# Comments on "On the Definition of Parameters in Ferrite-Electromagnetic Wave Interactions"

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In the above paper,[1] Bolle and Lewin discuss definitions of some parameters characterizing the material in ferrite-electromagnetic wave interactions. According to this discussion, the direction of propagation, and not the direction of magnetization, is recommended as a reference direction. In this letter, it is shown, however, that this is not generally valid. Some examples are used to show instants where the parameters are better referred to the direction of magnetization in order to avoid unnecessary confusion.

*Examples*

*1) Definition of the Sense of a Circularly Polarized Wave:* Consider the permeability tensor

$$[\mu] = \begin{bmatrix} \mu_1 & -j\mu_2 & 0 \\ j\mu_2 & \mu_1 & 0 \\ 0 & 0 & \mu_0 \end{bmatrix}$$

with $\mu_2$ as a negative real quantity ($\omega_0 > \omega$). When an infinite ferrite medium, magnetized in the $z$-direction, is excited by an electromagnetic wave propagating along the $z$-direction, and circularly polarized in the $x-y$ plane, the ferrite presents a scalar permeability $\mu_{e+} = \mu_1 - \mu_2$ for one sense of polarization, and $\mu_{e-} = \mu_1 + \mu_2$ for the other sense. A resonance occurs in $\mu_{e+}$ due to the strong interaction between the precessing electrons of the ferrite and the corresponding electromagnetic wave [1]. Here, the circularly polarized wave rotates in the same direction as that of the precessing electrons about the dc field, as shown in Fig. 1. The rotation is clockwise for a dc field along the $z$-axis. Notice that the anticlockwise direction indicated is with respect to the $(-z)$ axis, inside the paper, which becomes clockwise with respect to the $z$-axis.

On the other hand, when the exciting wave is plane-polarized, a split occurs such that two counter rotating circularly polarized components propagate with different propagation constants. For a uniform plane wave in an infinite medium, the two propagation constants are associated with $\mu_{e+}$ and $\mu_{e-}$. For a nonuniform plane wave, such as a guided wave in a ferrite-loaded circular waveguide, a usual $\theta$-dependence of the form $\exp jn\theta$, $n = 1, 2, \ldots$, and $n = -1, -2, \ldots$, is taken to account for the negative and the positive components, respectively (assuming $\exp j\omega t$ time dependence).

In all these cases, the sense of rotation is defined with respect to the direction of rotation of the precessing electrons about the dc field. When the direction of the dc field is reversed, the sense of the circularly polarized wave should also be reversed such that the positive component is associated with the scalar permeability which exhibits resonance, or with the $\exp(-jn\theta)$ dependence. Taking the definition with respect to the direction of propagation may cause confusion since no reference to the direction of the precessing electrons will be possible.

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[1]P. M. Bolle and L. Lewin, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-21, p. 118, Feb. 1973.

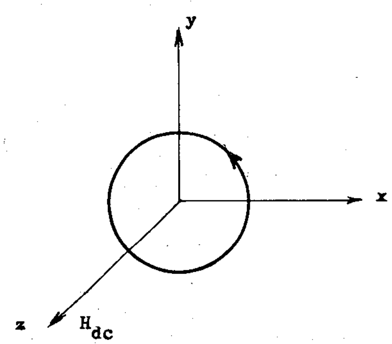


Fig. 1. Direction of rotation in positive circular polarization and direction of electron precession, both indicated by the arrow in the circular path.

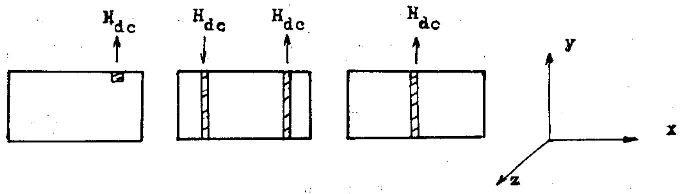


Fig. 2. Structures with transversely magnetized ferrites.

*2) Case of a Transversely Magnetized Ferrite:* Approximate solutions to problems incorporating nonuniform plane-wave propagation through transversely magnetized ferrites may be obtained by considering circularly polarized waves with longitudinally magnetized ferrites. Structures such as shown in Fig. 2 are dealt with by considering $h_x$ and $h_z$ as constituting a circularly polarized magnetic field [2]. Since the dc field (in the $y$-direction) is normal to the plane of polarization (the $x-z$ plane), the problem becomes approximately equivalent to the cases of longitudinally magnetized ferrites considered in Example 1 where the permeability tensor is reduced to $\mu_{e+}$ and $\mu_{e-}$.

