TRUE TIME-DELAY FIBER-OPTIC CONTROL OF A PHASED-ARRAY TRANSMITTER WITH THREE-OCTAVE BANDWIDTH

R.D. Esman[1], M.Y. Frankel[1], and M.G. Parent[2]

[1]Fiber-Optic Microwave Signal Processing Section, Code 5672, and [2]Antenna Section, Code 5317
Naval Research Laboratory, Washington, DC 20375-5338

ABSTRACT

We demonstrate a true time-delay fiber-optically controlled phased-array transmitter with eight broadband spiral elements in a sparsely-populated array. The transmitter bandwidth is microwave-component limited to 2-18 GHz frequency range. The transmitter shows ±50° azimuth steering with no observed squint over a complete frequency range.

INTRODUCTION

There are several well-known benefits that fiber-optic control of phased-array antennas can provide that include size, weight reduction, interference immunity, remoting capability, etc. Most importantly, the optical control systems make possible such desirable functions as true time delay beamsteering required for wide instantaneous bandwidth and squint free operation. Many optical techniques have been conceived for obtaining true time-delay capability [1-3]. However, these suffer from the requirements for a large number of precisely matched optical elements, excessive power losses, instability, or specialized element development. A novel fiber-optic true time-delay technique was proposed that alleviates the above requirements [4]. It requires only one wavelength-tunable laser for each steering dimension, while still providing feeds to each antenna element. The system is based on all commercially-available components and has potentially high reliability and stability.

Here we demonstrate an implementation of a true time-delay fiber-optic beamformer feeding a sparsely-populated linear eight-element phased-array transmitter. The transmitter has an instantaneous bandwidth of 2 to 18 GHz, limited by the available microwave components. It shows ±50° azimuth steering characteristics without observable squint that would be associated with phase-steering beamformers.

TRANSMIT ARRAY

The complete system is shown in Fig. 1. The optical source is a fiber-optic σ-laser with a single-polarization 0.06-nm linewidth output continuously tunable over >50 nm. The output of the laser is amplitude-modulated, amplified, and fed to a fiber-optic 1:8 splitter. The 1:8 splitter feeds an eight-channel fiber-optic dispersive prism providing a channel dispersion proportional to the corresponding antenna element position within the array. Each channel of the prism feeds an individual InGaAs p-i-n photodiode driving an antenna element.

The antenna was tested in a compact radar range using a network analyzer to drive the amplitude modulator and to detect the received signal. The antenna elements were cavity-

