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SIGNAL IDENTIFICATION AND ISOLATION UTILIZING RADIO FREQUENCY PHOTONICS

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14. ABSTRACT

Signal identification and isolation are important to applications such as radio astronomy. Radio frequency (RF) photonics can provide solutions to these areas. Spectrum analyzers can measure the frequency of signals and filters can be used to separate the signals apart from one another. This report will review different techniques for spectrum analysis and isolation.

15. SUBJECT TERMS

radio frequency, photonics, spectrum analyzer, filters

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1. INTRODUCTION

A single antenna can be used for both transmission and reception. To accomplish this, the transmission must be isolated from the reception. In Figure 1, a radio frequency (RF) circulator is connected right after the antenna. The three port device separates the transmit path from the receive path. After the circulator, a system can be used to identify the frequency of different signals. Once the frequency has been found, a filter with the right passband frequency can be used to isolate signals from each other.

RF photonics can be used for RF circulator, frequency identification and filters. The photonic filters are tunable and are narrow. A photonic based circulator isolates the transmit path from the receive paths. Multiple photonic methods can be used to identify the frequency of the signal. A review of these methods will be discussed in the following report.

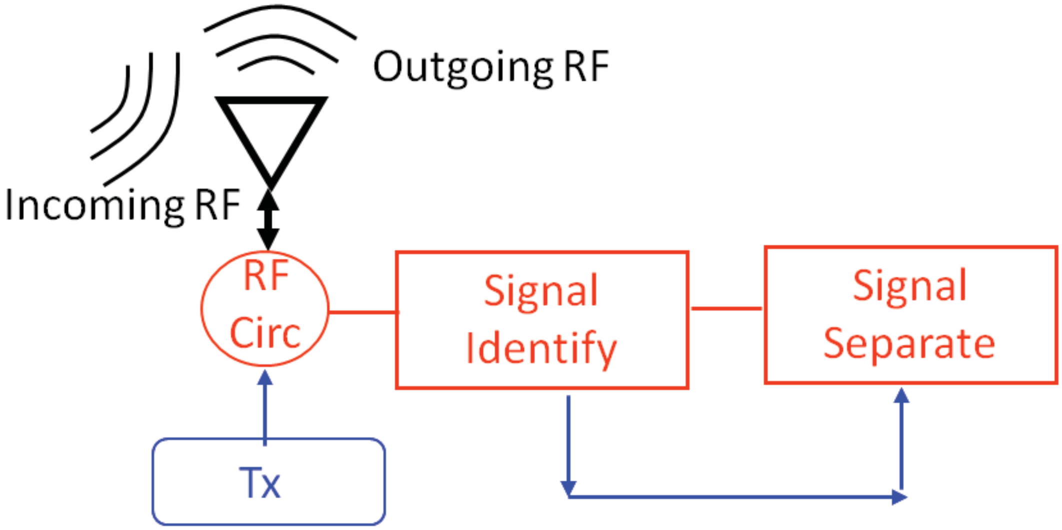

Figure 1: Example of an RF Photonic Circulator with a Signal Identifier and Separator

2. THE NEED FOR SIGNAL IDENTIFICATION AND ISOLATION

New signals continue to fill the available spectrum. Amateur radio and television signals fill the high frequency (HF), very high frequency (VHF), and ultra high frequency (UHF) bands. Air Traffic Control (118-136 MHz) and emergency radio communications (138-144 MHz) also use VHF. In the UHF band, 400 MHz frequency is used for time and frequency standard transmission to satellites, while wireless phones use the 900 MHZ frequency band. Above 1 GHz, phones and Wi-Fi also use the 2.5 and 5 GHz bands. Commercial GPS uses the 1.2 and 1.5-1.6 GHz frequencies. The 2.7-2.9 GHz band is used for Airport Surveillance Radars. As these signals increase usage, isolation is required. Filters can separate out these various signals. Before separation, the frequency of the signal has to be determined in order to set the filter appropriately.

