Beam steerable IR-UWB antenna array with FCC-compliant impulse generators

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A novel method for beam steering with an active ultra-wideband antenna array is presented for impulse-radio ultra-wideband. The antenna array consists of four planar Vivaldi antennas in a collinear arrangement with an impulse generator circuit mounted chip-on-board on each antenna element. The beam steering is done by shifting the phase of the control signals triggering the impulse generators. In the array arrangement a measured beamwidth of 16° is achieved for an antenna spacing of 4 cm compared to 80° for a single Vivaldi antenna. Beam steering is experimentally demonstrated for a steering angle of 30°.

Introduction: Antenna arrays are applied to increase the directivity, concentrating the transmitted energy into a smaller main beam, or reducing signal perturbations in a receiver by suppressing interference from other angles. An additional advantage of an array is that the direction of the antenna's maximum radiation can be controlled by modifying the signal delay for the individual antennas. If this is done electronically, the antenna beam can be shifted without mechanical rotation of the antenna. For single frequency or narrowband systems this is typically achieved by a phase shifter. For broadband systems true time delays are usually applied, since broadband phase-shifters are not available.

In the FCC allocated ultra-wideband (UWB) frequency range from 3.1–10.6 GHz promising UWB antennas (e.g. [1, 2]) and antenna arrays (e.g. [3, 4]) have been reported, fulfilling the requirements of this multioctave frequency band. While the advantages of beam steering have been frequently described, only few actual concepts have been published so far. This is mainly due to the difficulty of generating a tunable ultra-wideband true time delay element in the RF domain. One interesting beam steering concept is shown in [5], where broadband power dividers split an input signal to four microstrip lines feeding the antenna array. Above these feeding lines, a triangular perturber is placed. Bringing the perturber closer to the transmission lines alters the phase velocity on the four feeding lines and results in a delay of signals. This concept works for all UWB signals, e.g. OFDM UWB as well as impulse radio (IR), but requires mechanical parts and a large control voltage for the piezoelectric perturber actuation. In this Letter, an easier approach of beam steering for IR-UWB systems is presented. In IR-UWB short impulses are generated for communications or radar applications, triggered by a low frequency control signal. The idea is to phase shift the trigger control signal in the low frequency domain, which is much easier than broadband delaying in the RF domain. In the following, this concept is described for an IR-UWB radar transmit array. The beam steering concept can equally be applied to correlation UWB receiver arrays, provided that complete receiver modules are mounted on each antenna and the reference impulse can be phase shifted individually.

Active antenna element implementation: To demonstrate the new concept, four identical Vivaldi antennas have been constructed with an impulse generator integrated circuit (IC) mounted chip-on-board at each antenna feed point. The Vivaldi antennas are designed as those described in [2]. A modified Marchand balun is exploited to achieve a broadband transition from a microstrip feeding line to a slot line. An exponentially tapered slot forms the radiating structure. The antennas are realised on an RO4003 substrate with thickness of 0.51 mm. The individual antenna has a return loss of more than 10 dB in the frequency range 3.1–10.6 GHz and a maximum gain of 9.3 dBi, see [6]. The impulse generator IC produces a transient very similar to a fifth derivative of a Gaussian impulse with a standard deviation of 51 ps when excited by the falling slope of a triggering input signal. The impulse makes efficient use of the FCC UWB indoor mask and provides an amplitude of 600 mV_{pp} at 50 Ω. A detailed description of the impulse generator and its application together with a Vivaldi antenna in a radar system is given in [7] and [8], respectively.

Active array and measurement setup: The four Vivaldi antennas are placed in a collinear arrangement in the H-plane (see Fig. 1). Each impulse transmitter is fed with a sinusoidal triggering signal. The four signal sources are synchronised with each other via the 10 MHz synchronisation reference. The individual time delay of each impulse can be controlled by changing the phase (φ_N) of the triggering signal for each source (N). To adjust the steering angle (Φ), the phase of the triggering signal must be adjusted according to

$$\varphi_N = [(f_{rep} \times d)/c_0] \times [360^\circ/(N-1)] \times \sin\Phi \qquad (1)$$

where f_{rep} is the impulse repetition rate (here $f_{rep} = 200$ MHz), d the lateral distance between the antennas (here d = 4 cm) and c_0 the speed of light. The measurements are conducted in an anechoic chamber at a distance of 6 m between transmitter and receiver. At the receiving side an UWB low-dispersive ridged-waveguide horn antenna is connected to an UWB low-noise amplifier (LNA) and a real-time oscilloscope. The 10 MHz synchronisation reference is used to trigger the oscilloscope. The array is rotated from −90° to +90° in steps of 1°, and the received time domain impulse signal is stored continuously.

