Comments on "The Definition of Cross Polarization"

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The following comments relate to two points discussed by Dr. Ludwig in the above communication.[1] The first point is the connection between cross polarization and aperture illumination efficiency, and the statement "Finally, it has been previously shown by the author [6][2] that a feed with no cross polarization by definition 3 is optimum from the viewpoint of antenna aperture efficiency." It is not clear either from Dr. Ludwig's communication or from [1] what he has in mind here. Because it is unclear to me, I shall not pursue this point further.

The second point has to do with the major topic of Dr. Ludwig's paper, a proposed best choice for the definition of cross polarization. He discusses three possible definitions of cross polarization, for nominally linearly polarized radiators. An antenna or source-current distribution in the xy plane is assumed with the z axis the broadside direction. Cross polarization is defined as 1) the radiated x-directed electric field where the radiated y-directed electric field is the reference polarization, or 2) the polarization orthogonal to that radiated by a y-directed electric dipole, or 3) the polarization orthogonal to that radiated by a Huygens source with electric current in the y direction. Definition 3 is just the polarization of radiation of a crossed Huygens source, with electric current in the x direction. This definition is consistent with what one measures as the reference and cross polarizations when antenna patterns are taken in the usual manner [2, pp. 557–564]. That is, when one measures normal and cross-polarized patterns in the usual way, he is measuring in polarization states of radiation which are those of normal and crossed Huygens sources, respectively. After a discussion, Dr. Ludwig proposes the third definition as the best choice.

However, if this definition is used as the standard definition, an electric or magnetic dipole would have significant cross polarization out of the E plane and the H plane. Only a Huygens source would have no cross polarization. It seems, therefore, that this definition of cross polarization is not *useful* for radiating systems whose nominal radiated polarization is other than that of a Huygens source. In order to be useful the cross-polarization characteristic of an antenna should provide a measure of the deviation of the antenna polarization from a *meaningful* nominal state. This depends on the intended use of the antenna.

As an example, consider radar tracking of a symmetrical target with a linearly polarized antenna. Any radiated linear polarization may be acceptable (ignoring clutter and ground-reflection effects) since there is no system polarization-mismatch loss. However, a deviation of radiated polarization from linear will cause a round-trip polarization mismatch loss and is therefore undesirable. In this case, therefore, one would like the cross polarization to be a measure of the deviation of the polarization of radiation from linear. It seems that neither definition 3 nor any other definition of cross polarization (as a unique polarization state) is adequate in this case.

As a second example, consider the design of a two-port phased-array antenna to radiate orthogonal polarizations throughout a scan volume, one from each port. There is no general definition of cross polarization which, when measured for radiation from each port, will provide information about nonorthogonality of the two polarizations in space.

The two examples just cited raise an important question. Is the term "cross polarization" useful? I believe that it is not except in certain special cases like the near-broadside nominally linearly polarized situation with which Dr. Ludwig was primarily concerned. The reason that "cross polarization" is not useful is that in many cases it is difficult or impossible to define a *meaningful* cross-polarization characteristic. It would seem that the IEEE standard definition of cross polarization [3] as "the polarization orthogonal to a reference polarization" is the best definition, being neither too detailed nor too nebulous.

Rather than measure (or compute) the normal and cross-polarized patterns of an antenna, as seems to be the standard practice [4, p. 11], it would be better to characterize the radiation properties[3] of an antenna by the radiated power density (regardless of how polarized) and the polarization in which the power is contained, as functions of angular direction. This is a useful format for display of the antenna radiation properties and for the determination of other quantities such as gain, noise temperature, system polarization-mismatch loss, and antenna polarization orthogonality to some other polarization.

