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Performance of Mıllımeter Wave Photonıc Notch Fılter

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Abstract

A millimeter wave photonic notch filter structure is proposed we present a millimeter wave notch filter spectrum with a millimeter band which is operated in the optical domain. The filter is based on a Recirculating Delay Line (RDL) loop with a Semiconductor Optical Amplifier (SOA) followed by a Tunable Narrowband Optical Filter (TNOF). The notch filter frequency can be also continuously tuned by controlling the phase shift. The notch filter has a robust response and high Signal to Noise Ratio (SNR) performance with the help of notch filter and we can remove unwanted interfacing signals. Simulation result will be shows that notch filter gives millimeter band performance according to change the length of RDL. We prove that the integrated notch filters are able to provide acceptable system performance through both experiment and simulation in optiwave software.

Keywords:Millimetre wave photonic, Optical signal processing, Recirculating delay line loop, Semiconductor optical amplifier, Optiwave software.

1 Introduction

Millimeter photonic notch filters have attracted significant interest in the past few years. Compared with traditional electronics based radio frequency circuits, millimeter photonic wave filters provide advantages such as low loss, light weight, broad bandwidth, good tunability and immunity to electromagnetic interference [1].
Several millimeter photonic wave notch filter structures have been presented and demonstrated. There have been some photonic filter structures which can provide both a - at the same time to transmit the wanted signal over a millimeter band[2]. The notch filter allows for the reconfigurable and independent tuning of the center frequency, null depth, and bandwidth for one or more notches simultaneously. It is constructed using a Mach-Zehnder Interferometer (MZI) with cascaded tunable All Pass Filter (APF) ring resonators in its arms[3]. Measured filter nulling response exhibits ultra narrow notch 3 dB BW of and nulling depth of 60 GHz. This filter is compact and integrated in an area of 1.97 mm2. Using this device, a novel method to cancel undesired bands of 3 dB bandwidth of < 60 GHz in millimeter photonic systems is demonstrated. The notch filter response properties have been realized based on optiwave developed software [13][14].
To lower the cost and to improve the reliability of next generation fronthaul links, propose and demonstrate an analog 60 GHz radio over fiber fronthaul link employing two wavelength tunable integrated milliwave photonics filters for the first time. An integrated notch filter is cascaded with an integrated millimeter notch filter to offer the optical filtering function, resulting in a single notch filter profile with frequency separation of 70 GHz.
The notch filter with millimeter band can eliminate interference with minimal impact on the wanted signal. The notch frequency response is tunable by adjusting a variable delay line in the Recirculating Delay Line (RDL) loop. We prove that the integrated notch filters are able to provide acceptable system performance through both experiment and numerical simulation in optiwave software.

2 Notch Filter

The development of a digital filter using sampled data theory techniques and having a desired frequency response characteristic is described. Specifically, design of a digital notch filter is accomplished through formulation of a regression equation for application to sampled input and output values from the filter. After first expressing the desired transfer function in the continuous domain, the equation is developed using sampled data theory relationships. Although the techniques are applied to a specific type of filter, they are general in nature. The problem considered involves attenuation of a particular frequency and those in its immediate vicinity while leaving other even slightly distant frequencies relatively un attenuated. An additional requirement calls for tracking and attenuating an input whose frequency is time variable. In particular, a linearly (with respect to time) variable frequency is considered and discussed [4][5]. Testing and evaluation were performed through simulation on a general purpose digital computer.

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The notch filter is a filter that passes all the frequencies except those in a stop band centered on a centered frequency. A closely related knowledge item discusses the concept of the quality filter. The amplitude response of a notch filter is flat at all frequencies except for the stop band on either side of the centered frequency. The standard reference point for the roll off on each side of the stop band are the points where the amplitude decreased by 3 db to 98.7% of its original amplitude. Many people think that the higher the quality then deeper the notch this is not true. The depth of a notch depends on the matching of components.

In signal processing, a band stop filter or band rejection filter is a filter that passes most frequencies unaltered, but attenuates those in a specific range to very low levels. It is the opposite of a band pass filter. A notch filter is a band stop filter with a narrow stop-band (high quality factor) [6].Narrow notch filters (optical) are used in Raman spectroscopy, live sound reproduction (public address systems or PA systems) and in instrument amplifiers (especially amplifiers or preamplifiers for acoustic instruments such as acoustic guitar, mandolin, bass instrument amplifier etc.) to reduce or prevent audio feedback, while having little noticeable effect on the rest of the frequency spectrum (electronic or software filters). Other names include 'band limit filter', 'T notch filter', 'band elimination filter', and 'band reject filter'[7][8].

