Novel Method to Orient Ferrimagnetic Single-Crystal Spheres*

The method used to orient ferrimagnetic single-crystal spheres has been the traditional X-ray technique. It is the purpose of this article to propose an orientation method which is simple and inexpensive, and which may be carried out by the microwave engineer or technician in his own laboratory.

Most of the ferrimagnetic materials have either a cubic or hexagonal crystal structure. The easy direction of magnetization in a cubic crystal is, in most cases, the body diagonal or sometimes the cube edge. If the specimen has a hexagonal structure, then the easy direction could be found along the C axis or in an easy plane of magnetizaion perpendicular to the c axis.

In a uniform magnetic field, an easy axis of such a material aligns itself with the field lines, provided it is freely rotatable. This condition can be attained by a low-viscosity liquid with a specific density greater than that of the sample in question, *e.g.*, mercury. The crystal sphere will be able to float on its surface. For most materials, the determination and marking of two of the easy axes are sufficient to obtain an intermediate or hard direction (Fig. 1).

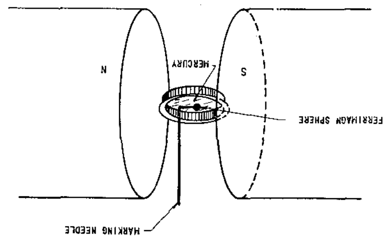

Fig. 1.

For the cubic structure, with the body diagonal as the easy direction (*e.g.*, YIG, $NiFe_2O_4$, Fe_3O_4), an intermediate axis will be found in a direction which is represented by the bisecting line of two easy axes when they are $70\frac{1}{2}°$ apart. A hard axis will be found in a direction which is given by the bisecting line of two easy axes when they are $109\frac{1}{2}°$ apart. For the cubic structure with the cube edge as the easy direction (*e.g.*, $CoFe_2O_4$), an intermediate axis will be found in a direction which is represented by the bisecting line of two easy axes. A hard axis (now the body diagonal) will be found in a direction which is $35\frac{1}{4}°$ apart from the bisecting line of the easy axes, as shown in Fig. 2. In the case of the hexagonal crystal structure with the easy direction along the c axis, the hard direction is anywhere within a plane perpendicular to the c axis. The c axis, being a hard direction, may be found at an angle of 90° from the easy plane, which is determined by two markings.

The accuracy of this method is influenced mainly by the marking and mounting technique. Deviations by the marking needle from the correct alignment can result in inaccuracies in marking the easy axes. Another source of inaccuracy resides in the possibility of asymmetric distribution of the marking paint on the sphere with respect to the needle point.

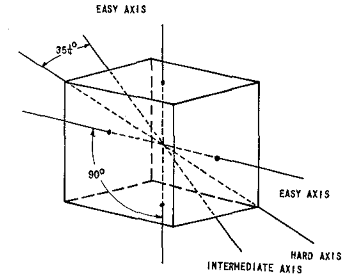

Fig. 2—Magnetization axis in a cubic crystal of the $CoFe_2O_4$ type.

The tests carried out to date on the described crystal orientation method have yielded satisfactory results. These results reflect the angle dependence, which is to be expected. A YIG sphere was mounted on a teflon rod and rotated around its intermediate axis, thereby permitting the display of all three main axes in a plane normal to the axis of rotation. This was verified in a longitudinally-pumped, parametric amplifier utilizing the magnetostatic mode of operation. The applied H_{DC} field necessary for parametric interaction showed a distinct variation with changes in angle, whereby the maxima and minima coincided closely with the main crystal axes.

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Tunnel Diode Burnout from the Video Transient of Gaseous Noise Sources*

The helix-coupled, coaxial, gaseous noise source poses a burnout hazard to tunnel diodes unless certain precautions are taken. The attached oscillograms illustrate the transient in question. Typical short-circuit peak currents are 300 ma. The transient is a consequence of the sudden forced transition of the helix core from a nonconducting, unionized gaseous media to that of a conducting plasma. The transient coupled to the helix is easily suppressed with a high-pass or band-pass filter, or even by adequate padding. If only a pad is used, a word of warning is in order. The pad must be of the type that attenuates video, as well as radio, frequency.

Fig. 1 shows the transient coupled to the helix with the helix unterminated at both ends. Fig. 2 shows the transient on a faster time base when the helix is terminated at one end in a 50-ohm resistor. The average power for a 500-cps switching rate measured with a 50-ohm thermistor bridge was observed to be 1.2 mw with the helix unterminated, and 0.1 mw with the helix terminated in a 50-ohm resistor. Several diodes were destroyed when subjected directly to the transient, *i.e.*, with the helix otherwise unterminated.

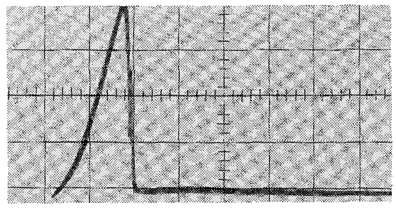

Fig. 1—Capacitively coupled transients measured between helix and ground with the helix loaded by the Tektronix high-impedance probe, (impedance 4 pf and 10 MΩ). The abscissa is 5 μsec per cm (large division); the ordinate is 200 v/cm.

