Size Miniaturization by Slow Wave and Metamaterial

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Component miniaturization is an inevitable requirement as a result of the shrinking space for individual components in communication modules. The purpose of this paper is to review two different implementations leading to miniaturization of antennas and passive components. The first method is based on the slow wave structure obtained by periodically loading the transmission line with lumped elements, effectively enhancing the propagation constant for a decreased guided wavelength. The second method is the use of metamaterial structure, specifically the composite right/left-handed (CRLH) structure. By engineering the CRLH dispersion curve, size reduction is feasible by replacing conventional phase-delay microstrip lines with the phase-advance CRLH transmission structures. The miniaturized dual-band rat-race coupler and branch-line coupler are given as examples.

By applying the periodic transmission line theory to the slow wave structures, it is found that the propagation constant can be enhanced by increasing the effective series inductance or/and the shunt capacitance in the equivalent circuit model. Furthermore, the proposed slow wave factor (β/k) investigation based on the circuit model predicts the size reduction accurately. Two compact antennas are demonstrated as examples. A slot-loop antenna loaded with shunt capacitors along the slot line exhibits six-time size reduction. This loaded slot-loop maintains the omni-directional radiation pattern and has a maximum gain of -2 dBi at 0.56 GHz. Similarly, a capacitor-loaded planar inverted F antenna (PIFA) is capable of reducing the operating frequency to one-tenth. The input impedance match is easily obtained and improved by employing coaxial feeding structures.

CRLH transmission structures have been shown to have non-linear phase responses with respect to frequency, and also demonstrate both phase delay and advance depending on the frequency and the constituent circuit parameters (L_R, C_R, L_L, C_L). This phase-engineerable characteristic makes arbitrary dual-band operation possible. Moreover, by considering all possible dual-band phase variations of the constituent transmission lines of the directional couplers, this design approach ensures the compactness of the hybrids and reduces footprint size significantly compared to the previously exhibited standard transmission line based and CRLH-based hybrids. The proposed dual-band rat-race coupler and branch-line coupler achieved 55% and 10% size reduction respectively, compared to the conventional directional coupler in the lower band of the dual frequency operation.