

Experimental demonstration of deflection angle tuning in unidirectional fishnet metamaterials at millimeter-waves

Supplementary Material:

In order to demonstrate that the frequency blue-shift corresponds mainly to the existence of thin air layers, simulations including these layers have been carried out. To this end, the thickness of the stacked hole array was measured with a caliper. The result obtained was 140 μm excess of thickness. This excess of thickness can be judiciously attributed to thin air gaps between the four joints of the structure (i.e. 35 μm for each air gap). Figure S1 shows forward transmission and forward-to-backward transmission contrast for the ideal and the non-ideal (air gaps and absorption losses, $\tan \delta = 0.018$ at 60 GHz, included) structures. Similarly to experimental results, spectra are blue-shifted and transmission deteriorated compared to the ideal cases studied in Ref 21. The shift of the first band (45 – 55 GHz) is approximately of 4 GHz whereas the second band (59-74 GHz) remains practically stable. However in the second band case, the frequency- angle of incidence area seems to be reduced in the non-ideal case with respect to the ideal one. Furthermore, in general, forward-to-backward transmission contrast for positive deflection cases achieves better values than for negative deflection ones as can be seen in the figure.

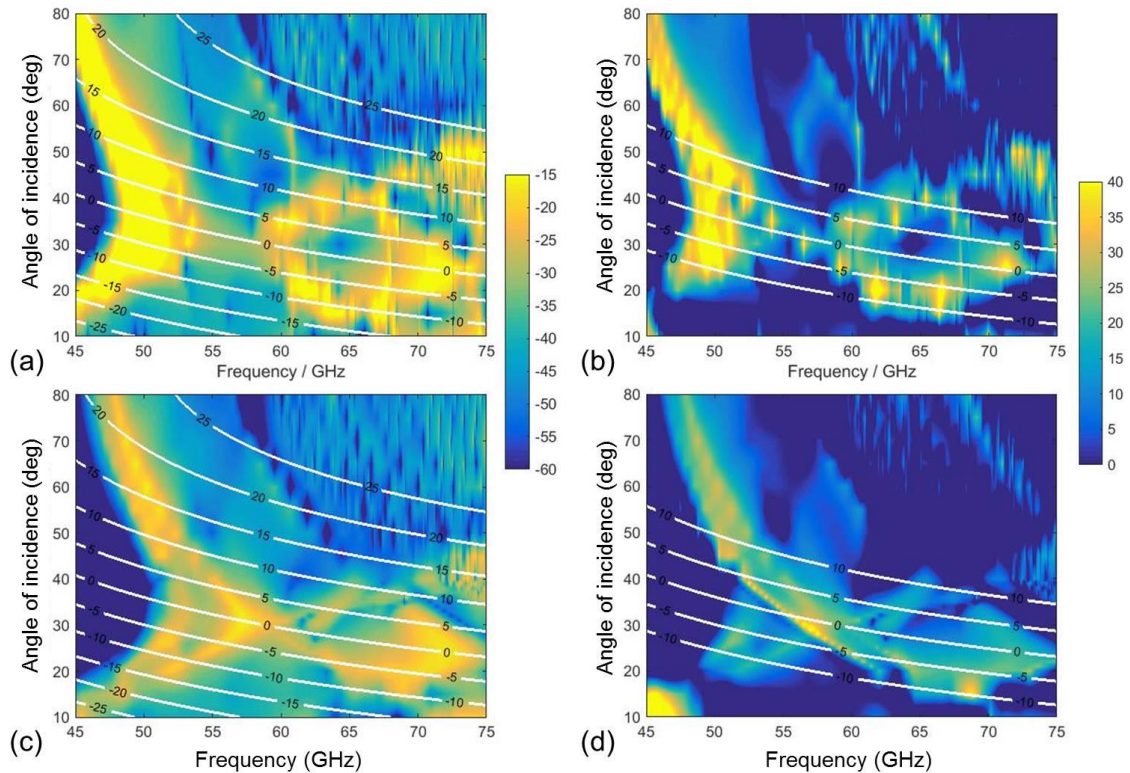


FIG. S1. (Color online) Transmission results corresponding to $m=-1$ for ideal and non-ideal stacked hole array ($f - \theta$)-plane in dB scale. (a) Ideal case. Forward transmission. (b) Ideal case. Forward-to-backward transmission contrast. (c) Non-ideal case. Forward transmission. (d) Non-ideal case. Forward-to-backward transmission contrast. White lines- isolines corresponding to ϕ_{-1} .

In order to validate tunable deflection cases presented in Fig. 4 of the paper one may provide the forward transmission and forward-to-backward transmission contrast. In that way, forward transmission should be high enough for assuring that the received energy is way above the dynamic range of the instrument and high forward-to-backward contrast values assures that unidirectionality is taking place.

Measurement results demonstrate both high forward transmission and forward-to-backward contrast, in the cases analyzed in Fig. 4 (a) of the manuscript, see Fig. S2.