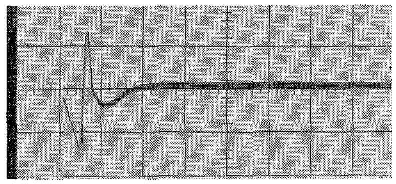

Fig. 2—The picture here differs from Fig. 1 in that the anode end of the helix is terminated with a −50-ohm resistor. The abscissa is 0.5 μsec per cm; the ordinate is 10/cm.

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Some Remarks on "Radiation from a Rectangular Waveguide Filled with Ferrite"*

These remarks concern the solution of the boundary value problem for the case of longitudinally magnetized ferrites between two perfectly conducting parallel planes. The above-mentioned paper by Tyras and Held[1] treated only a very special particular case of propagation in the anisotropic media. A more general approach to the problem and a general solution will be given in this note. Throughout this note the author has kept most of the notation as in the original paper.

Tyras and Held have stated the required boundary conditions in the form:

$$E_z = 0 \tag{1a}$$

$$\frac{dE_z}{dx} + M \int E_z dx = 0 \tag{1b}$$

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[1] G. Tyras and G. Held, "Radiation from a rectangular waveguide filled with ferrite," IRE Trans. on Micorwave Theory and Techniques" vol. MTT-6, pp. 267–277; July, 1958.

on the boundaries $x=0$ and $x=a$, where

$$M = k_e^2 - \beta^2 = \omega^2\epsilon\frac{\mu^2 - k^2}{\mu} - \beta^2 \qquad (2)$$

and the wave factor is $e^{j(\omega t - \beta z)}$. A general solution has been suggested by them in the form:

$$E_z = A\cos\rho_1 x + B\sin\rho_1 x + C\cos\rho_2 x + D\sin\rho_2 x, \qquad (3)$$

where one has

$$\rho_{1,2} = \sqrt{\frac{\psi}{2} \pm \sqrt{\left(\frac{\psi}{2}\right)^2 - \Gamma^2}} \qquad (4)$$

and ψ, Γ are functions of the media parameters (k, μ, μ_0, ϵ) and the propagation constant β.

Substituting solution (3) in the boundary conditions in (1), they got

$$A + C = 0 \qquad (5a)$$

$$A\cos\rho_1 a + B\sin\rho_1 a + C\cos\rho_2 a + D\sin\rho_2 a = 0 \qquad (5b)$$

$$B\left(\rho_1 - \frac{M}{\rho_1}\right) + D\left(\rho_2 - \frac{M}{\rho_2}\right) = 0 \qquad (5c)$$

$$-A\left(\rho_1 - \frac{M}{\rho_1}\right)\sin\rho_1 a + B\left(\rho_1 - \frac{M}{\rho_1}\right)\cos\rho_1 a - C\left(\rho_2 - \frac{M}{\rho_2}\right)\sin\rho_2 a + D\left(\rho_2 - \frac{M}{\rho_2}\right)\cos\rho_2 a = 0. \qquad (5d)$$

Eq. (5) will give a nontrivial solution if the determinant of the coefficients is zero. Using this, Tyras and Held got the equation:

$$2\left(\rho_1 - \frac{M}{\rho_1}\right)\left(\rho_2 - \frac{M}{\rho_2}\right)(1 - \cos\rho_1 a\cos\rho_2 a) = \left[\left(\rho_1 - \frac{M}{\rho_1}\right)^2 + \left(\rho_2 - \frac{M}{\rho_2}\right)^2\right]\cdot\sin\rho_1 a\sin\rho_2 a. \qquad (6)$$

According to the theory of linear equations, one can disregard now (5d) and solve the other three homogeneous equations to give:

$$\frac{B}{A} = -\left(\rho_2 - \frac{M}{\rho_2}\right)\cdot\frac{\cos\rho_1 a - \cos\rho_2 a}{\left(\rho_2 - \frac{M}{\rho_2}\right)\sin\rho_1 a - \left(\rho_1 - \frac{M}{\rho_1}\right)\sin\rho_2 a} \qquad (7a)$$

$$\frac{C}{A} = -1 \qquad (7b)$$

$$\frac{D}{A} = +\left(\rho_1 - \frac{M}{\rho_1}\right)\cdot\frac{\cos\rho_1 a - \cos\rho_2 a}{\left(\rho_2 - \frac{M}{\rho_2}\right)\sin\rho_1 a - \left(\rho_1 - \frac{M}{\rho_1}\right)\sin\rho_2 a}. \qquad (7c)$$

The authors have suggested that the relation in (6) may be satisfied by

$$\rho_1 = \frac{m\pi}{a} \qquad \rho_2 = \frac{n\pi}{a}, \qquad (8)$$

where m, n are two integers $m \neq n$, both simultaneously odd or even.

