An 8–18-GHz All-Optical Microwave Downconverter With Channelization

Shane J. Strutz, *Member, IEEE*, and Keith J. Williams, *Member, IEEE*

***Abstract*—A wide-band fiber-optic image-rejection downconverter capable of channelizing received signals into a 500-MHz intermediate frequency band is demonstrated. The downconverter utilizes phase modulators to convert received signals into optical side-bands prior to heterodyne detection with the system local oscillator. Experimental measurements performed on a two-channel system which maps 8–18-GHz signals into intermediate frequencies between 2 and 2.5 GHz reveal an image rejection of 20 dB and a spur-free dynamic range of 107 dB/Hz$^{2/3}$.**

***Index Terms*—Microwave communication, microwave frequency conversion, microwave mixers, optical filters, optical frequency conversion.**

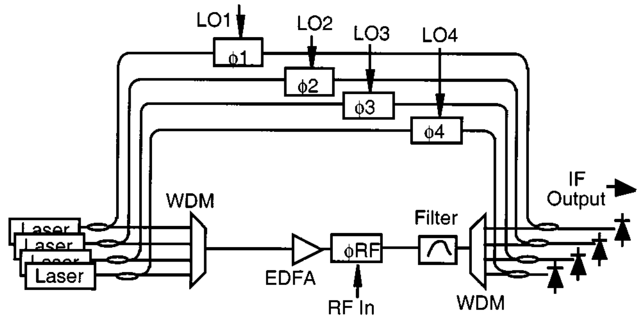

Fig. 1. Block diagram of the image rejection downconverter/channelizer.

I. Introduction

THERE ARE many commercial and military applications that require the use of microwave channelizers to sort received signals according to their frequency. For example, the wide bandwidths of antenna arrays and high-capacity analog-communications systems often need to be downconverted into predetermined narrow bandwidths prior to digitization. Channelization allows the entire receive band of an antenna to be digitized and analyzed. Though microwave photonic links [1]–[8] capable of wide-bandwidth downconversion have been developed, these links lack the channelization capability required to instantaneously downconvert signals from today's ultrawide-band systems while simultaneously sorting individual frequency bands to separate subsystems.

A simple microwave channelizer may be formed by splitting a received signal into N paths with a microwave power divider, followed by selective filtering of each path with bandpass filters. A similar channelizer may be formed by simply replacing the microwave power divider with a $1 \times N$ fiber-optic coupler with optical filters at the end of each path. In the optical domain, the filters would select RF sidebands near the fundamental laser wavelength for use in heterodyne detection at the system output.

Though the channelizers discussed in the previous paragraph are useful, splitting a signal into N paths incurs significant power loss, and, as a result, the microwave/optical channelizers described above require multiple low-noise amplifiers. In addition, wide bandwidth applications would require a significant number of expensive filters, increasing the system complexity. In an effort to reduce the complexity of microwave channelizers while enabling downconversion, we present an all-optical image-rejection downconverter/channelizer. We report the conversion loss, image rejection, spur-free dynamic range (SFDR), spurious signal performance, and noise figure of this system.

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II. System Description

A block diagram illustrating a four-channel version of our optical channelizer/downconverter is shown in Fig. 1. A two-channel version of the system was used in our experiments with the WDM components replaced by 3-dB couplers. For each channel, light from a fiber-coupled laser is divided into two paths by a 3-dB polarization maintaining coupler. A 1551-nm solid-state laser and a 1552-nm DFB were used in channels 1 and 2, respectively. In one path, the lasers are separately modulated by phase modulators $\phi 1$ or $\phi 2$ (8-V V_π), which are driven with local oscillators $\mathrm{LO1}$, $\mathrm{LO2} =$ 6–15.5 GHz (+30 dBm), respectively. The phase modulation creates sidebands around the laser center wavelength.

