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

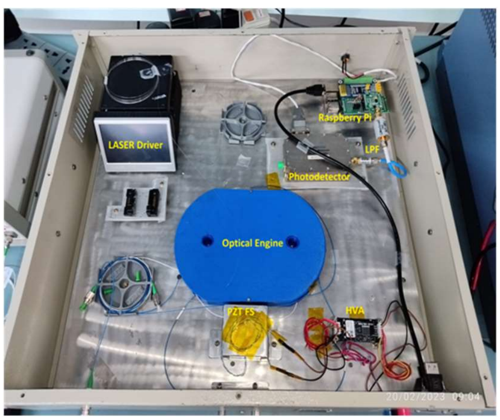
4. Significant achievements (not more than 500 words to include List of patents, publications, prototype, deployment etc)

Instantaneous frequency measurement (IFM) is a critical technology in a wide range of applications, including electronic warfare, radar, communications, and signal processing. IFM measures the instantaneous frequency of a signal, which is the rate of change of the signal's phase at a given point in time. Traditional electronic IFM implementations are bulky, slow, power-hungry, and susceptible to electromagnetic interference (EMI). There are three possible approaches to solve these problems through Photonics.

Instantaneous frequency (RFin), when modulated on a spectrally rich optical pulsed source, can be stretched in the optical domain through a dispersive medium, thus converting high-frequency RF signals into effectively low-frequency signals. This reduces the input bandwidth requirements of the back-end ADC as many times as the stretch factor of the optical pulse. The other Photonic approach is to use an optical clock whose timing jitter is better than an electronic clock; which is possible with a short pulsed laser. High bandwidth RF signals, when sampled with stable optical clocks, can provide a much higher effective number of bits (ENOB) compared to electronic clocks. The third approach is to use parallel photonic interleavers with Sub-Nyquist sampling to sense the wideband signal frequency.

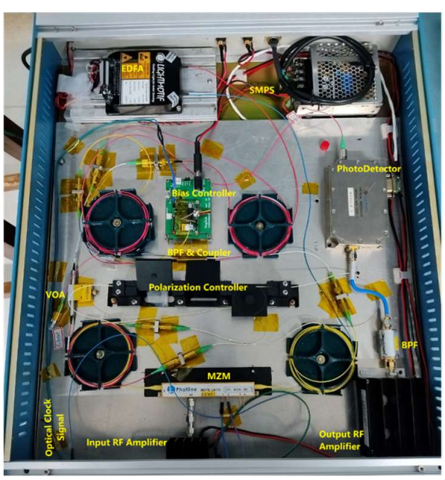
- Designed and developed prototypes of fiber-based mode locked laser (MLL), which works as an optical clock with a timing jitter of ~ 60 fs
- Designed and developed Sub-Nyquist sampler (bandwidth 500 MHz) – a sub-Nyquist photonic analog to digital converter (PADC) operating in S, C and X bands
- Designed and developed time-stretched photonic ADC whose effective bandwidth is 12 times higher than EADC
- Patented (pending) precise frequency determination system using parallel photonic sub-Nyquist sampling and binary deduction algorithm.

Photographs Below :

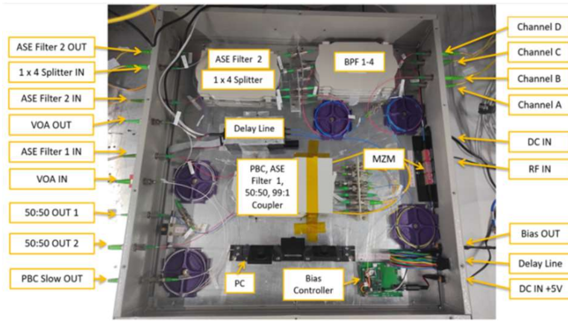


Top view of MLL

Packaged unit of MLL



Top view of Sub-Nyquist PADC **Packaged unit of Sub-Nyquist PADC**



Top view of the packaged Time stretch PADC **Packaged unit of Time stretch PADC**

Packaged unit of a four stage MLL interleaver

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. Siva Subramaniyam C N, Karamdeep Singh, Sreeraj S J, Balaji Srinivasan, and Deepa Venkitesh, "Sub-Nyquist photonic sampled analog-to-digital converter with simultaneous operation in S, C, and X-band", Optica Advanced Photonics Congress, 2023.
2. Joydip Dutta, Karamdeep Singh, Sreeraj S J, Deepa Venkitesh, "An Arbitrary

Biased EOM-based Pulse-Picker with Programmable Repetition Rate using FPGA", CLEO®/Europe-EQEC, 2023.

3. "Sreeraj, SJ; Venkitesh, Deepa; Koilpillai, Ravinder David; Nirmalathas, Ampalavanapillai; ",Analog optical generation and transport for 5G millimeter wave systems,2021 IEEE Photonics Conference (IPC),1-2,2021,IEEE
4. "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, Optica
5. "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),1-2,2022,IEEE
6. "CN, Siva Subramaniyam; Venkitesh, Deepa; ",Experimental Demonstration of Multimode Optoelectronic Oscillator at 2.4 GHz,2022 Workshop on Recent Advances in Photonics (WRAP),1-2,2022,IEEE
7. "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
8. Siva Subramaniyam C N, Karamdeep Singh, Balaji Srinivasan, and Deepa Venkitesh, "Development of optical clock with low timing jitter for photonic ADC," in JSAP-Optica Joint Symposia 2022 Abstracts, (Optica Publishing Group, 2022), paper 23a_C205_5.
9. Karamdeep Singh, Sreeraj S J, Siva Subramaniyam C N, Balaji Srinivasan, and Deepa Venkitesh, "Compact photonic transient digitizer operating with one-twelfth of required electronic bandwidth," in Frontiers in Optics + Laser Science 2022 (FIO, LS), Technical Digest Series (Optica Publishing Group, 2022), paper JW4A.72.
10. Karamdeep Singh, Sreeraj S J, Siva Subramaniyam C N, Balaji Srinivasan, and Deepa Venkitesh, Optical Sub-Nyquist Sampling of S and C-band Signals with 1 GHz Clock Source and Its Performance," ACP 2022: Asia Communications and Photonics Conference, Shenzhen, China, November 5-8, 2022.

Concluding remarks

In general, the advancement of the project focused on IFM measurement through the utilization of photonic techniques is making good progress.

In addition, the PI is the Project Laed for the consortium project on Advanced Optical Communication Testbed, which consists of 6 industry partners and 4 academic partners. The objective of the consortium is to carry out product development in the direction current and futuristic requirements in the telecom sector in the country. Total funding of Rs 169.5 crores is provided by the Department of telecommunication, Govt of India. Duration of the project is 2.5 years.