Harmonic Suppression for Electro-Optic Communication Systems

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***Abstract*—For future networks to function properly, it is necessary to have synchronized clock and radio frequency carriers for precise positioning and highly dependable, low-latency communications. Multiple RF bands must be accessible by remote units (RUs) and wireless devices. Future 6G infrastructures face the challenge of offering precise clock and timing services to customers in addition to high rate data connections and to have such signals distributed widely across various parts of the network hierarchy. Radio-over-fiber (RoF) systems may be utilised to address such challenge, where RF signals are sent through low loss optical fibers, transmitted on optical carriers or frequency combs and received using broadband photodetectors. This paper deals with such systems, where a filtered optoelectronic frequency comb, with fixed frequency/wavelength spacing is advantageously used. The comb generates synchronized RF tones across a wide bandwidth. The work reported here allows multi-frequency RF signal transmission to several radio units. The study utilises cutting-edge RoF technology to combine optical and electrical signals and transmit them over fibre to radio units.In such RoF systems, however, extracting the desired electrical signal from the multi-frequency signal set suffers from harmonic interference, across a wide frequency band, which depends on the comb generation and the system frequency map particulars. For this work such band ranges from 5 GHz to 40 GHz. The work reported here considers the design and implementation of low-pass and band-pass filter combination for signal extraction and harmonic suppression, thus eliminating undesired harmonics and delivering the desired signals with frequencies at 6.25 GHz and 12.5 GHz. The paper reports the design method and experimental results, showing the efficacy of the techniques proposed.**

***Index Terms*—Radio-over-fiber, Optical frequency comb, Electro-optic system , Low pass- filter, Band-pass filter, Radio units.**

I. INTRODUCTION

Wireless communication services have been increasingly in demand with The total number of mobile devices, requiring broadband connectivity and services, is expected to exceed 18 billion by the end of 2025 [1]. Researchers are investigating different technologies for 5G and upcoming 6G networks to provide high-speed and broadband services, which include sensing and localisation provision. Mobile and wireless networks combine the use of Optical fibre and microwave radio technologies at different points in a network transmission systems. Networks commonly use optical fibre transmission for its advantages of higher bandwidth, low latency, security, reliability, and data transmission across longer distances.

RF/microwave photonics combines microwave engineering and photonics to create innovative applications in telecommunications, radar, sensors, and imaging. RoF technology distributes modulated RF signals from a central offices to radio units via optical fiber links [2]. This technology offers several advantages over electrical signal distribution, including low signal attenuation, high bandwidth and low power consumption. Optical fiber can transfer high-bandwidth data up to THz over long distances with minimal distortion[3]. Fig.1 illustrates the concept of radio over fiber as a distributor of radio signals from a central station to radio units.

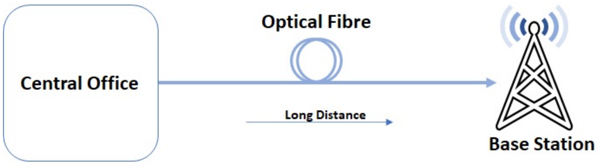

Fig. 1. Radio over fiber concept.

Frequency combs are regularly spaced lines in the frequency domain. In optical systems, they are generated by lasers, modulators, or resonators and have applications in metrology, optical communications, atomic clocks, and others [4]. The electro-optic modulator-generated frequency comb is being studied for use in wireless networks. The general idea is not new and almost as old as the 1960 ruby laser itself, which revolutionised physics by producing coherent red light [5]. It took only four years to invent the mode locked laser and the optical frequency comb. Hall and Hansch were awarded the Nobel Prize in Physics for their invention of the frequency comb synthesizer that precisely measures optical frequencies [6], [7].From there on many optical frequency combs have been reported. An optical frequency comb is essentially a set of optical spectral lines that are evenly spaced, where such frequency/wavelength separation depending on repetition rate of ultrashort optical pulses. The optical frequency comb is effectively an optical ruler in the time domain, abstractly illustrated in Fig.2 , where fr refers to the pulse repetition frequency.

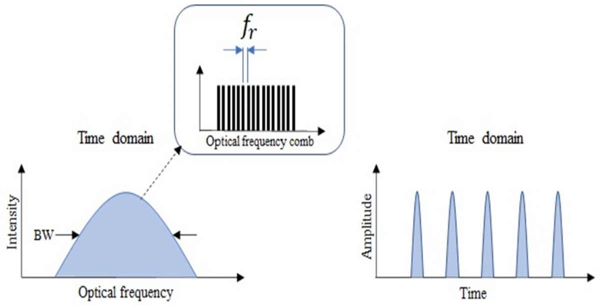

Fig. 2. Optical frequency combs in time and frequency domain.

