# Multichannel Signal Synthesis in Free Space

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***Abstract*—A two antennae, software controllable phased array was designed and fabricated to study the generation and transmission of short, nanosecond, nonperiodic pulses. This system allows transmitting a train of appropriately scaled and time-shifted bipolar signals to generate received signals with major frequency components adjustable from approximately 600 MHz to 1.5 GHz. The main components in the system include two digital to analog converters (DACs), two data pattern generators (DPG), and two power amplifiers which drive two TEM Horn antennas. The horn antennas are based on a Chebyshev taper design and a Microstrip-type balun is utilized for the transition from the coaxial feed. This approach yielded a reasonably flat frequency response in a wide range from 0.2 to 3 GHz. Thus far, 100 ps synchronization between channels was achieved, and signals of varying shape and amplitude have been received via the shifting and inverting of Gaussian input pulses defined by the user generated data input vectors. This paper presents an experimental evaluation of the hardware used to generate the multichannel array, the ability to steer the signals and generate signals of varied frequency via superposition in free space.**

***Keywords—signal synthesis; bipolar impulse; wideband***

## I. INTRODUCTION

A two or more antenna array is used for the purpose of demonstrating that the received signal shape/frequency may be manipulated by appropriately scaling and time-shifting bipolar signals radiated from the individual antennas. This is achieved by changing the input signal delay for each individual antenna, in turn controlling the excitation phase. In the demonstrated example, two in-phase antennae at equal path lengths will experience constructive signal interference in the far field. Since both antennae have equal path lengths, the signals will arrive in-phase and with equal amplitude. This means that the received signal in the far field will have twice the amplitude of the signal transmitted by a single antenna. If one changes the path lengths or phase of the transmitting antennae to be half a wavelength apart from each other, the signals would perfectly be out-of-phase and cause destructive interference [1]. This principle is of course utilized for rf transmission and receiving in many applications that exploit phased antenna arrays. While the signals fed into a phased antenna array are simply phase shifted from each other, the presented approach may also introduce an amplitude scale factor and time stretch. Based on this principle, using discrete, nonperiodic signals a continuous waveform of a desired frequency may be synthesized. This continuous signal synthesis is achieved by using the phased array technique described above in tandem with nonperiodic impulse excitation [2]. A prototype antenna array was designed and fabricated enabling the demonstration of signal synthesis in free space.

## II. EXPERIMENTAL SETUP

For the purposes of this experiment, a system was constructed to study the synthesis of signals in the far field of the antenna array. This system uses a two antennae array with fixed position; and a receiving antenna which is mounted on a track that allows it to move laterally with respect to the array. In order to manipulate the phasing of the array, electrical length is added to one of the antennae to correspond to a time delay in the signal propagation. This in turn will cause interference which changes the received signal's amplitude and frequency content. For future flexibility of the system a provision to create multiple impulses of different shape and frequency for transmission was built in.

Regarding the system block diagram depicted in Fig. 1, the creation of the impulses to be transmitted is accomplished by using an Analog Devices Data Pattern Generator 3 (DPG), with an Analog Devices 9129 14-bit RF DAC (DAC). A data vector is created by the system user which will be uploaded to the DPG via a laptop USB connection. Once playback is initiated by the user from the laptop, the DPG will feed the data vector to the DAC for conversion. The DAC is attached to the DPG via a low-voltage differential signaling (LVDS) connection. The AD9129 has a conversion rate up to 2.8 GSPS, with the DPG3 having a data rate up to 38.4 Gbps.

Each antenna has its own dedicated DPG and DAC. Both use two in-phase 2.4 GHz clock signals which are fed into the DAC. The DAC provides the clock signal to the DPG which is divided by a factor of four, setting the DPG clock at 600 MHz.

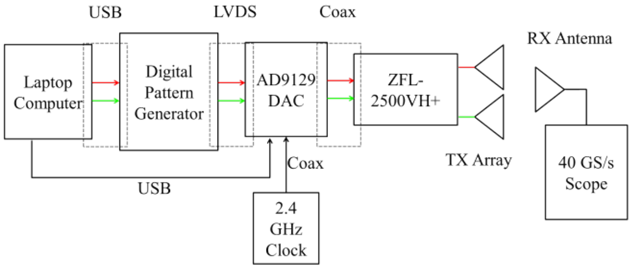

Fig. 1. System block diagram. Each arrow corresponds to an individual set of components. While there are two DPGs, DACs, and power amplifiers, there is only one laptop to control the system.

