Magnetic Shielding

Magnetic proximity is a subject that must be considered in packaging components in electronic systems, particularly those components that have magnetic structures and involve electron-beam focusing, as do many microwave devices. Components that may be susceptible to magnetic influences include the following general categories:

- Permanent-magnet-type meters
- Magnetic tape and magnetic reluctance pickups
- Electromagnetic relays
- Transformers, saturable reactors
- Hall-effect devices
- Photomultipliers
- Microwave devices [magnetrons, traveling-wave tubes, backward-wave oscillators, klystrons, r-f isolators and circulators, garnet resonators (YIG's), ferrite devices, parametric amplifiers]
- Masers, plasma devices
- Vacuum tubes

The effects of strong magnetic fields are quite well known to the makers and users of simple meters, but many meter cases are still not designed to shield against intense external fields. Magnetic taped information can be completely destroyed or garbled by unfortunate coincidence with strong, magnetic fields. Shielded cans are therefore used for the storage and transport of magnetic tapes.

There are a number of ways in which relays can be disturbed by magnetic fields: they can fail to function, they can "hang-up," or their action can be slowed. Knowledge of the relative alignment of the disturbing field can be used advantageously if it is possible to orient the relay to minimize the disturbance.

Transformers and magnetic amplifiers (in fact, most devices using ferous cores) can be disturbed to some degree by the presence of a strong biasing field. (Open-core devices are particularly susceptible; toroidal-core devices have more tolerance.) If such devices must be packaged in close proximity to a strong magnet, the breadboarded version of the system should be checked by placing a strong magnet within range and observing the resulting disturbance. Again, choice of orientation may eliminate or reduce the problem.

In relation to electron tube devices, if there is a special flow of electrons which must be aligned or focussed to achieve some function, then stray magnetic fields will disturb alignment and cause faulty operation. The various faults are peculiar to the specific device and can vary widely in their seriousness. Magnetrons, backward-wave oscillators and traveling wave tubes react to asymmetries introduced into their focusing fields by showing a power-output loss. This may not occur over the entire frequency band for which they have been designed, but only at specific frequencies; these loss areas are called "holes." There may be wholesale shifting of frequency and—even worse—there may be catastrophic tube failure because of excessive helix current or destructive cathode operation. Asymmetry in the focusing field may be caused by placing the tube next to one which has a powerful permanent magnet or even by placing the tube near a large ferrous object such as a steel structure or a transformer. Transformer operation can cause modulation of the tube output.

Electron-tube magnets come in various shapes and sizes as shown in Figure 1. Magnetron magnets are often C-shaped, and newer designs are shaped like two facing C's joined to place the air gap across the points of the C's. The carcinotron magnet also has this general form. Backward-wave oscillators have solenoid-shaped magnets with the r-f tube lying in the main axis of the solenoid. Traveling-wave tubes generally have periodic solenoid magnets spaced along the main axis of the tube without using a solenoid shape. Figure 2 tabulates the disturbing effects of magnetic fields on the permanent-magnet solenoid of a backward-wave oscillator.

The use of shielding-metal shields around cathode-ray tubes is familiar to most designers. These same shielding techniques will shield r-f devices, but each device has its own peculiarities which must be taken into account.

