Epsilon-near-zero (ENZ)-type transmission resonance through thick and thin slots

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Interesting transmission resonant phenomena occur when an electromagnetic plane wave is incident upon a narrow rectangular slot perforated in a thick conducting screen with the electric field vector normal to the slot axis, and the transmitted power through the slot is remarkably increased. There are two kinds of transmission resonance phenomena. The first is Epsilon-Near-Zero (ENZ) channel-type transmission resonance, which occurs when the propagation constant βz (assuming the z-axis to be the guided direction of the rectangular guide region inside the thick slot) along the guided (longitudinal) direction of the region inside the slot becomes nearly identical to zero, i.e., the lowest guided TE_{10} mode inside the slot region is cut off. The other is Fabry-Parot (FP) cavity-type transmission resonance, which occurs when the longitudinal length corresponding to the thickness of the conducting screen of the slot inside (constituting the FP cavity) is somewhat smaller than the integral multiples of the half wavelength of the lowest guided TE_{10} mode inside the slot.

When $\beta z \approx 0$, the phase velocity of the lowest guided TE_{10} mode becomes infinite and thus the hollow rectangular waveguide inside the narrow slot in the thick conducting screen around the cutoff frequency of its TE_{10} mode may behave as a metamaterial with ε_{eff} (effective permittivity) ≈ 0, i.e., as an ENZ metamaterial. As such, this transmission resonance is called ENZ channel type as distinct from FP cavity type. Recent theoretical research has revealed that the frequency at which ENZ channel-type transmission resonance occurs approaches the exact cutoff frequency of the TE_{10} mode (the lowest guided mode) when increasing the thickness of the conducting screen. Accordingly, this article investigates the variation of the ENZ channel-type transmission resonance frequency when varying the thickness of the conducting screen perforated with narrow rectangular slots, i.e. comparing the ENZ channel-type transmission resonance frequency with thick and thin slots.

When connecting a coaxial-to-waveguide adapter to the input/output ports of a narrow slot window with various thicknesses centrally located in a rectangular guide and measuring the scattering parameters |S11| and |S12|, the following experimental results were confirmed: when using a narrow slot window in a thick conducting screen, the ENZ channel-type transmission resonance frequency was observed to approach the exact cutoff frequency of the lowest guided TE_{10} inside the narrow slot in the thick conducting screen. In this case, the transverse length of the narrow slot window (corresponding to the rectangular waveguide) became exactly identical to half the free space wavelength $\lambda_0/2$. Conversely, when using a narrow slot window in a thin conducting screen, the transmission resonance occurred when the transverse length of the narrow slot along the slot axis was slightly smaller than half the free space wavelength, $\lambda_0/2$. This is analogous to the physical situation where the resonant length of a half-wave dipole antenna needs to be reduced by a shortening factor for resonance, i.e. to cancel the reactance (susceptance) of the input impedance (admittance).

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References

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