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Each DPG is triggered externally, once playback is started by the user, by a Stanford Research Systems DG645 (delay generator). In order for a fast rise time on the trigger signal to be achieved, the delay generator is outfitted with an in line step response diode (SRD1).The SRD1 reduces the delay generator output rise time to approximately 100 ps.

A 20dB power amplifier (ZFL-2500VH+) is used to amplify the output of the DAC before being transmitted via a TEM Horn antenna. All antennae are constructed with a Chebyshev taper and microstrip-type balun. The TEM Horn design was chosen due to its wide bandwidth, which is needed for the range of frequencies that can be transmitted by the system itself. The Chebyshev taper is used due to providing small, equal-amplitude side lobes for the antenna radiation pattern. Small side lobes allow for more power to be concentrated into the main lobe of the radiation pattern [3,4,5].

## III. Mathematic Representation of Signal Synthesis

Mathematic representation of the transmitted impulses and received signal is used to help with the initial alignment of the system. For this purpose, individual, bipolar pulses with adjustable amplitude, width, and time step are represented by

$$S(t,a,r,c) = -\frac{a\cdot c}{2\pi^{-\frac{1}{2}}}\cdot(t-r)\cdot e^{\frac{-(t-r)^4}{2a^2}} \qquad (1)$$

where $S$ is the bipolar pulse, $t$ is time, $a$ is width, $r$ is the step resolution of the system (417 ps), and $c$ is the amplitude. The transmission of a data vector from one antenna can be represented by summing multiple bipolar impulses at different time steps.

$$Ant(t,m) = \sum_{i=1} S(t,a,r\cdot m\cdot i,c) \qquad (2)$$

where $Ant$ is the waveform and the variable $m$ is the number of steps between each bipolar pulse. For simplicity's sake, both the ideal and experimental results demonstrated have seven steps (2.919 ns) between each impulse. The number of steps was arbitrarily chosen, due to the results being similar at higher numbers of steps. This equation can then be used to calculate the received signal by the addition of the two individual antenna transmissions

$$Ant_{RX}(t,m,\Delta t) = Ant_1(t,m) + Ant_2(t+\Delta t,m) \qquad (3)$$

The second antenna includes $\Delta t$, which represents the temporal shift added to one of the transmitting antennae. This added shift is accomplished by increasing the electrical length from the DAC to the transmitting antenna. This was accomplished by adding short lengths of coaxial cable or coax male to female adapters in the signal path. A temporal shift will cause the received signal to have different amplitude and frequency content compared to a signal which was transmitted in phase.

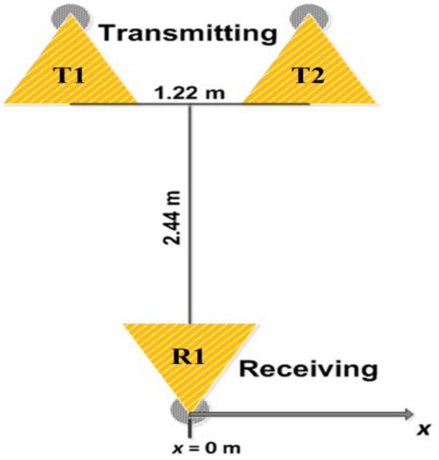

Fig. 2. Experimental setup of antennae. Transmitting antennae T1 and T2 are set 1.22 m apart, center-to-center. Receiving antenna R1 is centered between T1 and T2 at 2.44 m away.

The positioning of each antenna is shown in Fig. 2. The centerline position is designated with $x = 0$. It is crucial that the initial physical alignment of the system is accurate within a few millimeters in order to ensure that maximum signal is received on centerline for a zero phase shift between the signals fed into the antennae.

## IV. Experimental Results

Both antennae in this experiment transmit the same data vector with bipolar impulses seven steps apart. At the beginning of the experiment, the array is in-phase with no extra electrical length used. As the experiment progresses coaxial cable of known length will be added to the antenna labeled T2 in Fig. 2. For the results shown, the receiving antenna is kept stationary, centered with the transmitting array. Waveforms and frequency spectra will be shown for both the ideal and experimental results for direct comparison.

