or low permeability requirements with a range of electrical conductivities. Foil is easily, quickly cut with ordinary scissors and hand shaped to the desired outline. It is ideal for R/D, hard-to-get-at places, or for small quantity or extremely compact applications. Many shielding problems thus can be solved quickly.

After hand shaping around the component to be shielded, the foil can be held in place with simple adhesive tape. Thickness and number of layers can be determined by ordinary trial and error procedure, or a formula to follow may be requested from the manufacturer. Begin by using a single layer and then adding layers until the desired shielding effect is achieved.

When using multiple layers in steady fields and at low frequencies, the low permeability layer should be closest to the field source. This tends to increase the flux density shielding capabilities. The low permeability layer diverts the major portion of the field, permitting the high permeability layer or layers to operate in a lower reluctance mode. If you need relatively few shields or are experimenting, foil is the swift, economical solution.

Once foil shielding is functioning satisfactorily in either experimental or production applications, it is time to evaluate the economics. The cost of foil versus prefabricated shields for that particular application should be compared. A prefabricated shield is less costly in larger quantities and for certain complex applications.

For designing and manufacturing prefabricated magnetic shields in-house, sheet stock may be ordered. Sheet stock may be formed by bending, stamping, drawing, finishing, etc. on ordinary sheet metal equipment and finished by plating, MIL spec painting, etc. For optimum magnetic shielding characteristics, shields *must be heat treated* after all forming, welding and machining operations.

Your supplier will guide you in the use of the various available states of heat treatment, such as the one which permits ease of forming (mill annealed) or the treatment which assures the maximum mechanically stable permeability or the absolute maximum permeability (which is not necessarily stable mechanically or thermally in some high nickel alloys).

High electrical conductivity and high magnetic permeability both contribute to the effectiveness of thin foils in fast-rising pulse shielding by reducing the skin depth. Distinctions have lately been made between the case where the foil thickness exceeds the skin depth and where it is greater. This type of shielding against pulse-type interference achieves the highest order of shielding effectiveness generally obtained by any means. Attenuations between 300 dB and 1000 dB are not unusual. ●

Richard D. Vance
Ad-Vance Magnetics, Inc.
Rochester, Ind.

SHARPENING RESOLUTION OF CRT DISPLAYS

Introduction

Many displays are not as sharp and clean as the potential built into them by the Cathode Ray Tube (CRT) manufacturer, even after magnetic shielding is later installed. This is often the avoidable result of not enough space allowed by the packaging designer to install the optimum shield. The cause lies in the modern emphasis on ever denser packaging. Hence electromagnetic shielding of CRTs is liable to be considered a negative factor by designers. The ultimate price is a display not as sharp and clean as it could be.

Effective electromagnetic shield performance for static magnetic field interference and low frequency alternating electromagnetic fields depends on more physical space than generally allowed. Substantial spacing between concentric shielding layers makes for efficient use of high permeability conductive cylindrical shields. When the interfering field is virtually uniform, due to its source being at least several meters away, two concentric shells usually provide what shielding is needed. But this cannot be achieved without adequate clearance space around the CRT neck. Diameter of the outer shield shell should be 1.25 to 1.41 times the diameter of the inner shell. This depends on whether the shields have approximate spherical symmetry or approach more closely to long cylinder shape.

If adequate clearance around the CRT neck has not been preassigned by the packaging designer, thicker shielding material in more closely spaced layers is the only alternative. This not only is more costly but it does not provide the maximum shielding effectiveness per unit weight of magnetic metal. When concentric shielding shells are spaced optimally, total absorption shielding effectiveness greater than the product of the individual layer attenuations is often achieved. However, should shielding layers be crammed into lesser space for "afterthought shielding", the total shielding derived is merely the sum of the individual shell attenuations. The far superior method is for the packaging engineer to set aside adequate shielding space even at the cost of slightly less packaging density. Futhermore, there is approximately a 17 dB advantage at low frequencies for optimally spaced shields versus single layer or laminated shields of the same total mass.

The Optimum Neck Clearance

What is the optimum neck clearance for a shield? It should be equal to 0.7 of the CRT neck glass outer diameter. When deflection yokes are used, additional clearance is needed because deflection linearity is affected by high permeability shield material if yoke and shield are too close. This additional clearance space may also serve another purpose: it permits prototype testing with pliable magnetic shielding foils of various standard thicknesses to find out the necessary thickness and permeability of shield material for optimum shielding. Foil is cut with scissors, shaped by hand or convenient pipe, and placed around the tube neck. A few tests can quickly determine appropriate thicknesses and shield outlines. Calculated designs may then be evaluated and alternate materials compared. Such empirical evaluation applies to both high gradient or near

Fig. 1—Attenuation of Single Shields vs. Nested Shields

Shields .014" thick, 9" high, 2" or 3" dia.
Test: In uniform 60 cycle field from 1 to 10 Oersteds
Annealing Cycle: 2050 F for 4 hrs. in pure dry hydrogen. Cooled at 600 F per hr.

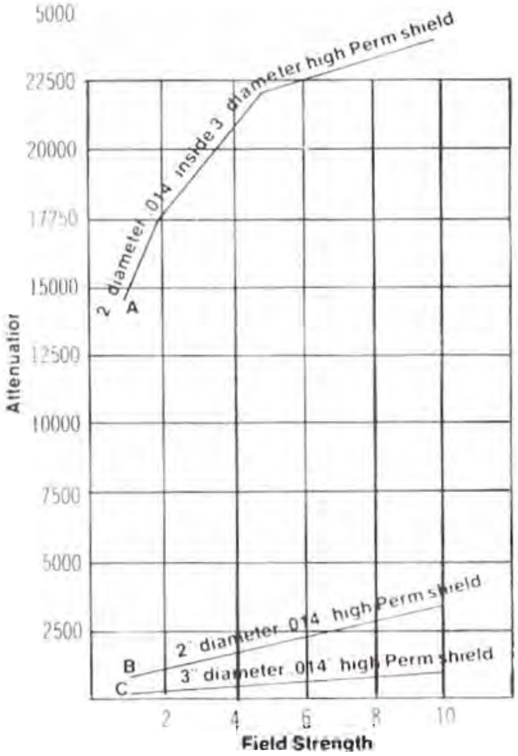


Fig. 2—Attenuation vs. Distance Between Nested Shields

Shields .014" thick, 6" high, 2" dia. inside shield only
Test: In uniform 60 cycle 2 Oersted field
Annealing Cycle: 2050 F for 4 hrs. in pure dry hydrogen. Cooled at 600 F per hr.

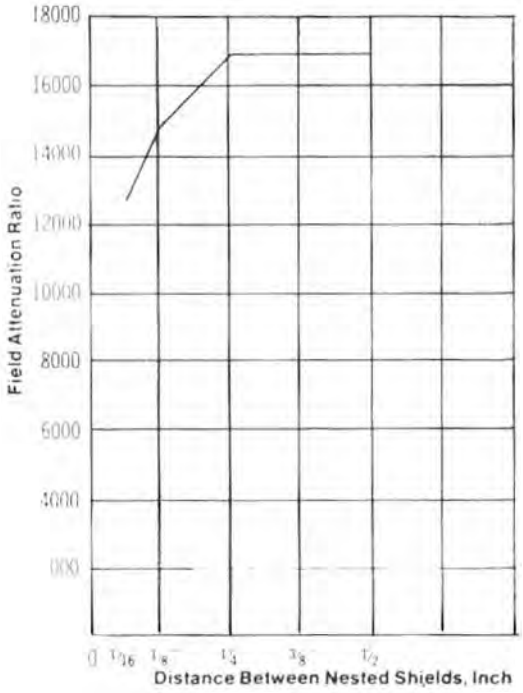


Fig. 1 & 2 Reference: Publ. # EM36-Edl-7M-372 Magnetic Shielding Electrical Materials, Allegheny Ludlum Steel Co field problems and to uniform or far field problems.

Leaving adequate clearance around the CRT neck is imperative not only for optimum magnetic shielding, but may enhance better convection or forced ventilation cooling of the neck area.

The distance of the undersired magnetic field source from the shield is important in estimating a concentric or simple shield. The distance must be sufficient to permit meaningful calculations by means of accepted uniform field approximations or plane wave assumptions. If the distance is within a meter or two from the display module, then the static or V.L.F. attenuation of practical shield structures such as circular cylinders is modified by the distribution of resulting magnetic induction, particularly in the outer shield shell. Such non-uniform impinging field is especially troublesome on scanning field emission type electron microscope units of high magnification. The scanning beam is modulated by the very slightest non-uniformity of the residual static magnetic field inside the shield assembly. The visual effect is quite similar to that of AC magnetic fields impinging on unshielded CRTs.

Estimating Shield Thicknesses

Successful functioning of a device containing a CRT depends on very low field gradients. Properly spaced magnetic shield layers reduce the field gradients by about the same factor as they reduce average field magnitude. In the case of "near field" problems, the outer shell may have to be thicker or thinner than for a uniform permeability in the shield obtained with AD-Mu80 for transverse field when max-induction is less than 200 gauss. Or, it may require using lower permeability and higher saturation flux density materials. But if adequate clearance for proper shielding has been provided, the inner shell's functioning can be predicted by simple calculations and can provide in its interior an even smaller static field gradient. If the length of a long cylindrical shield measures less than three times its diameter, certain variations can be expected in its performance. For example, with a shield's axis parallel to the interfering field, the greatest attenuation will be towards the ends of the axis, and the least attenuation in the middle.

Shielding Against Steady Magnetic Fields

The aforementioned optimum spacing numbers apply primarily to shielding the earth's and other steady magnetic fields. This procedure has substantial advantages over conventional AC shield design procedures, especially when thin layers are used and both types of fields must be shielded out.

The above article was prepared by Richard D. Vance, President, and William F. Griffith, Engineer, Ad-Vance Magnetics, Inc., Rochester, Ind. ITEM

TERMINOLOGY, IN ORDER OF USE, WITH SI UNIT AND SYMBOL

ϕ = Magnetic flux (weber, Wb)
B = Magnetic flux density (tesla, T)
$\mathfrak{R}$ = Reluctance
$\mathcal{F}$ = Magnetomotive force
H = Magnetizing force (inducing magnetic force field)
μ = Permeability (B/H)
μ_o = Permeability of free space (vacuum)
μ_r = Relative permeability, μ/μ_o
L = Coefficient of self-inductance (inductance, henry, H)
E = Induced voltage (volt, V)
I = Current (ampere, A)
J = Intensity of magnetization
x = Magnetic susceptibility
N = Number of turns
r = Radius

BASIC MAGNETIC RELATIONS

$F = k\,mm'/r^2$	Force between magnetic poles m, m'
$MMF = \phi\mathfrak{R}$	Magnetic Ohm's Law
$MMF = NI$	Magnetomotive Force
$B = \mu H = H + 4\pi J = \mu_o (H + J) = \mu_o (1 + x) H$	Flux Density, by definition
$E_L = -N\,d\phi/dt$	Induced EMF in N turns
$E = BLv$	Induced EMF in straight wire length L, velocuity v, in field B
$E = -L\,dI/dt$	Coefficient of self-inductance (inductance L), by definition
$x = J/H$	Magnetic Susceptibility, by definition
$\mu_r = \mu/\mu_o$	Relative Permeability, by definition
$L = N\phi/I$	Inductance of coil of N turns

FLUX AND FLUX DENSITY

	CGS UNIT	MKS UNIT	RELATIONS
FLUX (ϕ)	line (maxwell)	weber	1 weber = 10^8 lines
FLUX DENSITY (B)	gauss* (1 line/cm^2)	tesla (weber/m^2)	1 tesla = 10^4 gausses

*Terrestrial magnetic fields often are described in units of gammas (1 gamma = 10^{-5} gauss = 10^{-9} telsa)

MAGNETIC FORCES—MMF AND H

	CGS UNIT	MKS UNIT	RELATIONS
Magnetomotive Force (MMF, $\mathcal{F}$)	gilbert (dyne/unit pole)	ampere-turn	1 gilbert = $10/4\pi$, or 0.796 ampere-turn
Magnetizing Force Field (magnetizing field, H)	oersted (gilbert/cm)	ampere-turn/meter	1 oersted = $10^3/4\pi$ or 79.577 ampere-turn/meter

FLUX DENSITY

SYMBOL	DEFINITION	MKS UNIT	CGS UNIT	RELATION
B	Flux density resulting from magnetizing force field H. $B = \mu H$ $\phi = \iint BdA$ (flux = B × Area)	tesla, T (weber/m^2)	gauss (1 line/cm^2)	1 tesla = 10^4 gausses

RELUCTANCE AND PERMEABILITY

SYMBOL	CGS UNIT	MKS UNIT	RELATION
Reluctance, $\mathfrak{R}$	$\frac{\text{gilbert}}{\text{maxwell}}$	$\frac{\text{ampere-turn}}{\text{weber}}$	Magnetic resistance ($\mathfrak{R} = \mathcal{F}/\phi$); "magnetic ohm"
Permeability, μ	gauss/oersted	$\frac{\text{weber}}{\text{m}^2} \Big/ \frac{\text{amp-turns}}{\text{m}} = \frac{\text{weber}}{\text{m-amp-turns}}$	Reciprocal of reluctivity; B/H; $\mu_r = \mu/\mu_o$; $\mu_r = 1 + x$
Permeance $\mathcal{P}$			Reciprocal of reluctance
Reluctivity ν			Reluctance/unit volume; reciprocal of permeability

The neck of CRT tubes are especially vulnerable to EMI. Even for prototype packaging, extraneous radiation can inhibit optimum performance. **Richard D. Vance** and **William F. Griffith** of Ad-Vance Magnetics describe how a concentric shield configuration can offer maximum protection. A big factor is in early planning so that adequate volume is available; page 125

Packaging CRT Displays In Near-Field Environments

The neck of a CRT is vulnerable to EMI. Concentric shields require the allotment of adequate volume.

