RF/Microwave Photonic Data Links

IPITEK's products cover pure analog transmission for direct conversion to analog television signals, QAM transmission for digital video, internet, and other digital signals sent over the cable networks, and binary digital transmission for backbone networks. These all can be applied to government systems; however, analog transmission has received a lot of interest because sensors used by the defense department and other agencies can have their output directly impressed onto optical carriers by using analog modulation. This is attractive because it requires no analog-to-digital conversion or signal processing at the sensor itself. IPITEK is involved with high-performance versions of these analog links, developing applications and improved performance.

A primary direction of research at IPITEK is reduction of the optical power required by high-performance analog links. In order to achieve high dynamic range, direct-detection analog links require high optical power (several mW) transmitted to the receiver. This can cause problems in several applications. One example of this is mixed-signal transmission

IPITEK is also working on increasing the dynamic range of analog links by linearizing the transmitter. For its commercial products, IPITEK uses a cost-effective form of electronic linearization. For high performance links at frequencies up to 20 GHz, IPITEK uses optical linearization, where the optical modulator itself is made more linear. This technique can be applied to either traditional direct-detection analog links, or to the new low-power suppressed-carrier links, improving the dynamic range by as much as 20 dB in either case.

IPITEK has begun development of suppressed-carrier transmission and coherent detection as a means to reduce the transmitted optical power. Figure 1 shows an implementation of a single-sideband suppressed-carrier link. Single-sideband suppressed-carrier (SSB-SC) modulation is the most efficient form of amplitude-modulated transmission because the only power transmitted is the information sideband.

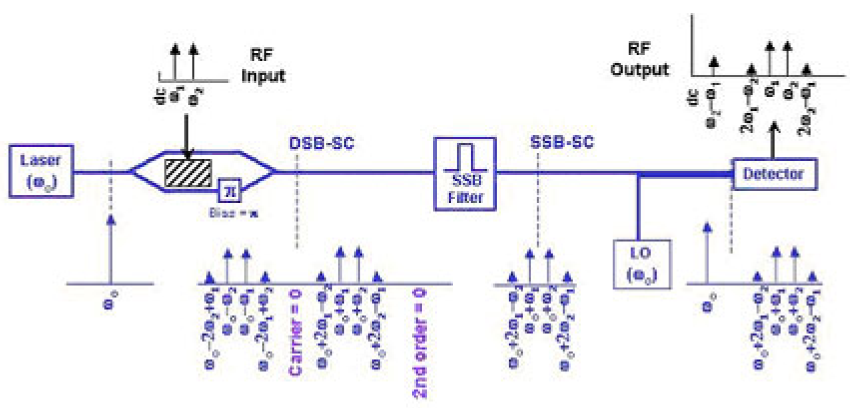

Figure 1: Single-sideband suppressed-carrier analog link

Figure 1 shows one way of achieving SSB-SC modulation. The Mach-Zehnder modulator is biased off which results in only odd-order sidebands. The carrier and all even-order sidebands are eliminated. The optical filter passes only one of the sidebands, so only the power in one sideband is transmitted through the optical link to the detector. An optical local oscillator (LO) must be used at the detector to produce an intensity-modulated signal.

A very small amount of power by analog optical link standards can produce a reasonable signal-to-noise ratio (SNR) at the detector, as shown in Figure 2. The power level we are primarily concerned with is the power transmitted through the link. The power at the detector is larger due to the LO, but the LO power only has to be large enough that LO shot noise exceeds receiver thermal noise (if the LO power equals the received sideband power, which could happen in a very large dynamic range case, the optical modulation depth at the detector is 100%).

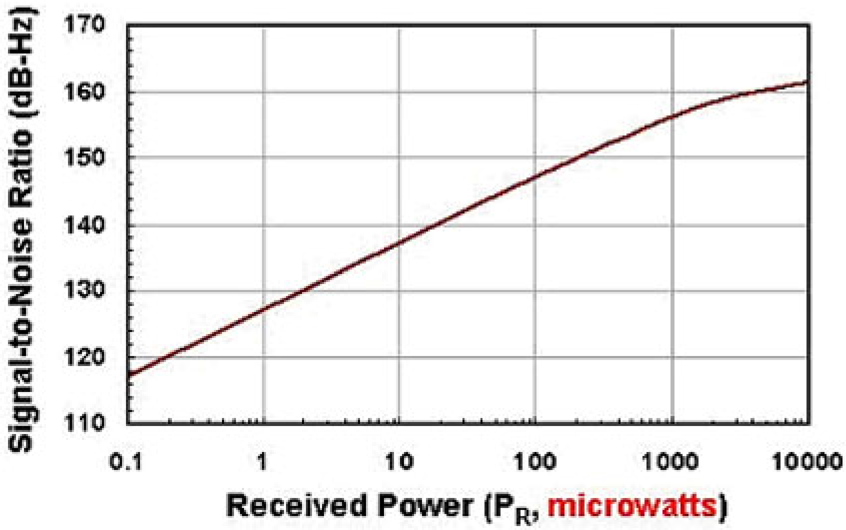

Figure 2: Signal-to-noise ratio of a single-sideband suppressed-carrier analog link

In addition to the desired first-order sideband, unwanted third-order intermodulation products are produced in the optical spectrum by the nonlinearity of the modulator. These can be made arbitrarily small by using a small modulation depth. For a given sideband power, the transmitter laser power can be increased and the modulation depth decreased to achieve any level of third-order intermodulation suppression. Almost all of this laser power is thrown away at the modulator output, though, so only the small sideband power goes through the link. Although this could theoretically be extended to any desired dynamic range by using very large laser power, it is more practical to use a linearized modulator and lower laser power. For a given transmitter laser power, the transmitter nonlinearity sets an upper limit on the modulation depth and thereby the received optical power.

