A COMPACT PROTOTYPE OPTICAL PROCESSOR FOR X-BAND ARRAYS

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Abstract – **We present the realization and preliminary characterization of a compact two-channel optical processor for an X-band antenna array. This lens array partially separates the signals based on their angle of arrival. The received audio-modulated signals, downconverted to HF band, drive a two-channel electro-optic modulator. The optical beam is carrier suppressed and sent to a miniature adaptive photorefractive oscillator that separates the signals based on their strength and correlation. The optical output is detected, demodulated and sent to a speaker. The system fits in a 33x45x15cm briefcase and consumes less than 20W. The prototype is also equipped with portable transmitters for on-site demonstration purposes.**

I. INTRODUCTION

Adaptive processing in smart microwave antenna systems [1] can either be done at the analog front-end at the carrier frequency or after down conversion and analog-to-digital conversion at baseband using digital signal processing (DSP) techniques [2].

The system presented here is a portable realization of an X-band smart antenna array in which the adaptive processing is performed by nonlinear optical circuitry. The goal is to eliminate either microwave variable gain and phase control elements and/or reduce system complexity associated with power-hungry DSP adaptive processors for broadband signals. The elements of the initial implementation of the optical adaptive processor for an X-band array are presented in [3].

The optical circuitry extracts the principal component of its input signal space, meaning that the separation of the signals operates on a correlation and strength basis. This allows the transmitted signals to share the same portion of the frequency spectrum. Our prototype isolates the strongest signal transmitted.

Our goal is to show that the use of nonlinear optical techniques can simplify adaptive antenna systems and relieve the computational burden placed on the DSP circuitry. In particular, the realization of a portable prototype is meant to demonstrate the practical feasibility and the low power consumption of the system.

II. DESCRIPTION OF THE SYSTEM

Figure 1 describes the system with a block diagram. The front-end consists of a discrete lens antenna array followed by active antenna receivers positioned along the E-plane focal arc of the lens. Each receiver position corresponds to a specific direction of a plane wave received by the lens array.

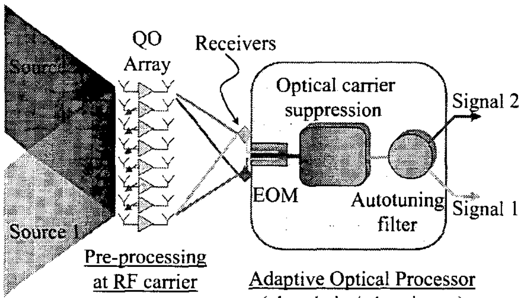

Figure 1. Block diagram of a two-channel optically smart antenna array. The active integrated antenna receivers are positioned on the focal arc of a lens antenna array. The IF signals are then imposed onto the optical beam and processed by the adaptive optical circuit.

The IF signals are imposed as phase modulation (PM) sidebands on the optical carrier using

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electrooptic modulation. An adaptive holographic element suppresses the optical carrier [6], a requirement for the optical oscillator, also referred to as the auto-tuning filter. The optical beam, modulated with the two received signals, is then focused into the filter which separates the two principal components of the signal input space.

Pre-processing at RF front-end

The quasi-optical lens antenna array, shown schematically in Figure 1, has 30 patch antenna elements. The lensing is accomplished with varying delay lines across the array between input and output antenna elements [4]. The lens has a number of imperfect focal points in the E-plane, each preferentially receiving one spatial beam.

With two sources placed in the far field of the array transmitting the same power, each feed antenna on the focal arc will receive both signals in a ratio depending on the relative position of transmitters and feeds. This ratio, referred to as cross talk, defines the pre-processing performance of the RF front end [3].

Each receiver consists of a patch antenna followed by an active downconversion stage. The antenna is designed for 10 GHz, with a bandwidth of 150 MHz. The wideband variable-gain IF amplifiers after the downconversion provide more than 40-dB of gain control through a single high impedance voltage input. The control over the downconversion gain allows an increase of the overall dynamic range of the system.

The adaptive optical processor

The partially separated and downconverted IF signals are imposed as phase-modulated sidebands on an optical carrier using an electrooptic modulator. The electrooptic crystal is a thin slab (0.3x7x30mm) of magnesium-doped lithium-niobate (Mg:$LiNbO_3$) with two microstrip electrodes. The optical input to the modulator is a laser beam formed into a vertical line segment, so that the upper and lower portions of it are modulated by different IF signals. The optical beam at the output of the modulator is therefore both spatially and temporally modulated.