By Richard D. Vance and William F. Griffith, Ad-Vance Magnetics, Inc., Rochester, Ind.

The increased emphasis on shielding techniques that can cope with nonuniform magnetic fields is partly due to trends in building design observable in newer industrial laboratories. These include lower ceilings and the accompanying concentrations of structural steel beams and reinforcing rods in the concrete. The earth's magnetic field is almost unrecognizable in some new buildings. A compass needle moved across a floor area in such a building is liable to spin indecisively and to reverse direction as it passes under successive I-beam supports. It could be said that some research laboratory areas of recent construction have, pervasively, gradients of magnetic field that are an order of magnitude greater compared with older styles of reinforced concrete construction. Shielding of electronic equipment, therefore, is of added importance.

Often, in prototype packaging of equipment using CRTs, electromagnetic shielding is not a mayor consideration. But it should be. The physical laws governing the effectiveness of electromagnetic shield performance for static magnetic field interference and low-frequency alternating E-M fields tend to spatial relationships that are incompatible with the high density packaging of today's display modules. Efficient use of conductive cylindrical shields of high magnetic permeability requires substantial spacing between concentric shielding shells. However, for nearly all cases where the undesired field is nearly uniform (generally due to a source more than several meters distant) two shells are sufficient when adequate clearance space is available around the CRT neck portion. The outer layer diameter should be between 1.25 and 1.41 times the inner layer diameter, depending on whether the shells have equal masses of nickel alloy or equal thicknesses, respectively.

When sufficient space has not been preassigned by the layout draftsman designing the package, then thicker shielding material in closely spaced layers must be used. This expedient is neither cost effective nor attractive for best shielding effectiveness per unit weight of magnetic metal. Optimally spaced concentric shields tend to give total absorption shielding effectiveness that is multiplicative, *i.e.*, equal to the product of the shielding factors of the separate layers. On the other hand, constrained shields with little space between layers yield shielding effectiveness that is merely additive, equal to the sum of the magnetic shielding effectivenesses of the separate layers, (not decibel effectiveness—but the attenuation factor.)

As in automobiles, where space is devoted to protective neck rests, space in CRT display layout should be assigned for shielding around the cathode ray tube. Trying to cram shields into less space—as an afterthought—is analogous to providing surgical neck braces to car drivers after they have suffered whiplash neck injuries. Both are after-the-fact solutions to preventable problems. The proverbial ounce of prevention (or cubic decameter) is preferable by far.

Space equal to 0.7 of the CRT neck glass diameter, at least, should be left as clearance around the neck for magnetic shielding. An even larger


Various CRT shield designs. Wider-spaced, concentric, thin-wall shields are preferred over closely spaced thick shields.

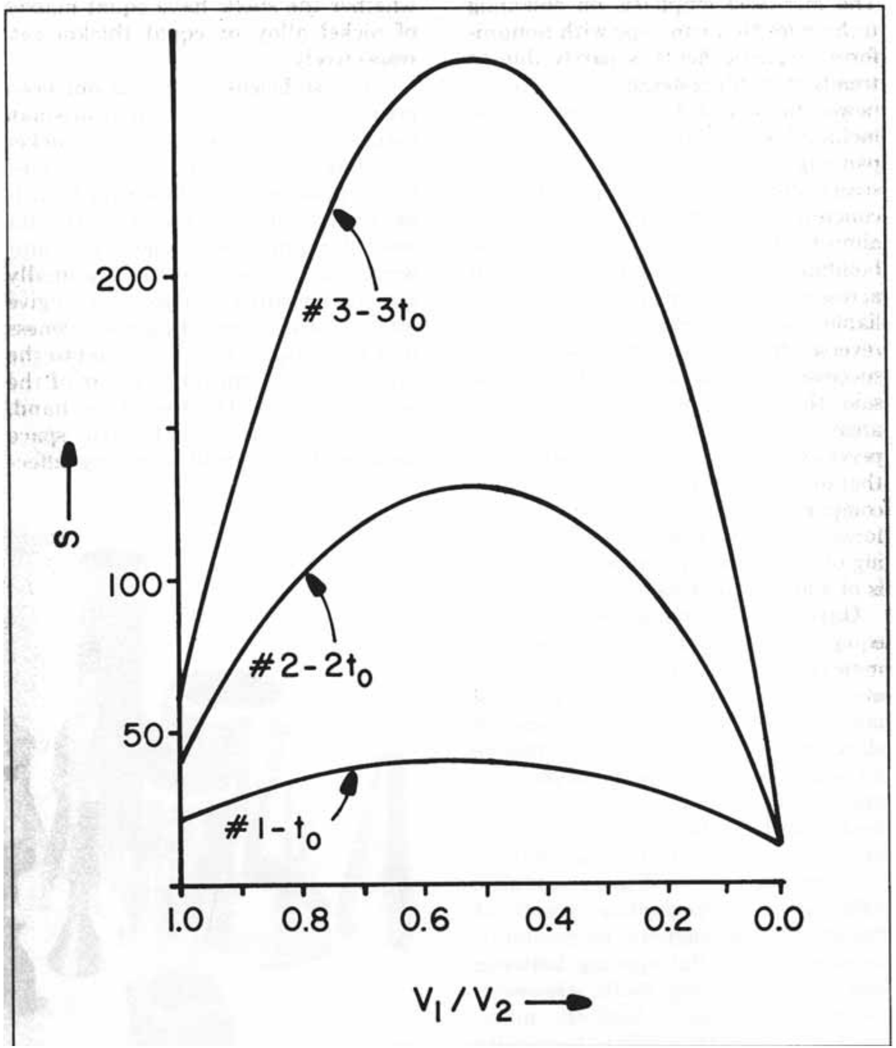
clearance is needed when magnetic deflection yokes are present because permeable shield material affects deflection linearity when placed too near most yokes. This clearance space is useful for determining the necessary thickess and permeability of shield material in prototype tests by means of pliable magnetic shielding foils of various standard thicknesses. A quantity of foil is cut out with scissors, conformed to shape by hand on any convenient pipe, for example, and inserted. By a few such tests, appropriate thicknesses and outlines are determined, calculated designs are evaluated, and alternative materials can be compared. Empirical evaluation by this means applies to both "near field" and "far field" problems (*i.e.,* uniform field and high gradient problems, respectively).

In many applications of CRT tubes there is additional reason to opt for the spacing around the tube that was recommended on grounds of shielding weight and cost effectiveness, namely better convection or forced ventilation cooling of the electron gun region of the neck. Comparing the recommended practice of optimal shield spacing with the usual afterthought heavier-type shield in terms of decibels of AC attenuation, there is about a 17 dB advantage for equal masses of magnetic shield material at low frequencies.

In estimating a concentric or simple shield, it is important to determine whether the source of undesired magnetic field is sufficiently distant from the shield to permit meaningful calculations by means of accepted uniform field approximations or plane wave assumptions. If a source of such field is within a meter or two from the display module, then the static or VLF attenuation of practical shield structures, such as circular cylinders, is modified by the distribution of resulting magnetic induction, particularly in the outer shield layer. Such nonuniform impinging field is particularly troublesome on scanning field emission-type electron microscope units of high magnification. This is the best example, perhaps, for illustrating the problem in shield design—and the solution—posed by nearby magnets, transformers, solenoids or power cables. In these 'scopes, the slightest nonuniformity of the residual static magnetic field inside the shield assembly acts to modulate the scanning beam. This produces a visual effect which, at first sight, suggests effects long associated with strong AC magnetic fields impinging on unshielded CRTs.

When a package includes a device which is dependent for its successful operation on very low field gradients, then it is essential to understand that properly spaced magnetic shield shells

Display unit is designed keeping CRT neck area free of electronic components. CRT with shield (upper); and with shield installed (lower).



Shielding factor versus separation parameter V_1V_2. Plots of S for one, two, and three units of metal equally separated into two spherical shells with the radius and thickness of the inner shell held constant for each curve. (Graph courtesy IEEE©)

reduce the field gradients by approximately the same factor as the average attenuation factor for field strength. For "near field" problems, the outer layer may have to be thicker than it would be in the case of a uniform impinging flux or may require the use of lower permeability or higher saturation flux density materials; but, if the sufficient space for efficient shielding has been provided, then the inner layer can function in a manner predictable by simple calculations and can provide in its interior an even smaller static field gradient. Certain variations from the performance of a long cylinder can be expected when the length becomes less than three diameters; for example in a shield with its axis parallel to the field, the field will be attenuated least in the middle and more towards the ends of the axis.

The "optimum spacing" recommended in this article was primarily intended for shielding against steady magnetic fields, such as the earth's field. When thin shells are used specially and when both alternating and steady fields must be shielded out, then it has substantial advantages over the design for purely alternating fields. For AC only, it is well known that ¼ in. interlayer spacing is the maximum required and the AC permeability is at a maximum when the thickness of the shells or layers is kept minimum.

When the two shells are well separated ($V_1/V_2 << 1$) and each individual shell has high $\mu_i\, t_i/R_i$, the last term dominates, giving further simplification. In this case the shells are decoupled and their shielding is multiplicative rather than additive which is the case for small separation ($V_1/V_2 \approx 1$).

The graph shows the effect of shell separation on the shielding factor S for a fixed amount of shielding material in each shell. The radius R_0 of the inner shell is held constant; this shell has thickness t_m, $2t_m$, and $3t_m$, corresponding to curves one, two and three, respectively, such that the S_i for this shell is 10, 20, and 30, respectively. The outer shell has the same amount of material. Thus, when the outer shell radius R is R_m, the thickness is t_m, $2t_m$, and $3t_m$, respectively. As the radius of the outer shell R is increased, keeping the amount of metal constant (which is optimum), the shell thickness decreases proportionately, but the total shielding factor increases until $R = 1.26R_0$ (where $V_1/V_2 = 1/2$) and thereafter decreases again with increasing separation. The effect is clearly more pronounced as the total amount of material is increased.

The individual shell shielding factor for cylinders is

$$S_i = \frac{1}{2}\frac{\mu_i t_i}{R_i}$$

The total shielding factor for any number of cylindrical shells is

$$S = 1 + S_1 + S_2 + S_3 + \ldots + S_N + S_1 S_2 \left(1 - \frac{A_1}{A_2}\right) S_3 \left(1 - \frac{A_2}{A_3}\right) \ldots S_N \left(1 - \frac{A_{N-1}}{A_N}\right)$$

S = Gross shielding factor, giving the ratio of the uniform ambient DC (steady state) field H_0 to the field H_{in} at the shield's center.

