Analysis of SLL at UWB Scanning Array Based on TTD BFN

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1. Abstract

A beam scanning technique is developed with a TDD (true time delay) for UWB (Ultra Wideband) arrays. The performance of SLL (Side Lobe Level) for this kind of array based on TDD BFN (Beam-forming network) will analysis and discussed. In addition, we give a formulation for the time domain array factor for UWB antenna arrays. An UWB comb taper slot antenna array with large element spacing and impulse excitation is studied and four-element UWB linear array system with element spacing of 18 cm and 20 degree scanning is implemented. The voltage response and energy pattern for from simulation and measurement are in good agreement. The periodic grating lobes of the UWB antenna array do not occur in the energy pattern, even if the element spacing and scan angle are large. Simulation and measurement results for the energy pattern and voltage response in various directions are studied to validate the theory of an UWB antenna array with scan capability.

2. Introduction

The frequency bandwidth of a conventional phased array antenna is ultimately limited by the antenna elements, amplifiers, and BFN bandwidth [1]–[3]. However, a more severe limitation is often caused by the use of phase shifters to scan the beam [4]. TTD technology potentially eliminates this bandwidth restriction; however, standard time-delay technology consists of switched transmission line sections and the weight, loss, and cost increase rapidly with the phase-tuning resolution. A delay line concept was previously presented in a proof-of-principle demonstration, where a linear delay line was used as a low-loss, beam scanning controlled and broadband TTD line [5].

Traditional radar systems have a narrow band and high power; the proposed radar system affords an UWB and low power. This paper presents an UWB four-element beam scanning array, controlled by a linear delay line. The system consists of various wideband components, including a microstrip UWB power divider, UWB comb tapered slot antenna array, linear delay line, and broadband transitions. The combination of these wideband elements provides significant flexibility for a broadband system design. For the current system, delay line elements support use from 3.1 to 10.6 GHz; however, the same system components and implementation can be used at frequencies up to 18 GHz, using a delay line with lower loss, to produce an extremely wideband array system.

3. Theory of UWB Antenna Array in Time Domain

The transient properties of UWB arrays have been discussed in the literature [6], [7]. The antenna array design was based on modified array theory; the beam maximum scan angle $\theta_{\max}$ for a given antenna spacing d between adjacent antenna elements, is given in Eq. (1):

$$\begin{aligned}\Delta\tau &= \tau_n - \tau_{n-1} \\ &= \frac{d\sin\theta_{\max}}{c}\end{aligned} \tag{1}$$

where $\Delta\tau$ is the relative excitation time delay between adjacent antenna elements, τ_n is the excitation time delay for the *n*th element, and *c* is the speed of light.

Typically, the transmit signal is a Gaussian pulse. UWB arrays require true time delay components to steer the maximum beam direction. To achieve the maximum signal in the scan direction, the array outputs must be in phase. For a linear array with uniform spacing between the antennas, the relative excitation time delay is given in Eq. (1) for a scanned angle at $\theta_{\max}$. If the output signals are not in phase, the summed signal will not have a maximum in the desired beam direction. Compared with traditional phased array antennas, the UWB time domain antenna array is realized through different time delays among antenna elements—a phase shifter is unnecessary.

The transient transmission characteristic of an UWB array is calculated as the convolution of the antenna element transient response with the time-domain array factor. In UWB antenna arrays, each antenna element radiates impulses. The superposition of these signals in free space is determined by both the impulse waveform impulse and the relative time delay.

For a uniformly spaced one-dimensional linear array with elements excited by identical impulses, if the mutual coupling is negligible, the convolution time waveform $s(t,\theta)$ can be obtained by Eq. (2):

$$\begin{aligned} s(t,\theta) &= f(t,\theta) * AF(t) \\ &= f(t,\theta) * \sum_{1}^{N} a_n \delta\left(t-(N-n)\Delta t+\tau_n\right) \\ &= \sum_{1}^{N} a_n f\left(t-(N-n)\Delta t+\tau_n,\theta\right) \end{aligned} \tag{2}$$

where

$$\begin{aligned} \Delta t &= \frac{r_n - r_{n-1}}{c} \\ &= -\frac{d\sin\theta}{c} \end{aligned} \tag{3}$$

where $f(t,\theta)$ is the radiated waveform for an antenna element in the θ direction, $AF(t)$ is the array factor in the time domain, $*$ is the convolution operator, *N* is the number of antenna elements, a_n is the amplitude excitation, τ_n is the excitation time delay for the *n*th element, Δt is the relative space time delay between neighboring elements if the wave is incident in the θ direction, *c* is the light speed, and *d* is the antenna spacing between adjacent antenna elements.