Typically the width of the stop band is 1 to 2 decades (that is the highest frequency attenuated is 10 to 100 times the lowest frequency attenuated). However in the audio band, a notch filter has high and low frequencies that may be only semitones apart.

2.1 Analysis of Notch Filter

A controllable half width 50 Hz software notch filter is obtained by aoptiwave program through Fast Fourier Transform (FFT), second order Infinite Impulse Response (IIR) notch filter for 50 Hz and Inverse FFT (IFFT), illustrated in Figure 1. Transforming the raw data from temporal domain to frequency domain by fast Fourier transform and then defining a tunable half width second order IIR notch filter with the central frequency of 50 Hz and calculate its frequency response, processing the frequency domain data that multiplied by the frequency response of notch filter through Inverse FFT to temporal domain, the new data after 50 Hz notch filter can be obtained. It should be noted that the new data after previous notch filter is not the expectant result that without the 50 Hz noise although the 50 Hz noise has been removed in frequency domain by the notch filter. The new data is a complex data with the imaginary part of pure 50 Hz noise on the other hand the real part is the signal combines the 50 Hz noise. There is a 90 degree phase lag between real part and imaginary part, that is to say, the imaginary part has a 1/4 period delay in time. The real and imaginary part should be separated for the new data, and shift the imaginary part to the same or inverse phase of the real part. Removing the phase modified imaginary part of 50 Hz from the whole real part, the actual signal without any 50 Hz pick up can be achieved consequently.

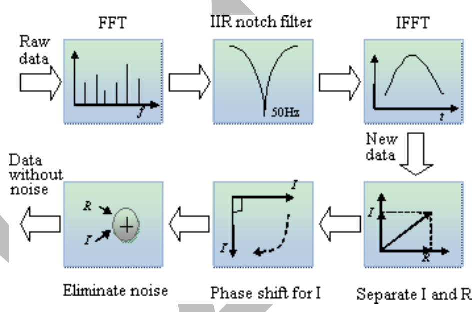

Figure 1. Schematic graph for 50 Hz of notch filter

2.2 Analysis of Millimeter wave Photonic Notch Filter

A millimeter photonic wave notch filter can be implemented based on a multi tap delay line filter with a Finite Impulse Response (FIR). The taps can be realized using a sliced broadband light source or a laser array. The tuning of the center frequency is usually performed by tuning the wavelength spacing, which is very complicated and costly. A millimeter photonic notch filter can also be implemented based on a delay line filter with an IIR, but the implementation is more complicated, especially the stability is poorer due to the feedback nature of an IIR configuration. In addition, for a millimeter photonic notch filter with either an FIR or IIR, due to the discrete nature of the sampling process in the time domain, the spectral response is periodic. If the time delay difference between two adjacent taps is large, which is true for most implementations, especially for implementations based on fiber delay lines, the Free Spectral Range (FSR) is small, which may make the filter to have multiple notches within the spectral range of interest. Thus, it is highly demanded to implement a millimeter photonic wave notch filter with only a single notch. Furthermore, for adaptive jamming mitigation, a notch with a tunable central frequency and tunable notch depth is also needed. Recently Millimeter Photonic Wave Filters (MPWFs) with a single notch based on Stimulated Brillouin Scattering

(SBS) were proposed. The basic concept to achieve a single notch is to manipulate the phase and the amplitude of the two optical sidebands to fully cancel the microwave signals at a specific frequency at the output of a Photo Detector (PD) to achieve a high rejection ratio. The main limitation of an SBS based approach is the complexity of the system [9][12].

3. Mıllımeter Wave Photonıc And Notch Fılter Technıques

3.1 Millimeter Wave Generation Using External Modulation Techniques

Being different from the approach using two phase locked laser diodes to generate a high quality MM wave signal in this Section we present two approaches based on external modulation techniques to generate tunable MM wave signals with high system stability and low phase noise. For system applications with frequency reconfigurability such as wideband surveillance radar spread spectrum or software defined radio continuously tunable MM wave signals are highly desirable. The generation of a wide band continuously tunable single frequency MM wave signal using fixed optical filters and narrow bandwidth optical modulators then becomes very attractive.

