TWO-DIMENSIONAL FIBER-OPTIC CONTROL OF A TRUE TIME-STEERED ARRAY TRANSMITTER

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ABSTRACT

We report a first demonstration of a transmit array with fiber-optic control for independent two-dimensional true time-delay steering. The 4x4 array consists of flared-notch elements and shows ±30° azimuth and ±30° elevation steering with no observed squint over the microwave component-limited bandwidth of 6-18 GHz.

INTRODUCTION

Fiber-optic control of phased-array antennas has seen active recent development, mostly due to the expected benefits in the areas of size, weight reduction, interference immunity, remoting capability, etc. In particular, fiber-optics can be an enabling technology for true time-delay beam steering which permits wide instantaneous bandwidths and squint free operation. A variety of techniques have been proposed for obtaining true time-delay capability, but their demands for matched optical elements, excessive power losses, instability, or specialized element development limit their applicability [1, 2, 3]. Recently we have demonstrated a true time-delay technique using a dispersive fiber-optic prism that alleviates the above requirements [4]. The transmitter array consisted of eight broadband elements and exhibited a ±50° azimuth steering over a 2 to 18 GHz frequency range. However, it was limited to one-dimensional steering only, which precluded its application to many real array systems.

Here, we demonstrate what we believe is the first complete two-dimensional true time-delay control of an ultrawideband array. The system demonstrates an unprecedented combination of independent ±30° azimuth and ±30° elevation steering over a microwave component-limited bandwidth of 6 to 18 GHz. Thus, the technique shows the capability to be transitioned to real-world ultrawideband array transmitters.

SYSTEM CONFIGURATION

The fiber-optic beamformer system is shown schematically in Fig. 1. The optical source is a fiber-optic Iota-laser [5] with a single-polarization output continuously tunable over a range of >50 nm around 1540 nm. The output of the laser is amplitude-modulated by an electro-optic Mach-Zehnder modulator (MZM), amplified by an Er-fiber amplifier, and fed to a 4-channel fiber-optic dispersive prism. The prism provides dispersion in each channel which is proportional to the position of a corresponding column of antenna elements within the array. Thus, tuning the wavelength of the laser changes the delay of the microwave signal demodulated by the channel p-i-n photodiode and produces azimuth steering.

The microwave signals, appropriately time-delayed for azimuth control, are in turn amplified and fed as inputs to a bank of nominally-identical MZMs. The optical carrier from another Iota laser is corporately distributed to the MZMs and fed to a set of nominally-identical fiber-optic dispersive prisms providing dispersion proportional to the position of the corresponding row of antenna elements within the array. Thus, tuning the wavelength of the second laser imparts additional delays onto the microwave signals and effects elevation steering.

