Analytical Circuit Approach for (2+1)D Structures: Application to Spacetime Metasurfaces

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Historically, scientists and engineers have focused their studies on finding analytical models that allow accurate modeling of the electromagnetic response of radiant devices. Commercial software based on numerical full-wave techniques such as the finite element method (FEM) or the finite-difference time-domain method (FDTD), among others, allows simulating many different scenarios at the expense of assuming a high computational cost, especially when the radiant elements are sub-wavelength or when a complete multi-modal description of the fields is required.

As an alternative, circuit models based on transmission lines and lumped elements represent a great solution for these proposes due to their low computational cost and their physical insight. In fact, a circuital method is considered fully analytical when it is unnecessary to extract any information from external full-wave tools [1], [2]. However, the main difficulty lies in finding equivalent circuits of the structure under study [3].

This paper presents a multi-modal, fully analytical circuit model for simulating (2+1)D spacetime-periodic modulated structures. A closed formulation is proposed in terms of Floquet-Bloch harmonic expansions, from which all parameters related to diffraction and scattering can be extracted, providing information on the propagative or transient nature of the spacetime harmonics. We already applied this formulation in our previous works for simulating metastructures based on spatial modulations [4] and (1+1)D spacetime modulations [5].

As an example, Fig. 1 and Fig. 2 depict a comparison between the obtained results by the proposed theoretical analysis and external tools for a 2D spatial case and (1+1)D spacetime case, respectively.

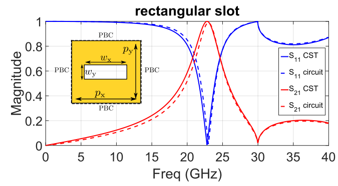
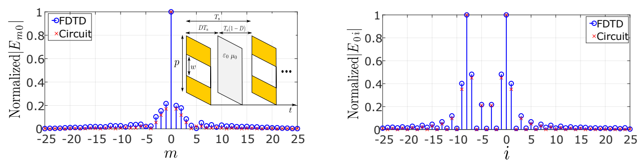


Fig. 1. Reflection and transmission coefficients in a space-modulated 2D metasurface. TE normal incidence. Structure parameters: $p_\mathrm{x} = p_\mathrm{y} = 10\,\mathrm{mm}$, $w_\mathrm{x} = 6\,\mathrm{mm}$, $w_\mathrm{y} = 2\,\mathrm{mm}$, $\varepsilon_\mathrm{r}^{(1)} = \varepsilon_\mathrm{r}^{(2)} = 1$, $\mu_\mathrm{r}^{(1)} = \mu_\mathrm{r}^{(2)} = 1$.



(a) (b)

Fig. 2. Normalized amplitude of the Floquet harmonics in a spacetime-modulated (1+1)D metasurface. (a): Harmonics with $i = 0, \forall m$. (b): Harmonics with $m = 0, \forall i$. TE normal incidence. Structure parameters: $p = 10\,\mathrm{mm}$, $w = 3\,\mathrm{mm}$, $D = 0.5$, $T_\mathrm{s}/T_0 = 4$, $f_0 = 40\,\mathrm{GHz}$.

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