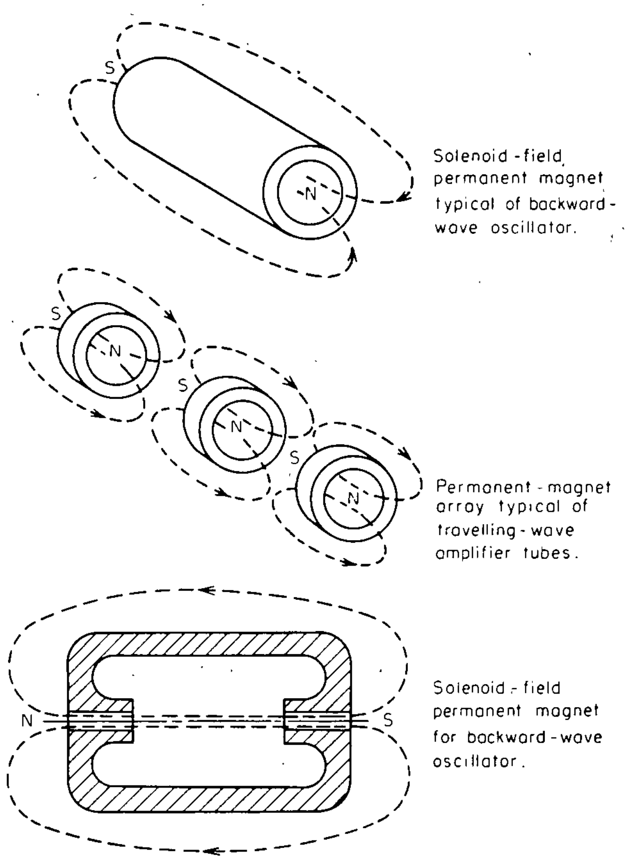
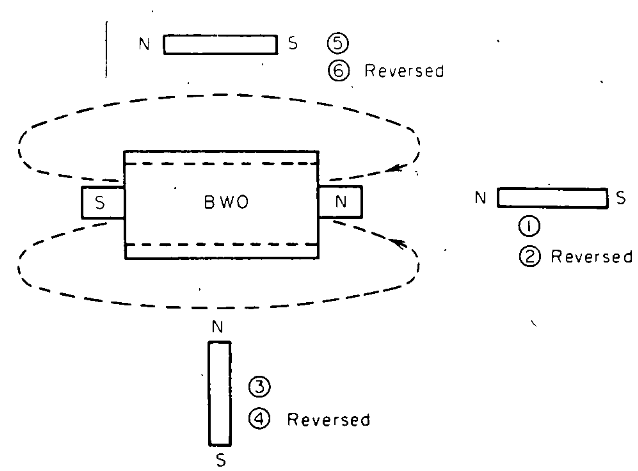


Fig. 1 — Magnetic fields associated with various microwave tubes employing permanent magnets.



Condition	1	2	3	4	5	6
Effect	Possibly bad	Likely OK	Bad	Bad	Possibly bad	Possibly OK

Fig. 2 — Effect of placement of disturbing magnetic fields on the alignment of a BWO field axis.

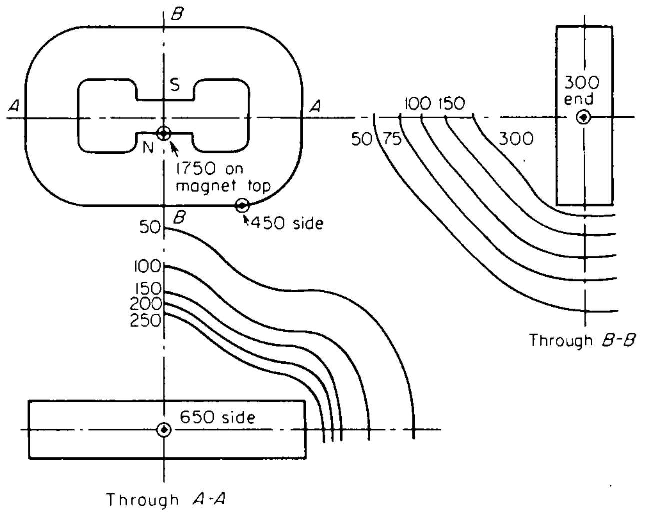


Fig. 3 — Field plot in gauss typical of a small vacuum-tube magnetron magnet.

Makers of microwave tubes which incorporate magnets could do the packaging engineer and EMC engineer a great service by supplying a plot of field strength and polarity for each of their tube types. With this data, the designer could set up magnetic-proximity limits or spell out the symmetry necessary to preserve tube focus. He would also need to know the gauss level surrounding a tube to apply shielding effectively. The external field surrounding the magnet of a typical backward-wave oscillator or magnetron will vary depending on the proximity to the magnet air gap as shown in Figure 3. Within the gap it may be over 5000 gauss. Away from the gap but on the outer surface of the magnet it may drop to perhaps 300 gauss. The field may still be as high as 100 gauss 2 in. away from the magnet.

General Shielding Practice

Full and completely enveloping shielding is the only sure type of magnetic shielding, and the less this envelope is broken by holes and cutouts the better the protection will be. Shielding materials in the form of thin tapes and foils are quite soft and can be used to wrap items to be shielded, thus furnishing an all-enveloping shield.

Overlapping joints can function well if the main portion of the shield is adequate for the disturbing flux present. Small gaps in seams can also be tolerated (0.005 in., for example). It is for this reason that welds in the shield joints can also be tolerated, provided the recommended heat treatment flows. Placement of magnetic shielding in a single-plane partition is not too satisfactory unless all the factors are considered. Single-plane shielding is particularly bad from the standpoint of symmetry. The lines of flux which would normally pass out beyond the shield will instead tend to concentrate along the shield. If an insufficient thickness of shielding metal is used, the shield will appear to be transparent beyond the point of saturation.

