Circuit model for FSS structures under conical oblique incidence

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The modeling of 1D and 2D distributions of planar metallic scatterers (strips or patches) or apertures (slits or slots) made in thin metal screens has been carried out by using a variety of quasi-analytical to purely numerical methods along several decades. The advantages of analytical approaches are obvious, but their scope use to be limited to a number of relatively simple situations. The analytical or quasi-analytical point of view has been traditionally associated with the development of circuit models, and this is still an active research area (R. Rodríguez-Berral *et al.*, *IEEE Trans. Mic. Theory Tech.*, **60**, 2012, pp. 3908-3918; F. Costa *et al.*, *IEEE Trans. Antennas & Propagat.*, **61**, 2013, pp. 1201-1209). One the typical restrictions of most circuit models available in the literature is that they are conceived for structures excited by plane waves impinging normally or along principal planes of symmetry of periodic distributions of highly symmetrical scatterers. As a result, the reflected and transmitted zeroth-order plane wave has the same polarization as the incident wave. In such cases the equivalent circuits have a single input and a single output transmission line. Moreover, the effect of the scatterers use to be embedded in simple frequency-independent lumped circuits made of inductors, capacitors and, if required, resistors.

The purpose of this contribution is to provide a systematic approach to generate the circuit model suitable to deal with periodic FSSs (both, patches and apertures based FSSs) under conical incidence conditions. In that case the incidence plane is not a principal plane of the periodic structure and cross-pol effects become significant. In such cases two input and two output transmission lines will be required to account for the two orthogonal polarizations (S. Maci *et al.*, *IEEE Trans. Antennas & Propagat.*, **53**, 2005, pp. 70-81). Our approach, in contrast with a few previous papers dealing with a similar problem, yields the exact equivalent network for the structure under analysis. In our model lumped components are used to account for the contributions of high enough order modes (or harmonics in a Floquet analysis), which operate well below cutoff, but low-order modal (or harmonic) contributions are retained as distributed transmission lines, thus accounting for a signficant frequency-dependence which is usually ignored. For the case of rectangularly shaped patches or slots a procedure to extract the numerical values of the appropriate equivalent circuit components is reported. The quality of the analytical models is demonstrated by comparison with lengthy full-wave simulations.