MAGNETIC SHIELD REFINEMENTS FOR LOW TEMPERATURE VLSI PACKAGING

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 1/S) and speed-power product (inversely proportional 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 inital 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)

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

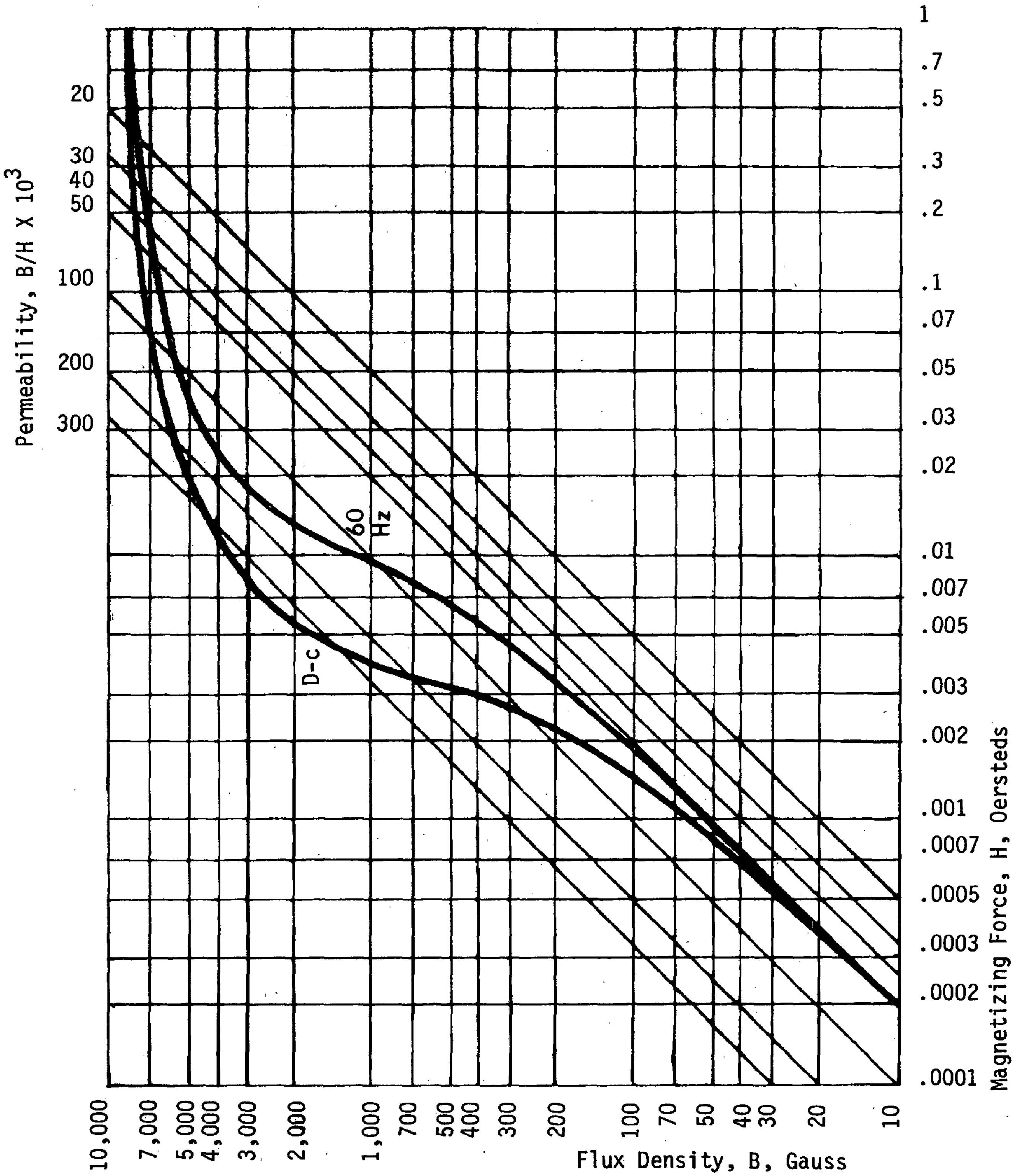

Figure 1. Typical Magnetization Curves of AD-MU-80 (.014 Thickness)

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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