In the second path, the unmodulated laser outputs are combined, amplified, and passed through a third phase modulator, ϕ_{RF}, which is used as the system's RF input. The RF input generates optical sidebands on each wavelength simultaneously (Fig. 2). These sidebands are selected by a polarization-maintaining Fabry–Perot (3-dB bandwidth $=$ 0.6 GHz) filter (free-spectral-range $=$ 135 GHz) and pass to the system output. Each passband of the optical filter is a separate channel in our system. Thus, by temperature tuning each laser 8–18 GHz below a separate optical passband, we are able to select which RF frequency band passes through the Fabry–Perot and select a separate portion of the RF receive band for each laser wavelength. The Fabry–Perot filter output is split into two paths, recombined with the local oscillator paths, and the beat signal is detected. It should be noted that the use of 3-dB couplers requires that the laser wavelengths be separated such that only

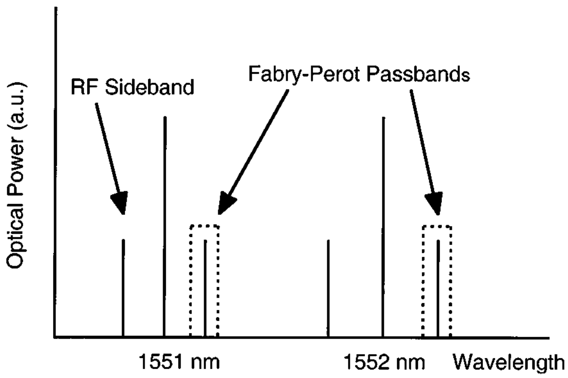

Fig. 2. Optical sidebands selected by the Fabry–Perot Filter. The dashed boxes represent the filter passbands. Only those RF sidebands within the filter passbands will reach the system output. The optical passbands sort the RF input.

one RF/LO combination produces output frequencies within the output band of the system. The Fabry–Perot filters were manually aligned with the laser wavelengths in this proof of principle experiment. A functional, multichannel verion of this experiment would require electronic feedback to maintain the proper laser wavelengths and filter alignment. In addition, the path lengths of each channel must be matched since they are within the laser coherence lengths. Failure to path match would result in unwanted amplitude-noise due to the phase noise of the lasers.

The Fabry–Perot filters provide image rejection in addition to channelization. Only those optical sidebands within the passband of the optical filter will reach the system output undiminished. As a result, image frequencies present at the RF input are filtered out, or rejected. The result is an image rejection downconverter with frequency sorting capability. Each channel enables 0.5 GHz of received bandwidth to be downconverted into an arbitrary RF frequency band, 2–2.5 GHz in the example below.

III. Results and Discussion

To verify the functionality of the two-channel system presented here, the conversion loss, image rejection, SFDR, range, noise figure, and spurious-signal response were measured. The conversion loss and image rejection were investigated by injecting a +5-dBm signal (8–18 GHz) into the system's RF input and measuring the output power levels at both output channels. The 8–18-GHz receive band was broken into 1 GHz segments, with each channel downconverting a 0.5-GHz bandwidth. For example, input frequencies between 8 and 9 GHz were simultaneously downconverted into two separate 2–2.5 GHz output channels by tuning the lasers 8 and 8.5 GHz away from adjacent passbands of the Fabry–Perot filter while utilizing local oscillators of 6 and 6.5 GHz, respectively. This procedure was carried out over the entire 8–18-GHz RF input range. As shown in Fig. 3, the desired signal output was 35–47 dB below the +5-dBm input power level with higher conversion losses at higher frequencies. The variation in the conversion loss was due in part to the lineshape of the optical filter, which was set to a fixed wavelength value for each LO. Lower conversion losses resulted from frequency shifts close to the optical filter's