The auto-tuning filter distinguishes various signals by correlation. The optical carrier that remains after phase modulation is common to all the signals and therefore introduces an unwanted false correlation between them, which will make the signals indistinguishable for the auto-tuning filter. We implement an optical carrier suppression system for this reason. This is accomplished through two-beam coupling in a barium titanate photorefractive crystal ($BaTiO_3$ PRC) [6].

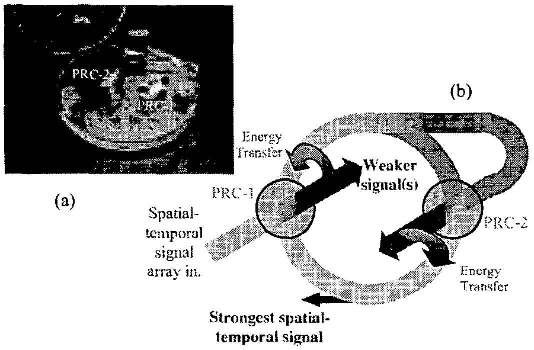

Figure 2. (a) Photograph and (b) schematic of auto-tuning filter.

The auto-tuning filter is fundamentally an optical oscillator where gain is supplied by photorefractive two-beam coupling. One output, a sample of the oscillating ring, provides the strongest principal component of the input signal space. The other output provides all the remaining weaker components, as illustrated in Figure 2b.

The 5cm^2 filter of Figure 2a requires less than 5mW of CW optical power to operate. The signal processing bandwidth, extrapolated from the oscillator's round-trip path length is about 3 GHz.

III. THE PORTABLE PROTOTYPE

For demonstration purposes we added a complete audio link to our system. Two battery-powered transmitters, see Figure 3, simulate the two independent sources placed in the far field of the RF lens antenna.

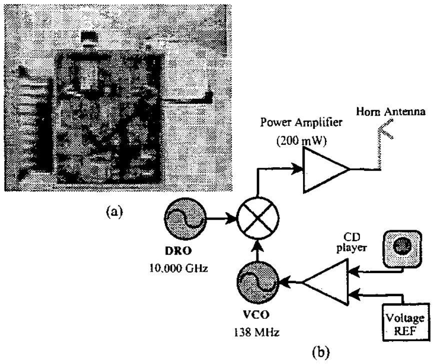

Figure 3. (a) Photograph and (b) block diagram of each of the transmitters.

An audio signal FM modulates the HF sidebands of a 10 GHz signal from a dielectric resonator oscillator (DRO). Custom-made horn antennas then transmit the resulting signals.

The transmitted signals are then received and processed by our system. We chose the output of the optical processor to be the stronger signal broadcast by the transmitters. After photodiode detection, a phase-lock loop (PLL) FM demodulator retrieves the audio modulation imposed on the transmitted RF signal.

The portable prototype includes the RF front end, the optical processor, the PLL demodulator and the power supply electronics. It has been packaged (excluding the antennas) into a 33cm by 45cm by 15cm briefcase, shown in Figure 4. On the left hand side is the optical processor, while on the right hand side are all the electronics and the power supply, as well as the power amplifiers driving the EOM. The total power consumption is below 20 W, including the laser used for the optical processor.

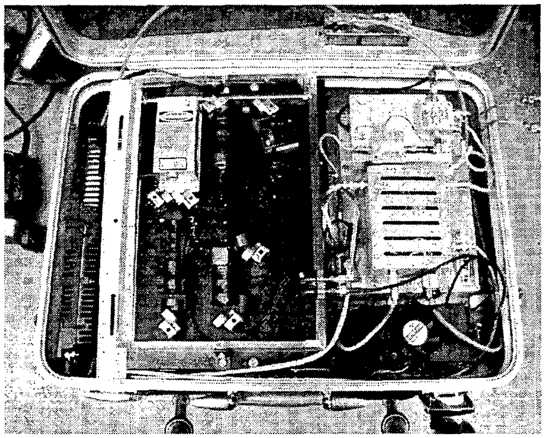

Figure 4. Photograph of the portable processor. The briefcase dimensions are 33cm by 45cm by 15cm. On the left is the optical system, while in the right portion of the briefcase are all the electronics for the modulation and demodulation, plus the power supply.

IV. END-TO-END CHARACTERIZATION OF THE PROTOTYPE

The first step to evaluate the processing performance of our system is to compare the power ratio of the two signals at three different places along the link. Referring to Figure 5, T_1 and T_2 are the transmitted signals and R_{jk} is the received T_j signal on receiver k. In particular the ratio R_{jk}/R_{jj} is the cross talk of the lens antenna array.

