Signal Bandwidth and Reflection Angle of Intelligent Reflective Surfaces

G. Virone(1), A. Nordio(1), A. Tarable(1), L. Dossi(1), R. Nebuloni(1) and F. Malandrino(1)
(1) CNR-IEIIT National Research Council of Italy, Torino, Italy

Extended Abstract

We describe the behavior of Intelligent Reflective Surfaces (IRS) when employed to relay signals with large bandwidth, B, compared to the central frequency f_c. IRS are arrays of programmable reflective elements, each capable of applying a frequency-constant phase-shift to the impinging signal. They are typically implemented by directly integrating active devices on reflective elements and can be modelled as arrays of tunable (and reciprocal) phase shifters having a short-circuited termination. When an IRS is excited by a plane-wave of frequency f, hitting the surface at angle ϑ_{I}[1] and the distribution of the phase-shifts has a constant gradient[1, 2], g, across the aperture, the radiation pattern of the reflected signal shows a main lobe whose direction ϑ_{R}, depends on g, on ϑ_{I} and on f. Therefore, for wideband signals a non negligible variation of ϑ_{R} across the frequencies in the bandwidth B can be expected. As an example the black line in Fig. 1(left) shows the variation of ϑ_{R}, denoted as $\Delta\vartheta_{\mathrm{R}}$, plotted versus the normalized bandwidth $\bar{B} = \frac{B}{f_c}$ for $\vartheta_{\mathrm{I}} = -45°$, and $\vartheta_{\mathrm{R}} = -15°$. It is apparent that for $\bar{B} = 20\%$ we have $\Delta\vartheta_{\mathrm{R}} \geq 5°$. Such high value for $\Delta\vartheta_{\mathrm{R}}$ may be acceptable or not depending on the beamwidth of the main lobe generated by the IRS, which depends on the number of elements per side, N, the IRS is made of (we assume a square IRS made of $N \times N$ elements, spaced by $\lambda/2$, where $\lambda = cf_c$ and c is the speed-of-light). For this reason, in Figure 1(left) we also show by using colored lines, the values corresponding to $1/3$ of the Full Half-Power BeamWidth (FHPBW), for four values of N. The value $\frac{1}{3}$FHPBW has been chosen in order to maintain the beam decay below 1.5 dB for frequencies at the edge of the bandwidth. As can be observed, for $\bar{B} \geq 6\%$, $\Delta\vartheta_{\mathrm{R}}$ is larger than $\frac{1}{3}$FHPBW even for relatively small surfaces ($N \geq 21$). This is confirmed in Fig. 1(right) where the reflected normalized beam pattern is shown for an IRS having $N = 51$ elements per side, properly phased so as to achieve $\vartheta_{\mathrm{R}} = -15°$ at $f_c = 100\,\mathrm{GHz}$. In this case $\Delta\vartheta_{\mathrm{R}} \approx 0.7°$ for a bandwidth of about 2.6% in agreement with the intersection between purple and black lines in Fig. 1(left). As well known, increasing the number of elements N reduces the beamwidth. However, from Fig. 1, it becomes apparent that a smaller beamwidth should be counteracted by a smaller bandwidth to maintain the same decay of 1.5 dB for the reflected signal towards ϑ_{R} at the edge of the bandwidth. It can be shown that the bandwidth limitation is even more severe for $\vartheta_{\mathrm{R}} \leq -15°$. Such bandwidth limitation can be overcome if proper delay lines i.e. phase shifter with linear frequency behavior are adopted at the cost of a much higher IRS complexity.

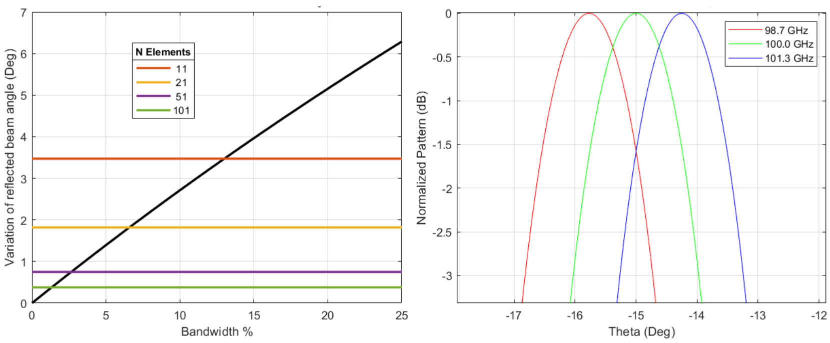

Figure 1. (left) $\Delta\vartheta_{\mathrm{R}}$ versus normalized bandwidth $\bar{B}$; (right) normalized radiation pattern for $N = 51$ elements within the identified bandwidth limit.

References

[1] Ö. Özdogan, E. Björnson, and E. G. Larsson, "Intelligent reflecting surfaces: Physics, propagation, and pathloss modeling," *IEEE Wireless Commun. Lett.,* vol. 9, no. 5, pp. 581âĂŞ585, 2020.

[2] A. Tarable, F. Malandrino, L. Dossi, R. Nebuloni, G. Virone, and A. Nordio, "Meta-surface optimization in 6G sub-THz communications," in *IEEE ICC,* 2020.

[1] Angles are measured w.r.t. the normal to the surface