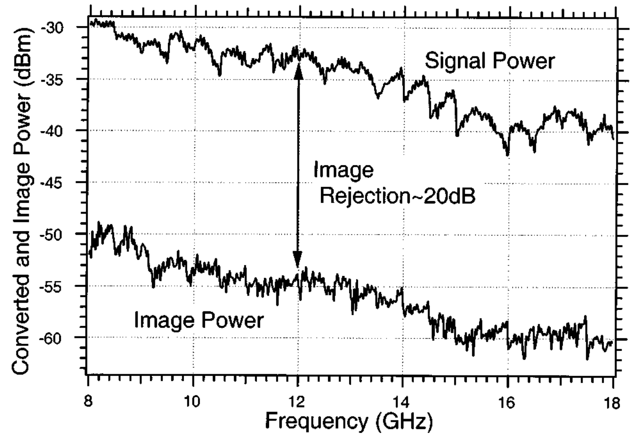

Fig. 3. Measured conversion loss and image rejection of the system. RF input power = +5 dBm.

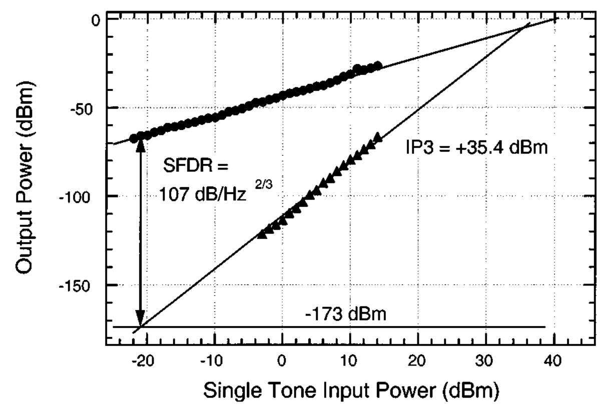

Fig. 4. Measured two-tone third-order nonlinearity of the system. The signal and third-order system outputs are plotted versus the input power of a single tone.

center wavelength. In addition, the Fabry–Perot filters were not controlled actively. Filter drift caused the output signal to vary by as much as 6 dB within a 60-min period. Active control of the filter position should eliminate this problem and would be required in a practical system. The high conversion loss (35–47 dB) was due to the low photocurrent present at the photodetectors. The optical insertion losses limited the photocurrent to approximately 1 mA, most of which was from light at the fundamental laser wavelength. The contribution from the desired optical sidebands measured only 0.2 mA. The photocurrent should be increased in future systems through the use of optical amplifiers or lower loss optical filters. Our current experiment was limited to the available components. The image power level was approximately 20 dB below the power level of the converted signals over the entire bandwidth, as Fig. 3 also shows. The image rejection is a function of filter extinction and should increase with the use of higher extinction optical filters; however, it should be noted that higher extinction requires a smaller free-spectral range. There will be a tradeoff between filter extinction and wavelength separation.

The two-tone intermodulation distortion and noise figure of the system were measured with similar conditions as noted above. Fig. 4 shows the power of both the downconverted signal and intermodulation products versus the single-frequency input

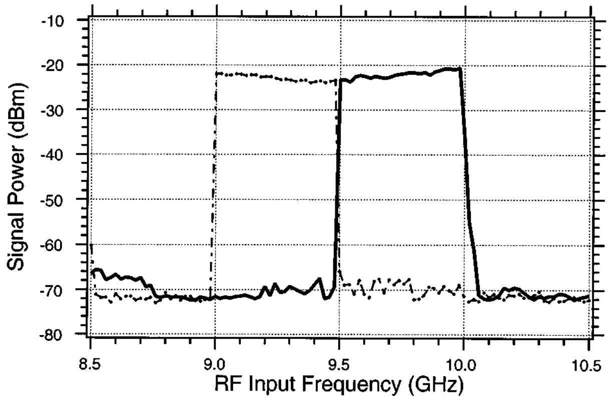

Fig. 5. Measured spurious crosstalk between adjacent channels. RF input power $= +10$ dBm.