3.1.1 Intensity Modulator Based Approach

Here continuously tunable MM wave signal was generated without using a tunable optical filter. The system consists of an optical intensity modulator which is biased to suppress the odd order optical sidebands shown in figure 2. A Fiber Bragg Grating (FBG) serving as a wavelength fixed notch filter is then used to filter out the optical carrier. A stable low phase noise MM wave signal that has 4 times the frequency of the electrical drive signal is generated at the output of a photo detector. A 32 to 50 GHz MM wave signal is observed on an electrical spectrum analyzer when the electrical drive signal is tuned from 8 to 12.5 GHz. The quality of the generated MM wave signal is maintained after transmission over a 25km Standard Single Mode Fiber (SSMF).

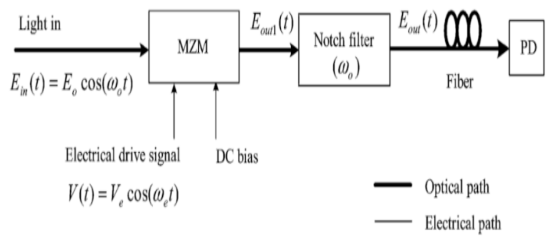

Figure 2 Diagram of the Microwave Signal Generation System Using an IntensityModulation

3.1.2 Phase Modulator Based Approach

The approach using an intensity modulator to generate MM wave signal as discussed above can produce a high quality frequency tunable MM wave signal with a simple system structure. However to suppress the odd or even order optical sideband the IM should be biased in the nonlinear region which would cause the bias drifting problem leading to poor system robustness. A solution to this problem is to use an optical phase modulator (PM) since no bias adjustment is required. An experimental setup used to generate mm-wave using an optical PM is illustrated in figure 3

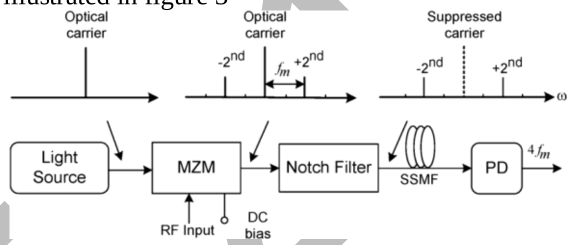

Figure 3 Experimental setup for Optical Generation of MM Wave Signals Using a PM.

3.2 Notch Filter Techniques

DSP techniques are integral parts of almost all electronic systems. These techniques are rapidly developing day by day due to tremendous technological developments in high speed computers, integrated circuit fabrication and FPGA. With these, digital signal processing has now become more reliable and speed processing is almost near infinity. DSP techniques find applications in variety of areas such as in speech processing, data transmission on telephone channels, image processing, instrumentation, bio medical engineering, seismology, oil exploration, detection of nuclear explosion etc. There are many commonly used DSP operations such as Differentiation, Integration, Hilbert transformation and Filtering. Among these, filtering is the operation that is invariably used in most of the applications. There are various types of filters such as High pass (HP), Low pass (LP), Band stop (BS), Band pass (BP) and Notch filters. Digital notch filters are of two types IIR and FIR.

3.2.1 Characteristic of Notch Filter

Detection, estimation and filtering of narrow band signals in the presence of noise represent some of the important applications of signal processing techniques. In most of these applications it is desired to remove the narrow band signal while leaving the broad band energy unchanged. This can be achieved by 13 passing the

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signals through a notch filter where the notches are centered on the narrow band signals.

A notch filter is essentially a band stop filter with a very narrow stop band and two pass bands. The amplitude response $H_1(\omega)$ of a typical notch filter (designated as NF1) shown in Figure 4 is characterized by a notch frequency ωd (radians) and -3 dB Rejection Band Width (RBW). For an ideal notch filter this RBW should be zero the pass band magnitude should be unity and the attenuation at the notch frequency should be infinite. We may alternatively have the amplitude response $H_2(\omega)$ of a notch filter (designated as NF2) as shown in Figure 5 $H_2(\omega)$ has 180 degrees phase shift at the notch frequency ωd i.e. it has opposite signs in the two pass bands. In this paper we propose the design methodologies for both these type of filters. Before considering the design aspects of the notch filters, it is relevant to highlight some of the important applications of the notch filters.

