Executive Summary

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1. Title of the Project: *Sub-Nyquist Photonic Analog to Digital Converter for instantaneous frequency measurement.*

2. Date of Start of the Project: 1st October, 2021

3. Aims and Objectives:

   To design and develop a photonic analog to digital converter to
   a. determine the instantaneous frequency of an incoming RF signal
   b. digitize the signal accurately with low bandwidth ADCs

4. Significant achievements (not more than 500 words to include List of patents, publications, prototype, deployment etc)

In modern electronic warfare, RADAR warning systems, electronic intelligence and anti-stealth defense systems, instantaneous frequency measurement (IFM) of the unknown intercepted signals is of imminence importance. Electronic implementations are very bulky, slow, power hungry, prone to electro-magnetic interference (EMI).

We have designed time-stretch assisted IFM system, the instantaneous frequency (RFin) to be measured is mapped on top of an optical pulse, which is time-stretched using a dispersive medium. The stretched version of RF is photo-detected and digitized using a low-rate electronic analog-digital converter (ADC). The experimental setup is shown in

Fig 1a and the measurement results in Fig 1b. Light from a spectrally rich mode locked laser is time stretched through a dispersive medium, and the RF to be measured is modulated on this pulse through the electro-optic modulator (EOM). A two-output modulator is chosen for shape corrections, the modulated RF is further time-stretched in the second medium, followed by a photodetector and a low-bandwidth electronic ADC. The bandwidth required by the electronic ADC is reduced by the stretch factor. The resolution of measurement is decided by the width of the optical pulse before modulation, which is itself constrained by the repetition rate of the mode locked laser that generates the pulse. We have carried out experiments upto simulations and have proved that a 5 MHz repetition rate pulse can detect a wide range of RF frequencies from C band to V band, with a frequency accuracy of < 250 MHz.