To achieve maximum signal in the desired direction, the array outputs must be in phase ($\Delta\tau + \Delta t = 0$); when the output signals are not in phase ($\Delta\tau + \Delta t \neq 0$), the summed signals will spread in the time domain and the voltage will not increase in the desired direction.

4. The UWB Array with Beam Scanning

The UWB antenna array is composed of four antenna elements aligned in the H-plane, a multistage, with a four-way microstrip UWB power divider, and four coaxial cable lines, as shown in Fig. 1. The simulated field intensity and measured voltage in the time domain in various directions ($\theta = 0^\circ, \pm10^\circ, \pm20^\circ, \pm30^\circ, \pm40^\circ$) in the H-plane, for an array with element spacing of 18 cm at a designed BFN for 20 degree beam scanning, are shown in Fig. 2. For a beam direction in 20 degree with array element spacing of 18 cm, the relative space time delay (Δt) is -0.205 ns, the relative excitation time delay ($\Delta\tau$) is 0.205 ns, and the summation of relative time delay ($\Delta\tau + \Delta t$) is 0 ns. There is a maximum output in the 20 degree beam direction. For a beam direction of -20 degree, the relative space time delay (Δt) and relative excitation time delay ($\Delta\tau$) are 0.205 ns for element spacing of 18 cm, and the summation of relative time delay ($\Delta\tau + \Delta t$) is 0.41 ns. The array output is not in phase and the summed signal will not have a maximum. The simulation and measurement results are in agreement for element spacing of and 18 cm. The simulated and measured normalized energy pattern of Fig. 2 is shown in Fig. 3. The larger the array aperture is, the higher the directivity of the UWB array will be. The beam width of an array with larger element spacing is narrower than for smaller element spacing. The peak side lobe level (SLL) is about 5 dB (angular region between -10 and -40 degrees) below the main beam level. Far from the +-40 degrees, the energy pattern decays very fast; this is caused by the antenna element energy pattern.

5. Conclusion

UWB antenna arrays were analyzed on the basis of their transient response, which provides all relevant information about their transient radiation and reception characteristics. The far-field voltage consists of the time-domain superposition of the pulse radiated by each of the individual elements. The transient response is given by the convolution of the transient response for the single element with the time-domain array factor. The theory of the UWB time-domain antenna array is derived for computation of the time-domain array factor and beam scanning direction.

A uniformly spaced linear UWB antenna array with large element spacing for beam scanning was investigated. An UWB comb taper slot antenna was selected as the array element and beam scanning capability with a linear delay line concept was demonstrated.

The antenna energy pattern was presented for the UWB antennae from the time-domain field. Simulated and measured energy patterns of UWB array, with and without beam scanning, were compared. The energy pattern does not have periodical grating lobes even if the element spacing of the UWB array is large. To achieve the maximum signal in a desired beam direction, the outputs of the array BFN must be in phase. When the output signals of the array BFN are not in phase, the signal output will not have a maximum in the desired beam direction.