Multiple methods exist for determining the frequency of signals. One commonly used one is the electrical spectrum analyzer. A block diagram of an electronic spectrum analyzer appears in Figure 2. The signal is low pass filtered (LPF) and then mixed with a local oscillator (LO) from a voltage controlled oscillator (VCO). The resulting intermediate frequency (IF) is amplified (IF Amp), passed through a band pass filter (BPF), and detected (DET). Finally the signal is displayed. The ramp generator sweeps the LO and syncs the output to the display. In the following sections, RF photonic methods for determining the frequency and then filtering them will be discussed.

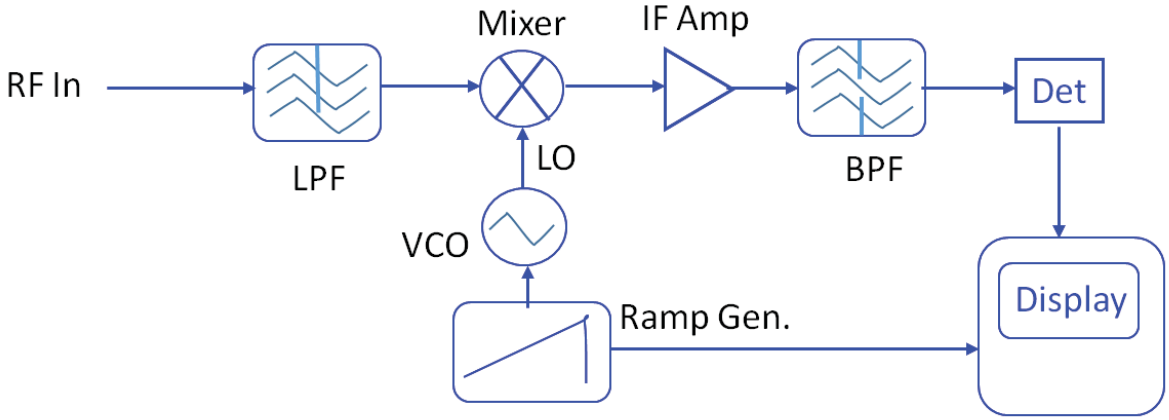

Figure 2: Block Diagram of Spectrum Analyzer

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3. RF PHOTONICS FOR SIGNAL IDENTIFICATION

RF photonics can play a role in frequency identification. Multiple methods exist for accomplishing this task. In the following sections, a review of these different methods will be provided.

3.1 Photonic Spectrum Analyzers

A photonics based spectrum analyzer replaces the electronic components with photonic components. The figure shows an optical modulator, taking the place of the mixer. A Fabry-Perot (FP) filter now scans rather than the local oscillator. The resulting output is then sent to a photodetector where a display of power as a function of RF frequency can be obtained. The block diagram appears in Figure 3.

Another type of photonic spectrum analyzer has been developed based on rare earth doped crystals. The absorption of the crystal can be modified by a laser. Figure 4 shows two laser beams at different angles to the surface of the crystal. They create an absorption grating on the crystal. A third laser is input to the crystal from the opposite side of the other lasers. The absorption grating set up in the crystal then deflects the beam with the RF information onto a photodiode array. The deflection of the beam with the RF signals will be precisely mapped to the photodiode array.