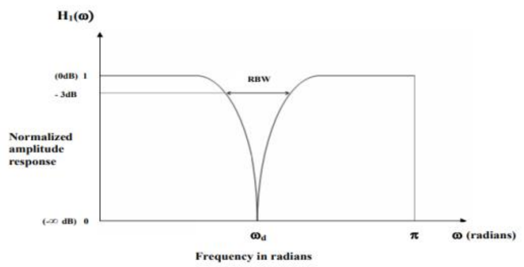

Figure 4 The Normalized Amplitude Response $H_1(\omega)$ of the Notch Filter NF1

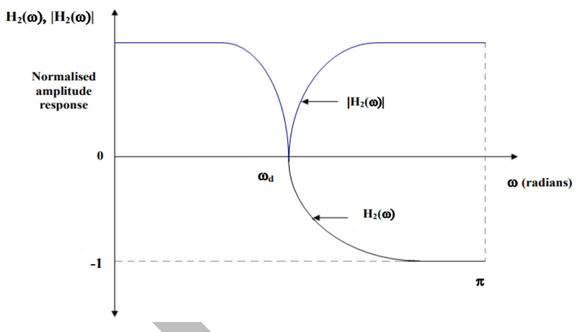

Figure 5 The Normalized Amplitude Response $H_1(\omega)$ and $H_2(\omega)$ of the Notch Filter NF2

4. Diagram of Millimeter Wave Photonic Notch Filter

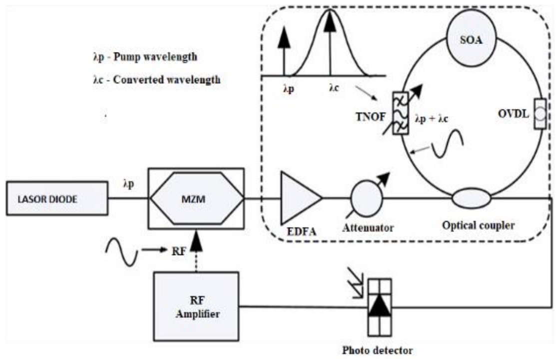

Figure 6 Block Diagram of Millimeter Wave Photonic Notch Filter

Millimeter photonic wave filters have attracted significant interest in the past few years. Compared with traditional electronics-based radio frequency circuits, microwave photonic filters provide advantages such as low loss, light weight, broad bandwidth, good tunability and immunity to electromagnetic interference. Furthe0rmore, such structures have the benefit of being inherently compatible with fiber-based transmission system and can be incorporated into the optical fiber network. Various milliwave filter structures based on the infinite impulse response or finite impulse response have previously been presented and demonstrated. Among them a notch filter for interference suppression of millimeter wave signals is a very useful component in several applications such as fiber radio links and phased array antennas because milliwave fiber optic systems carry not only the desired signal but also unwanted interfering signals that are picked up by the antenna.

Several millimeter photonic wave notch filter structures have been presented and demonstrated. However, these previous structures are mostly based on a few taps. Hence, they have some drawbacks such as producing a slow variation response and causing significant frequency dependent attenuation in the required pass band, which can corrupt the wanted information signal itself. This makes such filter structures inappropriate for interference suppression in some applications.
There have been some photonic filter structures which can provide both a narrow stop band for rejecting RF interference and at the same time to transmit the wanted signal over a millimeter band. But they are not in the optical domain they need extra electrical components such as an electrical millimeter band filter or one more photo detector, electronic subtractor or adder. This makes the filter structure complex and expensive.

In this block diagram we present a milliwave notch filter with a millimeter band which is operated in the optical domain. The filter is based on a recirculating delay line loop with a Semiconductor Optical Amplifier (SOA) followed by a tunable narrowband optical filter. The converted signal acting as a negative tap is generated through wavelength conversion based on cross gain modulation of Amplified Spontaneous Emission (ASE) spectrum of the SOA without a probe light. A narrow band pass response with negative coefficients and a broadband all pass response for milliwave signals are combined to achieve a narrow notch response with flat pass band. The notch filter with flat pass band can eliminate interference with minimal impact on the wanted signal. The notch frequency response is tunable by adjusting an Optical Variable Delay Line (OVDL) in the RDL loop.