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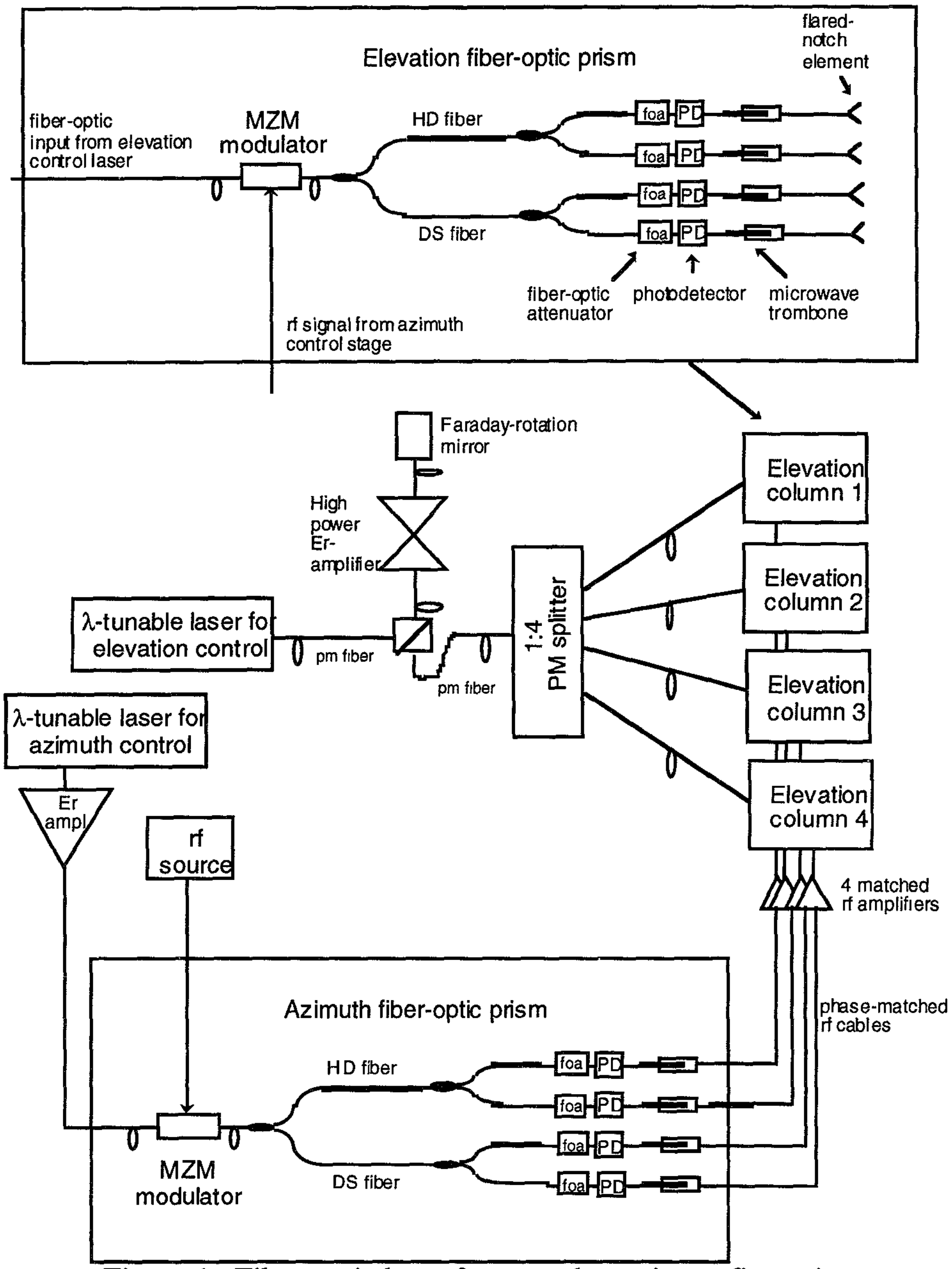

Figure 1. Fiber-optic beamformer schematic configuration.

A nominal unit length of 200 m of high-dispersion (HD) fiber (D~-88 ps/nm·km) was used in the azimuth-controlling prism, with the overall lengths equalized with dispersion-shifted fiber to produce equal interchannel delay at $\lambda_{azimuth}$=1540 nm. A nominal unit length of 50 m of HD fiber was used in the elevation-controlling prism, with the overall delays equalized with dispersion-shifted fiber at $\lambda_{elevation}$=1540.5 nm.

The antenna was tested in a compact radar range using a network analyzer to drive the system and to detect the received signal. The 4 x 4 array antenna elements were flared-notch elements suitable for operation over the 6 to 18 GHz band, and were arranged on a rectangular grid [6]. The actively-driven elements were separated by 3.7 cm and 0.93 cm in the azimuth and elevation directions, respectively.

RESULTS AND DISCUSSION

Figure 2 shows the comparison between the measured and the calculated ideal array azimuth and elevation patterns with the laser wavelengths adjusted for broadside radiation ($\lambda_{azimuth}$=1540 nm, $\lambda_{elevation}$=1540.5 nm). The measured array patterns were normalized by a measured single-element pattern. We observe good agreement over the complete frequency range, with the main lobe narrowing with increasing frequency. The azimuth pattern shows the presence of grating lobes at higher frequencies, which is expected for the chosen large column separation.

The elevation patterns were measured point-by-point with a fairly large 15° angle increment to keep the measurement time within a reasonable range. Still, the elevation pattern shows the expected broad main lobe, which narrows with increasing frequency. Agreement with the calculated ideal pattern is good. Both the azimuth and the elevation patterns show the main lobes properly steered to broadside.