Author's Reply[4,5]

The first point raised by Dr. Knittel is a question in regard to the meaning of the statement that a feed with no cross polarization by definition 3 is optimum from the viewpoint of antenna aperture efficiency.[1] In [1] antenna aperture illumination efficiency η of a paraboloidal reflector of diameter D is defined by

$$\eta = \frac{G}{(\pi D/\lambda)^2} \tag{1}$$

where G is the peak gain of the antenna and λ is the operating wavelength. This is consistent with the IEEE standard definition [3], and with the usage in standard texts [2]. It is shown in [1] that for circular paraboloidal reflectors there is a loss in efficiency (i.e., gain) due to cross-polarized surface currents, which contribute to the total radiated power, but do not contribute to the peak gain on axis. It is further shown that a circular feed with equal E- and H-plane amplitude and phase patterns does not produce cross-polarized currents and therefore no cross-polarization loss. This is of course equivalent to definition 3, which also implies zero cross-polarized surface currents.

Perhaps it is useful to mention the distinction between the definition of "aperture illumination efficiency" and "polarization efficiency" as defined by Knittel [5]. The latter definition refers to the loss in power transfer between two antennas due to polarization mismatch, whereas the former refers to loss in peak gain (power radiated on axis in any polarization) of a single antenna.

The second point raised by Dr. Knittel is that a meaningful definition is dependent on the intended application of the antenna. In the communication under discussion[1] three applications are considered: 1) an antenna system to achieve nearly orthogonal polarizations everywhere in some coverage region in order to create two communications channels for each frequency band; 2) a feed for a paraboloidal reflector which will in turn be used for the first application; and 3) a feed for a paraboloidal reflector in which the objective is maximum aperture efficiency (peak gain). It was found that definition 3 applies to all of these cases; i.e., an antenna with no cross polarization by definition 3 is optimum, in a reasonable sense, for all three of these applications. Therefore, in my opinion, definition 3 is meaningful, at least for these three applications.

It is certainly true, as Dr. Knittel states, that by definition 3 an electric or magnetic dipole would have significant cross polarization out of the E plane and the H plane. I think this is also meaningful in that if these "ideal" devices are used to feed a paraboloidal reflector they do indeed produce high cross polarization in the secondary patterns by any definition, and the resulting aperture efficiency is poor. It should be emphasized that a Huygens source

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[1] A. C. Ludwig, "The definition of cross polarization," *IEEE Trans. Antennas Propagat.* (Commun.), vol. AP-21, pp. 116–119, Jan. 1973.
[2] Same as [1] in this communication.

[3] The phase property is left out here, and it is assumed that the radiation from the antenna is coherent, i.e., that it is all contained in some polarization state for each angular direction.
[4] Manuscript received February 28, 1973.
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is not the only radiator which has no cross polarization by definition 3. As previously stated,[1] any circular feed with equal E- and H-plane amplitude and phase patterns will have no cross polarization by definition 3.[6] A very practical example which approaches this ideal very closely is a corrugated horn.

Dr. Knittel discusses two additional applications which were not considered in the original communication.[1] In the first case the criteria is deviation of polarization from linear, and I agree that none of the definitions previously considered[1] are appropriate for this application. However I would suggest that the definition of "axial ratio" as given by Knittel [5] applies to this case very nicely and perhaps could be used in lieu of the term "cross polarization."

The second application is a two-port array designed to radiate orthogonal polarizations throughout a scan volume, one from each port. First consider linear polarization. For the special case of an antenna which is symmetrical with respect to the two ports (i.e., the antenna radiates the same electromagnetic field when excited through port 2 as when excited by port 1 except that it is rotated 90° in space about the z axis), definition 3 does in fact directly measure the nonorthogonality of the polarizations from the two ports. For an antenna which does not have this symmetry property, and for the general case of elliptical polarization, the cross polarization by definition 3 does not directly correspond to a nonorthogonality between the polarizations from the two ports, but the reference- and cross-polarization components by definition 3 still form a convenient pair of orthogonal basis vectors to express the fields. If one measures the amplitude and phase of these two patterns (which is now relatively easy using a Scientific Atlanta dual-channel receiver or a Hewlett Packard network analyzer), or computes them, it is then straightforward to convert these data to any other form, such as the radiated power density, axial ratio, polarization-ellipse tilt, and rotation sense format favored by Dr. Knittel. An excellent description of these transformations is given in [6]. Alternatively, one could compute the nonorthogonality of the polarizations from the two ports directly from the reference- and cross-polarization data. Even if one prefers to directly measure the polarization ellipse in the standard manner [4], the tilt of the polarization ellipse Ψ is in fact measured with respect to the local unit vectors reference and cross as given by definition 3. This is of course exactly the same angle one would compute using the amplitude and phase data as already outlined.