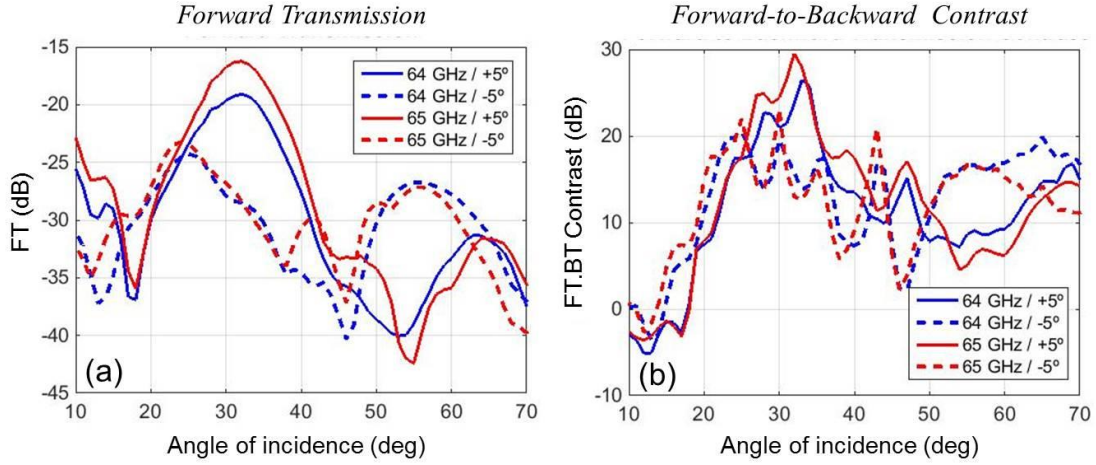


FIG.S2. (Color online). Frequency cuts at $\theta_{out} = +5$ and $\theta_{out} = -5$ deg scenarios. (a) Forward transmission. (b) Forward-to-backward transmission contrast.

Measurement results also demonstrate both high forward transmission and forward-to-backward contrast, in the cases analyzed in Fig. 4 (b) of the manuscript, see Fig. S3.

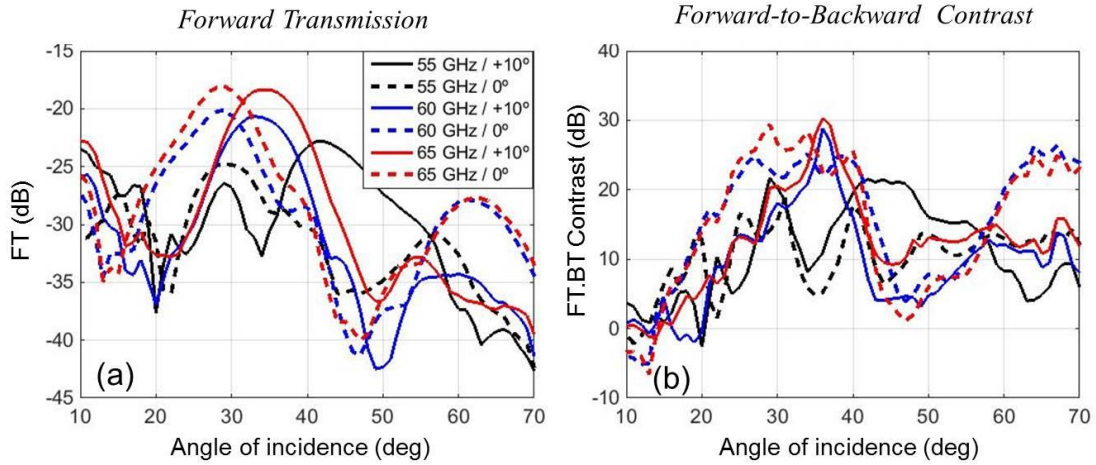


FIG.S3. (Color online). Frequency cuts at $\theta_{out} = +10$ and $\theta_{out} = 0$ deg scenarios. (a) Forward transmission. (b) Forward-to-backward transmission contrast.

Besides switching scenarios presented in Fig. 4 of the paper, additional ones can be found at different output angle combinations. For example, sign switching is observed at 55 and 64 GHz by using $\theta_{out}=+10$ deg and $\theta_{out}=-5$ deg, see Fig. S4.

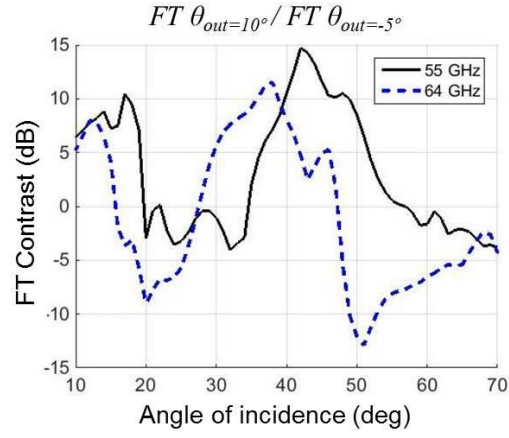


FIG. S4. (Color online) Forward-to-forward transmission contrast versus angle of incidence at different frequencies. $FT(\theta_{out} = +10) / FT(\theta_{out} = -5)$.