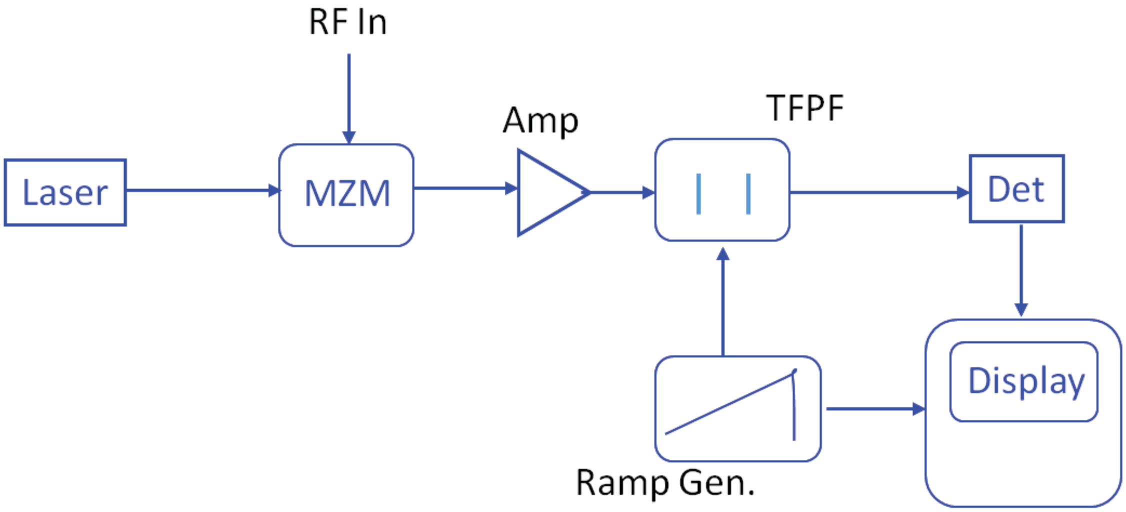

Figure 3: RF Photonic Version of Spectrum Analyzer

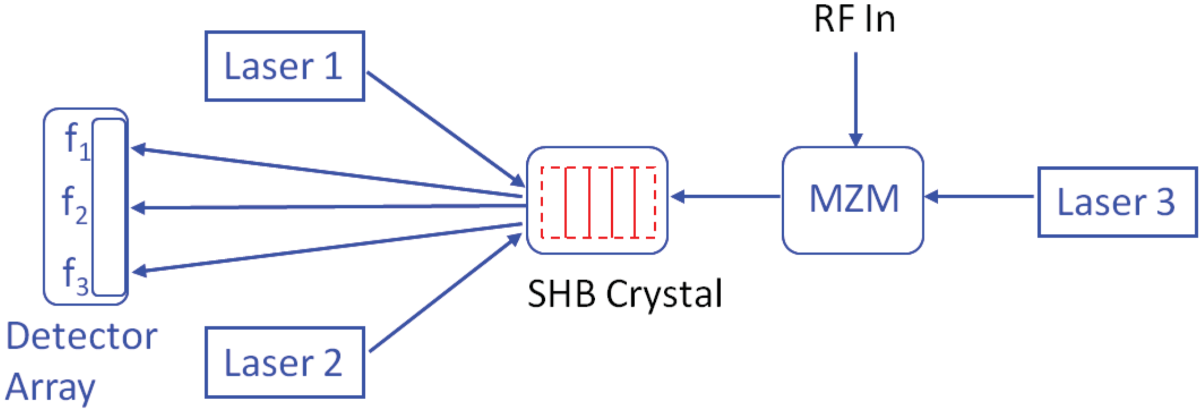

Figure 4: RF Photonic Spectrum Analyzer using an Optical Crystal

3.2 Frequency Identification using Filters

One method for finding the signal frequency involves optical filters. The fixed optical filter has a sinusoidal response. Combined with two lasers of different wavelengths, the signal frequency can be determined. The first laser's wavelength is set at the null of the response while the second laser is set at the peak. Figure 5 shows the generated sidebands appear on complementary slopes of the response.

The optical power of each wavelength is demuxed and detected. The ratio of powers from the two photodiodes is called the amplitude comparison function (ACF). It can be used to determine the frequency of the signal. The middle figure shows a plot of the monotonically increasing ratio in Figure 6. The frequency is recovered with knowledge from the ACF response.

Another approach uses two filters instead. Similar to two laser case, the setup provides measurement of the signal frequency. However it does not require two lasers, which can reduce the power consumption. Figure 7 shows an example setup using the two filters.

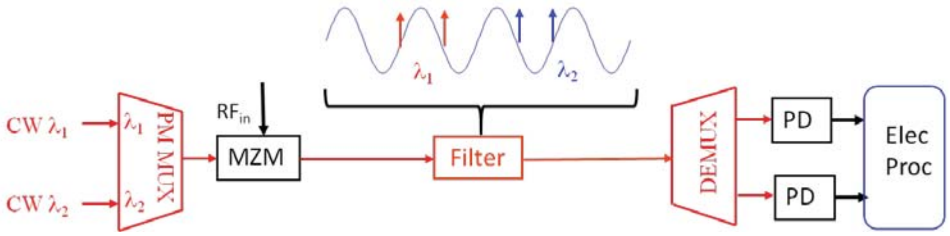

Figure 5: System using Two Lasers for Frequency Identification

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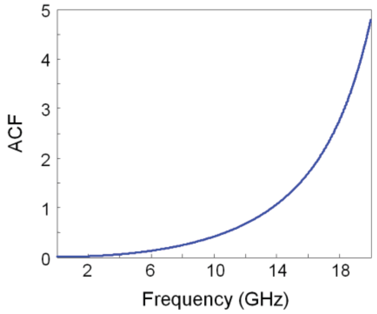