Synchronization is essential for telecommunications networks. Advanced radio access technologies are used to increase capacity, reduce latency, improve radio spectrum utilization and to enable precise synchronization for higher spectral efficiency and aggregated bandwidth in future mobile networks. Synchronized clock and RF carriers are required for many applications in 5G and future 6G wireless networks.Radio-over-fiber (RoF) technique sends RF signals via low-loss optical fiber lines to produce synchronized RF signals with broadband photodetectors [8], [9]. Optical frequency combs can produce multiple similarly spaced RF tones that are coherent and evenly spaced. A filtered opto-electronic frequency comb is utilized to produce low-noise RF tones up to 40 GHz. Reliable RF power delivery is achieved by filtering techniques of one side-band of the frequency comb to avoid frequency fading caused by fiber scattering [10]. Fig.3 shows the proposed conceptual system.

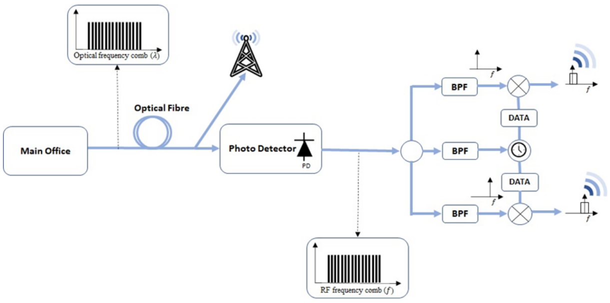

Fig. 3. Conceptual illustration of the proposed system.

This study's major objective is to use radio over fiber technology to transmit radio frequency signals over a range of distances to various radio units. On the optical side, optical and electric signals combine and transmit through fiber cables to radio units. The mixed signals are separated in the radio unit section to extract electrical signals and send them through antennas. This process produces interference between signals due to harmonics across frequencies ranging from 5GHz to 40 GHz. In this study, we attempt to eliminate undesired harmonics and extract desired frequencies at 6.12 GHz and 12.5 GHz by designing appropriate low-pass and band-pass filters. The work consists of two circuits with filters and antennas operating at 6.25 GHz and 12.5 GHz. The Fig.4 shows the primary process and frequency extraction of the desired signals. The electrical signal moves to the processing part after extracting the RF frequency comb from the optical frequency comb by a photo-detector. In this section, we show the filtering of unwanted signals with low pass and band-pass filters. The extracted signals include a 6.25 GHz clock signal and a modulated carrier signals at 12.5 GHz.

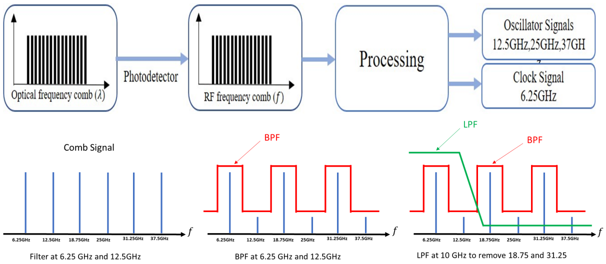

Fig. 4. Extracting RF frequency comb.

The signal filtering system still experiences interference from harmonics, which makes it challenging to extract the desired frequencies. We use a low-pass filter (LPF) at 10 GHz in conjunction with a band-pass filter (BPF) at 6.25 GHz to eliminate unwanted harmonics from clock signals. Furthermore, we extract the local carrier signals using a low-pass filter (LPF) at 15 GHz followed by a bandpass filter (BPF) at 12.5 GHz. The main parts that are used for extracting signals at 12.5 GHz and clock signals at 6.25 GHz are shown in Fig. 5 and Fig. 6, respectively.

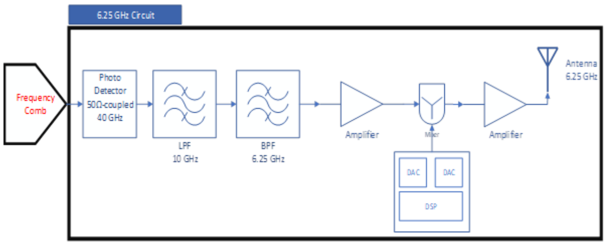

Fig. 5. Clock signals at 6.25 GHz.

This paper includes designing and testing four different filters. Firstly, we designed two low-pass filters, one at 6 GHz and the other at 15 GHz. These filters are critical in eliminating high-frequency noise and harmonics from signals. Secondly, we designed two band-pass filters at 6.25GHz and 12.5GHz, which allow only signals within a specific frequency range to pass through. The filters are concatenated and test results of such concatenation are reported.