This suggests that it was perhaps an error to implicitly give the connotation of "undesired polarization" to the term "cross polarization,"[1] and that it might be better to consider reference and cross polarizations by definition 3 as convenient unit vectors, which happen to correspond to good polarization and bad polarization in certain special (but important) cases.

It is clear from the preceding discussion that I feel a meaningful definition is possible for situations not restricted to the case of near-broadside nominally linearly polarized antennas. In fact the original motivation for my previous communication[1] was to choose a definition which was meaningful far from broadside, where the three definitions which I considered seriously disagree—in the case of feed patterns, a reflector typically intercepts energy radiated 60° or more away from broadside.

Finally, I do not personally feel that definition 3 is the *only* way to describe antenna patterns; the radiated power density/polarization format seems appropriate for some applications, and conventional spherical unit vectors are also convenient for some applications such as theoretical work. I still think that an important basis of engineering work is to have unambiguous definitions that are as meaningful as possible.

I would like to thank Dr. Knittel for stimulating my thinking on this topic, and I hope that others will also contribute comments which might eventually evolve into a consensus.

[6] It is assumed that the feed is excited by TE_{mn} and TM_{mn} modes with $m = 1$ only.

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Effect of Losses on Transient Propagation in Dispersive Media—A Systems Study

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***Abstract*—This communication refers the reader to a report in which the effect of losses on transient propagation in dispersive media is considered in detail.**

The purpose of this communication is to point out an extensive analytical systems study[1] of the effect of losses on transient propagation in dispersive media. Numerous results have been obtained for the transient propagation characteristics of various types of signals. As an example of our results, consider Fig. 1, which illustrates the transient response within a spatially homogeneous plasma at a position $x = 5c/\omega_p$ (ω_p = electron plasma frequency, c = speed of light) to a unit-step input at $x = 0$. Note that when $\nu_c/\omega_p \neq 0$ (ν_c = electron-neutral collision frequency) the step response approaches unity for large times t rather than zero, as is the case in the collisionless limit.[2] Analytical expressions have been obtained for the asymptotic transient response, and we find that for the unit-step input considered above, the time asymptotic electric field is $E \rightarrow 1 - \text{erf}\,[\omega_p x/2c(\nu_c t)^{1/2}]$, indicating that the time required for the step response to recover to its final value of unity is inversely proportional to ν_c. The complete details of the study are available upon request.[1]

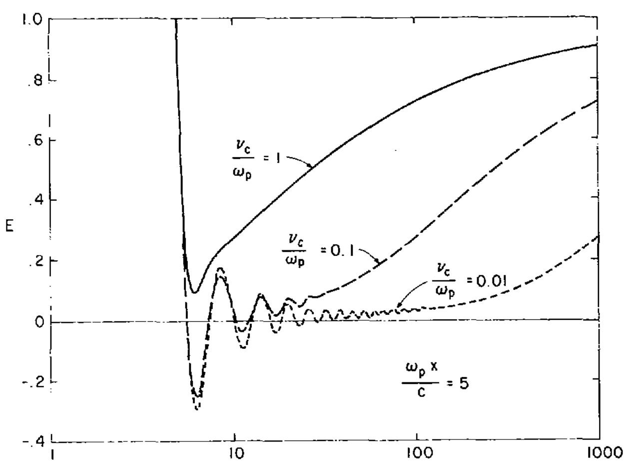

Fig. 1. Transient electric field response within plasma to unit-step input applied at $x = 0$.

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[1] R. L. Fante and R. L. Taylor, "Transient signal propagation in lossy dispersive media," Air Force Cambridge Res. Labs., Bedford, Mass., Rep AFCRL-73-0277, Apr. 1973.

[2] R. Haskell and C. Case, "Transient signal propagation in lossless isotropic plasmas," Air Force Cambridge Res. Labs., Bedford, Mass., Rep. AFCRL-66-234, Apr. 1966.