Figure 6: Example ACF for Frequency Identification

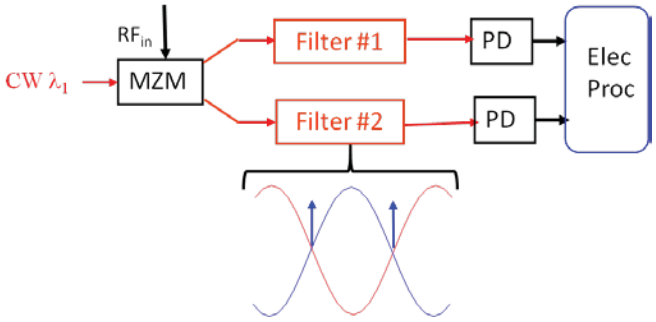

Figure 7: System with Two Filters for Frequency Identification

3.3 Dispersion for Frequency Identification

Another method uses RF fading due to dispersion as a filter. The dispersion-based filter provides an ACF similar to the one in the previous section. In Figure 8, a two laser method makes the ACF shown in Figure 9. The ratio of the two different frequency responses (dotted lines in lower figure) generates the solid black line ACF.

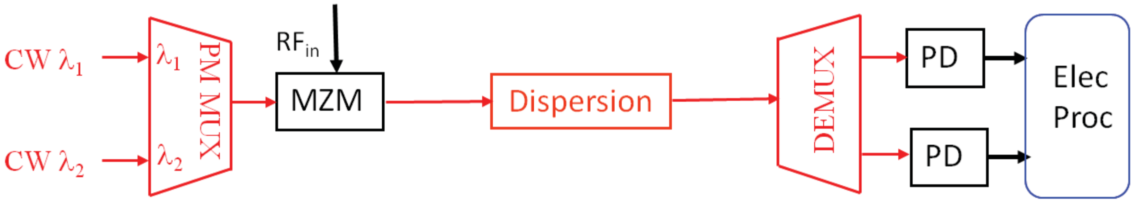

Figure 8: Two Laser System with Dispersion for Frequency Identification

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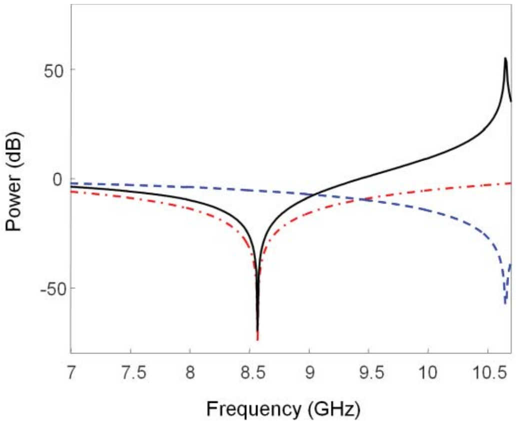

Figure 9: ACF for each Laser (dotted lines) and Total Response (solid line)

Yet another version of the dispersion based system was demonstrated. The figure shows a single laser followed by a dispersive element and a photodetector. Due to the dispersion, a frequency to time mapping of the dual optical sidebands occurs. The time delay through dispersion must have a linear response as a function of wavelength. Under this condition, the optical sidebands arrive at different times to the photodetector. Figure 10 shows this effect. The difference in time between the first sideband and its twin is proportional to twice the RF frequency.