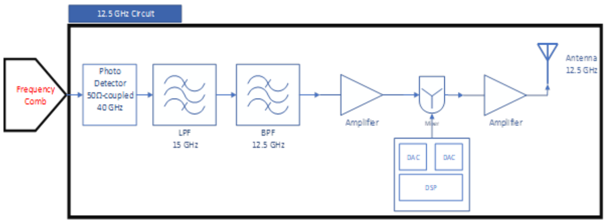

Fig. 6. Carrier signals at 12.5 GHz.

II. RF Microwave Filters Design

In (RF) or microwave systems, a filter is a two-port network that uses the pass band to enable certain frequencies to be sent and the reject band to reduce the signal in order to control the frequency response.. Its purpose is to control the frequency response at a specific frequency. Filters have a wide range of applications in electronics, particularly in the radio frequency (RF) domain. (RF) filters serve the purpose of accepting or eliminating signals that occupy specific portions of the radio spectrum. Four different types of filters can be identified. It is possible to accept the necessary signals and reject the unwanted ones by employing the proper type of RF filter since each type rejects or accepts signals in a different way [11].

Microstrip technology is a popular choice for designing microwave filters because it has a lightweight, planar structure, low cost, compact size, and is easy to fabricate. Moreover, microstrip transmission lines can be easily combined with other components on a printed circuit board. To create filters for any frequency, low pass filter prototypes that are normalized in terms of both frequency and impedance can be used. Once the low pass prototypes are created, they can be adjusted to the desired frequency and appropriate impedance. Finally, the lumped element components can be replaced with distributed circuit elements for implementation. [12]. Fig.7 illustrates the design process.

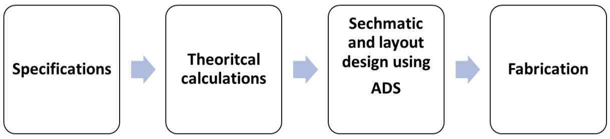

Fig. 7. Filter design process.

III. Filters Design for Clock Signals at 6.25 GHz.

The design's primary objective is to extract the 6.25GHz frequency tone from a frequency comb received from radio over fiber system. The system still contains harmonics after designing a parallel coupled band pass filter for 6.25GHz, which is not desirable results. A stepped impedance low pass filter at 10 GHz was created to prevent this by attenuating frequency harmonics from 10 GHz to roughly 30 GHz [13], [14].

A parallel coupled band pass filter consists of a cascade of pairs of parallel resonant lines that act like an open circuit at both ends. Transmission lines connected to the centre conductor are parallel to one another with lengths equal to the desired centre frequency of the filter. The parallel coupled filter bandwidth is smaller than 20%, and for more bandwidth, filters require very close coupled lines space, which control the bandwidth. The width of each centre conductor can affect and control the reflection coefficient. The filter has a N resonant structure since it is constructed from N+1 sections of equal length at the center frequency. The impedance on the parallel conductor in the even and odd mode characteristics define the electrical design [15], [16].The design has been simulated using ADS and tested in the lab with a VNA, as shown in Fig.8. After combining the stepped impedance low pass filter at 10GHz and the parallel coupled band-pass filter at 6.25GHz, the harmonics attenuated as shown in Fig.9 and Fig.10. The figures show a comparison of S11 between measured and simulated results.

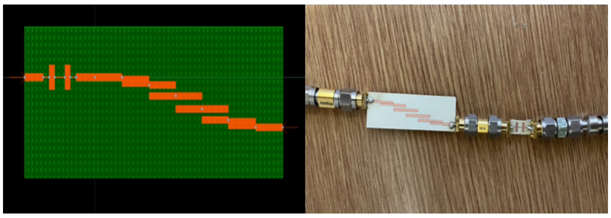

Fig. 8. Design and fabricated filter at 6.25 GHz.

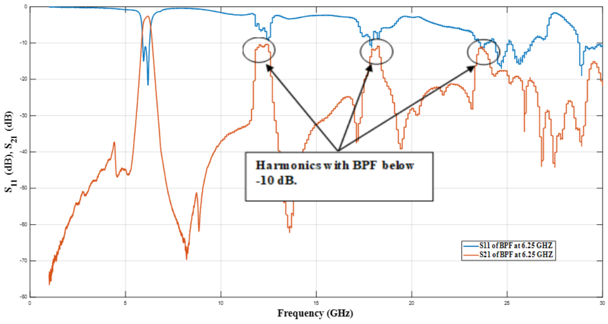

Fig. 9. Harmonics with one filter (BPF).