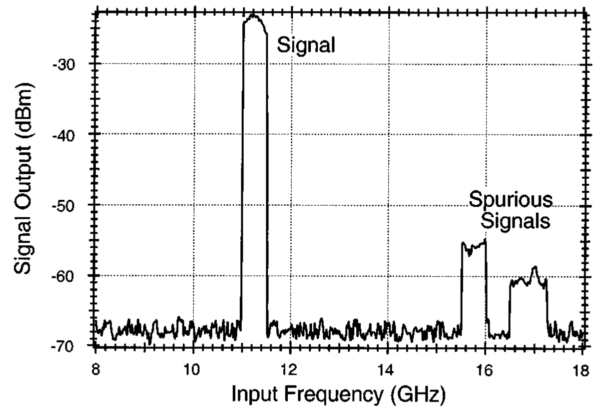

Fig. 6. Measured spurious signal performance of the system. RF input power $= +10$ dBm.

power of the system. The input frequencies were 17.325 and 17.175 GHz, with a local oscillator of 15 GHz. As shown in Fig. 4, the SFDR of the system is 107 dB/Hz$^{2/3}$ with a third-order intercept point of +35.4 dBm. The noise figure was measured by adding a preamplifier (noise figure$_{\rm AMP} = 2.4$ dB, gain = 43 dB) to the channelizer. The noise figure measured between 5 and 7 dB with the addition of the preamplifier resulting in a calculated noise figure of 45–48 dB without preamplification. The high noise figure is primarily due to the large conversion loss of the system and may be reduced through our efforts to increase the photocurrent at the system output. Requiring a preamp reduces the noise figure but it would degrade the SFDR.

Our experience suggests that an evaluation of the system's spurious signal performance is required when analyzing downconverting systems. A previous version of our image rejection downconverter [9] that utilized both microwave and photonic technology exhibited excellent image rejection capability (>60 dB) but the spurious signals at the system output severely limited its useful bandwidth. The crosstalk between adjacent channels in the system presented here was determined by tuning the laser wavelengths to adjacent pass bands of the Fabry–Perot filter. The RF receive bands were 9–9.5 and 9.5–10 GHz, with local oscillators of 7 and 7.5 GHz, respectively. During the measurement, the RF input frequency (+10 dBm) was swept from 8.5 to 10.5 GHz and the signal outputs were monitored. Fig. 5 shows that the spurious signals resulting from an adjacent channel were more than 45 dB below the power level of the desired signals.

Next, we investigated the single-channel spurious signal performance by measuring the power of the spurious signals present at the system output while the RF input frequency was swept between 8 and 18 GHz (+10 dBm). Fig. 6 shows the spurious signal performance for the 9–9.5 GHz channel (LO = 7 GHz). The spurious signals were >30 dB below the power level of the signal for each channel.

Having described the performance of the two-channel system, which uses 3-dB couplers to multiplex the wavelengths, it is important discuss some of the issues that will need attention when DWDM technology is used to increase the number of channels. Fiber nonlinearities, such as stimulated Raman scattering, self-phase modulation, cross-phase modulation, and the optical Kerr effect, contribute to the crosstalk in analog photonic links and will need to be overcome [10]. In addition, including a WDM in our systems output will further complicate the situation by adding wavelength-dependent power transmission and incomplete channel isolation [11]. The effects described above will be detrimental to a multichannel version of our system and will need to be addressed prior to its development.

IV. Conclusions

We have used phase modulators and a Fabry–Perot filter to develop an all-optical image rejection downconverter with channelization. A conversion loss of 35–47 dB, 20 dB of image rejection, and a 107-dB/Hz$^{2/3}$ SFDR were demonstrated. We intend to improve these parameters in our future research by increasing the photocurrent, and by utilizing optical filters with higher extinction.

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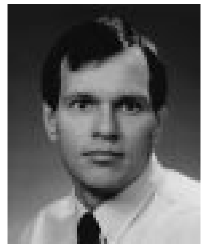

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