R_i = Outer radius of shell i.

A_i = Cross section area of outer cylinder surface of shell i. (Numbers i begin at inner shell, $i = 1$ and increase by integers for successive shells up to the outer shell, $i = N$).

μ = DC or gross permeability applying to the conditions of the aforementioned S in shell i. It is a function of the induction in the shell i.

t_i = Thickness of shell i.

V_1 = Volume contained by inner shell.

V_2 = Volume contained by outer shell.

This formula shows how the shielding effects of the individual shells are coupled. The coupling is additive when the coupling coefficients $(1 - A_{i-1}/A_i)$ are small and otherwise multiplicative.

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2. Adams, W.S. and Mills, A.H. "Electromagnetic Shielding In The Near Field." *1968 IEEE Electromagnetic Compatibility Symposium Record*, pp. 317-329.
3. Thomas, A.K., "Magnetic Shielding Enclosure Design In The DC and VLF Region." *IEEE Transactions on Electromagnetic Compatibility*, Vol. EMC-10, No. 1, March 1968.

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ELECTRONIC PACKAGING and PRODUCTION

Magnetic Shielding Foil is the Quick Economical Solution to Many Problems

If you need relatively few shields, or are experimenting, or designing, or trying to locate and eliminate an unexpected magnetically emanating source during production, foil is your quick, economical solution. Not only may you save days or weeks of valuable time, you also may eliminate designing, tooling and manufacturing costs for prefabricated shields. In addition, you may gain another cost reducing objective — that of compacting assemblies because magnetically reacting components can now be placed closer to each other without operating disabilities.

The convenience of foil ductility permits cutting with ordinary scissors, hand shaping and trimming into the required outline and applying immediately. The amount of shielding needed in an application can be swiftly and easily determined by trial and error at a saving of many days' time and frustration especially to designers and researchers.

Single or multiple layers can be used until the desired shielding level is attained. Adhesive backed foils are available to hold foil shields in place.

When shielding requirements dictate using a graded permeability shielding system, the low permeability foil should be positoned closest to the field source. This is accomplished by the low permeability foil diverting the major portion of the field, permitting the high permeability to operate in a lower reluctance mode. Low permeability materials tend to have high saturation flux densities.

In a number of individual research applications, this hand-cut, hand-formed foil magnetic shield solves the entire shielding problem. In other experiemental applications and in various production applications, prefabricated shields might serve better. Economics and time are the determining factors.

On the production line, unanticipated magnetic fields may be discovered that affect the performance of the component or system being manufactured or assembled. The handiness of foil shielding could provide a quick, effective cost-saving solution, holding downtime to minutes or hours rather than days or weeks.

Shielding Small Motors Effectively

Another practical example of foil's advantages is typified by Model SMS-70F "triple action" flexible magnetic shields for small motors. The foil sheilds: 1) Add dB's safely to small motor compatibility performance by diverting interfering magnetic radiation. 2) Provide excellent electrical and thermal conductivity. 3) Save design time and costs.

Applications are in tight packaging areas such as avionics, where sensitive instruments are in close proximity to interference radiating from small motors.

Construction consists of high permeability, flexible .010" (0.254mm) thick foil alloy. The foil shield may be used both as a self-sufficient shield and as an auxiliary shield over the motor's normal steel case when case shielding alone is inadequate.

Major factors in diverting radiation effectively are a carefully calculated large bend radius and sufficient overlaps to handle the magnetic fields.

Should the radiating field be strong enough to saturate the high permeability alloy, low permeability alloy may be used by itself or in addition to the high permeability alloy foil. It will absorb a higher total flux than an equal thickness of alloy and will not make ripples in the field (high gradient regions) to the same extent as would a high permeability layer.

Model SMS-70F Performance Test Data

Using a 3-layer cylindrical motor shield of .010" (0.254mm) flexible foil, closed at one end and 3" (76.2mm) from motor axis:

1) Without shield, 400 Hz. radiated field, 177m Gauss. With shield, 80dB less.
2) Without shield, 10 KHz radiated field, .64 Gauss. With shield, approx. 85 dB less.
3) Spacing effect. If space permits, an additional 15 dB can be obtained, approximately, by spacing the outer layer to a radius of 1.4 x the inner shield radius (a shield of 2 equal layers).

Figure 1: Flexible foil is cut easily with scissors and quickly wrapped around CRT neck to provide needed shielding.

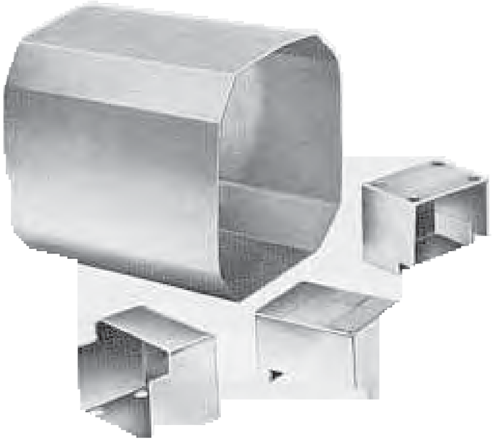


Figure 2: Model SMS-70F "triple action" magnetic shields.

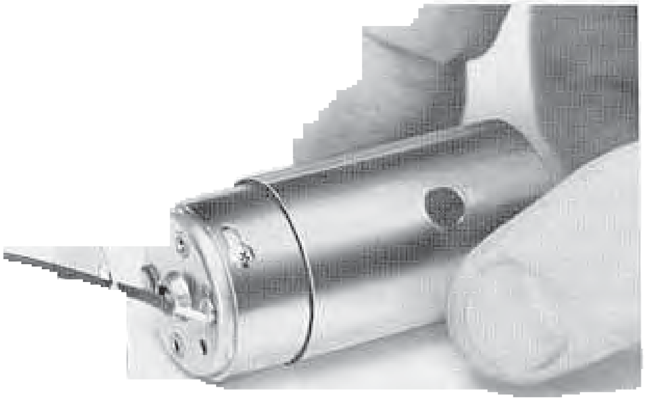


Figure 3: Foil shield wrapped around motor case & foil shielding of cable entry.

An Approach to Creating the Optimum Shield

Which should be shielded — the source of the undesired field or the affected sensor? If a choice exists, some analysts have concluded it is best to shield the source if at all practical.

In any shielding problem it should be remembered, too, that more than just figures may be needed to design a magnetic shield. The reason is that it is difficult to predict precisely how a magnetic field affects a given piece of ferro magnetic alloy, except for a few basic shapes.

Certain estimates must be made in initial calculations of shielding performance expected in a magnetic shielding structure. A number must be established to express the anticipated flux density "H" to which the shield will be exposed. Then an additional estimate must be made that this flux exposure will result in a line density "B" in the shielding material derived from the BH curve for the specific alloy used and the geometry, using a standard shape (cube or cylinder) to represent the desired shape of shield to a first approximation.

Fortunately, in foil shielding, this problem can be empirically solved regardless of shape complexity. For many practical purposes this solves the problem. All that remains is the cutting, trimming, shaping and applying of the foil shields, using normal trial and error means to achieve optimum shielding.

When purchased, foil should arrive fully annealed and ready for immediate use. It should not be subjected to severe forming or welding. However, ordinary cutting and shaping should not affect its shielding properties.

Foil Quality Control Procedure

The procedure is described if, for any reason, you may wish to duplicate it.

The standard inspection set-up should permit continual monitoring of the attenuation capabilities of a strip of foil. A table and adjustable guides on the table's surface direct the foil's travel properly past the test probe area. A controllable magnetic field radiation should be constructed.

Basically used are two solenoid type coils wound on bobbins having a central hole large enough to accommodate a 3/8" dia. soft iron pole piece. These coils are two standard windings removed from commercial 110 AC solenoids — each coil of approximnately 6000 turns of #36 enameled wire. A soft iron pole piece 3/8" OD and approximately 3¼" long is positioned in the assembly, and the two coils connected series aiding. The outside terminations are brought out to a standard AC plug. At the top end of the pole piece, a "flux" sensor made by winding a single layer coil consisting of ten turns of #20 enameled wire is brought out in a twisted pair.

The assembly is then mounted below the table with the top end of the pole piece approximately 1" below the table's surface. A non-magnetically permeable frame locates the magnetic field generator assembly below the table. The top portion of this assembly, holding the calibrated magnetic field probe, is adjustable vertically. A hole or slot in the table is vertically cut normal to the direction of the foil's travel. This slot is wide enough to allow entry of the field test probe. The twisted pair on the flux intensity sensor is brought out and connected to a Hewlett-Packard VTVM (#1), Model 400B or equivalent. The shielded plug on the calibrated magnetic field probe is connected to another VTVM (#2) of the same type. The AC plug from the solenoid winding is connected to a Variac. The calibrated magnetic field probe is then lowered into positon with its field reference plane parallel and in line with the table's surface. The voltage on the Variac is adjusted until the output voltage on the VTVM (#2) indicates 5 oersteds. (In this case the calibrated magnetic field probe had a sensivity of 20 mv per Gauss at 60Hz.) The output of the flux sensor coil is then noted on the VTVM (#1). The sole purpose of the flux sensor is to have a reference to re-establish the flux density appearing at the surface of the table at any time simply by adjusting the Variac for the corresponding voltage.

The calibrated probe is then positioned slightly above the table and locked into position. This position would not be critical and only requires that a reasonable mechanical clearance be maintained between it and the foil. Always maintaining VTVM (#1) at its original setting, the VTVM (#2) reading is noted and designated E1. The foil is then slid under the field probe and across the table. A second voltage, designated E2, is read from VTVM (#2).

Using the voltages noted: $\mathrm{DB} = 20 \log_{10} \frac{V1}{V2}$

The entire order of the 15" AD-MU-78 was passed through the probe area noting the DB level. All of the material had to display a minimum of 18 DB attenuation.

This article was prepared for ITEM by Richard D. Vance, President, Ad-Vance Magnetics, Inc.

Achieving Electromagnetic Field Control in Mini Computers

by Richard D. Vance, President, &
W.F. Griffith, Engineer
Ad-Vance Magnetics, Inc.,
Rochester, Indiana

Graphic computers are being condensed into portable, compact new forms in spite of recommendations of some disk drive manufacturers that their floppy disk units be kept at least 25 cm away from any magnetic deflection yoke. One design tool lately developed, in the EMC science area, facilitates calculation of shielding effectiveness of cylinders in the case where direction of applied magnetic field is parallel to the tube's axis. The estimation of this performance was easy for the case of the transverse field, but cumbersome for the longitudinal field case. This was advised in IEEE Transactions on EMC, Vol. EMC-20, No. 4, November 1978 *A Simplified Computational Technique for Longitudinal H-Field Shielding* by Ernest M. Freeman and M. H. S. El-Markabi, pp. 514–516. The results of their efforts for low frequencies are summarized in the following graph.

Conventional CRT circuitry with a 15.75 kHz vertical output transformer and deflection yoke must be included among the display units encountered in conjunction with the floppy disk equipment. Many displays, however, have yokes operating at substantially lower frequencies. In many cases, the disk reading heads can be enclosed in a tight-fitting permeable-shield cylinder but there is a limit to the cylinder length which should make it advantageous to orient the disk drive assembly so that the yoke field is transverse to the shield cylinder. Alternatively, (and easier to realize in most cases) the yoke field in the region of the disks can be turned 90 degrees by providing a permeable magnetic shield that will divert the stray yoke field down the partition between the CRT and disk drives, or over the yoke field and down the partition between the CRT and disk drive assemblies, or around the whole disk drive assembly. At 15 kHz and higher frequencies it is advantageous to use a multilayer shield consisting of three, four or more layers each having a thickness of 2 to 4 mils.