IV. Filters Design for Carrier Signal at 12.5 GHz.

To generate modulated signal at 12.5GHz, we will use the same design method as that of clock signals for both (LBF) and (BPF). Our first step will be to design a low pass filter at 15 GHz to suppress any signals between 1 to 15 GHz. We will then connect it to a parallel coupled band pass filter at 12.5 GHz to extract the desired frequency. Fig.11 depicts the layout design created using ADS, along with the fabricated filter [17].

Fig.12 shows the results of a parallel coupled band pass filter operating at 12.5 GHz. However, it also produces a harmonic at 25 GHz that needs to be eliminated. To achieve

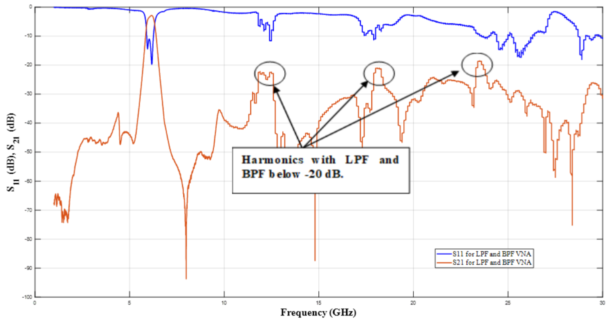

Fig. 10. Harmonics with (LPF) and (BPF) below -20 dB.

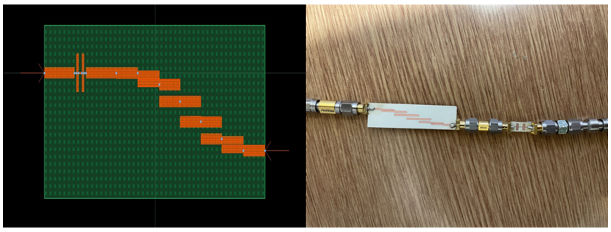

Fig. 11. Design and fabricated filter at 12.5 GHz.

this, a stepped impedance low pass filter was designed and connected to the parallel coupled band pass filter at 12.5 GHz. The idea behind using both filters is to allow frequencies from 1 to 15 GHz to pass through the low pass filter and eliminate frequencies from 15 to 30 GHz. By doing so, the unwanted harmonics at 25 GHz can be reduced, and the desired one at 12.5 GHz can be extracted. The result is depicted in Fig.13.

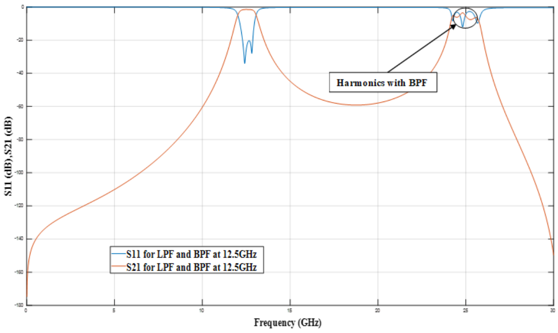

Fig. 12. (BPF) at 12.5 GHz with one harmonic at 25 GHz.

V. CONCLUSION

This paper presents the design of a harmonic suppression concatenated parallel coupled band pass filter, centred at 6.25 GHz, which is fed from the output of a 10 GHz stepped impedance low pass filter. This design allows for the extraction of a 6.25 GHz clock signal and removing undesirable harmonics at integer multiples of 6.25 GHz. Moreover, a parallel coupled band pass filter at 12.5 GHz, connected to a 15 GHz stepped impedance low pass, enables the extraction of modulated signals at 12.5 GHz. Both filters are constructed on microwave substrates and results show that combining the stepped impedance low pass filters at 10 GHz and 15 GHz with the parallel coupled band-pass filters at 6.25 GHz and 12.5 GHz, respectively, undesired harmonics are significantly attenuated, allowing successful low interference extraction of the desired clock and data signals. Future work will focus on designing two planar antennas that operate at 6.25 GHz and 12.5 GHz and integrating them with the filter structures.

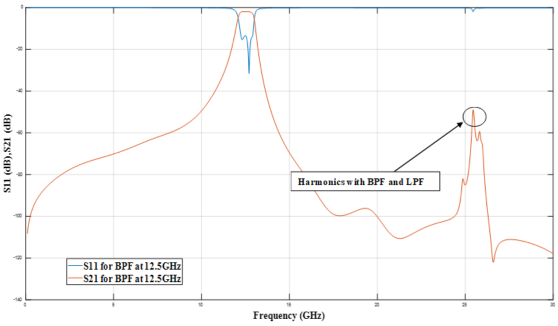

Fig. 13. Results after connect (LPF) at 15 GHz and (BPF) at 12.5 GHz.

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