*3) Case of a Circular Waveguide Loaded at the Center with a Longitudinally Magnetized Ferrite Rod:* The normal propagating modes of this structure are hybrid. It is only at cutoff, that is, at $\gamma_z = 0$, that these modes reduce to pure $E$ and $H$ modes [3]. The interesting fact is that the longitudinally magnetized structure behaves at cutoff as an infinite ferrite medium with the dc magnetization transverse to the direction of propagation. In both cases, there are two scalar permeabilities. The first is just $\mu_0$ leading to the usual TEM mode in the infinite medium and to the $H$ cutoff mode in the loaded circular guide. The second scalar permeability is equal to $\mu_e = (\mu_1^2 - \mu_2^2)/\mu_1$ leading to an $H$-mode propagation in the infinite medium. In the loaded circular guide, $\mu_e$ is associated with an $E$ cutoff mode which has $H$-mode characteristics at $\gamma_z \neq 0$ and in the limit of increasing radius. The common factor between the two problems is the absence of dependence along the direction of magnetization (the $z$-axis). This again would be difficult to detect if the different phenomena were referred to the direction of propagation.

## *Reply[2] by L. Lewin[3]*

The original 1973 letter by Bolle and Lewin was intended to draw attention to several possible different sources of sign error when using published formulas on ferrite parameters. It is not so

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much that one author's definition is better than another's as that the existence of different definitions itself can cause both error and confusion. The direction of precessing electrons certainly has relevance to the direction of an applied field; and the direction of circular polarization of a plane wave is similarly normally referred to its direction of propagation. The confusion arises, in part, when, say, a right-handed circular polarization of a propagating wave is referred to an applied field direction which could be parallel or antiparallel to the propagation direction. When the applied field changes direction, the polarization remains unaltered in the first case but becomes reversed in the second.

When reading a paper on the subject, one needs to be aware of which definition has been used, particularly since it may not have been explicitly stated. Mr. Eid's preference for defining circular polarization with respect to the applied field rather than the direction of propagation is exemplified by his statement, "....the parameters are better referred to the direction of magnetization in order to avoid unnecessary confusion." This may be contrasted with our penultimate paragraph which concludes with "Defining the sense of circular polarization with respect to the applied field, as is sometimes done, introduces yet a further source of sign confusion to the subject." I feel that the confusion really comes from the existence of differing definitions (which is something that cannot be expected to go away), together with an author's failure to clearly state which definition is being used, rather than because one particular definition may be *inherently* confusing. Mr. Eid's point about the difficulty in referring the polarization to the propagation direction when the wave is at cutoff is well taken, but the difficulty persists in the unmagnetized case, in which only the coordinate axis survives as a reference direction. (This is a yet further possible source of confusion that we hadn't come up with in our earlier letter!) Since, in the absence of an applied field, the latter cannot be used as a reference direction, we had preferred the propagation direction for the definition. The very last thing we want is to switch definitions according to the presence or absence of an applied field, the difficulty of the cutoff case notwithstanding. I think the lesson of all this remains as set out previously, namely, that one should a) specify the definition one is using, and b) when quoting from the literature, make sure that an unwitting error in presuming, incorrectly, the use of a certain definition, is not made.

### References

[1] C. L. Hogan, "The elements of non-reciprocal microwave devices," *Proc. IRE*, vol. 44, pp. 1345–1368, Oct. 1956.
[2] A. G. Fox, S. E. Miller, and M. T. Weiss, "Behavior of ferrites in the microwave region," *Bell Telephone Monograph*, no. 2370, p. 30.
[3] P. J. B. Clarricoats, *Microwave Ferrites*, Chapman and Hall, 1961, p. 156.

## Corrections to "A Short History of Microwave Acoustics"

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In regard to Section III of the above paper,[1] John Eshbach has brought to my attention that the original experiments on microwave magnetoelastic YIG delay lines were performed by him on disc-shaped geometries and published in 1962 [1]. His 1963 paper [2] gave the first details of the electromagnetic → spin → acoustic conversion process for a YIG disc, which is shown in Fig. 5 of the above paper[1] for a YIG rod. Premium in space precluded a full description of the entire conversion process for an axially magnetically biased YIG rod which is electromagnetic → magnetostatic → spin (exchange) → acoustic. This was originally proposed by B. Yazgan in her 1966 Ph.D. thesis submitted to Glasgow University and subsequently developed by J. H. Collins [3] and experimentally verified by B. A. Auld *et al.* [4]. Reference to the caption in Fig. 5 of the above paper[1] allows references [3] and [4] to be traced.

Also, on p. 1135 of the article,[1] it was stated that Graham Marshall and Ted Paige were awarded the Microwave Prize in 1974. They were, in fact, awarded the 1973 Best Paper Award of the IEEE Group on Sonics and Ultrasonics, along with their co-author Cleland Newton, for their research on multistrip couplers.

### References

[1] J. R. Eshbach, *Phys. Rev. Lett.*, vol. 8, p. 357, 1962.
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[3] J. H. Collins, *Electron. Lett.*, vol. 3, p. 59, 1967.
[4] J. A. Auld, J. H. Collins, and D. C. Webb, *J. Appl. Phys.*, vol. 39, p. 1598, 1968.

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[1] J. H. Collins, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-32, pp. 1127–1140, Sept. 1984.

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