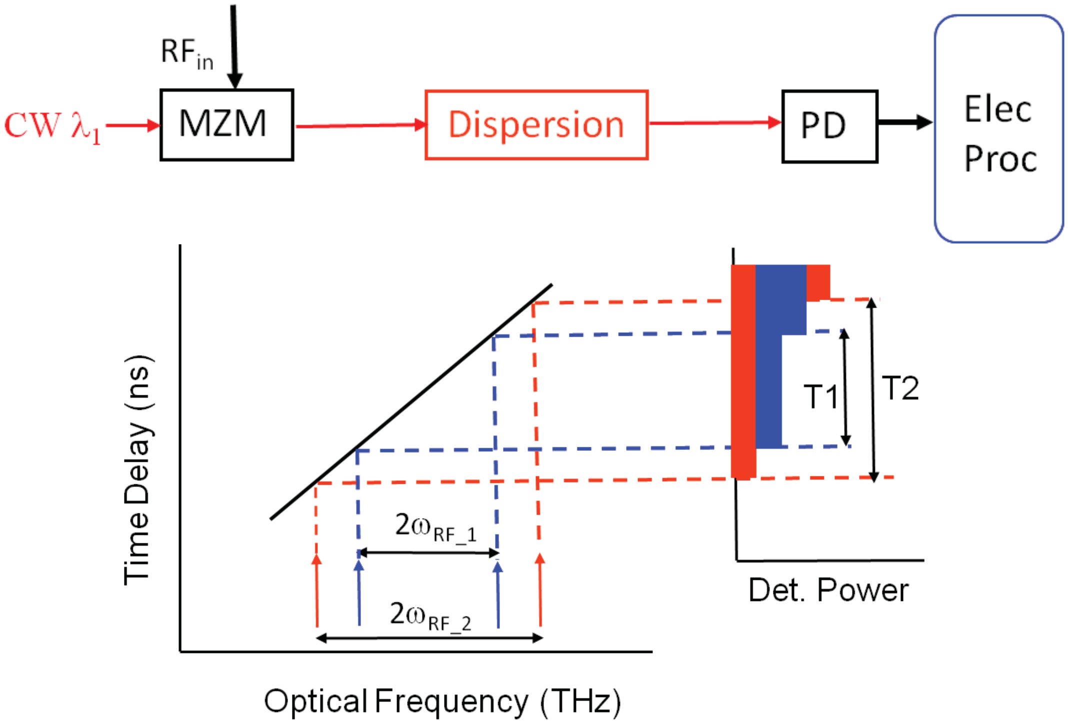

Figure 10: System using Dispersion for Wavelength-to-Time Mapping

3.4 Combination of Previous Methods

A combination above methods has also been demonstrated. A tunable laser can be used as one of the two lasers in a two laser dispersion system, as seen in Figure 11. A measurement of the power maps the signal frequency using an electronic processor. This is a combination of the swept spectrum analyzer and the dispersion method.

