An Ultrawideband Image Rejecting Microwave Downconverter Using WDM

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I. ABSTRACT

A microwave-photonic frequency shifting system capable of 60 dB image rejection over a DC to 18 GHz bandwidth is described. The final IF band can exist within the original RF frequency range with 60 dB isolation. The system allows antenna remoting via optical fiber, and maintains phase coherence through the use of WDM techniques.

II. INTRODUCTION

There are generally two types of conventional microwave components that may provide significant frequency translation with image rejection; the digital phase modulator and the electronic image rejection mixer. In the case of a digital phase modulator, a Serrodyne phase modulated waveform [1] is applied to the desired electrical signal to be shifted. Image rejection is limited by the number of discrete bits, typically less than ten, which limits the achievable rejection to less than 25 dB. In the case of an electronic image rejection mixer, an oscillator is used to shift the original frequency. The achievable image rejection is limited by the ability to create two broadband microwave signals exactly 90 degrees out of phase with identical amplitudes (independent of the input frequency). Typical devices with a 3-degree phase error and a 0.25 dB amplitude imbalance (achievable in commercial devices [2]) are limited in their image and carrier rejection to less than approximately 30 dB.

The image rejecting downconverter described here shifts microwave signals in the DC to 18 GHz range to an arbitrary intermediate frequency between DC and 18 GHz, without interference between the original and converted signals. In particular, the system prevents the image sideband associated with the intended frequency sideband to be converted to an intermediate frequency band between DC and 18 GHz. The primary design objectives of this system are to (a) provide RF to IF isolation of 60 dB or greater, (b) provide image rejection of 60 dB or greater, and (c) maintain phase coherence throughout the system to satisfy the requirements of coherent RF applications (e.g., phased arrays).

III. SYSTEM DESIGN AND OPERATION

Figure 1 shows a block diagram of the image rejecting downconverter. The laser L1 provides an optical carrier at a wavelength \( \lambda_1 \) for the signal generated by local oscillator LO1, while laser L2, centered at wavelength \( \lambda_2 \), provides an optical carrier for the signal generated by local oscillator LO2. Mach-Zehnder electro-optic Modulators (MZM1 and MZM2) modulate their respective LO signals onto the optical carriers. The two optical carriers are combined using a 3-dB polarization maintaining (PM) splitter, which sends the signal through a PM optical fiber of arbitrary length. Both carriers are transmitted through a single fiber to the remote site so that coherence is maintained between LO1 and LO2. At the remote site, another 3-dB splitter divides both carriers to two optical fiber paths.
One path transmits the carriers through an Etalon which has an optical passband centered at $\lambda_1$. LO1 is thus detected at PD1, which drives the upconverting mixer. The other path transmits the carriers through a PM Etalon, which is tuned to pass $\lambda_2$. This way, the carrier modulated by LO2 is transmitted to MZM3 on the proper polarization axis for the modulator.

The RF signal mixes with LO1 at the upconverting mixer M1. The upconverted wide-band signal is amplified at A2, then transmitted through a 2 GHz band-pass filter (BPF) into MZM3.

Finally, the IF1 band (defined by the BPF) is shifted using LO2 at MZM3. The resulting downconverted band, IF2, is transmitted via optical fiber back to the local site where it is detected by PD2.

LO1 is tunable, and acts to translate a desired portion of the received RF frequency band through the band-pass filter. Figure 2 depicts a graphical representation of the traditional and image rejecting downconverter input signals. Mixing occurs between the RF and the LO shown in Figure 2(a), with the resulting frequency response the superposition of the signals shown in Figure 2(b). Therefore, the overlapping part of the original RF band and image band interferes with the desired IF band. By using a two step frequency shift, the original RF band is upconverted using LO1 so that the desired portion of the band passes through a bandpass filter, as shown in Figure 2(c). The filtered IF1 band is then downconverted using a fixed LO2 signal to the desired frequency range (Figure 2(d)).