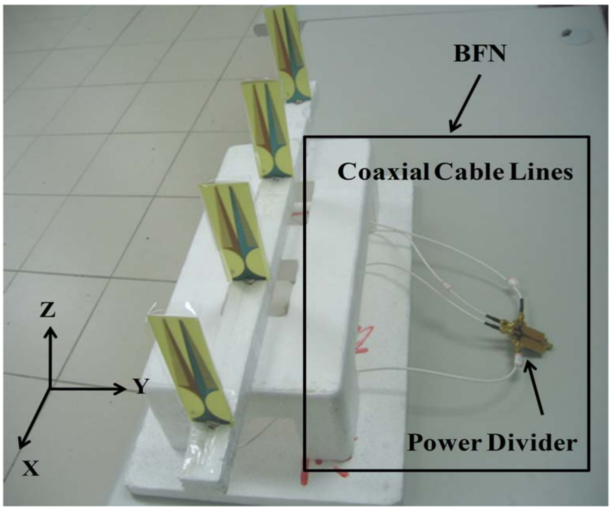
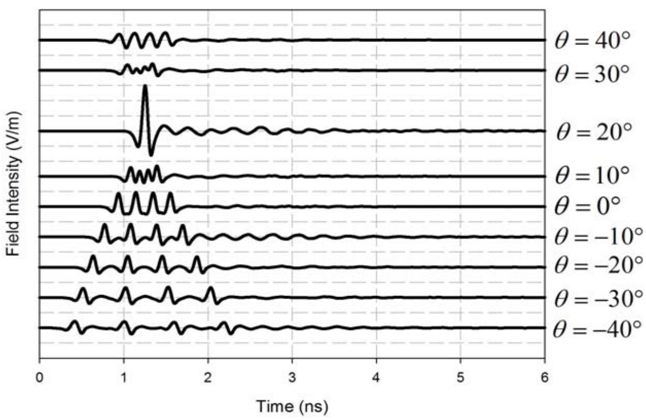
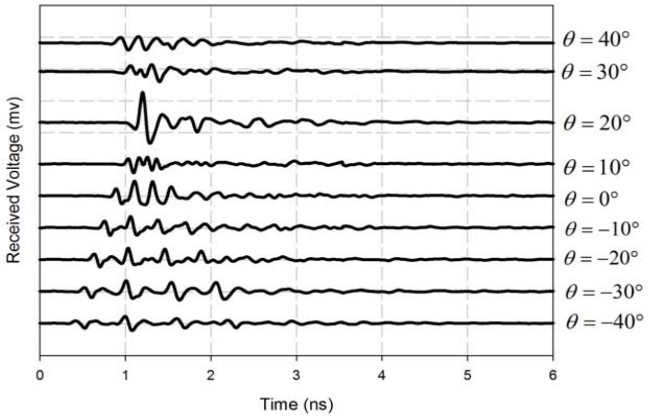


Figure 1: H-plane UWB antenna array.



(a) Simulation



(b) Measurement

Figure 2: Simulated field intensity (a) and measured voltage (b) in various directions for an array with 18 cm element spacing.

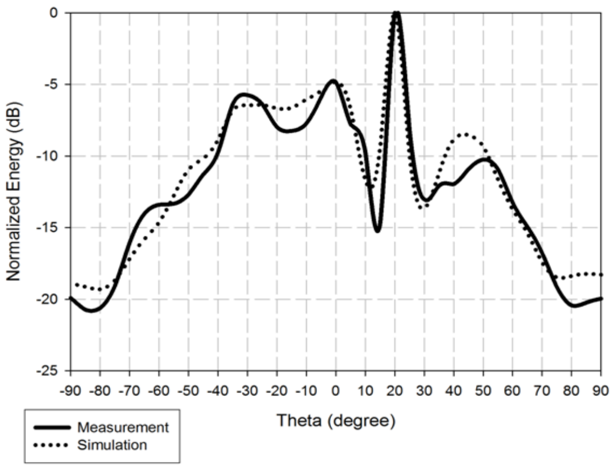


Figure 3: Simulation and measurement of the energy pattern with 20 degree beam scanning for an element spacing of 18 cm. (X-Z plane)

References

[1] C. T. Rodenbeck, S.-G. Kim, W.-H. Tu, M. R. Coutant, S. Hong, M. Li, and K. Chang, "Ultra-wideband low-cost phased-array radars," *IEEE Trans. Microw. Theory Tech.*, vol. 53, no. 12, pp. 3697–3703, Dec. 2005.

[2] C.-C. Chang *et al.*, "True time phased antenna array systems based on nonlinear delay line technology," in *Asia–Pacific Microw. Conf.*, Dec. 2001, pp. 795–800.

[3] K. S. Yngvesson *et al.*, "The tapered slot antenna—A new integrated element for millimeter-wave application," *IEEE Trans. Microw. Theory Tech.*, vol. 37, no. 2, pp. 365–374, Feb. 1989.

[4] R. J. Mailloux, *Phased Array Antenna Handbook.* Norwood, MA: Artech House, 1994.

[5] W. M. Zhang, R. P. Hsia, C. Liang, G. Song, C. W. Domier, and N. C. Luhmann, Jr., "Novel low-loss delay line for broadband phased antenna array applications," *IEEE Microwave Guided Wave Lett.,* vol. 6, pp. 395–397, Nov. 1996.

[6] R. W. Ziolkowsky, "Properties of electromagnetic beams generated by ultra-width bandwidth pulse-driven arrays," *IEEE Trans. Antennas Propag.*, vol. 40, no. 8, pp. 888–905, Aug. 1992.

[7] S. Werner, C. Strum, and W. Wiesbeck, "Impulse response of linear UWB antenna arrays and the application to beam steering," in *Proc. Int. Ultrawideband Conf.* , Sep. 2005, pp. 275–280.