Degenerate Band Edge Condition in Substrate-Integrated Waveguides

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Recent research on periodic artificial materials for electromagnetic wave propagation showed that higher degrees of symmetry within a single periodic cell (or a suitable introduced asymmetry) can provide additional degrees of freedom in the design of metamaterials and metasurfaces with desired frequency response. A specific strong dispersive behavior (the so-called "giant" resonance) provides ways to generate high power density in waveguides, due to a high density of electromagnetic states related to a very special degeneracy condition. It can have various applications in amplifier, oscillators, sensors, etc. An analysis based on single cell simulations and extrapolation of modes travelling in periodic structures is here proposed in order to obtain for the first time a substrate integrated-waveguide (SIW) supporting a giant resonance in a finite-length SIW, specifically associated a degenerate band edge (DBE).

A DBE occurs in a periodic structure at the edge of a Brillouin zone ($k_d = \pi/p$) when a closed stopband is reached with a dispersion with quartic shape. The occurrence of the DBE is determined by the matching of dispersion diagram with a specific fitting quartic curve,

$$f_d - f = \alpha \left(k - k_d\right)^4, \tag{1}$$

where f_d is the DBE frequency and p is the spatial period of the SIW, α is a positive constant that depends on the structural parameters. This condition is met if four eigenmodes close to the band edge (two propagating and two evanescent when $f < f_d$) degenerate into a single solution.

Analytical and experimental proofs of the dispersion curve (1) have been provided in certain structures (e.g. circular waveguides, microstrips, lumped-element lines) but practical structures compatible with integrated circuits still have to be explored. Here we will analyze two coupled parallel substrate-integrated waveguides, whose coupling is due to a suitable periodic arrangement of vias, that support two modes. Proper choice of parameters leads to the DBE whose dispersion diagram is shown in Fig. 1 together with the fitting curve (1) verifying the occurrence of the DBE. Giant resonances in finite-length SIW structures will be also discussed.

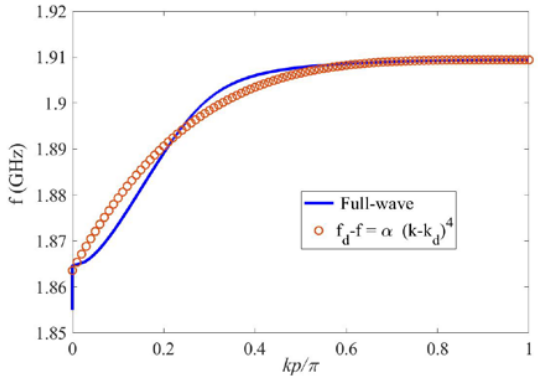

Fig. 1. Frequency-wavenumber dispersion relative to modes in a periodic SIW supporting a DBE characterized by the quartic law in the neighborhood of the edge of the first Brillouin zone. This degeneracy represents the coalescence of four Floquet-Bloch eigenmodes. p is the spatial period of the structure.