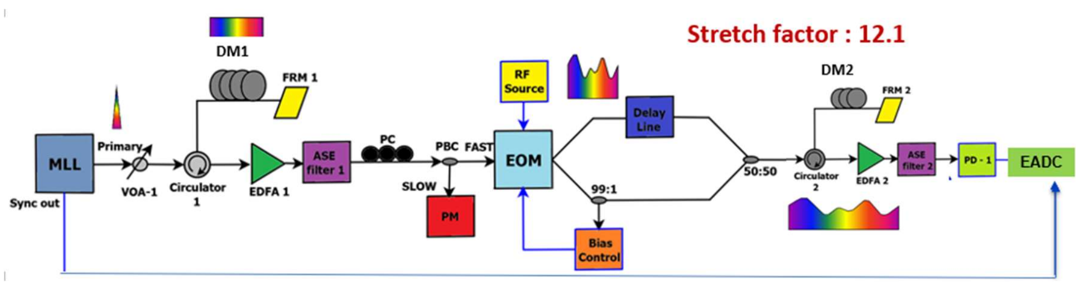

Fig 1a. Schematic of the experimental setup of photonic IFM measurement system

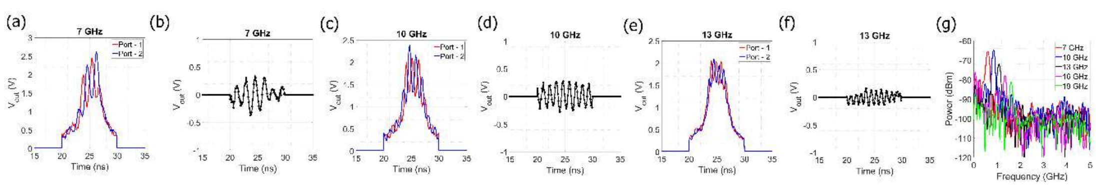

Fig 1b. Experimental results indicating the measurement of frequency

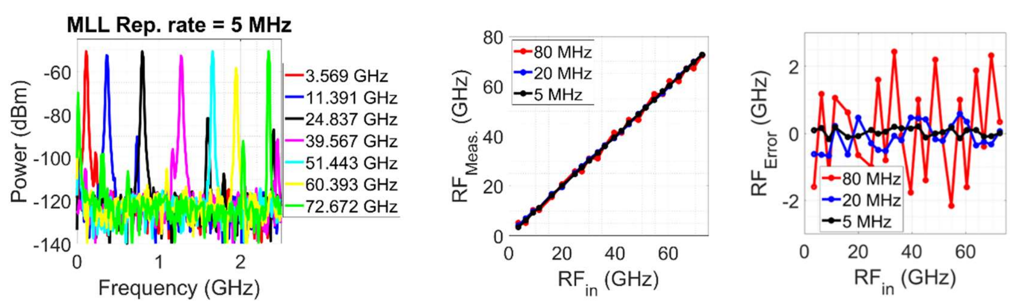

Fig 2a Extracted spectrum with a 5 MHz MLL, (b) Calibration curve of measured vs input RF (c) Error in the expected RF measured as a function of input RF frequency indicating that smaller repetition rates are critical to achieve minimal error.

We have demonstrated an experimental method for “pulse picking” to convert a 50 MHz laser to a 5 MHz laser. Schematic of the experiment is shown below:

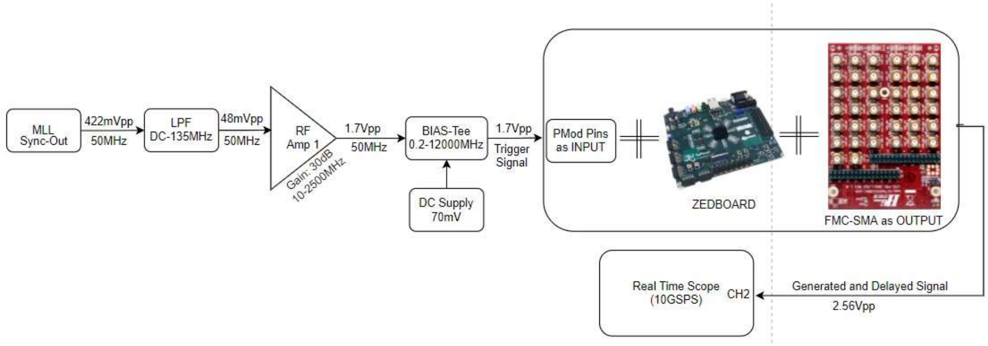

Fig 3 Pulsing picking for on-demand frequency resolution in IFM

We also have designed an optical interleaver for repetition rate multiplication to carry out the measurements in the sub-Nyquist approach. This interleaver is currently being fabricated with industry support.

Bias controller for modulator, and the RF link design are completed and demonstrated, which are the critical elements of the photonic IFM system.

Patents filed :

1. D. Venkitesh, B. Srinivasan, S. Christopher, Sreeraj S J and K. Singh. Instantaneous wideband frequency measurement and processing using parallel sub-Nyquist sampling based on an optical pulse source. Patent Application No: 202141031209, Date of filing – 12/07/2021.
2. Sreeraj SJ, Karamdeep Singh, Joydip Dutta, Deepa Venkitesh, David Koilpillai, A dither-free multi-channel any-point bias controller for DWDM Systems with time based polling”, patent filed

Publications :

1. Sreeraj, SJ; Singh, Karamdeep; Srinivasan, Balaji; Christopher, S; Venkitesh, Deepa; Simulation of a wideband frequency measurement system using parallel photonic sub-Nyquist sampling and binary deduction Asia Communications and Photonics Conference T4A. 246 2021, Optical Society of America
2. Singh, Karamdeep; Sreeraj, SJ; Srinivasan, Balaji; Venkitesh, Deepa; Influence of pulse repetition rate on SINAD performance of time-stretched

photonic ADCs 2022 Workshop on Recent Advances in Photonics (WRAP), 01-Feb 2022 IEEE

3. CN, Siva Subramaniyam; Venkitesh, Deepa; Experimental Demonstration of Multimode Optoelectronic Oscillator at 2.4 GHz 2022 Workshop on Recent Advances in Photonics (WRAP) 01-Feb 2022 IEEE
4. Sreeraj, SJ; Lakshman, B; Ganti, Radhakrishna; Koilpillai, David; Venkitesh, Deepa; Frequency Doubler Based Optical Generation and Transport of 5G mmWave Signals for Fronthauling CLEO: Applications and Technology, JTh3B. 45 2022 Optica Publishing Group

Concluding remarks

Overall, the progress of the project on IFM measurement using Photonic methods is proceeding well. We are also engaging with BEL for potential translation.