RF frequency analysis and separation by optical sampling

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***Abstract* — We demonstrate several schemes of RF frequency analysis by optical means. They are based on the sampling of RF signals in time-domain and subsequently translating them into the spatial domain where Fourier transformation and other signal processing operations are readily executed. The most general option introduces true-time delays in the form of optical fibers. A drawback of this method is the need to stabilize and control optical phases. We report the achievement of such control by closed-loop active phase stabilization.**

I. INTRODUCTION

The use of optical techniques in order to analyze, separate, handle and processing of RF signals have attracted attention for more than three decades. The application of photonics in RF signals offer at a first sight a considerable number of advantages: Optical fibers can replace common microwave waveguides of the type of coaxial cables and shielded wires, with the benefit of reduced loss, RFI immunity, essentially unlimited bandwidth, negligible dispersion within the RF band, and large parallelism potential. During the last decades, the development of optical communication devices was accelerated driven by the constant demand in capacity in communication links. As a consequence, many devices reached commercialization maturity and were implemented in communication networks. Examples for that are Arrayed Waveguide Gratings (AWG), Optical Amplifiers and Optical Switches. These developments encouraged constantly the revision of the applicability of optical techniques in order to perform diverse functions in RF signal processing.

This presentation will concentrate on reporting progress regarding the channelization of RF signals using optical methods. The definition of *channelizer* here accounts for a device which separates a wide-band RF carrier into sub-carriers of smaller bandwidth [1]. The first stage of the work dealt with the more restricted function of analyzing only the spectral contents of a wide-band signal. The actual separation and recovery of RF signals by homodyne detection is also discussed.

II. OPTICAL RF FREQUENCY ANALYSIS BY ELECTRONIC SAMPLING

The goal of the project during the first stage was to demonstrate the feasibility of utilizing the Optical Phase Array (OPA) switching technology developed by our group [2] in order to perform in a fully optical way the spectral analysis of RF signals. As demonstrated, RF signals were synthetically generated and fed into an A/D converter. The digital data acquired was conditioned to fit the level of input ranges and biases required by the waveguide array. An optical setup was specially constructed based on the switch's Input Module (IM), and the optics was arranged to image the output of the system onto a CCD infrared camera. The output was once more digitized and displayed for analysis. In parallel, the performance of the system was simulated according to the principles of physical optics and according to the parameters of design of the system. We found very good agreement between the measurements and the simulation. In our demonstrator we were limited in bandwidth much below the capabilities of the hardware and optical performance. The limitations originated in the electronic system that conditioned the voltage signals in amplitude and bias, and by the refresh rate of the camera. Working in the multi-GHz range as most RADAR and EW implementations request, involves performing the sampling in an all-optical fashion.

III. ALL-OPTICAL BEAM SAMPLING FROM TIME-DOMAIN INTO SPACE-DOMAIN

As known, optical methods allow the possibility of Fourier analysis and other signal processing procedures to take place at extremely fast timescales limited only by the light propagation time. This takes place however in space domain, whereas our goal is to analyze and separate a wide-band RF carrier into sub-carriers of smaller bandwidth. One possible general scheme for the translation of time samples from the tome into the space domain is based on the utilization of an array of optical fibers with different lengths. In our proposed scheme, light form a coherent source (laser), is split first into two portions, one to serve as a carrier for the frequency separation function and the other to serve as a reference for the homodyne mixing to be performed further-on. The first signal is fed into an optical Amplitude Modulator (AM), for the modulation of the RF signal to be analyzed on the optical frequency carrier. The output of the modulator is coupled into a passive splitter whose function is to provide equalized optical channels and condition them for further feeding them into an array of optical fibers. The optical fibers attached are differentiated in length by L. This increment determines the total RF bandwidth of the device. The delay in length is translated at the end of the fiber array into the time domain, so that at this plane a time sampled signal is attained at each fiber end with time intervals given by: • t = L n/c. The output of the fiber array is coupled into a waveguide channel condenser. This condenser is a passive device whose role is to reduce the pitch of the optical fibers outputs, as needed in order to perform efficiently the optical Fourier transformation, which is simply implemented by a lens. A main problem that arises is that the length intervals, which are integer multipliers of L, are of the order of magnitude of centimeters, and in order to create a coherent front, they need to be determined within fractions of the optical wavelength. Furthermore, these precise lengths should remain stable in long terms in spite of the temperature and other environmental changes taking under normal working conditions. An active OPA fed by a feedback loop is expected to compensate for these variations by means of the electro-optic (Pockels) effect. At the back focal plane of the lens an array of detectors is located, or alternatively, an array of optical fibers, each of them terminated by an individual detector. The reference signal also irradiates the detectors with an un-modulated signal, and beats are received at the RF frequencies.

EXPERIMENTAL RESULTS

Integrated Optic phase modulators were specially designed and fabricated at *AlCielo*'s facilities. Four modulators and corresponding phase-control units were implemented at first stage. From previous simulations and design, we concluded that one needs to control this length difference down to less than 1mm. At this stage we choosed to control these lengths by free-space propagation using collimators mounted on x-y-z controllers. Before the operation of the phase stabilization mechanism, one could see the light distribution at the far-field varying in time due to fluctuations in temperature and vibrations of the fiber array. Once the feedback-loop and phase compensation are turned on the distribution stabilizes into a "normal" interference picture with a central maximum peak as expected. Such a case is seen in Fig. 1.

CONCLUSION

Several options for RF signal frequency analysis and separation were proposed and discussed. Active optical phase control, a key issue in order to implement these and other RF photonic functions, was demonstrated.

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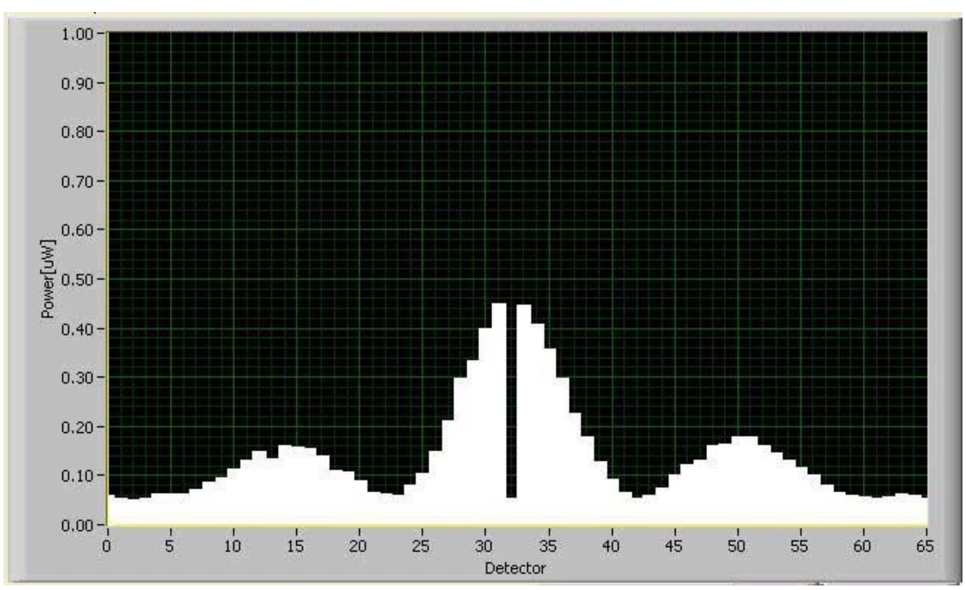

Figure 1: Interference pattern for at the output of the channelizer following active phase control at *f(RF) = 1GHz*