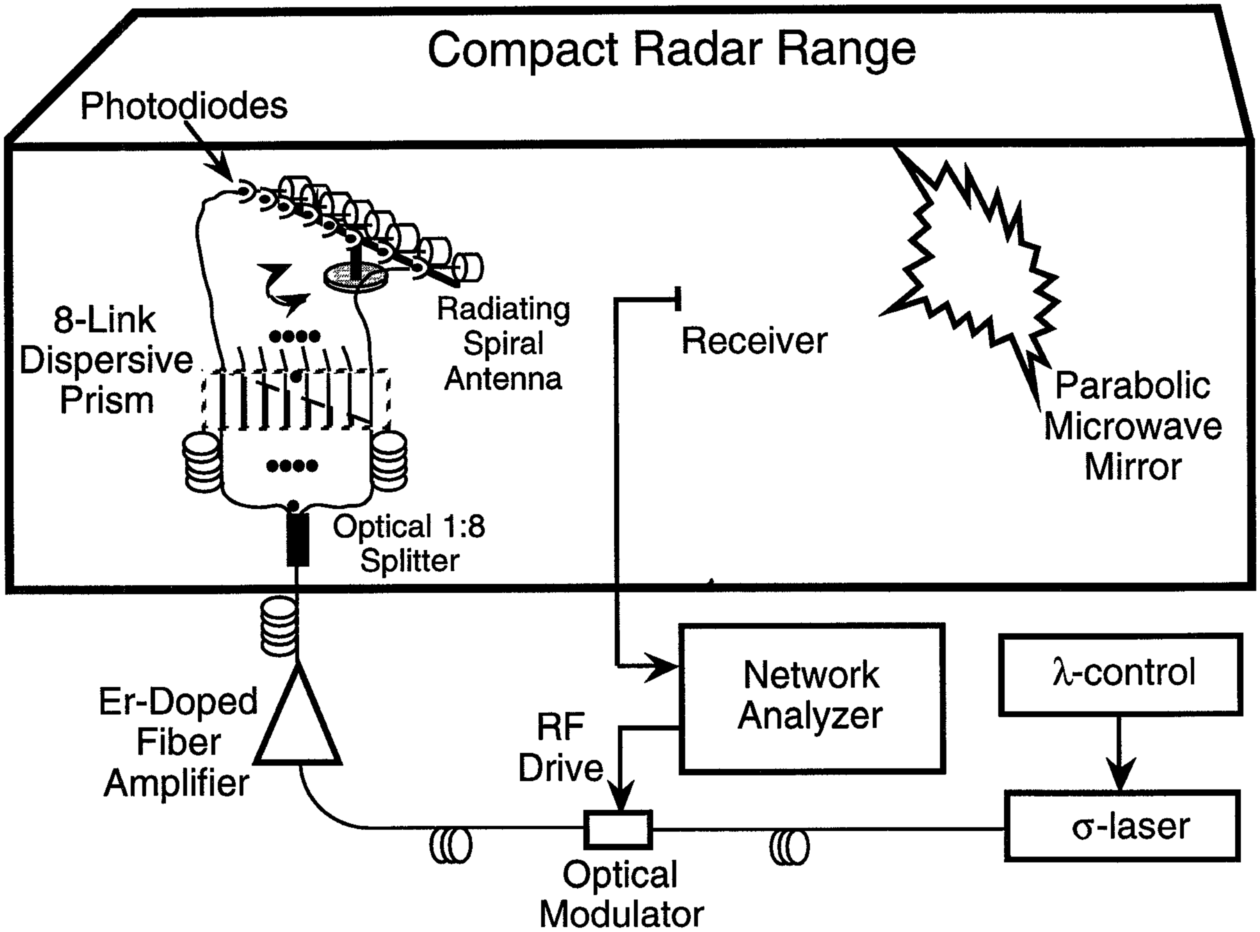

Figure 1. Measurement system cofiguration.

backed broadband spirals covering the 2-18 GHz band. The eight elements were separated by 7.5, 7.5, 7.5, 10., 10., 17.5, 12.5 cm to form a sparsely-populated array with a narrow main lobe and reduced grating lobes at the expense of increased side lobe amplitudes. The nominal lengths of 0, 138, 276, 414, 598, 782, 1104, 1334 m of the high-dispersion (HD) fiber (D~-70 ps/nm km) were used in each channel, with the overall lengths equalized with dispersion-shifted fiber to 1350 m.

ARRAY CHARACTERIZATION

Figure 2 shows the comparison between the measured and the ideal calculated array pattern with the laser wavelength adjusted for broadside radiation. The measured array patterns were normalized by an equivalent single-element pattern. We observe good agreement over the 2-18 GHz frequency band with the main lobe narrowing with increasing frequency. In spite of large interelement spacing, there are no grating lobes up to 12 GHz. For the sparsely-populated design, the sidelobe level is ~10 dB below the main lobe in its vicinity, and is 5 dB below far off the main lobe.

To demonstrate broadband array steering, the laser wavelength is detuned from the nominal center wavelength. Figure 3 shows the array pattern with the laser wavelength detuned by -10 nm, without any other adjustments. The