While the above suggestion is true, it is valid in general only for the case of isotropic media when $\rho_1 = \rho_2$, and (6) becomes an identity. In all other cases it can be valid only *accidentally*, when the media parameters are adjusted so that (41) of the original paper will be an identity between the two integers m, n. It will be then valid only for very special particular modes for each media. Only in this particular case are the constants pair A, C completely independent from the pair B, D because (7a) and (7c) become indetermined.

The general treatment of the problem should proceed as follows: One should take the values of ρ_1 and ρ_2, as found in (4), in terms of the propagation constant β and the media parameters, and substitute those values in (6). Taking into account (2), one gets a transcendental equation for the propagation constant β. This transcendental equation provides infinite numbers of solutions for β for any given media. Once β has been determined for a particular mode, the constants ρ_1 and ρ_2 could be evaluated from (4).

However, in this general anisotropic case, $\cos\rho_1 a \neq \cos\rho_2 a$ and the same applies to the denominators in (7). Therefore the constants A, B, C, D are not independent, and one could get from (3) and (7):

$$\frac{E_z}{A} = \cos\rho_1 x - \cos\rho_2 x - \frac{\cos\rho_1 a - \cos\rho_2 a}{\left(\rho_2 - \frac{M}{\rho_2}\right)\sin\rho_1 a - \left(\rho_1 - \frac{M}{\rho_1}\right)\sin\rho_2 a}\cdot\left[\left(\rho_2 - \frac{M}{\rho_2}\right)\sin\rho_1 x - \left(\rho_1 - \frac{M}{\rho_1}\right)\sin\rho_2 x\right]. \qquad (9)$$

Eq. (9) obeys the boundary conditions in (1). Once E_z is known as in (9), the rest of the field components could be found from (10)–(14) in the original paper. As a result, in general, there will be only one inseparable hybrid mode for each pair (ρ_1; ρ_2); the suggested separation to "Quasi TE mode" and "Quasi TM mode" is justified only for a very particular case. In the limiting case of isotropic waveguide, the generally inseparable hybrid mode will degenerate to the standard TE and TM modes between two parallel planes.

A more comprehensive analysis of this problem has been given by the author of this note in a recent report,[2] and will be published in a separate paper.

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Author's Comment[3]

The remarks of Prof. Unz are well taken but need to be put in proper light with reference to the purpose of the paper under discussion.

In our paper we were primarily concerned with a case not mentioned in literature before. Specifically, if one takes (20) of our paper as the starting point,

$$2\left(\rho_1 - \frac{M}{\rho_2}\right)\left(\rho_2 - \frac{M}{\rho_2}\right)(1 - \cos\rho_1 a\cos\rho_2 a) = \left[\left(\rho_1 - \frac{M}{\rho_1}\right)^2 + \left(\rho_2 - \frac{M}{\rho_2}\right)^2\right]\cdot\sin\rho_1 a\sin\rho_2 a, \qquad (1)$$

then, providing

$$\left(\rho_1 - \frac{M}{\rho_1}\right)\left(\rho_2 - \frac{M}{\rho_2}\right)(1 \pm \cos\rho_1 a)\cdot(1 \pm \cos\rho_2 a) \neq 0, \qquad (2)$$

one can put (1) with the help of well-known trigonometric identities in the form

$$\left[\tan\frac{\rho_1 a}{2} - \left(\frac{\rho_1 - \frac{M}{\rho_1}}{\rho_2 - \frac{M}{\rho_2}}\right)\tan\frac{\rho_2 a}{2}\right]\cdot\left[\tan\frac{\rho_1 a}{2} - \left(\frac{\rho_2 - \frac{M}{\rho_2}}{\rho_1 - \frac{M}{\rho_1}}\right)\tan\frac{\rho_2 a}{2}\right] = 0. \qquad (3)$$

It follows from (3) that setting either one of the expressions in the square brackets equal to zero will satisfy the boundary conditions for all cases except those for which (2) is violated. The case

$$\left(\rho_1 - \frac{M}{\rho_1}\right)\left(\rho_2 - \frac{M}{\rho_2}\right)(1 \pm \cos\rho_1 a)\cdot(1 \pm \cos\rho_2 a) = 0 \qquad (4)$$

about which (3) gives no information was considered by us, whereas the cases represented by (3) were considered earlier by Suhl and Walker.[4]

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[2] H. Unz, "Electromagnetic Waves in Longitudinally Magnetized Ferrites Between Two Conducting Parallel Planes," Antenna Lab., The Ohio State University Res., Foundation, Columbus, Ohio, Rept. No. 1021-10, Contract AF 33(616)-6782; December, 1961.

[3] Received by the PGMTT, October 19, 1961.

[4] H. Suhl and L. R. Walker, "Topics in guided-wave propagation through gyromagnetic media, Part III—Perturbation theory and miscellaneous results," *Bell Sys. Tech. J.*, vol. 33, pp. 1133–1194; September, 1954.