Using the sidebands of time modulated arrays

[Presentation]

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Using the Sidebands of Time Modulated Arrays

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  - Time-Modulated Arrays
  - Harmonics and Sidebands
- Using TMAs as a Method for Direction Finding
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Arrays and Beamforming

- By introducing delays or phase changes to each individual element, you can change the pattern or the direction in which this beam is steered.
- Although fine control can be obtained, delay networks; especially for radio applications can be complicated and expensive.

*Figure: Typical setup and directional response of a 5-element array*
Time-Modulated Arrays

- First demonstrated by Shanks [1].
- Each element can be switched “on” or “off”.
- Any pattern or combination of switches has its own properties.
- Power of the received signal is distributed among harmonics of the switching frequency, depending on angle of arrival.

Figure: Typical setup of a time-modulated array
Time-Modulated Arrays

- When a time-modulated array receives a signal from the broadside, each element receives the same phase.
- When the array receives a signal from any other direction, the elements receive a different phase, and periodic phase shifts are shown.

Figure: Time-Response of a 5 element array switched sequentially
Sideband Content

\[ X(h, \theta) = \text{sinc} \left( \frac{h}{N} \right) \cdot \sum_{n=0}^{N-1} e^{j2\pi nR \left( \sin \theta - \frac{h}{RN} \right)} \]

- Each harmonic \( h \) (-2 to 2 in the example above) has a unique maximum at angle \( \theta \)
- At each maximum, every other harmonic is at a minimum
  - Max(AF) @ \( \theta_h = \sin^{-1} \left( \frac{h}{RN} \right) \)

R is spacing/wavelength ratio (0.5)  
N is the number of elements (5)  [2]

![Diagram showing sideband content](image-url)
Direction of Arrival Estimation

- He et al. [3] showed how the ratio of sidebands could be used to calculate the Direction of Arrival (DoA).
- Only needs two elements for a full ±90° range.
- Perfect accuracy in ideal conditions.
- Uses complex numbers in a function that can be affected by noise and signal reflections [4]

\[ \theta = \sin^{-1}\left( \frac{2}{KD} \tan^{-1} \frac{\pi X_b}{2X_a} \right) \]

Figure: Target frequency and sideband complex content of a 2-element array
Direction of Arrival Estimation

- More recently, it has been shown that DoA estimation can be achieved with simple weighted averaging of two adjacent sidebands $X_a$ and $X_b$ [2].
- Results can be obtained by using real-valued DFT.
- Results are less accurate than the numerically derived methods in ideal conditions but can make use of more elements for better noise/reflection immunity.

$$\theta_{est} = \frac{(X_a\theta_a) + (X_b\theta_b)}{X_a + X_b}$$

Figure: Target frequency and sideband Amplitude of a 5-element array
Direction of Arrival Estimation

- Small number of signal samples needed.
- Ability to “ignore” some errors caused by reflections.
- Real-valued simple arithmetic, suitable for small, low-cost processors.
- Accuracy can be further improved by weighting the sidebands non-linearly.

*Figure: Accuracy of analytical method in ideal conditions with 15 (yellow), 9 (red) or 5 (blue) elements*
Planar Arrays for 2D Estimation

- Switching a Planar Array allows two-dimensional patterns to be created [5].
- Many more harmonics are energised and represent different axes if the array is switched sequentially.
- Once each axis broadside angle is estimated, they can be converted to azimuth and elevation.

Figure: Switching pattern example and response (at a single sideband) of a time-modulated planar array
Implementation

Figure: A Simulation of Time Modulated Arrays in LabVIEW
Accuracy of a 2D TMA DoA Estimator

- Initial results indicate small but frequent $\pm 5^\circ$ errors in the centre regions with larger, more accurate regions ($\pm 1^\circ$) in-between for a $9 \times 9$ array.
- More work on reducing the errors in these regions is being carried out, with focus on using the known maximum points and on averaging different switching patterns.

Figure: Combined X-Y broadside error in direction of arrival estimation
Conclusions

- The use of the sidebands generated by time-modulation looks interesting in the field of Direction of Arrival.
- Simple and efficient methods of DoA estimation have been described and briefly extended to planar arrays.
- Planar arrays can be modelled as two linear arrays, but harmonic analysis is more involved.
- Continued work is being done on separating the harmonics for accurate 2D Estimation.
References