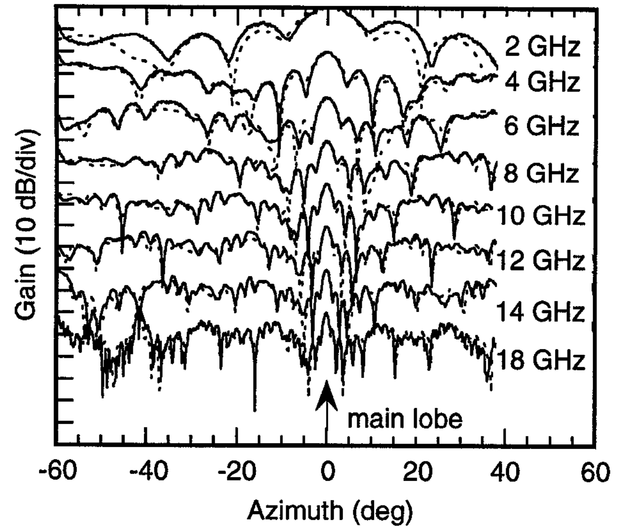

Figure 2. Comparison between antenna normalized measured (solid) and calculated (dashed) patterns with laser tuned for broadside radiation.

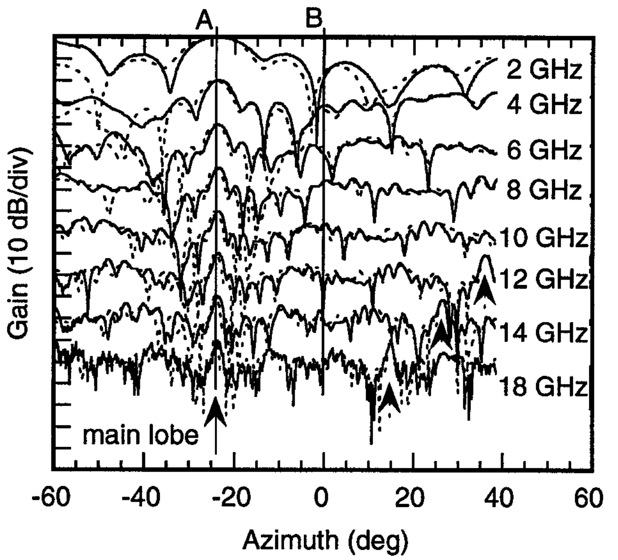

Figure 3. Comparison between antenna normalized measured (solid) and calculated (dashed) pattern with laser detuned by -20 nm for -53° radiation. Arrows point out the main lobe and grating lobes.

main lobe steers to -24° off broadside, and the steering angle is identical for all frequencies in the 2 to 18 GHz range. The agreement between the ideal calculated pattern and the measured one is good over the complete fre-quency and angular range. Grating lobes appear in the 10-18 GHz measured and calculated data as indicated

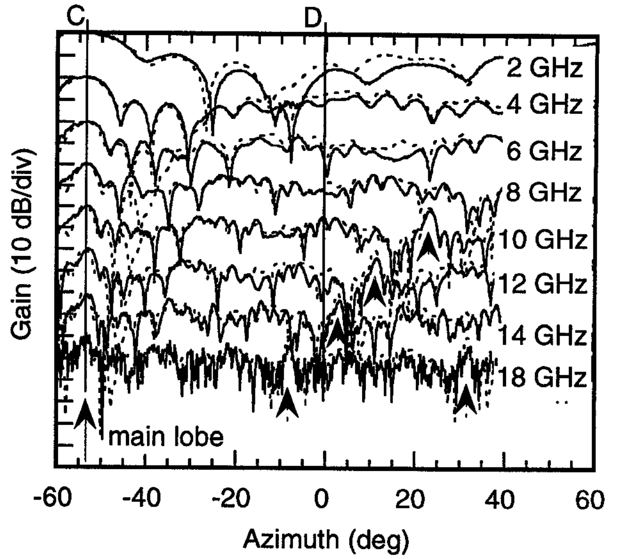

Figure 4. Comparison between antenna normalized mesured (solid) and calculated (dashed) patterns with laser detuned by -20 nm for -53° radiation. Arrows point out the main lobe and grating lobes.

by dashed arrows. Similar results were obtained with the laser detuned by +10 nm to steer the radiation to 23° off broadside. The small difference in the steering angle magnitude is due to the wave length dependence of the fiber dispersion.

The limits of the optical array steering can be tested by detuning the laser wavelength by -20 nm. Figure 4 shows that the main lobe is steered to -53° in this case for the whole frequency range. The grating lobes now appear in the 8-18 GHz frequency range, with multiple grating lobes at higher frequencies as indicated by dashed arrows. Similar results can be obtained by detuning the laser to +20 nm with the radiation steered to positive azimuth angles.