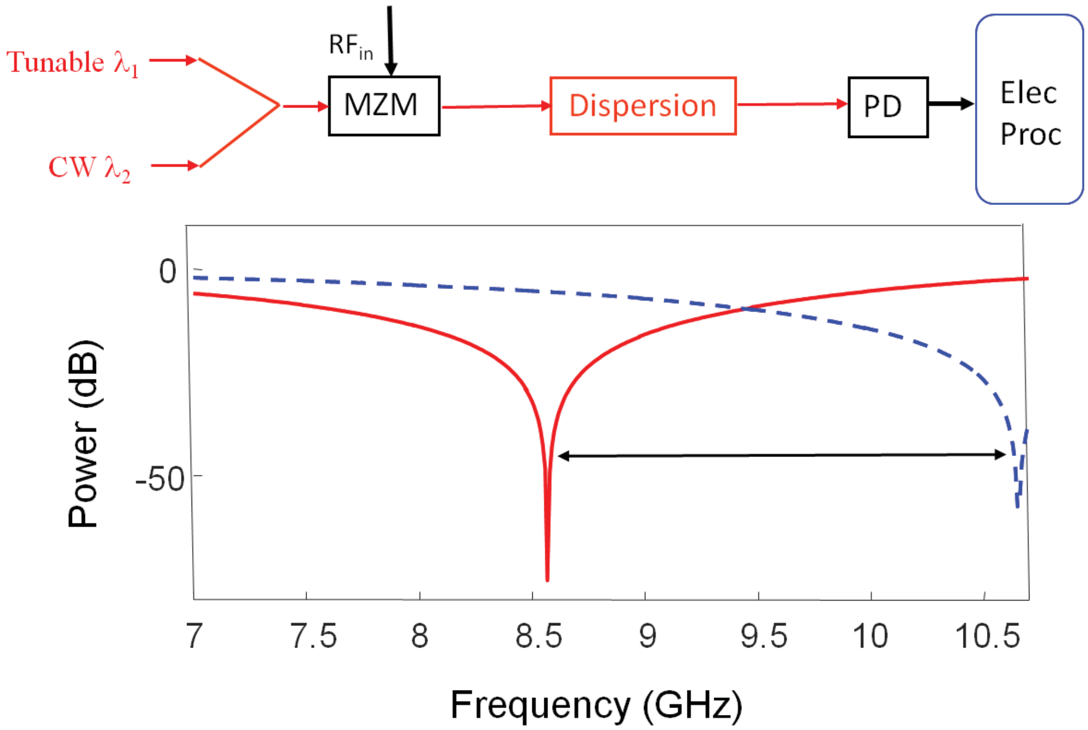

Figure 11: Combination of Swept Laser along with Dispersion

4. RF PHOTONICS FOR SIGNAL SEPARATION

RF photonics can also provide signal separation. Once the signal frequency is determined, a filter can be centered on the signal. The filter can be realized in different ways. One is a simply a band-pass filter. Others can use finite impulse response (FIR) to create different filter shapes. A review of different types is provided.

4.1 Photonic Filter

A photonic filter is often used to filter RF signals. The most common metric for filter is the quality factor, also known as Q-factor. The Q factor is defined as $Q = F_c / \Delta F$, where F_c is the center frequency of the filter and ΔF is the full width at half maximum bandwidth of the filter. Optical filters have been realized in many different ways.

The fiber Bragg grating (FBG) filter is one used frequently. The filter is designed to act as either a bandpass (in reflection) or a notch filter (in transmission). The wavelength that reflects satisfies $\Lambda = \lambda/2$ where λ is the wavelength of the light and Λ is the period of the grating. FBGs range from 100 MHz to 100 GHz. Figure 12 shows an example of a FBG.

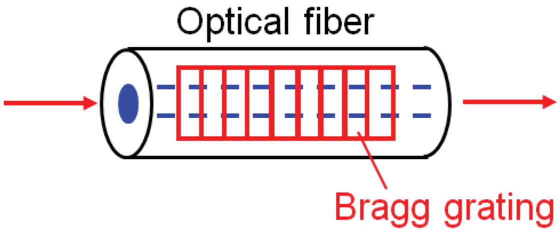

Figure 12: Example of a Fiber Bragg Grating

4.2 FIR and IIR Filters

Another method for generating an RF filter is the use of either a FIR or an infinite impulse response (IIR) filter. The FIR filter is simply the discrete convolution sum of the sampled impulse response of a given filter shape with multiple time delayed versions of the signal. The IIR filter is the same as the FIR filter but instead of a finite set of delays, the delays are modeled to continue forever.

Different ways exist to realize an FIR filter. Figure 13 shows an optical source with different optical carriers connected to a modulator. The RF signal appears on each wavelength. A demux separates the different wavelengths into parallel paths. Each path is attenuated and passed through a multiple of one time period delay. The signals are combined with a mux connected to a photodiode. The photodiode sums up the delayed RF signals.

Figure 14 shows another method. A multiple wavelength source and modulator is used. The output is connected to a fiber with multiple Bragg gratings. The gratings are spaced by a delay of T/2, providing an integer multiple of delays for each wavelength. The reflected wavelengths appear on a photodiode.