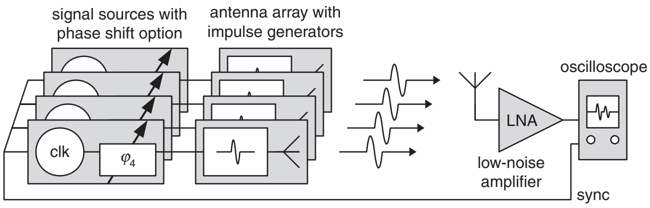

Fig. 1 *Block diagram of proposed antenna array and measurement setup*

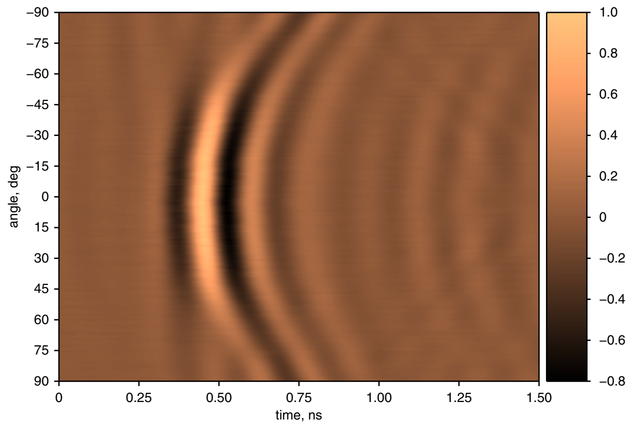

Fig. 2 *Normalised received amplitude against H-plane rotation angle and time of single antenna element*

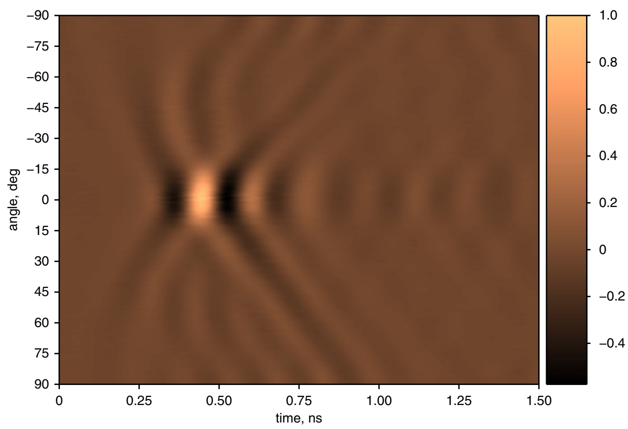

Fig. 3 *Normalised received amplitude of antenna array with antenna spacing of 4 cm and no phase shift between trigger control signals*

Measurement results: A transient measurement in the H-plane of a single Vivaldi transmit antenna is given in Fig. 2. It shows the normalised voltage amplitude against rotation angle and time. The multicycle transient behaviour of the time domain impulse can be clearly seen between 0.25 and 0.75 ns. The 3 dB beamwidth of the single transmit antenna is 80°. In Fig. 3, a measurement of the antenna array in the H-plane without phase shift between the triggering signals of the antenna elements is demonstrated. The graph shows a focusing of the main beam within $\pm 8^\circ$. Within the main beam the impulse of the different array elements sum up, while outside the impulses of the individual antenna elements partially cancel each other, and therefore only very small amplitudes can be seen. The beam steerability of the antenna array is demonstrated in Fig. 4 for a steering angle of 30°. To this end, the respective phase shifts are applied for each trigger signal according to (1). The main lobe shifts to 30°, and the beamwidth remains unchanged with a value of 16°. The wisps in the angular region between -15° and -60° are caused by the four individual impulses. The resulting side lobes, however, are attenuated by more than 8 dB compared to the main lobe.

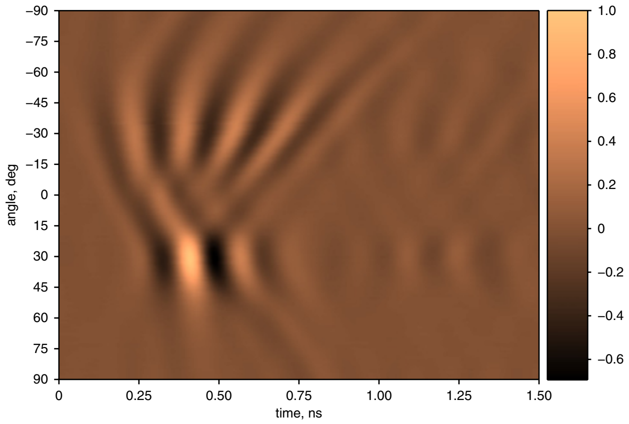

Fig. 4 *Normalised received amplitude of antenna array with antenna spacing of 4 cm and phase shift for radiation angle of 30°*

Conclusion: Presented is a novel electronically steerable antenna array for impulse radio ultra-wideband systems. It consists of four Vivaldi antennas with on-board impulse generators at the feedpoint of each radiator. The antenna array provides a narrow beamwidth of 16° in the azimuth plane in contrast to 80° for a single element. Introducing appropriate phase shifts to the clock signals of the individual impulse generators, beam steering can be achieved, which has been experimentally shown for a steering angle of 30°. A similar technique can also be used in arrays of correlation receivers and is generally applicable in many UWB-based high-resolution receivers.

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One or more of the Figures in this Letter are available in colour online.

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