Note that the period between bipolar pulses emitted from an individual antenna is governed by the resolution of the signal synthesis system of 417 ps. Further, while the bipolar signal emitted by each antenna is repeated, the delay between successive pulses has to be set sufficiently large, larger than ~ 2.5 ns, such that any overlap of the bipolar pulse in the individual antenna is avoided.

The ideal and experimentally realized in-phase signals are shown in Figs. 3 and 4 respectively. Minor ringing can be seen between each impulse in Fig. 4A. This is thought to be caused by the system itself, but ceases to be an issue as the array is shifted out of phase. Main frequency components of the spectrum occur at approximately 350 MHz, 675 MHz, and 1 GHz.

Next, electrical length is added to antenna T2. Results with a 0.6 ns temporal shift are shown in Figs. 5 and 6. The temporal waveforms in Figs. 5A and 6A exhibit reasonable similarity, and the spectral content of the ideal and experimental data demonstrate the suppression of the same frequencies.

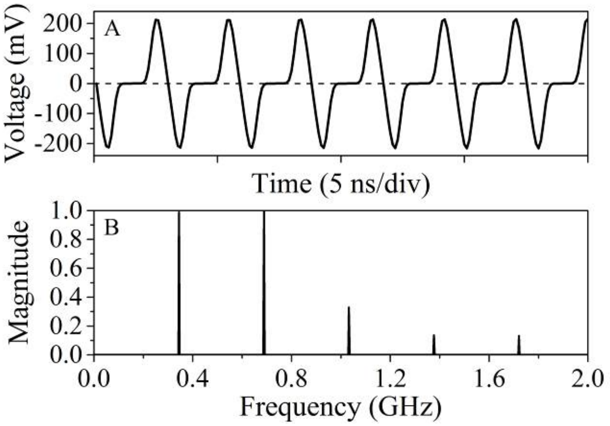

Fig. 3. Ideal waveform of received signal with in-phase antenna array (**0 ns** temporal shift between antennas; bipolar impulse train spaced 2.919 ns). A) Received temporal signal). B) Normalized frequency spectrum of ideal signal.

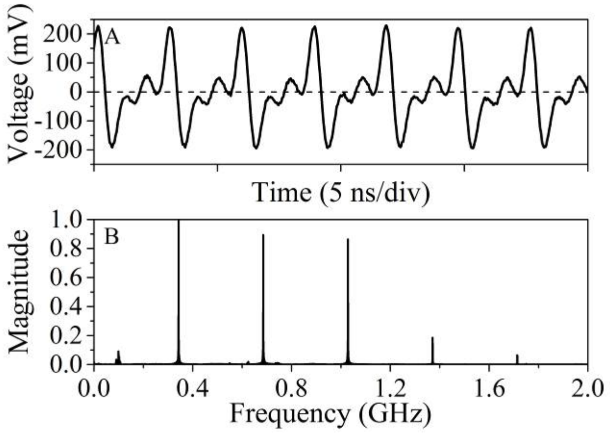

Fig. 4. Experimental waveform with settings of Fig.3.

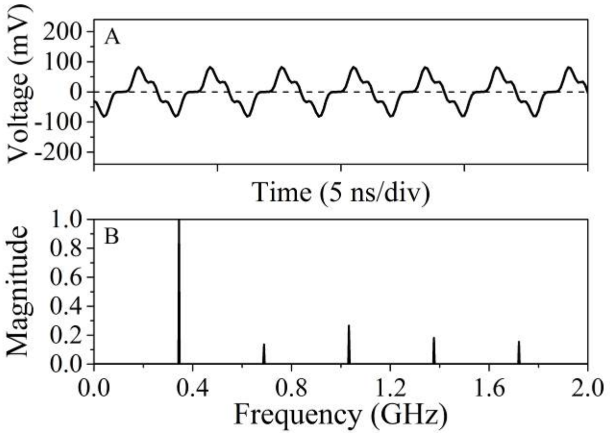

Fig. 5. Same as Fig. 3 with **0.6 ns** temporal shift between antennas.