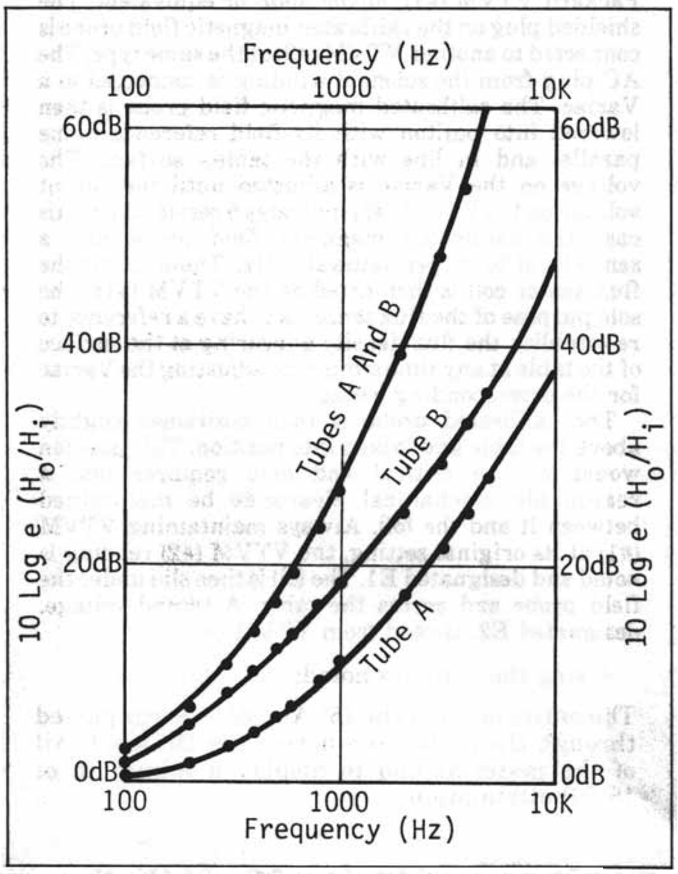


Figure 1—Shielding Effect of Long Concentric Conducting Cylinders in a Longitudinal Magnetic Field, Frequency in Hz

Of course, the interaction between the CRT magnetic deflection system and the disk memory equipment, in the adjacent compartment, can be anticipated at an early point in development and kept to a minimum if a yoke is chosen that has been specifically designed with a permeable magnetic shield. Therefore, a more sophisticated yoke design may be preferred over an industrial or commercial type.

When a sheet of lamina is insufficient is shielding effectiveness, it may be necessary to enclose the disk drives or associated circuitry, or both, completely in an electromagnetic shield enclosure. The disk and drives may have ventilation requirements. So part of the EMC design in this package is a calculation of perforation size for optimum ventilation and shielding. A general rule provided by EMC research results, circa 1968 for low frequencies, is that the perforation should be uniformly dispersed over 30% maximum of the shield surface. Design nomographs for perforated shielding were published in the 1968 IEEE Electromagnetic Compatibility Symposium Record (IEEE Publication number 68C12-EMC) in a paper by Robert B. Cowdell entitled *Simplified Shielding for Perforated Shields*. Complete enclosure of the disk drive or the CRT compartment is liable to be unavoidable when the design is such that the disks are vertically oriented instead of the more common horizontal position. In terms of relative costs, such a perforated enclosure may be more economical than a CRT-yoke shield. Ω

Information Display

The Official Journal of the Society For Information Display

Collection of Magnetic Shields for encapsulating various sizes of CRTs is shown with Richard D. Vance, president, Ad-Vance Magnetics, Inc., Rochester, Indiana. Shield fabrication involves deep drawing, metal spinning, and heliarc and spot welding. Materials range from 0.025 to 0.062 AD-MU-78 high permeability shielding alloy.

A unique CRT shield with support mounts and terminals is in SID member Rick Vance's hand. The accompanying article beginning next page discusses protection against the earth's magnetic field, denser packaging problems, unexpected hidden hazards to equipment performance in modern construction, solutions to certain CRT shielding problems, and the pros and cons of low cost "instant" CRT shields made of foil.

FRONT COVER MATERIAL WELCOMED: Every month **Information Display** usually features one or more active members of SID and the products with which they are most closely associated. Please send a glossy print and appropriate captions so that you, too, can be on our front cover. Send your material to Ted Lucas, Editor, P.O. Box 852, Cedar Glen, CA 92321, or to our National Office Manager, June Friend, for Information Display, 654 North Sepulveda Blvd., Los Angeles, CA 90049. Next deadline for material from you is April 10. If you miss that, try for the May issue. NOTE: We also welcome feature articles on interesting projects.

by Richard D. Vance, President,
Ad-Vance Magnetics, Inc.

When magnetic interference is present, it can cause an unwelcome deterrent to full functioning of products susceptible to it. Sometimes this problem may be foreseen and avoided by mandating proper magnetic shielding during the design stage. Otherwise, magnetic interference may cause consternation by appearing unexpectedly during the production or testing stages. At worst, it evidences itself when the customer uses the product. In any event, the consequential reduction in expected top performance from components and systems requires the addition of magnetic shielding to divert the interfering fields.

Protection Against The Earth's Magnetic Field

The pervasive earth's magnetic field is not a factor in some applications. However, it can be detrimental to certain specialized applications. One example is a 0.025" thick high permeability double cylinder shield used to transport rocks, degaussed of the present earth's field, safely to a site shielded against the earth's magnetic field. In the double cylinder shield illustrated by Figure 1 the required attenuation is approximately 1,000 times, with the cylinder in the field transverse to its axis. The geometric increase in shielding effectiveness of two cylinders vs. a single cylinder is expressed in this equation:

One cylinder static shield effectiveness, S_1,

given by $S_1 = 1 + \frac{1\mu}{2R}$

t = thickness of cylinder
R = outer radius of cylinder   in same units of length

Double cylinder static shield effectiveness, S'

$$S' = 1 + S_1 + S_2 + (S_1)(S_2)\left(1 - \frac{A_1}{A_2}\right)$$

A1= Cross section area (normal to flux) of outer surface of first cylinder
A2= Cross section area (normal to flux) of outer surface of second cylinder

$\left(1 - \frac{A_1}{A_2}\right) = 0.5$ usually.

Double cylinder construction of 0.025" high permeability fabricated alloy provides the required strength and shape stability. Aluminum bar spacers separating cylinders have milled reliefs for demagnetizing coils. The outer cylinder radius is $\sqrt{2}$ times the inner cylinder radius, with both cylinders having the same thickness.

Denser Packaging Problems

The closeness of components in ever denser modern systems makes magnetic radiation problems worse. Offending fields may originate in a small motor, or generator, or transformer, for example. Affected components may include CRTs, scan converter tubes, storage tubes, weather radar display tubes, high resolution video recorder head assemblies, etc.

Ease of access is the deciding factor on whether to shield the radiating component or the affected component. It is recommended that the radiation source be shielded when practical. However, in very close spacing, AC shielding should be achieved by absorption (magnetic hysteresis). This is because the reflection mechanism, which is a major cost-free shielding effect at plane wave conditions, changes sign and becomes counter-productive "antenna gain".

Figure 1

Figure 2

Magnetic Shielding. . .

Unexpected Hidden Hazards in Modern Construction

A firm moves proudly into its new reinforced concrete building. Equipment is set up and ready for use. But magnetic interference that seemingly defies tracing prevents optimum functioning of equipment. There was no such problem with identical equipment in the old building. Laboratory researchers and production technicians can't understand why the problem exists in the new building.

Typically, the hidden answer may lie in lower ceilings which contain more reinforced steel beams. Those lower ceilings bring nearer to sensitive equipment the performance-affecting magnetic fields which are generated by the steel beams. The older structures were constructed with higher ceilings; therefore the offending fields were farther away, so interference was less. Magnetic field gradients much more than the typical 150 Gamma/cm of the high ceiling structures are often present in low ceilinged reinforced concrete buildings.

Thus, while a magnetic radiation source is frequently apparent, even obvious, it can also be difficult to trace. In any event, magnetic shielding for sensitive equipment in low ceilinged reinforced concrete edifices is imperative. Otherwise, there is continuing excessive disturbance in such newer buildings, preventing research or production equipment from operating at desired resolution levels when the equipment is not packaged to function in such an inhomogeneous environment.

CRT Shielding Problems - The Magic Number is 0.2

The design stage is the foolproof time to realize the possible future need for a magnetic shield and to allow enough area for a shield in the design itself. Too often this possiblity is not considered, causing later complications with suboptimum performance and even customer dissatisfaction. Trying to cram the required magnetic shield into the too-small area available won't work. So a less effective shield that does fit into the available area is a familiar compromise attempt at a solution. Of course the less effective shield helps but cannot fully block out the magnetic fields interfering with top CRT performance.

The proper solution is to design in sufficient clearance around the neck of the CRT to permit placing of a shield system. A two cylinder system generally gives the optimum static field shielding effectiveness per unit of weight when the outer cylinder diameter is 1.414 times the diameter of the inner cylinder. Thus when ventilation is not required, and the inner shield cylinder fits closely around the neck glass, a clearance slightly greater than 0.2 times the neck diameter would be the typical clearance to be designed into the shielding system.

Some CRT Shielding Examples

In this example, the problem was to design and manufacture a CRT magnetic shield that would meet three basic requirements. These were: to shield the neck portion from detrimental local magnetic fields; to provide adequate structural support for the tube; and to achieve shielding at a cost lower than for the usual CRT shield. Cost was an urgent consideration because a large number of shields was needed.

As illustrated in Figure 2, the final design was based on skillfully combining magnetic with nonmagnetic materials. By actual experiment, it was determined that a cylindrical structure of 0.020" thick high permeability alloy around the magnetically critical neck area provided all the shielding needed for good resolution. The 0.020" thickness was chosen because it provided the needed safety against saturation. Furthermore, the alloy selected assured maximum permeability and minimum shock sensitivity. It was then possible to utilize a lower cost 0.031" thick nonmagnetic stainless steel for the desired structural support for the forward part of the shield. As both the shielding alloy and the stainless steel have similar coefficients of expansion, annealing the final assembly presented no problems.

Combining the shielding alloy with the stainless steel was accomplished by spin reducing one end of the larger cylinder to mate with the smaller neck cylinder. Structural rigidity was enhanced and fracturing eliminated by incorporating generous radii. A mounting flange was heliarc welded to the outer perimeter of the larger cylinder's open end. The shielding alloy cylinder and the spun section were then pressed together and permanently located by a series of spot welds in the overlapping area.

To optimize the cylinder's magnetic shielding characteristics, the assembly was given a complete anhydrous hydrogen atmosphere anneal. Because of the shielding alloy's relatively stable permeability characteristics, further annealing was not necessary. Finally, an attractive glossy baked enamel finish was applied to match the finish of the surrounding hardware.

When subjected to a directed 60 Hz magnetic field normal to the cylinder's axis, the neck portions of a group of shields showed attenuation ranging between 47 and 55 db (voltage ratio).

In testing, the radiation source originated from a soft iron pole approximately 3/8" in diameter by 3" in length located in the center of a solenoid winding of sufficient impedance to prevent overheating during a maximum 5-minute period of excitation. The structure was physically positioned with the pole normal to the shield's axis and approximately 1/4" from the shield cylinder's outer surface and centrally located along the length. Input current was Variac controlled. A thin Hall probe measured the flux density impinging on the shield's surface directly in line with the pole structure. This level was set in the 3 to 5 gauss range. Then the flux within the shield was measured, locating the same probe on the shield's axial center, orienting it for maximum response. The resultant ratio of these two measurements was noted in terms of decibel attenuation.

Figure 3

Figure 4

Magnetic Shielding . . .

In another example, illustrated in Figure 3, the problem was to provide an effective, economical, and simple structure for shielding a CRT's deflection yoke and neck, thereby eliminating the need for a larger, more costly and complex magnetic shield covering the entire CRT. Fast, easy access to the yoke assembly was also specified.

Figure 3 illustrates the 2-section shielding structure fabricated from a single high permeability alloy 0.025" thick that fulfilled all the requirements. The specified quick and easy access to the yoke assembly was provided by a removable slip-on-and-twist cover. A threaded stud welded to the outside of the cylinder section fits into an L-shaped slot in the overlapping flange of the cover and is locked by drawing down the nut. Tests made on the shield only in an anticipated low level magnetic field indicated attainable attenuation ranging from 45 to 50 db. No finishing was required after fabrication, as the chosen shielding alloy offered adequate resistance to the operating environment. Furthermore, the alloy selected would not saturate when properly used nor suffer excessive degradation of permeability from shock. In addition, it displayed minimal retentivity for its given permeability.