To demonstrate broadband array steering, the laser wavelengths are detuned from the nominal center wavelength to $\lambda_{azimuth}$=1536.4 nm, $\lambda_{elevation}$=1536.9 nm, without any other adjustments. The array is expected to be steered to -30° in azimuth and -30° in elevation. Figure 3 shows the measured array azimuth and elevation patterns. The agreement between the calculated ideal patterns and the measured ones is good over the complete frequency and angular range. The patterns show proper frequency-independent steering to -30° in azimuth and -30° in elevation, as expected.

Measurements at other azimuth and elevation steering angles are consistent with the results expected for a wideband array transmitter with independent azimuth and elevation time-delay steering over 6-18 GHz.

CONCLUSIONS

We developed a novel fiber-optic true time-delay beamforming approach for boradband steering of two-dimensional array antennas. The approach is demonstrated on a 4x4 flared-notch transmitter array, with the results substantiating squint-free array steering across a ±30° azimuth and ±30° elevation range over a 6 to 18 GHz frequency range. We believe this to be a first-ever demonstration of such wideband array steering capabilities in two dimensions.

ACKNOWLEDGMENT

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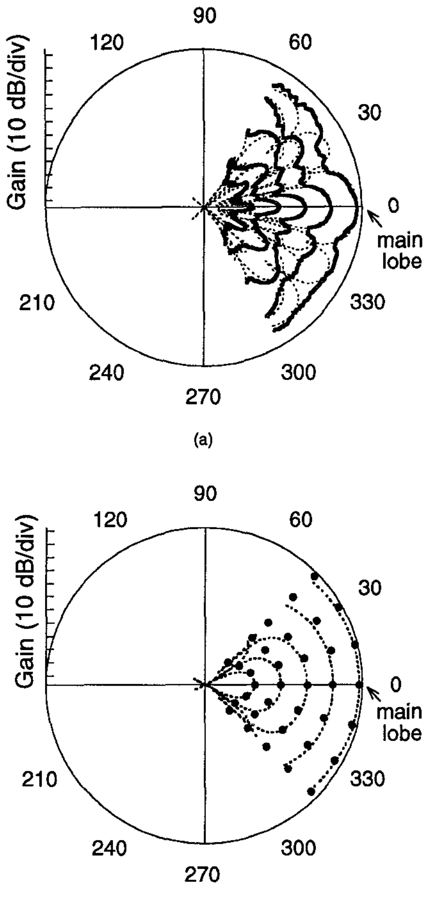

Figure 2. Comparison between antenna element-normalized measured (solid) and calculated (dashed) pattern with lasers tuned for broadside radiation. Frequencies of 6.4, 9.1, 12.2, 15.0, and 17.8 GHz are shown with offsets for clarity. (a) Azimuth cuts, (b) elevation cuts.

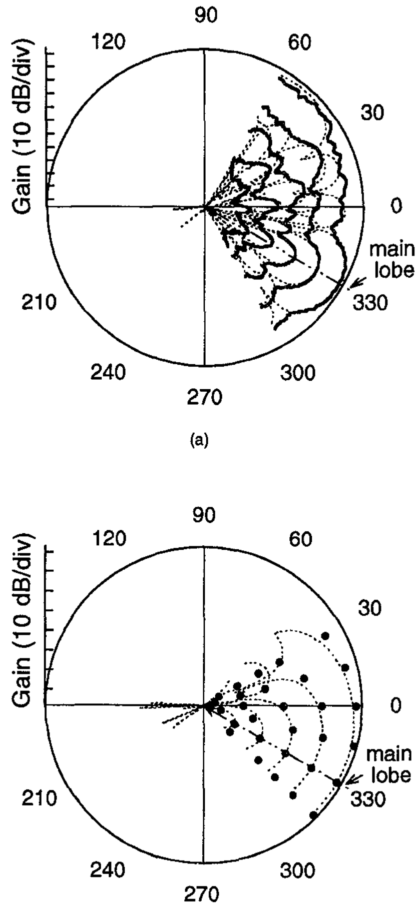

Figure 3. Comparison between antenna element-normalized measured (solid dots) and calculated (dashed) pattern with laser detuned for -30° azimuth and -30° elevation radiation. Frequencies of 6.4, 9.1, 12.2, 15.0, and 17.8 GHz are shown with offsets for clarity. (a) Azimuth cuts at -30° mechanical elevation, (b) elevation cuts at -30° mechanical azimuth.