IV. RESULTS

The image rejecting downconverter was tested using a Hewlett Packard 8510C network analyzer system and an HP 8563 spectrum analyzer. Two tones were applied to the RF input of the system using isolators and a 3-dB microwave coupler. One tone was set to a center frequency of 6000 MHz, representing the desired RF signal, and the second “undesired” tone was set to a center frequency of 2000 MHz plus a small offset of 40 MHz. Since the “undesired” image tone would be downconverted to the same IF2 frequency (with LO1 minus LO2 set to 4000 MHz), the small offset was added to distinguish between the image and the desired signal. Following the signal path through the system, the two RF tones are upconverted with LO1 set to 15.3 GHz. Thus, the tone representing the upper sideband is shifted to 21.3 GHz and the tone representing the lower sideband is shifted to 17.3 GHz. (The passband of the filter is between 21.3 to 23.3 GHz.) LO2 is set to 19.3 GHz which downconverts both the 21.3 GHz tone and the 17.3 GHz tone (the image) to 2 GHz, separated by the 40 MHz offset. Figure 3(a) shows that both the desired signal and the image appear at the output port of the system at IF2 when the bandpass filter is removed.
Figure 3(b) shows that the image is greatly attenuated when the filter is inserted, with very little attenuation of the desired IF. This test demonstrates both image rejection and RF to IF isolation of approximately 60 dB.

V. DISCUSSION

The system described herein provides image rejection of greater than 60 dB across more than 12 GHz, exceeding commercially available devices by 25 to 45 dB. By virtue of low-loss optical fibers, this system allows the lasers and local oscillators to be separated by several kilometers from the remainder of the system. Thus, this system may be implemented using a remote antenna site, which is advantageous to many military and commercial applications.

With traditional downconverting systems [3,4], the IF bandwidth is limited to the region outside the RF band. For a 0.1 – 18 GHz system, this would allow for only a DC - 100 MHz downconverted IF band. The present system allows the IF band to exist within the RF band (without interference) by using a two-step frequency shift technique and band-pass electronic filters.

With the microwave-photonic image rejecting downconverter, it is also possible to implement microwave sub-carrier modulation techniques [5] without concern for image frequency interference in the shifted signal. This allows telecommunication and CATV systems to downconvert densely multiplex communication channels into a low frequency band where conventional electronics can perform signal-processing functions.

Another feature is highlighted by considering the photonic link noise figure (NF). Assuming a 50-ohm, shot noise limited system [6], Nichols, et.al, have described the relationship between NF, detector current, and modulator half-wave voltage (Vπ) [7]. From this analysis, Figure 4 was generated to estimate the NF of a typical link. For a typical photodetector current and Vπ of 4 mA and 10 V, respectively, a noise figure well above a desired maximum NF of 15 dB is predicted [8]. Therefore, barring any advances in modulator Vπ, phase matched preamplifiers are necessary at an antenna array to sufficiently decrease the noise figure of the system. Phase matching of low-noise amplifiers across the entire wideband is difficult, limiting the performance of traditional downconverters for coherent RF systems.

However, since the present system mixes RF signals to a relatively narrow passband, the phase matching requirements of the amplifiers are reduced, thus improving system performance for coherent applications.
Also for array systems, coherence between the two LO signals is maintained so that relative phase information between antenna paths is not distorted. Wavelength division multiplexing (WDM) techniques were used to transmit the LO signals to the remote site on a single fiber, thus maintaining the relative phase relationship between signals.

VI. CONCLUSION

A downconverting system was constructed that allows ultrawideband signals to be arbitrarily shifted into an IF band, while still maintaining image rejection. Image rejection and RF to IF isolation are greater than 60 dB for this system.

This method makes phase-matched arrays much more practical due to the reduced sensitivity requirements of the modulators. In traditional phase sensitive arrays which use optical modulators at the antenna site, the use of phase and amplitude matched preamplifiers over the entire RF bandwidth are necessary to achieve low noise figures. This system relaxes those requirements since phase and amplitude matched amplifiers are only required over the desired filter pass-band, which in turn, is only as wide as the desired IF processing bandwidth.

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VIII. REFERENCES