The open-ended cylinder portion of the 2-piece shield assembly is 4" long by 3-⅝" ID. Inside, the deflection yoke is concentrically located and held in place by epoxy bonding. A rectangular cutout gives additional access when the cover is off. Cable entry is through an obround notch. Grounding is achieved by two tabs welded to the cylinder near the open front end. In the cover portion, a concentrically located welded 3" long tubulation completes the shielding of the neck. All seams are heliarc welded for maximum performance.

After fabrication, the shield is anhydrous hydrogen annealed to optimize magnetic shielding characteristics and to provide needed stability to avoid repeated time consuming and costly annealings.

A third example concerned designing and building a magnetic shield for 16" CRTs or memory tubes that can be used in areas subjected to shock and vibration and still deliver top performance shielding. Figure 4 shows such a shield for a complex radar system in a series of consoles. The main shield is on the table, the conformal cover in the model's right hand, and the aluminum bezel in her left hand.

Maximum protection against mechanical shock and vibration even in rough sea or mobile ground applications is provided by potting the tube in a resilient material within the shockmounted rugged dual-layer shield. Convenient access for periodic yoke adjustments is achieved through four rectangular holes 90° apart cut at the narrow end of the square-to-round transition. When operational, these holes are shielded by a removable conformally formed cover positioned and secured by tightening two screw clamps.

Despite exposure to wide variations in external magnetic environments, control tests determined that 43db minimum attenuation was held with approximately 5 gauss impinging on the shield plane. Operationally, widely varying exposure includes degaussing fields and radiating fields from neighboring associated electronic equipment such as power supplies, power carrying service ducts, etc., aboard ship.

Uniformity of performance is checked by measuring the attenuation actually achieved by the heat-treated shield. Good repeatibility of tests is assured by use of a Helmholz coil pair to apply a 60 Hz field perpendicular to the shield's axis. This coil pair is driven by a measured current. A calibrated AC magnetic field probe is positioned by a boom inside the shield, on its axis and parallel to the applied external field, i.e., in line with the axis of the Helmholz system.

The 3-⅝" wide forward section of the basic rectangular shield has a high permeability alloy inner shielding layer 0.040" thick and a high permeability alloy outside overlay 0.050" thick. This assembly is fusion heliarc welded per MIL-W-8611 to the transition section, which terminates cylindrically to mate with the neck section. This section is made of high permeability alloy 0.062" thick as the shielding material. The final neck section uses high permeability alloy 0.062" thick shielding material.

Four U-shaped stainless steel channels are positioned at each radius corner parallel to the shield's axis and vertical to the plane of the open end, reinforced using fitted gussets with the shield's tapered section. These plates and gussets are heliarc welded to the shield per MIL-W-8611.

Four flanges formed at right angles extend outward from the shield's open end to facilitate attachment of the embossed aluminum bezel. Bracketry is ⅛" stainless steel. The complete unit is formed over solid aluminum plugs.

After fabrication and fitting, the entire shield, except for the aluminum bezel, was subjected to an anhydrous hydrogen anneal to maximize the high permeability alloy's magnetic properties. The shield and tube assembly were then mounted inside the console by attaching to the U-shaped stainless steel channels.

Low Cost "Instant" Foil CRT Shields

In an emergency, or during experimental work, or when time is a factor, a ductile shielding foil shield may be used as illustrated in Figure 5. It can be cut and hand-shaped in moments to the exact contour required. It is wise to have on hand a modest quantity of both low and high permeability ductile shielding alloy foils. They can be ordered from any reputable shielding manufacturer and are delivered already heat treated, ready for immediate use. If one layer doesn't solve the radiation problem, as many more as are needed should be cut and added.

Shielding foils can save not only time, but cost, as they eliminate the designing and tooling charges of prefabricated shields. Foils are also ideal for hard-to-get-at places as well as for emergency or experimental work. They can do away with delays and possible costly downtime.

The foils are not without limitations, assuming electrical insulation between layers and proper grounding at a single point for each layer. Generally, their advantages are confined to situations requiring relatively small numbers of shields. In large volume, the economics indicate prefabricated shields.

Figure 5

Richard D. Vance
Ad-Vance Magnetics Inc.

Alloy shields can protect devices in magnetic fields

Stray radiation and magnetic interference can cause failure and false signals in operating electronic equipment. Metal alloy shield can be chosen to direct the fields around the equipment or to block field effects.

LABORATORY PERSONNEL gathered around to watch the final test as the long R&D project neared conclusion. But something was not quite right. A magnetic field was interferring and was preventing optimum performance of some of the components of the system.

A long delay seemed inevitable; researchers would have to look for a dependable shielding supplier, then decide what shield or shields to buy.—Does this sound familiar to you?

A much-quicker solution would be for the researcher to phone any reputable manufacturer of magnetic shielding and then order a quantity of heat-treated, ready-to-use magnetic shielding foil.

Off-the-shelf solution. One advantage to any researcher in using magnetic shielding foil is that there is no need to be an expert in the specialized field of magnetic shielding. The researcher merely keeps on hand both low-permeability and high-permeability magnetic shielding foils.

After hand shaping a foil shield, the researcher places it around the component or components to be shielded and holds it in place with ordinary adhesive tape. The foils

Scissors can cut magnetic shielding foils for quick application to protect any sensitive electronic equipment from field effects.

Custom-fabricated shields can be made to protect almost any kind of equipment in almost any configuration. Common applications include magnetic isolation chambers, shields for low-field research, and shields for many types of operating instruments and test chambers. When properly used, these shielding devices provide lasting protection.

should not be machine-formed or welded because worked or welded foil would require an additional annealing cycle after the forming operation.

When it is practical to do so, it is preferable to shield the affected component or components, rather than the offending source. The amount of shielding is quickly and easily determined on a trial-and-error basis, saving many days' time and avoiding frustration.

If a single layer of foil is not enough, it may be necessary to add one or more additional layers. If the high-permeability foil is transmitting too much of the field, then use low-permeability foil.

Low-permeability foil close to the field source can divert a major portion of the field, allowing the high-permeability foil to operate in a lower reluctance mode. This arrangement increases the shielding capability of the system. Avoid compressing the layers tightly together, since a small air gap between layers enhances shielding.

In many research applications, the hand-cut, hand-formed foil magnetic shield will solve the entire shielding problem.

The key to foil shielding convenience and economy lies primarily in the use of small quantities of foil.

Fabricated shields. In certain applications, fabricated shields are practical. The mobile shielding cylinders used in magnetism studies are one example.

This type of shield safely transports rocks, after degaussing of the Earth's magnetic field effects, to the testing laboratory. There the researcher can accurately measure the rocks' initial magnetism to ascertain facts about the history of the magnetic fields in the rocks' previous Earth environments.

For a cylinder in a field transverse to its axis, the required attenuation is approximately 1,000 times. The geometric increase in shielding effectiveness of two cylinders *vs.* a single cylinder is expressed in the following equation:

$$S_1 = 1 + (\mu t/2R)$$

where S_1 = one-cylinder static shield effectiveness.
μ = permeability of the foil alloy.
t = thickness of cylinder.
R = outer radius of cylinder.

Then, the double-cylinder static shield effectiveness is given by

$$S' = 1 + S_1 + S_2 + (S_1)(S_2)(1 - A_1/A_2)$$

where S' = double-cylinder effectiveness.
S_1 = shield effectiveness of first cylinder.
S_2 = shield effectiveness of second cylinder.
A_1 = cross-sectional area (normal to flux) of outer surface of first cylinder.
A_2 = Cross-sectional area (normal to flux) of outer surface of second cylinder.

Usually, $(1 - A_1/A_2) = 0.5$.

A commercial, double-cylinder construction of 0.025-in. high-permeability fabricated alloy provides both the strength and the shape stability required. Aluminum-bar spacers separating cylinders have milled reliefs for demagnetizing coils. The outer cylinder radius is 2X the radius of the inner cylinder. The thickness of the walls of both cylinders is the same.

For this type of shield, large spun-aluminum sliding caps fit over the ends of both cylinders, minimizing any attenuation loss

Double-cylinder construction of fabricated alloy provides strength and shape stability for transporting rocks for magnetism studies (left). A large sliding cap fits over the end of each cylinder to minimize any loss in magnetic attenuation from the air gaps.

For low-level-field research and for production testing, a magnetic isolation chamber provides an environment in which magnetically-sensitive devices may be observed without interference by external magnetic fields. An operator also can determine the presence of ferromagnetic contaminants in nonmagnetic materials.

through air gaps. End-cap uniformity of thickness and of fit in these large radii are the critical quality features in a shield of this type. These factors determine the quality of the residual field inside the shield.

A commercially-available cylinder of this type has a convenient carrying handle attached by two brass screws. The overall length, including the end caps is 12.5 in. Outside diameter of the outer cylinder is 1.875 in. The weight is 1.25 lb.

Such a shield can provide lasting protection because the high-permeability alloy does not saturate during normal use. In addition, the alloy will not suffer excessive permeability loss from shock; but it does display minimum retentivity.

Isolation chamber. Another example of a fabricated shield is a dual-purpose magnetic isolation chamber. This chamber is used both for low-level-field research and for production-line testing. It provides a low-level-field environment into which magnetically-sensitive devices may be placed to observe their characteristics while they are relatively unaffected by external magnetic fields.

One such device is a magnetometer probe that operates on a saturation or a reluctance principle. Likewise, we could use the chamber for testing of any other device capable of sensing magnetic perturbations, and for testing sensors that operate on magnetic principles. We can readily calibrate such sensors by installing Helmholz configuration coils. The chamber also may be used with a magnetometer for the detection of ferromagnetic contamination that often is found in nonferrous and nonmagnetic alloys.

The construction of the magnetic isolation chamber is fundamentally similar to that of the portable unit described above. It consists of a series of concentrically-positioned shielding chambers. One end of each cylinder is permanently closed. The other end of each cylinder is closed by a removable cover. Holes through the covers permit manual access to components under study. The magnetic attenuation is enhanced by nonmagnetic spacing between the cylinders.

Choosing alloys. In such a chamber, magnetic isolation requirements are the sole determining factor defining the number of concentric shield systems and the types of shielding alloys used. The entire assembly is mounted horizontally by two aluminum channel structures attached to the outermost shield. Plastic mounting feet prevent any possible marring of the work surface. The chamber is available with an optional degaussing coil system.

The user's application defines the choice of alloys used in manufacture of the chamber. For the inner shield and for the next layer or layers, we generally specify a high-permeability alloy that displays a maximum initial permeability, u_0. If the magnetic-field environment is intense to the point of creating saturation, the outermost shield is constructed of the low-permeability alloy.

All seams are welded by a tungsten-inert-gas (TIG) process. After fabrication, annealing either in a temperature-cycled hydrogen atmosphere or in a vacuum optimizes and stabilizes the permeability characteristics of each alloy.

By orienting the axis of the shield parallel to the Earth's plane, then rotating the assembly through 360 deg, the researcher can find the position giving the minimum magnetic field. Using this technique, we can assure ourselves that fields not exceeding 100 gamma (0.08 A/m) will be attained.

Proper degaussing of the inner shield structure can lower the field to the 10-gamma level. In favorable environments, fields as low as 2 gammas have been attained.

Puzzling interference. The uses for magnetic shielding sometimes appear in unexpected places. When a laboratory moves into a new concrete structure, there can be a mysterious magnetic field interference.

It was not present in the old laboratory. There, the equipment worked normally. But in the new facility, research is hampered by the unidentified, unwelcome field.

Today, we know that the problem probably is caused by modern concrete construction, characterized by many reinforcing bars, steel beams, and low ceilings. These often are factors that can create undesired magnetic fields. The interference is amplified by the lower ceilings, with their internal steel beams, which are much closer to laboratory equipment than they would be in the older buildings.

Steel beams in concrete posts throughout the laboratory also add to the emanating magnetic field interferences. The pervasive interfering magnetic fields thus generated can be tuned out by an experienced magnetic-shielding specialist after an on-the-spot study pinpoints the exact location and the intensity of the disturbing field.