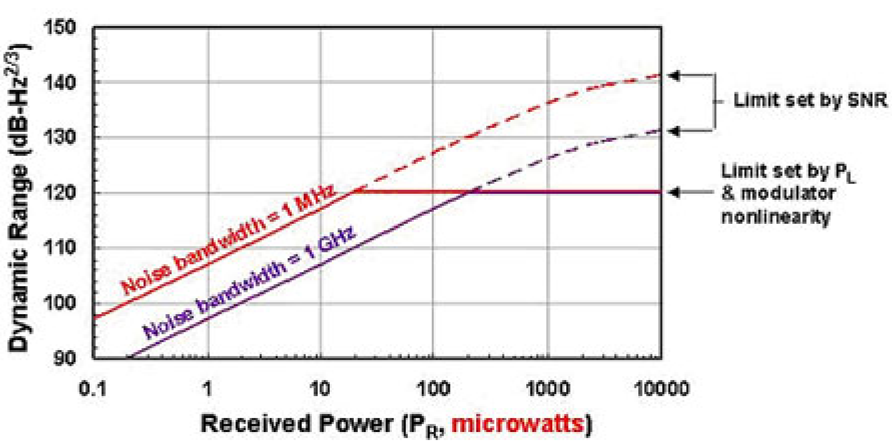

Figure 3: Dynamic range of a single-sideband suppressed-carrier analog link. Transmitter laser power (PL) is 100 mW and local oscillator power is 3 mW.

Figure 3: shows the third-order intermodulation-free dynamic range of a single-sideband link. At low received power, the limit is set by the signal-to-noise ratio and the dynamic range increases as the received power increases. There are different curves in this region for different noise bandwidths because larger noise bandwidths require larger received power for the same signal-to-noise ratio (note that in Figure 2, the signal-to-noise ratio is normalized to a 1-Hz noise bandwidth). At higher received power levels, the dynamic range is limited by the nonlinearity of the transmitter-third-order intermodulation products appear above the noise floor at the link output. Dynamic ranges of >110 dB-Hz$^{2/3}$ can thus be achieved with 10 to 100 µW of received power. This is a reduction in the received power of about 1000x compared to a direct-detection link with the same dynamic range.

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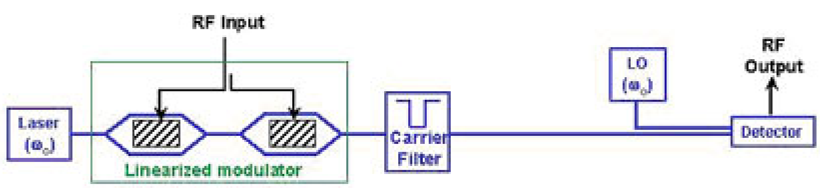

Figure 4: Linearized modulator formed by cascading two Mach-Zehnder modulators, used in a suppressed-carrier link.

The linearized modulator of Figure 4 can be used in a normal direct-detection analog link with good results. It can also be used in a suppressed-carrier link as shown in Figure 4. When used this way, very high dynamic range can be achieved while maintaining the very low received power of a suppressed-carrier link. Figure 5 shows the dynamic range in this case.

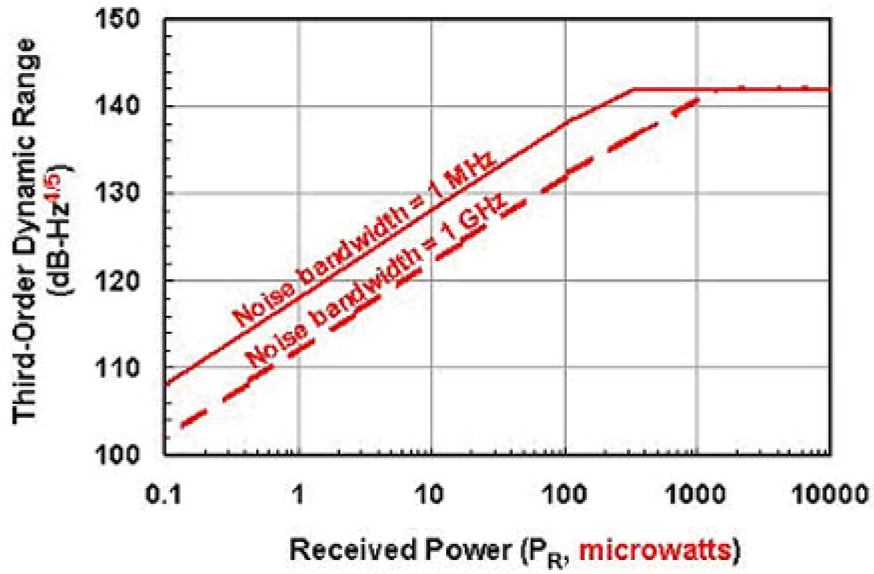

Figure 5: Dynamic range of a suppressed-carrier analog link using a linearized modulator. Transmitter laser power is 100 mW and local oscillator power is 3 mW.

These are just a few examples of the research being done at IPITEK on advanced, high-performance links for RF photonics. Please contact us to discuss your particular applications.

Publication:
1. G. Betts, "High dynamic range coherent analog links using AM-SSB", in LEOS annual meeting, Puerto Rico, Nov. 2004, Invited paper MN3.
2. Y.-C. Hung, B. Bortnik, H.R. Fetterman, R. Forber, W. Wang, "Suppressed carrier optical transmitter with intracavity modulation for coherent analog optical links", JWA63, Proceedings of OFC/NFOEC Conference, March, 2007.