5. Operatıon of Mıllımeter Wave Photonıcs Notch Fılter

The schematic diagram of a new SOA based millimeter photonic wave notch filter is shown in figure 6. The output of a laser diode with wavelength λp is externally modulated by a MZM which is driven by a RF signal being swept linearly from 30 to 60 GHz over a time period of about two generated by the vector network analyzer. The power of the modulated optical signal is controlled by the followed Erbium Doped Fiber Amplifier (EDFA) and A Tunable Attenuator (ATA). Then the modulated optical signal is split into two paths by a 50:50 optical coupler. One path is sent to the photo detector directly, which provides a broadband all pass microwave signal. A broadband all pass response is obtained after photo detection, as shown in Figure 7.

The other path goes into the RDL loop consisting of an OVDL and an SOA followed by a TNOF with 3 dB bandwidth of 0.3 nm. The OVDL is used to tune the length of the RDL loop. The ASE spectrum of the SOA is inverse modulated by the pump signal λ_p due to the XGM effect, while the modulation information at pump wavelength λ_p is inverse copied into other wavelengths of the ASE spectrum. The TNOF can extract out the converted signal at any other wavelength λ_c by tuning the TNOF within the wavelength operational range of the SOA. The converted signal can be used for negative tap. Then, the converted signal is divided into two parts by the OC one part goes to the PD. The other part re-enters into the RDL loop to generate delay and obtain the subsequent recursive taps. When the converted signal arrives at the SOA, it cannot modulate the ASE spectrum again because its power is small, it is amplified only by the SOA. The converted signal circulating in the RDL loop realizes a band pass response with negative coefficients, as shown in Figure 8. Since the two different wavelength (pump and converted wavelength) modulated optical signals have a 180◦ RF phase difference the two photocurrents generated by the two modulated optical signals are subtracted at the photo detector. Thus, the band pass response with negative coefficients and the broadband all pass response are combined to achieve a notch response with millimeter band as shown in Figure 9. At the output of the PD the filter frequency response is measured using the input port of the vector network analyzer.

However, when the central wavelength of the TNOF is just detuning from the pump wavelength a little the pump signal cannot be filtered out completely. Then a band pass response with positive coefficients can also be realized by the pump signal. Hence two band pass responses with opposite polarity coefficients are realized by the pump signal and the converted signal circulating in the same RDL loop. The two photocurrents generated by the two modulated optical signals are then subtracted at the photo detector. However, the converted signal is dominant. The band pass response realized by the converted signal is much sharper than that realized by the pump signal.

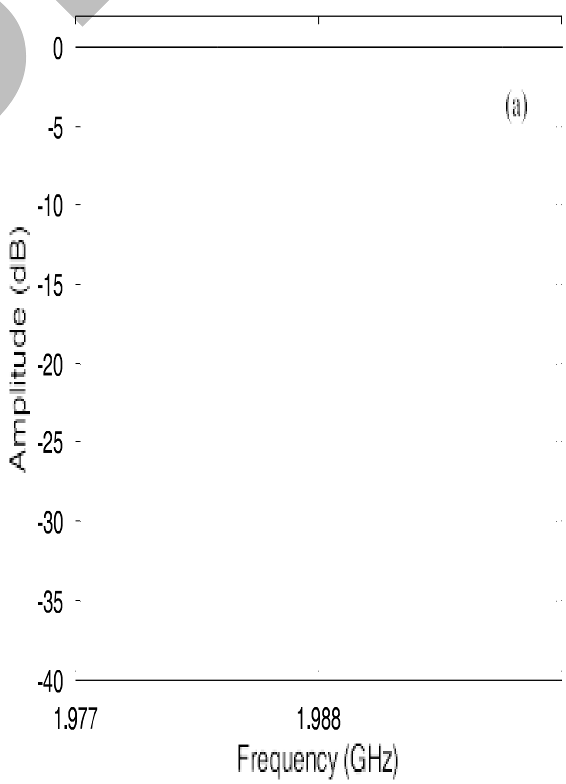

Figure 7 Realized by the Direct Pass Signal

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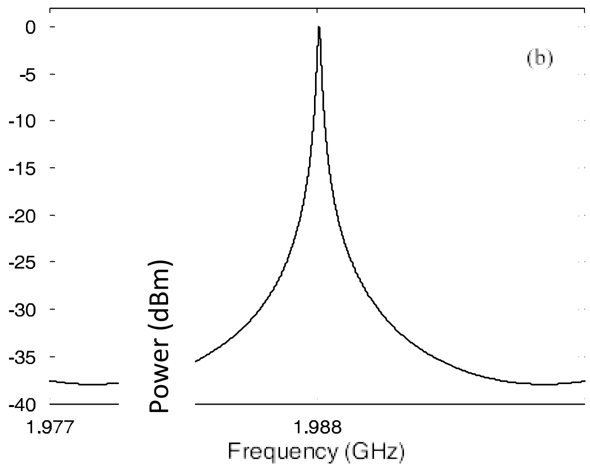