What's most convenient? In applications such as these, fabricated shielding enclosures are exactly tailored to a specific research requirement. Shield shapes may range from simple to quite complex—conical, cylindrical, and box configurations are the most common. For lower-intensity fields, a single layer of shielding may suffice; higher-intensity fields may require two or more shielding layers.

In situations in which the magnetic field conditions are known, or in which the problems expected could be classified as more or less standard, a custom-designed shield or a standard shield probably will be adequate. In other cases, the best answer may be a foil shield.

The foils offer the convenience of instant availability, as well as cost savings in experimental and production situations. For such applications, the prudent researcher will recognize the value of ready-to-use shielding foil as a time-saving research tool.

With a supply of foil always on hand, the researcher will need only minutes with ordinary scissors to eliminate interference from a magnetic field. The quick solution of forming and applying the needed protective shield avoids costly delays and permits the researcher to keep his project on schedule. ☐

THE AUTHOR

Richard D. Vance is president and chief executive officer of Ad-Vance Magnetics Inc., Rochester, IN. He works in all phases of magnetic shielding, including design, manufacturing, quality control, customer sales and service, and advertising and public relations, in addition to performing the customary duties of a CEO.

Magnetic shielding has become indispensable for optimum product performance as the trend to ever smaller layouts crowds components even closer to each other. This, of course, dramatically increases susceptibility to electromagnetic interaction even in the best engineered layouts.

To shield out a magnetic field, its source must first be determined. Usually, this is not difficult, but sometimes the source seems to elude discovery. For example, interfering magnetic fields are several times greater in modern, low-ceilinged concrete structures than in older, higher ceilinged buildings of different construction. This can be immensely perplexing, until the realization dawns that numerous reinforcing steel beams are incorporated into concrete construction and that low ceilings bring the resulting steel beams' extraneous magnetic interference much closer to sensitive equipment than in higher ceilinged rooms of different construction.

Once the unwelcome field's source is discovered, consideration is given whether to shield the source or the affected components. When practical, it is preferable to shield the affected component or components.

Other factors to consider in specifying the optimum shield are the strength of the field, the number of shielding layers required, whether to use high or low permeability alloy or a combination thereof, the shape of the shield and the accessibility of the component to be shielded. It is vital that the shielding alloys selected do not saturate when properly used, do not suffer excessive permeability loss from shock, display minimum retentivity, and exhibit relatively stable permeability characteristics after final anneal, avoiding the expense and inconvenience of regularly repeated annealings.

In accordance with the time tested "ounce of prevention," the shield should be incorporated at the equipment manufacturing stage whenever possible. CRTs are a good example. Retrofitting the optimum shield is often expensive and sometimes impossible if the tube designer hasn't allowed sufficient neck area. If the shield is designed into the tube at the very beginning, optimum shielding is attained easily.

Shield shapes range from a simple box, conical or cylindrical configurations to more complex shapes and sometimes conform to the glass bottle or the CRT. In complex applications, shields are tailored to fit exactly and can consist of many unusual configurations.

PM Tube Shielding in High Magnetic Environments

Selecting shielding for photomultiplier tubes is simplified because shielding manufacturers have fabricated shields already tooled up for most PM tube sizes. It is only necessary to inform one's shielding source of the PM tube manufacturer's name and the tube's type number to obtain the correct shielding shape. The strength of the magnetic field is the other factor involved.

Figure 1 shows a photomultiplier tube used in relatively high magnetic field environments commonly encountered in physics research set-ups and similar applications. There are five shielding layers to provide maximum flux diversion in such environments. In addition to its adaptability to many experimental applications, variations of this shield design finds use in specialized laboratory equipment production.

The outermost layer is heavy-gauge, low-permeability alloy. For mounting convenience, a stainless steel flange is heliarc welded near one end. An interface of .050 non-magnetic stainless steel is next, followed by another heavy-gauge, low-permeability shielding alloy layer enclosed in a .020 non-magnetic stainless steel cylinder. The innermost layer is .025 high permeability shielding alloy.

Figure 1

To maximize shielding effectiveness, the ferromagnetic layers were individually heat treated. The two low permeability layers were then coated with rust inhibiting oil for oxidation protection in average environments. The high permeability layer was not oil coated as it is relatively inert to normal environmental attack.

This article was prepared for ITEM by Richard D. Vance, President, Ad-Vance Magnetics, Inc.

Immobile Shielding Room vs. Mobile Shielded Chamber

Figure 2 illustrates a very large economical mobile multi-layer controlled magnetic environment chamber for determining response characteristics, sensitivity and orientation direction of magnetic sensor devices used for signature recognition, proximity sensing, etc. in a wide variety of industrial, military and commercial security applications. It diverts most of the external fields present.

The cost is far less than for an immobile shielded room. Two parallel 1″ x 4″ aluminum sections attached to the cradle's front and rear enable a forklift to move the entire 800 lb. structure easily, achieving desired field mobility.

The chamber's 36″ OD and 34″ ID x 40″ L dimensions contain a Helmholtz structure of required size without its suffering severe anomaly distortions caused by proximity of the shielding structure. Of course, larger or smaller shields can be constructed to meet any specific dimensional requirement.

The initial residual field level within the shield is established by incorporating a degaussing winding structure into the shield, located to produce its principal reaction on the inner shield. With the shield's axis parallel to the earth's plane, the degaussing cycle is continued until a minimum residual field of approximately one milligauss is reached. The degaussing operation is then terminated. The object is to reach a repeatable level rather than a low minimum. Once the internal ambient level has been normalized, a desired field level generated by the Helmholtz system can be established.

Physically, the shield consists of two concentrically located cylinders of .062″ high permeability alloy, each with welded bottom and removable cover top having a 5″ overlap flange minimizing external field entry possibility. Convenient handles on the outside cover simplify manual cover installation and removal.

Ten 1″ x 1″ bar stock aluminum spacers, the length of the cylinders symmetrically spaced, are attached to the inside of the outer cylinder. The two covers are installed simultaneously because they are spaced 1″ apart in all directions and made into an integrated assembly. The entire structure is mounted on a ¼″ thick aluminum cradle. Both cradle and shield are securely anchored to each other by ¼″ thick aluminum bands welded to the cradle structure and extending around the outer perimeter to a point beyond the shield midline.

Prior to final assembly, the shield and covers were subjected to a proper high temperature anneal. To optimize magnetic properties, the vacuum furnace was held at high termperature for an adequate soak time. Cooling rate was carefully controlled to give permeability optimization. Accordingly, the shielding alloys display stable permeability, will not saturate when properly used , will not suffer excessive permeability degradation from shock, and do not require periodic annealings.

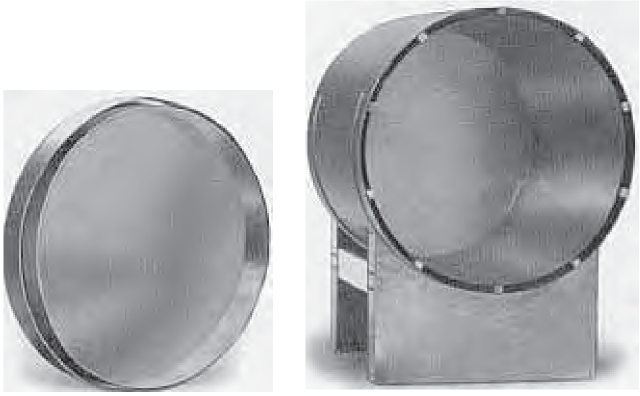


Figure 2.

Magnetic Shielding for Top Performance of Components and Equipment

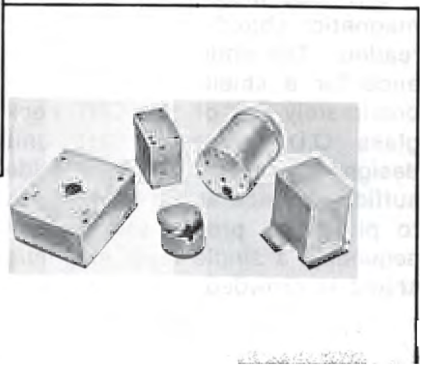
By Richard D. Vance, President, Ad-Vance Magnetics, Inc., Rochester, Ind.

More and more, firms are learning the necessity of using magnetic shielding to achieve the performance desired from their components and systems. Denser packaging has incited much of the recent interest in shields. With components positioned ever closer together, and radiating components affecting adjacent components, increased electromagnetic interference frequently occurs.

Depending on ease of access, either the offending or the affected component can be shielded. It is preferable to shield the source of interference. As spacing becomes very close, however, a-c shielding should be achieved by absorption (magnetic hysteresis), because the reflection mechanism, which is a major cost-free shielding effect at plane wave conditions, changes sign and becomes "antenna gain." This is counter productive.

On a larger scale, modern building construction, with its lower ceilings and increased number of reinforced steel beams, has also spurred interest in magnetic shielding. The lower ceilings bring steel beams closer to sensitive equipment, thereby creating magnetic fields that affect performance. Laboratory researchers and production technicians frequently mull over the cause of interference, especially when they had no such problem with identical equipment at their previous location.

In fact, a magnetic field gradient considerably greater than the 150 Gamma/cm typical of structures with high ceilings exists in the newer, reinforced concrete buildings with lower ceilings. Without magnetic shielding, there is too



Magnetic shields have found widespread application in the electrical/electronic industry. Shield types shown here are: small transformer (upper left), motor (upper right), specialized CRT (lower left), and CRT deflection yoke and neck (lower right).

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much disturbance in newer buildings for research or production equipment to operate at desired resolution levels.

Magnetic interference also can be caused by components such as motors, transformers, solenoids, and coils. Other disturbing sources include electro and permanent magnets, high current cables, power generating equipment, and passing or nearby radiating electronic and electrical gear or equipment.

Shielding Applications

Aircraft weather radar displays are subject to distortions caused by electromagnetic interferences generated by nearby electronic devices. In particular, tachometers with magnetic coupling must be shielded. They radiate a rotating magnetic field which significantly distorts the radar tube's performance. Other nearby radiating devices further deteriorate the display. For aircraft safety, a shielding enclosure should be used to minimize such effects. The shield also can support and position the tube.

High resolution video recorder head assemblies are affected by a wide range of magnetic field interferences that prevent full operation. Top performance cannot be assured without magnetic shielding.

CRT tube displays usually need magnetic shielding for clearest readout. The optimum neck clearance for a shield should be approximately 0.7 of the CRT neck glass O.D. However, CRT unit designs frequently do not provide sufficient space at the tube's neck to place the proper shield. Consequently, a single layer magnetic shield is crowded into inadequate space, and optimum shielding is impossible.

Foil alloy easily cuts with scissors and hand trims to desired outline.

Electron microscopes require proper shielding to prevent resolution deterioration caused by beam scattering, bending, or displacement from normal optimum focus position. By preventing external a-c magnetic disturbances from reacting on the scanning electron beam, the shield assures sharp, clear focus, permitting full magnification. Good grounding and absence of severe earth's field gradients are often equally important.

Magnetic tape data protectors can be used to store or transport valuable data contained on cassette or other magnetic tapes. They prevent distortion, partial erasure, or degradation of irreplaceable data recorded in magnetic tapes and used in aerospace, commercial, broadcast, industrial, and military applications. Since damage to precious recorded data could happen without anyone's knowledge during ordinary storage or routine transport, these protectors are regarded as cheap insurance.

Foil Shields Shaped by Hand

The simplest shield can be hand made from ductile foil alloy, by cutting it with a scissors. Ductile foils obtained from a shield manufacturer have already been heat treated and are ready for immediate use. They can be ordered for low, medium, or high permeability requirements, and a combination of two is recommended for many applications. In such cases, the low permeability foil should be placed closest to the offending field source. This arrangement tends to increase the flux density shielding capabilities because the low permeability foil diverts most of the field, allowing the high permeability foil to operate at a lower reluctance mode with maximum attenuation.

When working with hand made foils, the disturbing field must be identified. Then the foil should be cut with ordinary scissors and shaped by hand to the outline desired. If one layer does not solve the radiation problem, additional layers should be added as needed. Upon request, the shielding manufacturer will provide a single formula for guidance.

