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Comments on "Surface Wave Enhanced Broadband Planar Antenna for Wireless Applications"

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***Abstract*—The above paper [1] claims to present "a new class of broadband antenna in which TE_0 surface-wave is used as the primary source of free space radiation." After reviewing the references, and analyzing the parameters published, it does not appear that the antenna can operate in the manner claimed.**

I. Introduction

Surface waves are often of interest to antenna designers, usually as something to be avoided. The above paper [1] describes a "Quasi-Yagi" planar antenna, which appears to have been published first in [2]. A number of variations and references to this antenna structure have appeared in various publications [3]–[26]. The fundamental claim of this antenna structure is that it operates primarily by exciting the TE_0 surface wave, which is radiated in a "unilateral" manner to provide a high gain antenna with a number of useful properties.

II. Surface Waves and Antenna Operation

Surface waves became a topic of interest to engineers once antennas began to appear in planar form on microwave substrates. Antenna designs often avoid substrates that are conducive to surface wave formation. Energy coupled into surface waves represents a loss to the wanted radiated signal. A common "rule of thumb" is that a substrate should be less than about one-tenth of a wavelength *in the dielectric* ($\lambda_d/10$) to avoid a significant amount of surface wave generation.

In a finite substrate situation, any surface waves excited can strike the edge of the substrate and radiate in a way that interferes with the primary radiation mechanism. This is notable on finite substrate patch antennas where excessive surface waves cause interference in their proper operation. A notable indication of surface wave excitation shows up as ripples in broadband return loss measurements, which are a result of surface waves striking the edge of the substrate and returning to the antenna feed. The surface wave effect also shows up in changes to the radiated field patterns.

The relationship between surface wave excitation and substrate parameters were examined closely in [27], where both microstrip and slot type antennas were analyzed. It was shown that the substrate height, for a given dielectric constant, could be optimized to excite a maximum level of a particular surface wave mode. However, it was stated that when the substrate height was much less than about $\lambda_o/10$, no significant amount of surface waves are excited.

III. "Quasi-Yagi" Antenna

The fundamental mode of radiation for this antenna has been reported to be from the TE_0 surface wave, which allows for a "unilateral" radiation pattern along with other desirable properties. In [1], the antenna is printed on a 50 mil (1.27 mm) substrate with $\varepsilon_r = 10.2$. It was also published in [5] at approximately twice the frequency of operation using a 25 mil (0.635 mm) substrate of the same dielectric constant. Because of the similarities, the comments in this letter apply to all of the different published variations of the antenna.

Comparing these substrate parameters to the previously mentioned material raises the question as to whether a substantial amount of energy could be coupled into surface waves as is reported. At the frequencies given, the substrate is approximately $\lambda_d/17$ and $\lambda_o/55$ (on average).

Referring to [27, Fig. 2], it appears that the coupling into a particular surface wave is strongly dependant upon the substrate thickness. As such, it would seem reasonable to conclude that if the Quasi-Yagi antenna operated from an optimized surface wave excitation, it too would show a strong dependence upon substrate thickness. Again referring to the graph, it would seem that if the substrate was $\sim 0.1\lambda_o$ instead of $0.018\lambda_o$ then the TE_0 surface wave excitation would indeed have been maximized.

A finite element analysis was done on the published antenna structure using Ansoft HFSS software to determine how the substrate thickness influenced the radiation patterns. For the purpose of the FEM experiment, three antennas were simulated. The reference antenna was designed according to the published parameters. For the second and third simulation, the substrate was increased and decreased by 20%, respectively. Since the reference antenna simulation agreed fairly well with the published results, it was assumed that the simulations were defined properly and produced accurate results. The antenna patterns (sidelobe levels, cross-pol levels, F/B ratio) were very similar for the three different antennas, with the calculated directivity changing by only 0.3 dB for the different substrate thicknesses. Without a strong dependence on substrate thickness, as in [27], it would be difficult to conclude that the primary mode of operation for these antennas is based on surface wave excitation.

It was also implied in [1] and [28] that the distance from the "director element" to the edge of the substrate was critical for optimum performance. A fourth FEM experiment was done truncating the substrate of the reference antenna 115 mils (2.92 mm) from the director element. The resulting analysis showed less than 0.1 dB change in directivity even though the substrate had been reduced by 25% in length. This would again imply a very weak surface wave dependence.

IV. Conclusions

In [1], cited, along with the original presentation and variations, it was asserted that a "novel" surface wave antenna was presented. Upon closer analysis of the original references, the substrate parameters, and some additional numerical analysis, it does not appear that the fundamental operation of this antenna can agree with the given explanations. A broadband printed dipole was first presented in [29] and [30] and it does not appear that the basic mode of operation for the new antennas presented varies from that original work, although there is addition of a printed "director" element.

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Author's Reply

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The authors appreciate the investigation and comments by T. J. Ellis regarding the quasi-Yagi antenna. In fact, one of the co-authors (Y. Qian) has been challenged multiple times in the past on the novelty of the quasi-Yagi antenna and feels obliged to take this opportunity to make some clarifications and re-emphasize the uniqueness of this particular antenna structure.

We were definitely aware of the original publications by Edward and Rees [1], which we believe is great work. The difference of the quasi-Yagi structure, however, is really not just adding a printed director element. It is more fundamentally related to the surface wave behavior in the substrate. As a result, the two antennas belong to two different categories. In the E plane, the antenna by Brian and Rees is bi-directional, while the quasi-Yagi is "end-fire" by itself, without the need of extra reflectors.

As is well known, an ideal half-wavelength dipole radiates evenly to the front and back sides in the E plane. A printed dipole on electrically very thin substrate will have similar behavior, because the substrate in this case is mainly for the purpose of supporting the printed dipole and feeding circuitry. In the broadband printed dipole invented by Edward and Rees, a novel feeding structure based on a microstrip-to-slot transition was used cleverly to obtain broadband impedance matching for the printed dipole. However, the antenna operates in a similar manner as a normal dipole, without major surface wave phenomenon involved. As a result, to obtain good front-to-back ratio, the authors used a fairly large metal reflector perpendicular to the printed dipole. This is common practice to obtain unidirectional radiation patterns out of a dipole, whether printed or not.

The original Yagi-Uda dipole antenna is a work of genius, because it replaces the otherwise large and clumsy reflector with simple wires which are just slightly longer (reflector) and shorter (director) than the dipole itself, while delivering similar level of unidirectional radiation pattern. It is also noticed that a Yagi-Uda can maintain decent front-to-back ratio without any director elements, but the presence of the reflector is essential to turn a low-directivity dipole into an end-fire antenna.

If we consider the diameter of the reflector wire in a Yagi-Uda and come up with an effective area of the "reflector," we can easily appre-

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