Figure 8 Realized by the Converted Signal

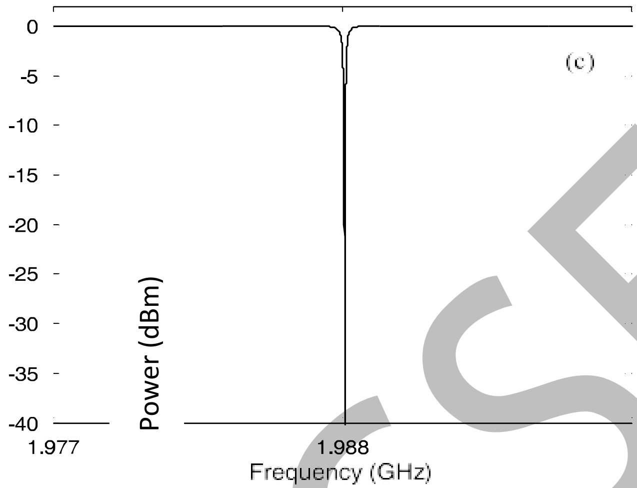

Figure 9 Realized by the Direct Signal Combined With the Converted Signal

6. Simulation Results

Photonic techniques provide many advantages over its electronic counter part for processing millimeter wave signals for applications such as millimeter band wireless access networks, radar, phased arrayed antennas, sensor networks and satellite communications. In this project diagram an overview about the developments of millimeter wave photonic notch filter based on SOA presented. In addition, the SOA can be used for photonic generation of millimeter wave signals and millimeter band by the RF spectrum analyzer signal.

A single notch millimeter wave photonic filter with both tunable frequency and tunable notch depth was proposed and experimentally demonstrated. The fundamental concept to produce a deep notch is to use the out of phase nature of the two sidebands of a phase modulated signal. A microwave notch filter with a 3 dB bandwidth of about 60 GHz and a notch depth of over 22.89 dBm was achieved. A frequency tunable range from 50 to 70 GHz was demonstrated as shown in Figure 10.

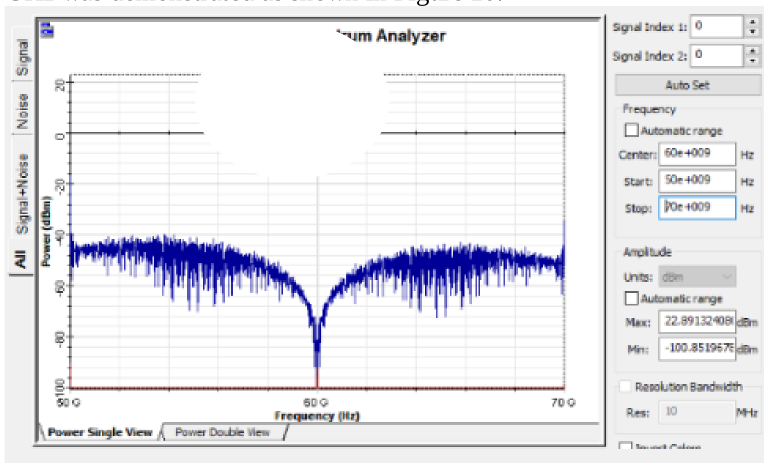

Figure10 Output of RF Spectrum Analyzer

7. Conclusion

The proposed notch filter performed at a pa frequency signal 60 GHz with bandwidth and its show the characteristics of notch filter with time variation at time period and also it can retain that particular frequency with the help of optical notch filter. This notch filter is based on an RDL loop with an SOA followed by a TNOF. While circulating in the RDL loop, the converted signal realizes a millimeter band response with negative coefficients. if the total wavelength of the RDL loop is optimized, which can eliminate interference with minimal impact on the wanted signal over a millimeter wave range. A notch filter with notched band stop frequency can be realized by subtracting the millimeter band response from the all pass response after photo detection.

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