Shielding foil offers the advantages of time and cost savings. Designing and tooling costs of prefabricated shields are eliminated. The shielding problem can be addressed at once, eliminating delays and possible costly downtime. Shielding foil also is ideal for research and experimental work and for hard-to-get-at places. Generally speaking, scissor-cut hand-shaped foil shields are advantageous primarily where relatively small quantities of shields are needed. In large volume, the economics favor prefabricated shields.

Prefabricated Shields

Prefabricated shields are generally tailored to specific applications. They are available in any shape from simple to extremely complex and can include eddy current shield layers of copper or aluminum.

For lighter fields, a single layer shield can suffice. Two or more layers must be used for stronger fields. The shielding material which best matches a particular application should be chosen after analyzing the field. Among the major factors considered are permeability, saturation, shock sensitivity, and proper annealing after fabrication.

Cylindrical, conical, and box shaped configurations constitute the most common shielding enclosures. The cylindrical design is best for scan converter and photomultiplier tubes, de-gaussed rock transports, isolation chambers, storage tubes, motors, meters, and tiny vacuum tubes. Cathode ray tube shields usually are conical. The box shaped shields are suited for video recorder head assemblies, magnetic tape containers, transformers, aircraft weather radar, power supplies, and reactors.

Shielding Effectiveness

Shielding effectiveness depends on material permeability, the ratio of wall thickness to the shield's outside radius, wave impedance, and the frequency (conductivity is more important than permeability at high frequencies). Air gap spacing can also influence effectiveness. The shield should be loosely fitted around component shielding, because the resulting air gap helps to produce optimum static magnetic shielding. When multiple layers of shielding are required, air gap spacing also is vital when absorption loss must be the main shielding mechanism.

Information Display

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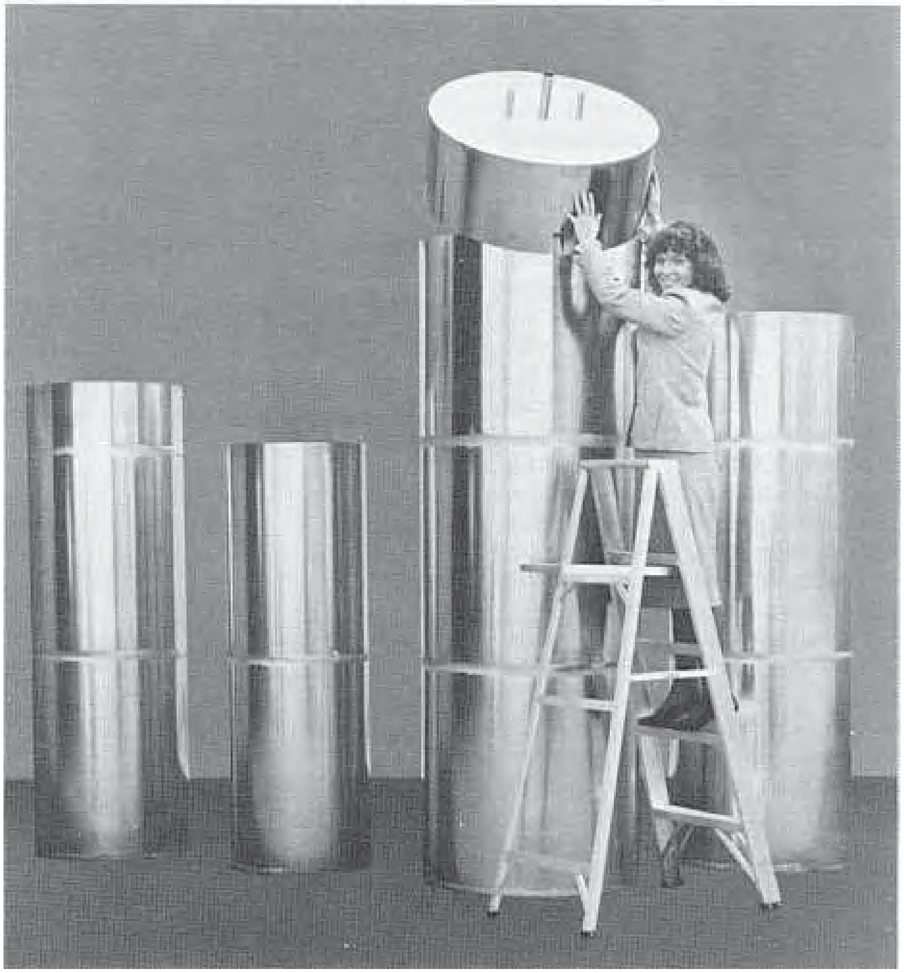

The magnetic shields shown in this picture are a new generation used to protect ultra-high speed VLSI cryostatic memories from electromagnetic interference. Such shields have only recently been developed by Ad-Vance Magnetic engineers in cooperation with VLSI manufacturers at the forefront of the high technology required for tomorrow's 5th generation computers.

Digital circuitry for signal processing, data communication, memory structure, and memory address has generally enjoyed greater immunity to noise limitations than analog systems. Resolution limits were reached for analog devices a few years ago, and the ongoing momentum of the VLSI revolution towards high memory density has lately brought the digital world up against noise limitations.

In the new field of fast processing, where devices such as interferometers and Josephson junctions are used as circuit elements for processing signals at wave lengths of light, there are various reasons requiring the cryostatic and room temperature systems to be in controlled electromagnetic environments.

The following article by SID members Richard D. Vance and William F. Griffith, Ad-Vance Magnetics, Inc., Rochester, IN, describes the design and the improvement of effectiveness of nested magnetic shields for VLSI applications.

FRONT COVER MATERIAL WELCOMED: Every month **Information Display** usually features one or more active members of SID and the products with which they are most closely associated. Please send a glossy print and appropriate captions so that you, too, can be on our front cover. Send your material to Ted. Lucas, Editor, P.O. Box 852, Cedar Glen, CA 92321, or to our National Office Manager, Bettye Burdett, for Information Display, 654 North Sepulveda Blvd., Los Angeles, CA 90049. Next deadline for material from you is May 10 for the June issue. If you miss it, try for the October issue. NOTE: We also welcome feature articles on interesting projects.

Magnetic Shield Refinements For Low Temperature VLSI Packaging

by Richard D. Vance, President, and William F. Griffith, Chief Engineer, Ad-Vance Magnetics, Inc., Rochester, IN.

In the cryostatic approach to VLSI systems, circuits and rapid memory types (cache), there are special requirements that push the state of the magnetic shielding art to new performance levels. Until about 1981, increases in packing density in terms of gates per integrated chip were steadily realized. Usually the results could neatly be stated as performance figures having a simple relationship to the "scaling factor," S, greater than or equal to unity. Further improvements in these figures such as gate time delay (proportional to $\frac{1}{S}$) and speed-power product (inversely porportional to S^3) in the MOS context have met with some noise and interconnection speed limitations. These improvements have been reported and discussed yearly at the International Solid State Circuits Conference of IEEE (Ref. 1), as well as the general economic impact of the VLSI revolution on our society.

Leading firms and academic participants in these developments have lucidly expounded their views at this conference regarding possible future trends. In the 1982 Discussion Session entitled "Is There Life After 64K" (64 Kb memory capacity RAM), the moderator, R.C. Foss, mentioned ". . . the economic pressures inherent in a marketplace worth upwards of $25 billion for a single chip specification . . . ." Also it was pointed out in related discussion by a panel at the 1981 Conference (Ref. 2) that the initial cost of nearly $10 million for a VLSI laboratory poses a problem for both universities and industry. This has led to searching questions about standardizing processes in an industry where, to quote Foss again, "Paradoxically, it is also still an area where individual talents have a major impact."

The apparent advantages of cryostatic design include better noise immunity than is attainable in room temperature designs, a need foreshadowed by 1981 experience with 64K RAMs which came up against a noise barrier. In this case, as reported in the 1982 discussion session previously cited, the problem was overcome for current MOS memory sizes by noncryostatic means.

The cryostatic approach is inseparable from the micropower type of memory using Josephson junction devices which dissipate microwatts in the "on" state as compared to hundreds of milliwatts from a semiconductor chip of comparable capacity. In this experimental memory, much more effective magnetic shielding is mandatory than that required for silicon devices due to the susceptibility of these junctions. Low operating temperatures generally tend to reduce the thermal noise throughout a system. This may be helpful in various types of device technologies because signal levels are predicted to fall considerably in the next generation of RAMs which will be powered by approximately 3 Vdc, about half the present supply voltage. However, the intent of this article is explained by a quotation from the Forword to the 1981 *ISSCC Digest of Technical Papers*: "As even the simplest of processing technologies become increasingly sophisticated, marked departures from past Standards become viable." (Bruce A. Wooley)

Past magnetic shielding standards were set for instrumentation using photomultiplier tubes, CRT displays, etc., which involved attenuation of the Earth's field down to levels of about 1 Gamma (10^{-5} Oersted), at best. At least an order of magnitude increase in shielding effectiveness seems to be the goal for designers of developmental cryostorage systems. Uniformity of permeability throughout a shield system (usually consisting of capped cylinders) becomes critical for these improved systems and implies the mandatory use of high nickel alloys of the AD-MU-80 type. This alloy is distinguished, for inductions below 100 Gauss, by normal magnetization curves lying parallel to the lines of constant permeability on an NBS trigraph (See Figure 1). Uniform demagnetization axially and circumferential demagnetization, known as "shaking" (Ref. 3), involve considerable changes in shielding standards and create pressure to provide improved, nonobtrusive means for optimum demagnetization.

Some proposed improvements are related here. They may offer shield systems with more effective demagnetization than has generally been realized in the past. When shaking is continually applied during use, it affords some of the ideal characteristics associated with superconducting shields, particularly very low effective remanence. Uniform permeability is designed-in by calculating the thicknesses of the alloy cylinders and the spacings between successive concentric shields so that peak induction caused in any layer by transverse field lies below 200 Gauss for ac, 100 Gauss for dc for the anticipated range of impinging fields. (Ref. 4)

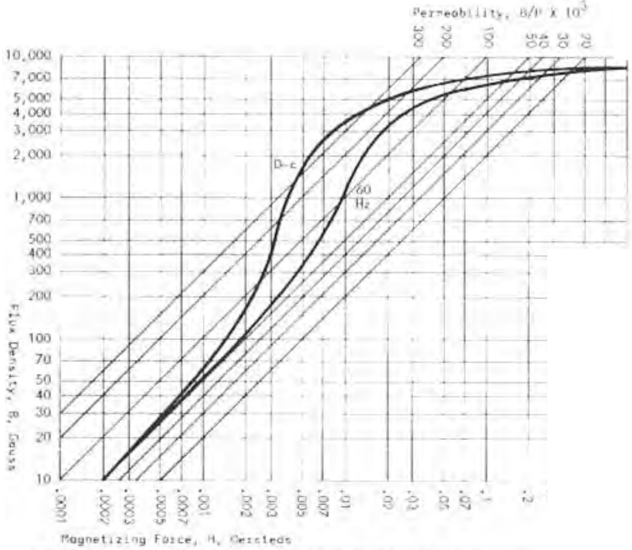

Figure 1. Typical magnetization curves of AD-MU-80 (.014 thickness).

Uniform axial demagnetization is ideally realized by a system of two coils wound on an aluminum cylinder which is to be geometrically positioned inside the shielding assembly according to Ref. 5 by Hanson & Pipkin. This coil geometry also permits an added function: the capability to generate an adjustable homogeneous field with a wide range of amplitude within a maximized percentage of the shielded volume, which VLSI designers might well bear in mind as a degree of freedom in their design. The possible implications of this adjustable homogeneous field are suggested by several recent reports on the use of transistors as magnetic field sensors (Ref. 8). The precise geometry of Hanson & Pipkin's synthesis cannot be equaled in performance by any off-the-shelf degaussing system.

The inner field homogeneity demonstrated by that mathematically rigorous design implies a uniformity of shield permeability (cf. Ref. 4, p. 148 "D. Effects of Variable Permeability.") In the context of new standards for homogeneity of residual fields, there seems to be no better way to ensure uniform demagnetization than to rely on such a controllable design, although initially it may appear to be an overdesign.

The process of continual demagnetization of a magnetic shield cylinder with its axis transverse to the Earth's field assures that incremental permeability which determines ac shielding effectiveness is continually optimized. This process of shaking was portrayed in original specifications as being realized by a toroidal winding of a few turns wound on an open cylinder. In many applications, shaking gives the most effective results when continuously applied during use.

