BIDIRECTIONALITY OF UNIFORM AND PERIODIC WAVEGUIDES MADE OF RECIPROCAL MATERIAL

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If the geometry and electromagnetic material parameters of an open or closed waveguide are symmetric about a plane perpendicular to the propagation axis (z axis), then it is obvious from a simple symmetry argument that every time-harmonic ($e^{-i\omega t}$) traveling wave propagating with $e^{i\beta z}$ dependence can also propagate in the opposite direction with $e^{-i\beta z}$ dependence, where β is the complex propagation constant. Thus, a waveguide possessing this "reflection symmetry" can be said to be "bidirectional."

If the waveguide does not possess this reflection symmetry, it may not be bidirectional, and thus it becomes of interest to obtain general conditions that are sufficient for a waveguide to be bidirectional (P.A. Chorney, MIT Technical Report 396, 1961). Toward this end, McIsaac (*IEEE MTT Trans.*, **39**, 1808–1816, 1991) has proven that a uniform waveguide that contains only lossless reciprocal material is bidirectional for traveling waves with real propagation constants β. In this paper, a general theorem is proven that states that both uniform and periodic waveguides containing lossy or lossless reciprocal material are bidirectional in that every traveling wave with complex propagation constant β has an associated traveling wave with propagation constant $-\beta$. This theorem is proven indirectly using two reciprocal antennas separated by asymptotically large distances along the waveguide. Direct application of the Maxwell differential equations also proves that every complex wave with $e^{i\beta z}$ dependence on a lossless reciprocal waveguide has an associated complex wave with $e^{-i\beta^* z}$ dependence, where the $*$ indicates the complex conjugate.

These theorems imply that complex waves on lossless reciprocal waveguides come in quadruplets, one bidirectional pair with propagation constants $\pm\beta$, and another bidirectional pair with propagation constants $\mp\beta^*$. An important consequence of the theorems is that for traveling waves with real propagation constants on lossless reciprocal periodic waveguides, the kd–βd diagram need cover only the range of βd from 0 to π, where $k = \omega/c$ with c denoting the free-space speed of light, and d is the spatial period of the periodic waveguide. It is noted that, although waveguides containing nonreciprocal material are not in general bidirectional, some nonreciprocal waveguides retain the property of bidirectionality.

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