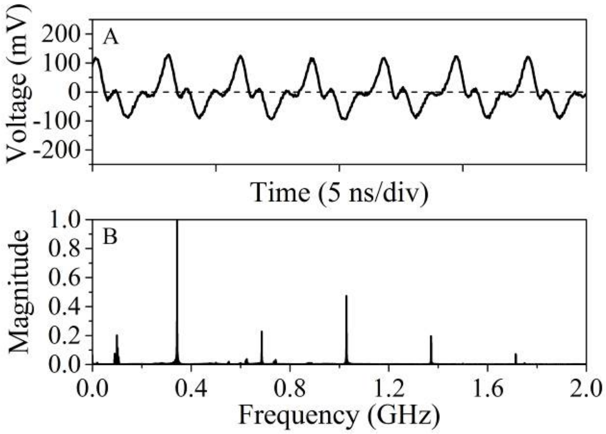

Fig. 6. Experimental waveform with settings of Fig. 5.

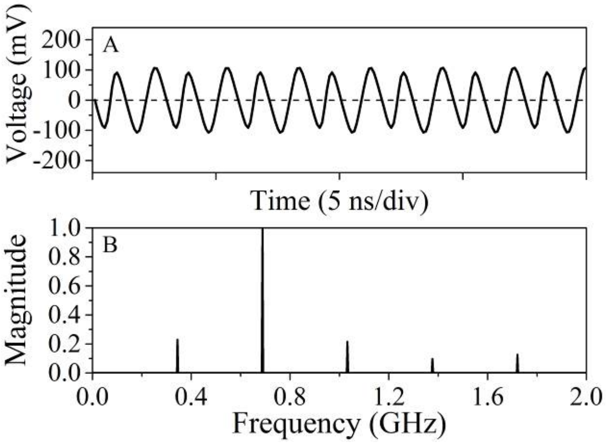

Fig. 7. Same as Fig. 3 with **1.65 ns** temporal shift between antennas.

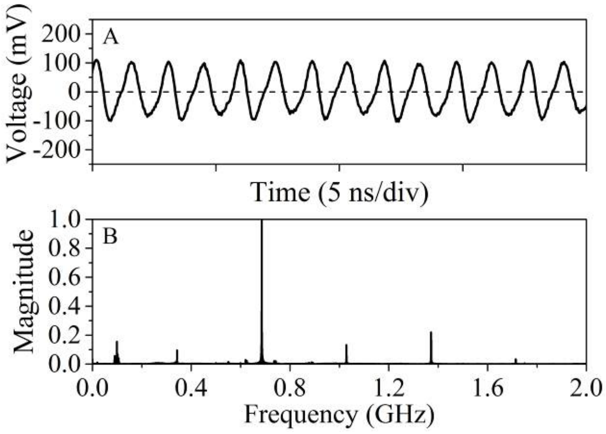

Fig. 8. Experimental waveform with settings of Fig. 7.

Finally, additional electrical length is added to the specified transmitting antenna that yielded a total temporal shift of 1.65 ns. Ideal and experimental results are shown in Figs. 7 and 8, respectively. Both waveforms are similar, while each spectrum again shows enhancement/suppression of specific frequencies.

The results demonstrate that signals of different amplitude and frequency content can be synthesized in free space by simply adjusting the phase of an antenna array. Adding temporal shifts causes constructive and destructive interference. This in turn causes the received signal to have differing frequency content from the transmitted signal.

## V. SUMMARY AND CONCLUSION

The constructive and destructive interference of bipolar impulses being transmitted by a phased antenna array may be utilized to produce received signals of different shape, amplitude and frequency content by applying temporal shifts and/or amplitude scaling to the individual antennas. This technique can be used to synthesize continuous signals in free space by only transmitting trains of nonperiodic, bipolar impulses. The limits of the types of signals to be synthesized has still yet to be seen, as the described is only a small fraction of what is achievable with the presented approach.

## VI. FUTURE WORK

The system described will gain additional flexibility for each extra antenna that is introduced into the transmitting array. As a next step upgrading the described system to have a four antenna transmitting array is considered. Doing so will enable synthesizing more complicated signals due to the increased number of bipolar impulses that may be transmitted simultaneously. Of course, increasing the number of transmitting antennae also increases the difficulty of calculating a set of solutions for a desired waveform. Additionally, higher power transmission may be achieved by appropriately selecting the driving source.

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