Above, the antenna patterns were obtained at discrete frequencies. To emphasize that the steering is continuous across the complete frequency band, we keep the antenna mechanical azimuth angle and the optical time-delay controls constant and sweep the frequency from 2 to 18 GHz. Figure 5 shows the measured transmitted microwave power along the lines indicated as A,

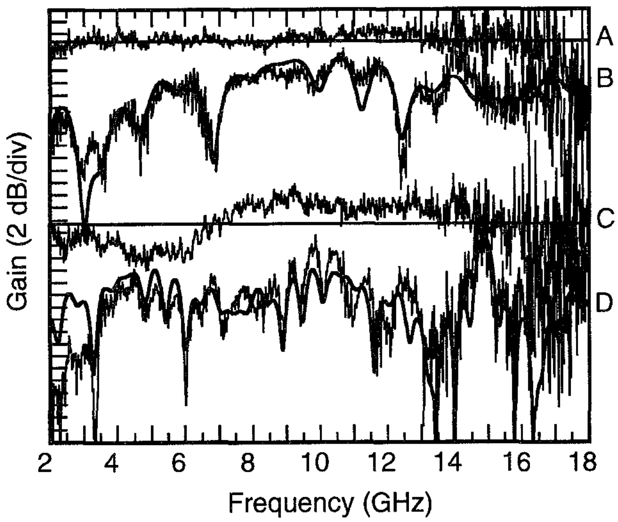

Figure 5. Measured (thin) and calculated (thick and smooth) transmitted power for (A) -10 nm laser and -24° azimuth angle; (B) -10 nm laser and broadside azimuth; (C) -20 nm and -53° azimuth angle; and (D) -20 nm laser and broadside azimuth.

B, C and D in Figs. 1 and 2, with each line corresponding to a specific azimuth and optical control setting. The microwave component frequency responses were calibrated out in these measurements. When antenna is steered to the main lobe with both mechanical and optical controls, the result is a nearly flat frequency response. However, when the antenna is at a mechanical broadside but the radiation is steered off optically, the power shows a number of peaks and nulls. The calculations reproduce all four steering conditions quite well; the small deviations are due to the uncalibrated array element pattern.

SUMMARY

We have developed and demonstrated a novel fiber-optic true time-delay beamforming system for phased-array antenna control applications. The optical sources and the beamformer itself are constructed from all commercially-available components requiring no specialized development. It is rugged, lightweight, and potentially low-cost and reliable. A single low-voltage control signal is used to set the optical steering angle, with the potential number of resolvable steering angles exceeding 800. The beamformer was used to steer a broadband eight-element linear sparsely-populated array. The system has demonstrated true time-delay squint-free steering over the 2 to 18 GHz frequency range across a >±50° azimuth range. The beamformer can be extended to two-dimensional array applications in a streightforward manner without introducing excessive complexity.

ACKNOWLEDGMENT

This work was sponsored by the Office of Naval Research.

REFERENCES

[1] E.N. Toughlian and H. Zmuda, "A photonic variable RF delay line for phased array antennas," *Journal of Lightwave Technology*, vol. 8, no. 12, pp. 1824-1828, December 1990.

[2] A.P. Goutzoulis, D.K. Davies, and J.M. Zomp, "Hybrid electronic fiber optic wavelength-multiplexed system for true time-delay steering of phased array antennas," *Optical Engineering*, vol. 31, no. 11, pp. 2312-2322, Nov. 1992.

[3] R. Soref, "Optical dispersion technique for time-delay beam steering," *Applied Optics*., vol. 31, no. 35, pp. 7395-7397, December 1992.

[4] R.D. Esman, M.Y. Frankel, J.L. Dexter, L. Goldberg, M.G. Parent, D. Stilwell, and D.G. Cooper, "Fiber-optic prism true time-delay antenna feed," *IEEE Photonics Technology Letters*, vol. 5, no. 11, pp. 1347-1349, Nov. 1993.