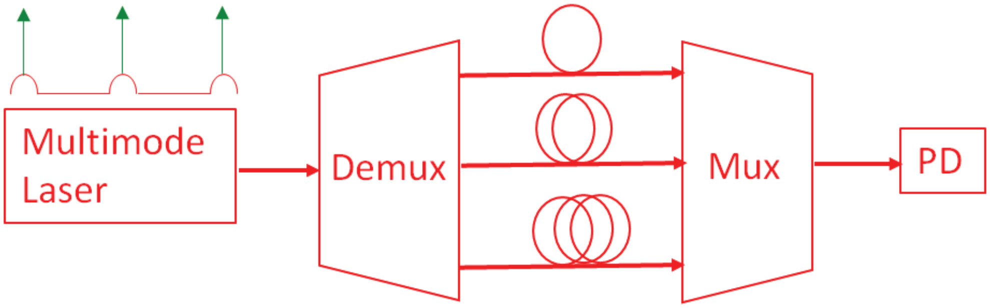

Figure 13: Example of an FIR Filter using Different Fiber Lengths

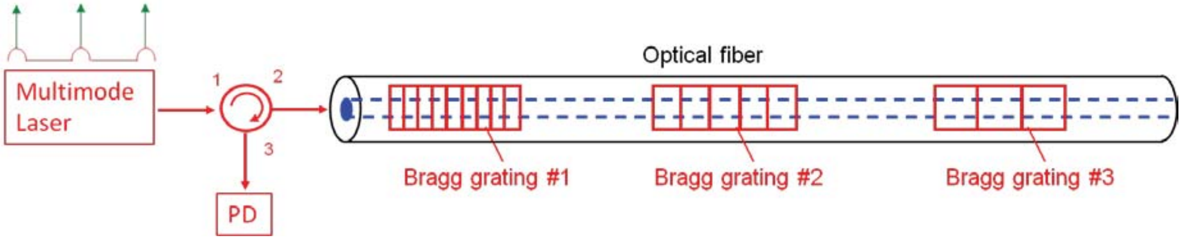

Figure 14: Example of an FIR Filter using Multiple Bragg Gratings.

An IIR filter can be realized simply by using a feedback loop of a fixed delay. In this case, the signal will ideally be a summation of an infinite number of delay round trips. While this is hard to realize in the electronic domain, the low loss of fiber can provide multiple round trips without a large amount of loss. An example of an IIR filter appears in Figure 15.

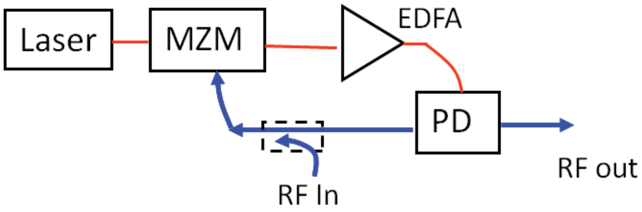

Figure 15: Example of an IIR Filter using Optical Feedback

A continuous and sampled version of a Sinc function appears in the Figure 16 (a) and (b). The sampled Sinc function can be used in the time domain will have a LPF response in frequency. The LPF response is shown in Figure 17.