The ability of the magnetic field to pass through a shield depends upon the permeability and saturation level of the shield material. Ideally, it should have high permeability, low retentivity, and the ability to carry a large magnetic-field density before saturating. The saturation level is determined by the thickness as related to the characteristic magnetic property and frequency of the disturbance (other than direct current). Economy in shielding can sometimes be gained by laminating the shield. A thin low-permeability material, for example, can be used to attenuate low-level, high-frequency fields and a heavier, medium-permeability material can then stop the heavy d-c fields. Prior to establishing the sequence of the laminations, a choice must be made between excluding or containing the disturbing field.

The maintenance of magnetic symmetry in the shielding process is very important. Made as it is of ferro-magnetic materials, the shield itself tends to degrade the performance of the r-f device because it decreases the effective field within the air gap or principal magnetic axis. If this shield is not symmetrical with the device magnetic field, the latter may be warped and the resultant field within the air gap altered. In assembly, the tube manufacturer usually shifts the tube proper within the magnetic field until he achieves desired focus and operation. At times, the apparent physical symmetry of the tube does not conform with the magnetic symmetry. When this happens, shielding becomes especially difficult since the main mass of the tube may lie awkwardly out of line within the shield. Within space limitations, it is not always possible to shield and still not change the tube characteristics. Shielding is always heavy when used to attenuate strong fields such as are used in backward-wave oscillators, magnetrons and certain klystrons.

After shielding has been applied, it is often found that the performance of the r-f device has deteriorated beyond the acceptable limit or that the shield must be made larger so that it does not drastically affect the item to be shielded. Even with successful shielding experience as a guide, the process remains cut and try. Boxes and tubing of various sizes of shielding materials are very helpful in approximating effects and thus the amount of shielding necessary. The maximum properties of the shielding are achieved if the shield material can be heat-treated after fabrication. It may be found, however, that a choice of another type of shielding material working at a lower saturation level may work as well for shielding powerful magnets.

Packaging designers must be cautioned to take the envelope dimensions given by the r-f device manufacturer with a grain of salt. Tolerances used in glass and ceramic-tube fabrication are generally quite large. The requirement for shifting of the tube within the magnet structure accounts for a great deal of the possible variation in the envelope and in the location of the r-f output plumbing. If tolerances are given, the package designer must be prepared to accept tubes having the widest combination of the given tolerance. Tube mountings must be designed with various adjustments built in or chances are high that the mounting may create trouble when the tube must be replaced.

Microwave-Tube Problems

When an r-f insolator device is to be added to a magnetron, both the magnetron and the isolator may be affected by their interacting fields. The magnetron frequency and output power may change slightly and the isolator, unless it is shielded, will fail to function if the proximity of the magnetron is such that a few hundred gauss can pass through it. Orientation may also enter the picture. When polarities and their directions are considered, the variations are many. In one case, an r-f isolator was packaged in conjunction with the tube and within the C-shaped magnet. The result was that the small magnets used in the isolator had to be turned around to buck the strong field of the magnetron magnet.

In another case, an yttrium-iron-garnet resonant device used as a notch filter was extremely sensitive to the slight magnetic field emanating from its twin, which was packaged 1 in. away. The frequency and the bandwidth of the notch were sufficiently disturbed that shielding and separation of the two devices became necessary. The shielding, in turn, caused shifts for which the manufacturer had to compensate. In this case, the shielding should have been incorporated by the manufacturer.

Again, one type of electrostatically focused microwave tube would have made a wonderful magnetometer rather than a backward-wave-oscillator because it picked up the motion of a very small horseshoe magnet at a distance of over 10 ft. This tube was subsequently encased within a magnetic shield by the user.

A traveling-wave tube using bar-type magnets and iron pole pieces measured 3 x 3 x 9 in. and the direction of the field lay in the 9-in. direction. This tube proved to be impossible to shield in a cylinder less than 9 in. in diam, 15 in. long and 0.060 in. thick. With any smaller diameter, the helix current rose to dangerously high levels and the life of the tube would have been short indeed.

A backward-wave oscillator which had a solenoid magnet 4 in. in diam by 4 in. long, when shielded in 6 in. tubing 12 in. long by 0.060 in. thick, developed so many "holes" in the power curve that shielding had to be abandoned in favor of a simple aluminum shroud. In some cases, such tubes are operated with 2000 volts or more on the mounting feet and outer shell. In this case, a protective shell for personnel is required whether it functions as a magnetic shield or not.