

Direction-of-arrival (DOA) estimation with a programmable space-time-modulated metamaterial receiver

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Abstract: A space-time-modulated metamaterial antenna is leveraged as a receiver to estimate the direction-of-arrival (DOA) of an incoming signal. This approach uses the power levels of first-order harmonics, generated due to the periodic time-modulation of the metamaterial unit-cells' phase constants, allowing for precise DOA estimation of waves impinging on the antenna.

DOA finding holds importance in wireless communication, radar tracking, and remote sensing. In this context, multiple methods and signal processing algorithms have been developed to estimate the direction of an incoming signal [1]. Furthermore, DOA estimation by employing a reflective metasurface has been recently proposed to reduce computational complexity and hardware costs [2], [3]. For example, in [2] a reflective space-time modulated metasurface is employed for DOA estimation of an incident plane wave through creating a pattern asymmetry for the scattered fields at the two first-order harmonics. In this method, a detecting antenna is required to collect the scattered waves from the metasurface for DOA finding. Here, we propose a method utilizing only one space-time modulated metamaterial antenna to estimate the DOA of a signal impinging on the antenna.

Very recently, a space-time-modulated composite right/left-handed (CRLH) antenna has been proposed in [4], exhibiting interesting properties such as non-reciprocity and harmonic beam-scanning, which can be used for simultaneous transmission and reception of signals. In this antenna, the phase constant (β) of each CRLH unit cell can be either positive or negative, depending on the bias voltages of the integrated varactors into the unit cell. By toggling β between these two states (i.e. β_0 and β_1 shown in Figure 1) in a periodic fashion, harmonics are produced within the receiving antenna upon receiving a signal at frequency f_0 arriving from angle θ . Figure 1 displays the received fundamental and first harmonic patterns for the illustrated space-time-modulated sequence, obtained by mathematically formulating the received patterns based on the array factor approach. By looking at the 1st harmonic and -1st harmonics' patterns ($f_0 \pm \Delta f$), it is noted that if the received powers at these harmonics are deducted from each other (Δ), in each θ angle within a particular range, a distinct value is achieved, as can be seen in (1) and Figure 1. Therefore, when a wave with a frequency of f_0 , coming from an angle of θ within the detection range, is captured by the antenna, by calculating Δ and referring to the plotted curve in Figure 1, the DOA of the signal can be estimated. It is noted that there is a trade-off between the detection resolution and detection range. As such, it is worth mentioning that while increasing the amount of $|\beta_0 p|$ and $|\beta_1 p|$ leads to a higher slope of the Δ curve (better detection resolution), this will also result in a decrease in the detection range.

$$\Delta = \text{Power of } (f_0 - \Delta f)(\text{dB}) - \text{Power of } (f_0 + \Delta f)(\text{dB}) \quad (1)$$

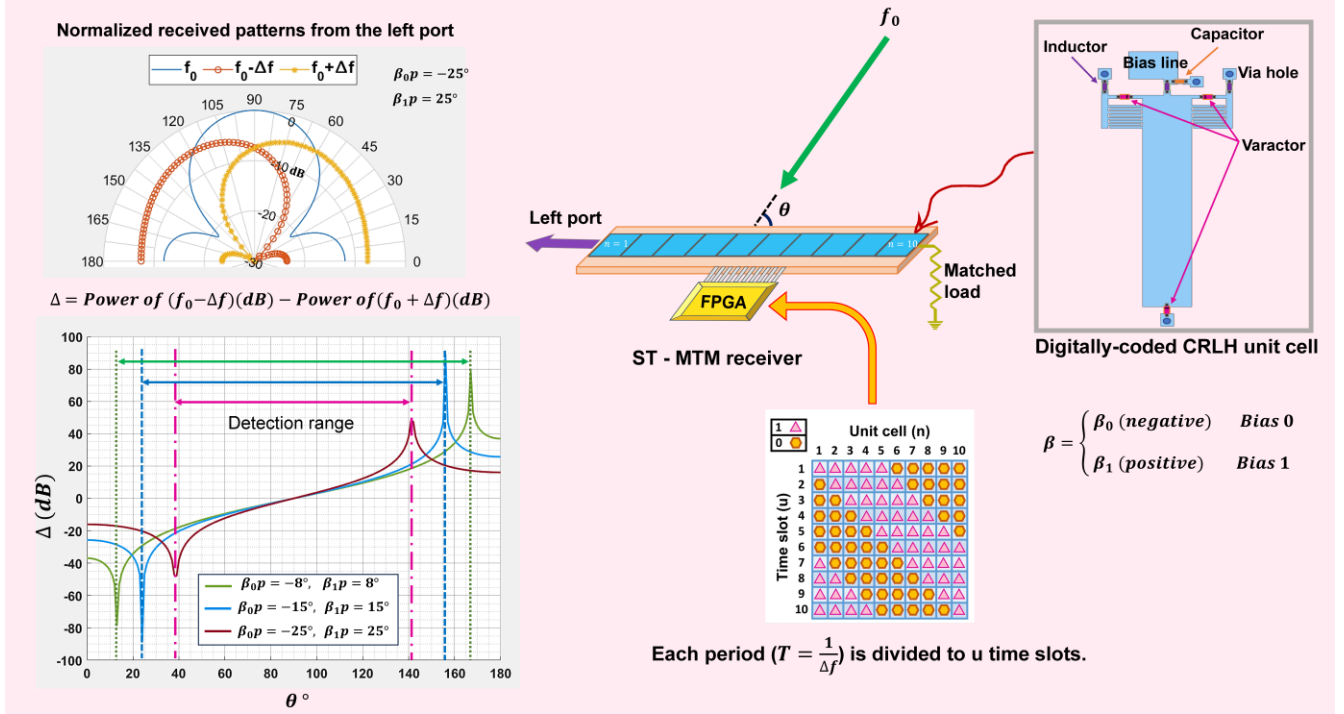


Figure 1. Space-time modulated metamaterial (ST-MTM) receiving antenna with 10 CRLH unit-cells for DOA estimation where p denotes the unit-cell length.

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References

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