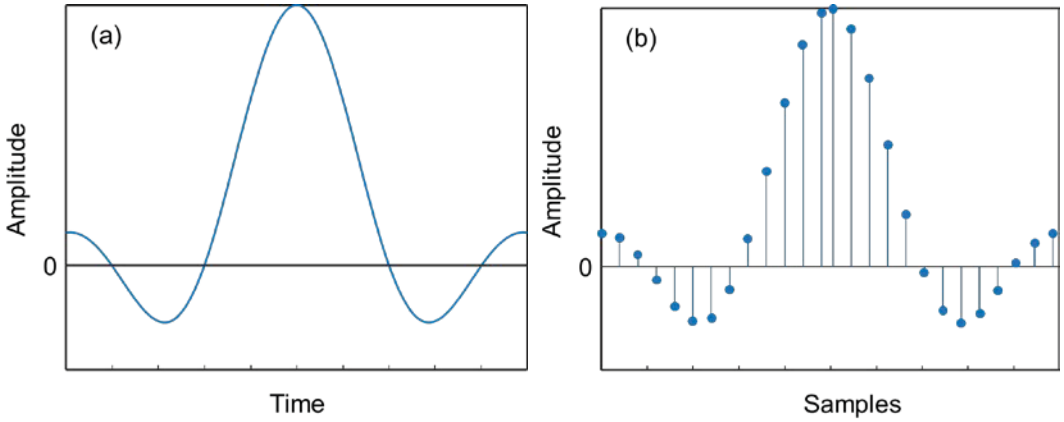

Figure 16: Sinc Function in both Continuous and Sampled Time

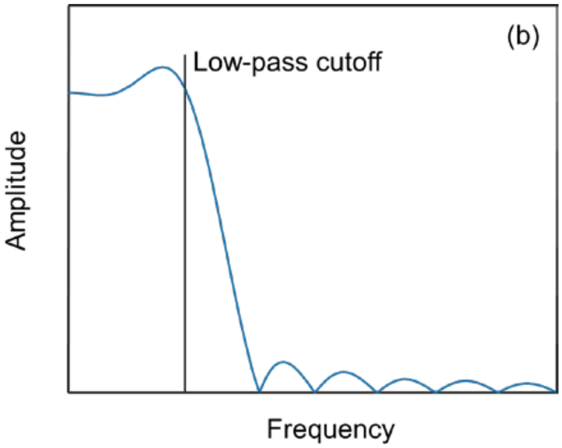

Figure 17: Low Pass Filter using Sampled Sinc Weights

4.3 FIR Filters for Signal Identification

Another method to measure the signal frequency uses Finite and Infinite Impulse Response filters. A combination of FIR and IIR filters can be used to identify the center frequency of an RF signal, as seen in Figure 18. The FIR filter is generated by splitting the light with a delay in one arm. The IIR filter is implemented by the electronic feedback from the photodiode back to the modulator. The detected power increases versus frequency as seen in Figure 19. The response is similar to methods shown above.

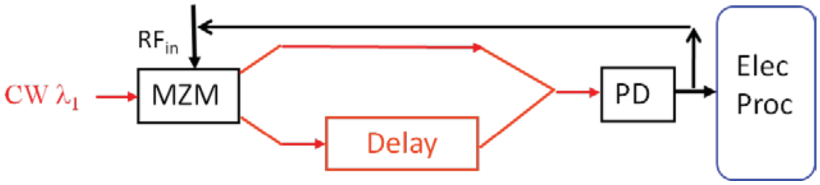

Figure 18: Example of an FIR and IIR Filter for Signal Identification

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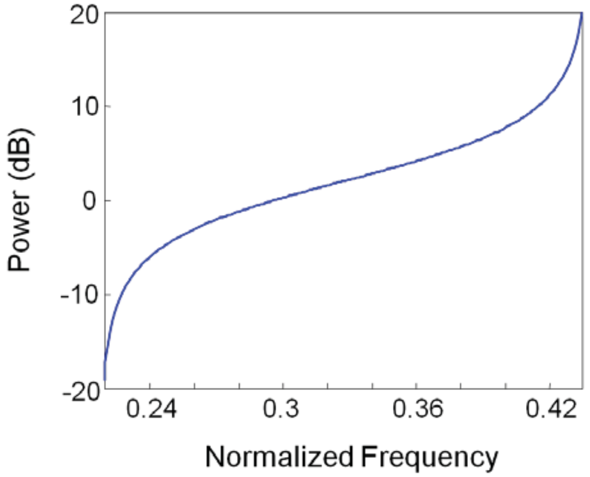

Figure 19: Power Response of FIR and IIR Filters

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5. CONCLUSIONS

Various advanced techniques have been demonstrated to improve the performance of the photonic links. Nonlinearities can be overcome by using different modulation formats. Optical fiber limits can also be overcome by using different fiber types and isolators. The noise of the erbium-doped fiber amplifier (EDFA) can be characterized and controlled by proper design to reduce the added noise. Finally the Mach Zehnder modulator (MZM) can be used at different biases to improve the RF performance.

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

ACRONYM	**DESCRIPTION**
ACF	amplitude comparison function
BPF	band pass filter
DET	detected/detector
EDFA	erbium-doped fiber amplifier
FBG	fiber Bragg grating
FIR	finite impulse response
FP	Fabry-Perot
HF	high frequency
IF	intermediate frequency
IIR	infinite impulse response
LO	local oscillator
LPF	low pass filter
MZM	Mach Zehnder modulator
RF	radio frequency
UHF	ultra high frequency
VCO	voltage controlled oscillator
VHF	very high frequency