Looking at the auto-tuning filter's output that samples the oscillating ring, the optical processor enhances the ratio of the stronger over the weaker transmitted signal.

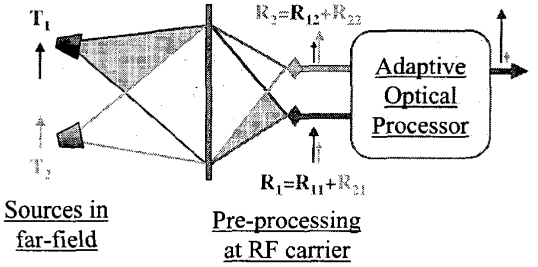

Figure 5. Block diagram of the transmission link used to characterize the optically smart antenna array. The two processing contributions of the lens array RF front-end and of the optical processor to the signal ratio are represented by arrows of different height and color.

The curve in Figure 6 plots the signal ratio at the output of the optical processor versus the signal ratio R_{jj}/R_{kk} at the two receivers, after downconversion. We observed a –10dB cross talk while taking the measurements with an angle between the transmitters of 48 degrees.

Ideally we would like the curve to be a step function: as soon as one signal is stronger than the other it should dominate in the oscillating ring, while they are exactly equal in power the filter cannot choose between them so the input ratio stays the same.

In practice when the signals are very close in power they compete fiercely for gain in the ring and the filter is not able to suppress the weaker one very well.

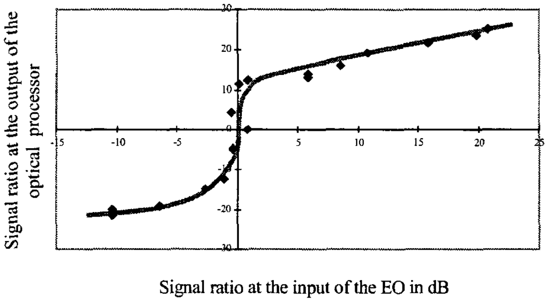

Figure 6. Signal ratio enhancement produced by the optical processor. On the horizontal axis is the power ratio R_{jj}/R_{kk} of the signals at the receivers, on the vertical axis is the power ratio of the signals at the output of the auto-tuning filter.

The cross talk of the lens antenna determines the amount of correlation between the two optical channels, which increases as the angle between the two transmitters decreases. We repeated further measurements for decreasing angles between the transmitters, which increased the cross talk. As the cross talk increased along with the correlation between the channels, the ratio enhancement curve tended towards a linear function, as expected for total correlation between channels [8].

V. CONCLUSION

We have built and packaged an RF-photonic signal processing system that uses nonlinear optical circuits. The system as a whole is in its early stages of characterization. The preliminary results show the system performing as expected when presented with two distinct microwave frequencies. The next step is to overlap the IF signals' frequencies and show that the system can still select the stronger source. The limitations of the system will be explored by evaluating how much multi-path it can handle, how small the angle between the sources may be and finally how fast a source can be moved in the far field without the system loosing track of it.

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VI. REFERENCES

[1] S. Meridith, A. Crowley, "Smart system antennas," *Mobile Radio Technology,* April 1, 1997.

[2] *Adaptive signal processing,* B. Widrow, S. Stearns, Prentice Hall, 1985.

[3] D. Z. Anderson, V. Damiao, E. Fotheringham, D. Popovic, S. Romisch and Z. Popovic, "Optical processor for X-band lens antenna array," *2000 MWP Digest.*

[4] Z. Popovic, A. Mortazawi, "Quasi-optical transmit/receive front ends," *invited paper, IEEE Trans. on Microwave Theory and Techniques, Vol. 48, No. 11,* pp. 1964-1975, Nov. 1998.

[5] D. Z. Anderson and J. Feinberg, "Optical Novelty Filters," *IEEE Journal of Quantum Electronics* ***25*** *(3),* 635-647 (1989).

[6] D. Z. Anderson, V. B. Damiao, D. Popovic, Z. Popovic, S. Romisch, A. Sullivan, "-70 dB Optical Carrier Suppression by Two-Beam Coupling in Photorefractive Media," *J. Appl. Phys. Invited, to appear in April 2001.*

[7] M. Saffman, C. Benkert, and D. Z. Anderson, "Self-Organizing Photorefractive Frequency Demultiplexer," *Optics Letters* ***16*** *(24)*, 1993-1995 (1991).

[8] A. A. Zozulya, M. Saffman, D. Z. Anderson, "Stability analysis of 2 photorefractive ring-resonator circuits-the flip-flop and the feature extractor," *J. Opt. Soc. Am. B 12 (6)*, 1036-1047(1995)