Marqués et al. Reply: The Comment [1] by Kondrat'ev and Smirnov (KS) provides an alternative explanation to the results in Ref. [2]. It is not unusual to explain a physical phenomenon from various perspectives. However, KS firmly state that the theory in Ref. [2] is wrong. In our opinion, KS start from a serious misinterpretation. Although it is obvious that a waveguide filled with an isotropic "medium having $\varepsilon \approx 1$ and $\mu = \mu_{\text{eff}} < 0$" does not transmit electromagnetic waves, such a model is not considered anywhere in Ref. [2]. In our work, the waveguide loaded with a single row of split ring resonators (SRRs) is just considered as the unit cell of a quasicontinuous (at a larger scale) effective medium (see Fig. 6 in [2] or Fig. 3 in [3]). The hollow waveguide behaves as a 1D plasma with effective permittivity $\epsilon_{\text{eff}} = \epsilon_0(1 - \omega_c^2/\omega^2)$. For the dominant mode, the average fields across the waveguide section are transverse, and the polarization of the unit cell arising from the walls current, $\mathbf{P} = \mathbf{p}/a^3$, is related to the average electric field by $\mathbf{P} = -\epsilon_0(\omega_c/\omega)^2\langle\mathbf{E}\rangle$. The unit cell magnetization is proportional to the average magnetic field through a (resonant) scalar effective magnetic susceptibility, χ_{eff}. This follows from the symmetry of the structure (see Fig. 2 in [2]): the average magnetic field is normal to the SRR axis, the unique possible direction of magnetization. As a first approximation, χ_{eff} was chosen to be the effective magnetic susceptibility (along the x axis) of the infinite 3D SRR medium. Since the average fields are transverse, they form a TEM plane wave whose dispersion relation is $k = \omega\sqrt{\mu_{\text{eff}}\epsilon_{\text{eff}}}$ [$\mu_{\text{eff}} = \mu_0(1 + \chi_{\text{eff}})$]. Thus, it is the whole system consisting of the waveguide plus the SRRs that behaves as the unit cell of a 1D left-handed medium in our picture. Note that the SRR-loaded waveguide is treated as a discrete system at the scale of the unit cell dimensions ($\Delta x = \Delta y = \Delta z = a$), but as a homogeneous medium at the larger scale of variation of the average electromagnetic field ($\lambda = 2\pi/k$). Although KS's interpretation leads to exactly the same quantitative result for the dispersion relation [see Eq. (5) of KS [1] and Eqs. (1) and (2) of [2]], the application of this analysis to the single row of rings in Ref. [2] does not seem to be plausible. Ultimately, what KS assume is that the electromagnetic waves propagating along the loaded waveguide are the superposition of two plane waves with wave vectors ($k_x = \pm\pi/a, k_z$), propagating along an infinite homogeneous anisotropic medium with $\mu_{xx} \sim 0$. However, at the scale of the variations of such hypothetical plane waves, $\lambda = 2\pi/\sqrt{k_x^2 + k_z^2} < 2a$, the SRR system should be viewed as a discrete periodic structure rather than as a continuous medium. In contrast, at the larger scale suggested in Ref. [2], Fig. 6, and in Ref. [3], Fig. 3, the continuous-medium perspective is fully justified, provided $a \ll \lambda$.
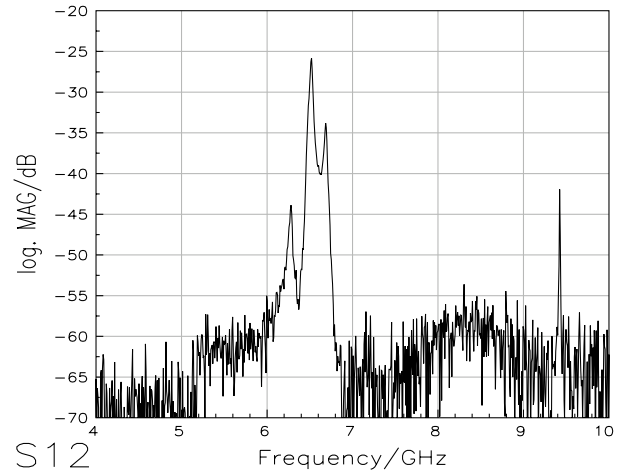

FIG. 1. Rough 1D left-handed medium simulation with additional SRRs.

In order to illustrate the above point, we have carried out an experiment similar to that reported in Fig. 5(a) of Ref. [2] including two additional SRRs located between the three SRRs considered in Ref. [2] but having their axes parallel to the waveguide axis. Following the rationale implicit in KS's Comment [1], the resulting structure would be, roughly speaking, equivalent to a waveguide filled with a homogeneous medium having $\mu_{zz} = \mu_{xx} = \mu_{\text{eff}}$ operating at cutoff. However, the experimental results in Fig. 1 show that the additional SRRs do not affect the qualitative behavior of the device. This result is in agreement with our point of view, which considers the whole system as the unit cell of a 1D left-handed medium (with the effective permeability of the SRR subsystem along the x axis, μ_{eff}, and the effective permittivity of the waveguide, ϵ_{eff}). We believe that this experiment conclusively supports our interpretation.

R. Marqués, J. Martel, F. Mesa, and F. Medina
  University of Sevilla,
  41012-Sevilla, Spain

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