Broadside Radiation in Frequency-Scanning Periodic Leaky-Wave Antennas: Circuit Analysis, Asymptotic Formulas, and Fundamental Behaviors

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Frequency-scanning periodic leaky-wave antennas are prone to gain degradation when scanned through the broadside direction (Paulotto, S.; Baccarelli, P.; Frezza, F. & Jackson, D. (2008), 'Full-Wave Modal Dispersion Analysis and Broadside Optimization for a Class of Microstrip CRLH Leaky-Wave Antennas', IEEE_J_MTT 56(12), 2826–2837.). Our contribution addresses this phenomenon using a simplified transmission line (TL) analysis and points out the required conditions to mitigate this issue. The radiation power and dissipation loss of an antenna unit cell can be decomposed into series and shunt contributions in the equivalent TL network model. We identify two regimes, the "broadside" and "off-broadside" regimes, for which we present asymptotic formulas for the propagation constant, quality factor, Bloch impedance, stored energy and dissipated power.

The proposed approach shows that when a leaky-wave antenna (assuming a transversally symmetric unit cell) radiates at broadside, the sum of the radiated and dissipated *powers* (in arbitrary ratios) in the series and in shunt elements are always equal. In some antennas, the ratios of radiated and dissipated powers in the series and shunt elements are very different. In the extreme case where only one of the two (series or shunt) elements is radiative, while the other is purely dissipative, the maximal radiation efficiency is of 50%. To achieve an ideal efficiency of 100%, each of the series and shunt elements must radiate without any dissipation, each contributing half of the overall efficiency. Practically, this means that a high efficiency can be obtained only by designing the antenna so that both its series and shunt elements radiate simultaneously and efficiently. In the off-broadside regime, the stored *energies* (as opposed to powers) in the series and in shunt elements are always equal. However, in this regime, high radiation efficiency may still be achieved even if only one of the series or shunt elements radiates.

The proposed theory and subsequent observations are validated with two practical examples of leaky-wave antennas, a series-fed patch array antenna and a composite right/left-handed antenna, using an eigenmode analysis of the unit cell to link TL network model and the exact electromagnetic field distributions.