Smart Antennas with Optical Processing for Broadband Blind Source Separation

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This paper presents an optical signal processing approach to the challenging problem of blind source separation in a multiple signal space. To detect and separate N signal sources, an antenna array with at least N elements is required. If the N signals are completely unknown, N measured linear combinations of the signals at the N antenna outputs are the only information available for determining the N signals and N^2 elements of the mixing matrix. This seems an impossible problem, however if one has minimal knowledge about the statistics of the signal, the original signals can be retrieved using higher order correlations of the measured signals. This algorithm is referred to in the literature as Independent Component Analysis (ICA) [1], and digital implementations are barely able to implement it for narrowband voice signals at best. Digital implementations of ICA are appropriate for use in areas where real-time processing is not required, and has to date been applied in image enhancement, analysis of astronomical data, electroencephalogram processing, and stock market trend analysis. In this work, we have implemented ICA for a 10-GHz smart antenna array and for two unknown signals. The adaptive processing of the received signals is performed by dynamic holographic optical circuitry, enabling orders of magnitude higher bandwidth than what is currently possibly electronically.

The first step in the ICA algorithm is principal component analysis (PCA) [2], which results in dynamically separated signals ordered by relative strength. A prototype two-channel system is designed to fit in a standard-size briefcase and consume less than 50 W of power, Fig.1. The inputs to the system are modulated waves with a carrier in X-band, and the output is an electronic demodulated signal. The signal can be traced through four major system blocks, Fig.2: the RF front end, the electrooptic modulation, the optical carrier suppression and processing and the electro-optic receiver. Two signals modulated onto 10-GHz carriers are mixed on a beamforming lens antenna array [3]. They are partially separated, downconverted and amplified and modulated onto a common 532nm optical carrier in a new type of multi-channel electrooptic modulator device. The optical carrier is then suppressed in a novel photorefractive 2-beam coupling circuit [4] and the two signals are separated in a holographic optical processor, implemented in a free-space prototype integrated on a glass coin the size of a US quarter, Fig.3a. The output beam of this circuit dynamically chooses the stronger of the two signals and separates the signals by over 20dB, Fig.3b. This beam is detected with a photodetector, and demodulated by a frequency-dividing phase lock loop. This adaptive receiver system can be used, for example, to mitigate multipath interference effects, and can separate one received signal from another even though their power spectra may entirely overlap. The system is also useful for jammer suppression in hostile signal environments.

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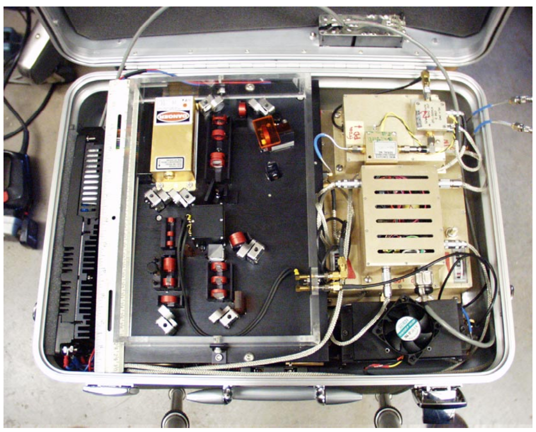

Fig.1. Photograph of integrated PCA smart antenna array processor. The antenna feeds are the cables on the righthand side. A single 110-V plug supplies the required 50W of power to all the optical and electronic parts of the system. The package is a standard size briefcase.

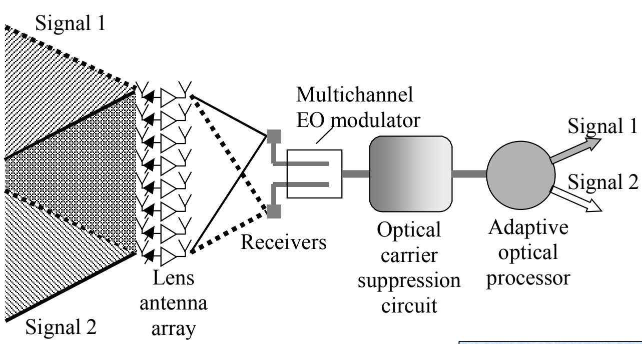

Fig.2. Block diagram of the PCA system from Fig.1, consisting of the microwave antenna and receivers, followed by the EO modulator, optical carrier suppression and optical processor.

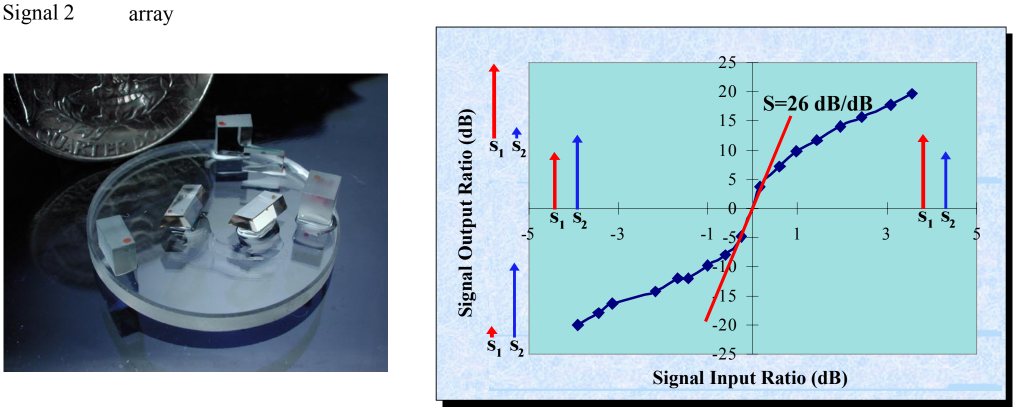

Fig.3. (a) Photograph of the optical processor integrated on a glass coin the size of a US quarter. (b) Measured signal separation at the output of the PCA circuit.