Sometimes the local ac field of the toroidal winding cannot be tolerated. Thus shaking is restricted to periodic routine demagnetization. In cases where the physical complications of the presence of the windings are intolerable and where the local fields are unacceptable, a uniform shaker field can be generated by means of a technique suggested by Refs. 6 and 7. The cross-section must have cylindrical geometry, and the best joining technique must be used for any seams. To quote a brief description of the experiment that suggested this ac adaptation: "When a longitudinal and a circular magnetic field are simultaneously applied to a long rod of ferromagnetic material, the resultant lines of force form helices about the axis of the rod and any change in dimension of the material along them causes the rod to twist." This is called the Wiedemann effect and can be interpreted in terms of magnetostriction data. *The circular field is obtained by passing a current through the specimen.* (Ref. 6). The rod nature of the specimen referred to facilitates attainment of uniform current density, since direct current is used and the rod is much longer than its diameter.

In the context of "shaking" a cylinder, the uniformity of current density of the ac applied is critical. This demands a precise fitting of a current-distributing ring electrode or end cap to the open end. Given such a precision-fitted electrode, which might be silver-plated aluminum, as used in the power distribution industry, the shaking method envisaged should offer controllability both of the uniformity of demagnetization and the penetration of shaker ac field into the cylindrical magnetic shield. The shaker field will invade the shielded space if the cylinder thickness measured in skin depths is less than one skin depth at the frequency used. With a frequency sufficiently high that more than a skin depth is present, then the shaker ac field will not be obtrusive inside the shield. For large nested shield assemblies, a generous thickness (0.0625") of high permeability alloy is necessary, so low frequencies below 10 Hz are called for in order to "shake" the system thoroughly.

An alternative to shaking is to design an extra concentric shield into the nested set, but this does not appear to take full advantage of the controllable aspects of the proposed method. The only obtrusive feature that will remain will be the need for electrical isolation of the concentric shields from one another, except at the center of the closed end. However, this improvement should be planned early in the design stage if the anticipated benefits seem worthwhile, a general rule that applies to all EMC projects.

For shield systems of the size and thickness range used for early cryostatic systems, this form of shaking can be expected to demand much more amperage than the longitudinal demagnetization; so high-power amplifiers for the low frequencies may be desirable as being the most compact and efficient means. For routine demagnetization, these amplifiers have to be adjustable as to output current which must be monotonically reduced to zero, allowing a time of several cycles per decibel of reduction. Metering or recording of this current versus time is obviously desirable in the same sense that recording of the cooling cycle of the annealing furnace is a routine quality control requirement of all magnetic shields.

Instrument calibrator type of equipment is most practical for shaking, measuring and testing. These tools incorporate the tightest possible linkage to measurement standards of current and voltage. Critical uniformity of permeability demanded by cryostatic memory shields can be inspected by "coating thickness" scanning to detect and measure any surface recrystallization layers. An ac bridge type coating thickness gauge, itself protected by a cast nickel alloy shield, has been used in the initial surface survey. More data in conjunction with mapping of residual fields inside the shields is needed before the coating thickness scanning can be standardized.

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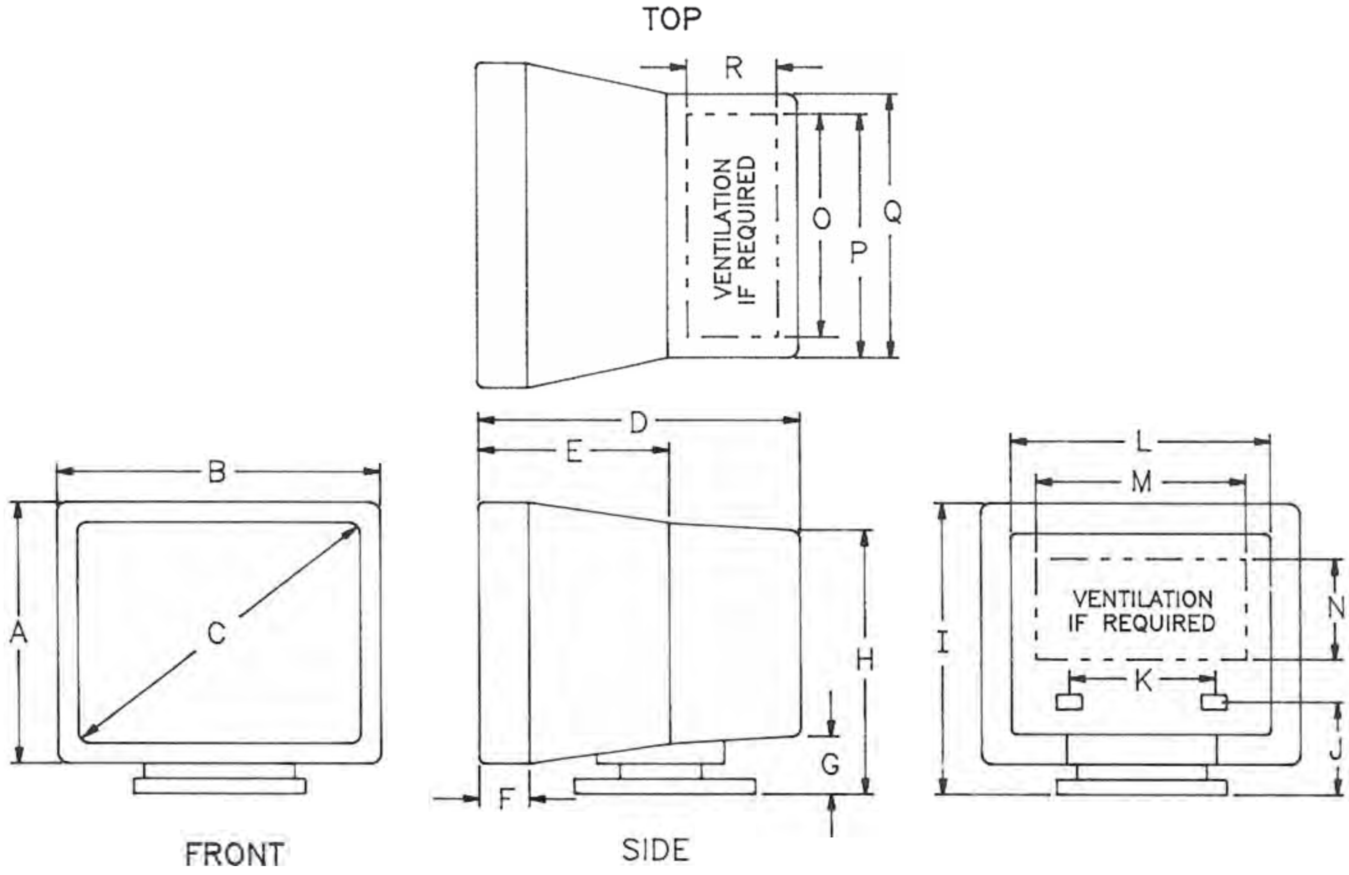

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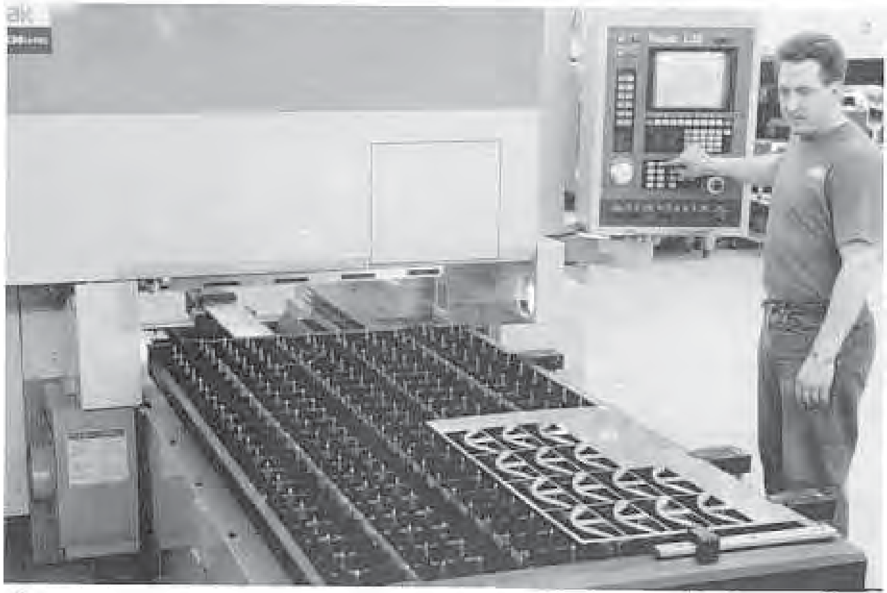

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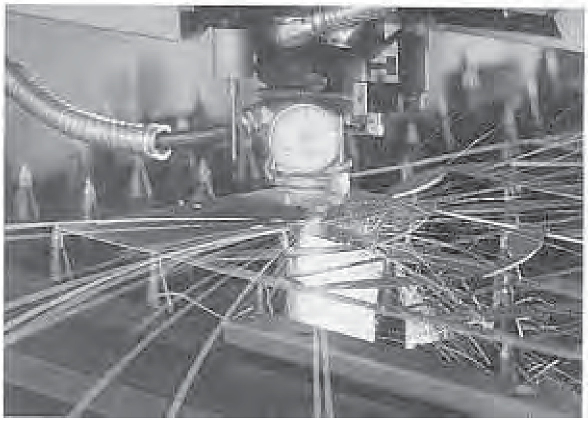

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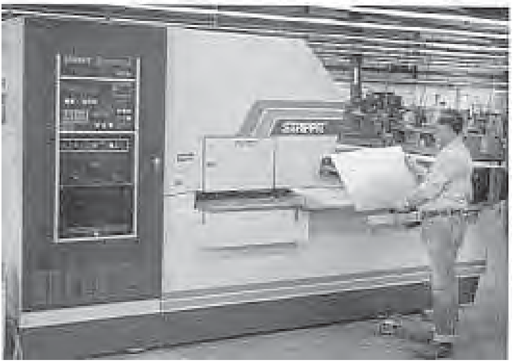

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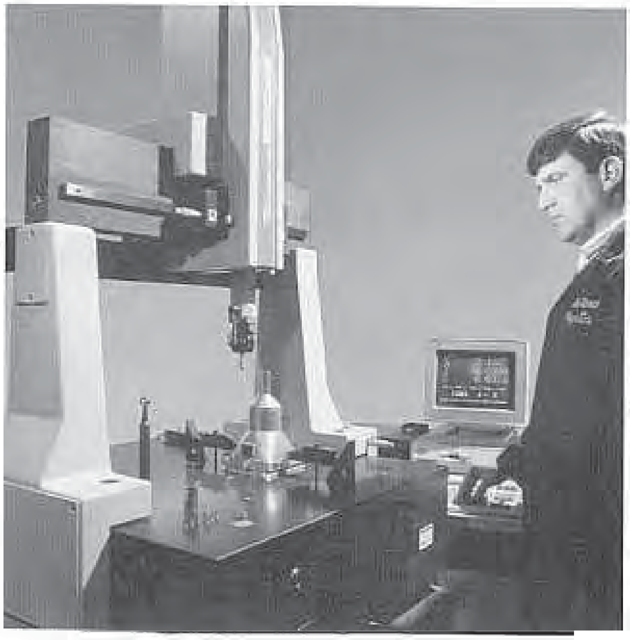

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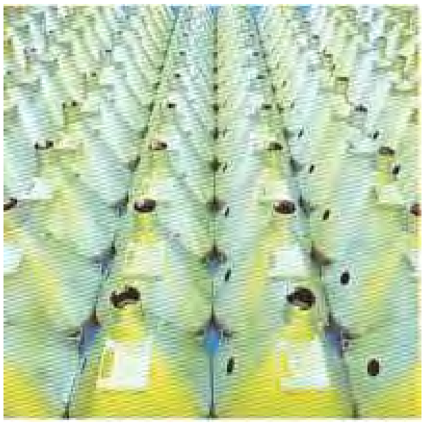

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