Interference Mitigation via the Nonlinear Transfer Function of Angle-modulated Optical Links

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Abstract: We demonstrate a novel interference mitigation technique that exploits the power-dependent transmission of an optical link. Requiring no knowledge of the interferer's frequency or absolute phase, this technique provides >30 dB suppression of wideband signals.

1. Motivation

With the advancement of high-fidelity radio-frequency (RF) receivers for radar, signals intelligence (SIGINT), and electronic support measures (ESM) applications detection capability for low-power signals of interest (SOIs) has dramatically increased. Improved sensitivity, however, comes with a price – these receivers are increasingly susceptible to high-power interference. A variety of photonic techniques have been proposed to address the interference problem. These include straight-forward cancellation [1] and techniques which exploit the common-mode suppression of interferometric modulators in the optical domain [2, 3]. While effective, these techniques require that the absolute phase of the interferer be known and reproducible with a fixed phase shift (0- or 180-degree) in order to achieve broad bandwidth applicability. Notch filtering achieved through microwave photonic filters has also been demonstrated [4, 5]. While these amplitude-based techniques do not require precise knowledge of the interferer's delay they are applicable only to fixed-frequency interference; tunability is – at best – limited. In this work we exploit the unique input RF power-dependent transmission function of an externally-modulated analog optical link to provide wideband interference suppression based on signal power – without detailed a priori knowledge of the interferer frequency or absolute phase.

2. Theoretical description

A general schematic of how an optical link may be applied for interference mitigation in an RF system is shown in Figure 1. Here, the output from the receiving antenna is passed through the angle-modulated analog optical link that is placed before the RF receiver. The link may be implemented in a variety of architectures including intensity-modulated direct-detection (IMDD), phase-modulated with interferometric detection (PMID), or polarization-modulated (PolM) with a polarizing beam splitter.

Fig. 1: Schematic representation of the use of an angle-modulated analog optical link for interference suppression.

The key concept in our technique is that the magnitude of a signal's complex envelope appears within the Bessel functions that mathematically describe the response of angle-modulated optical links. To illustrate this the RF input to the link is assumed to consist of N real, potentially amplitude- and phase- or frequency-modulated, signals $v_{in}(t) = \sum_{n=1}^N v_n(t) \cos[\omega_n t + \theta_n(t)]$. Here, $|v_n(t)|$, $\theta_n(t)$ and ω_n are the magnitude of the time-domain voltage envelope, the time-varying temporal phase representing phase or frequency modulation, and the center frequency of the n -th signal, respectively. The amplitude of the output current corresponding to the k -th input signal is given by

$$i_k(t) = 2I_{avg} J_1 \left[\pi |v_k(t)| / V_\pi(\omega_k) \right] \prod_{n \geq 1, n \neq k}^N J_0 \left[\pi |v_n(t)| / V_\pi(\omega_n) \right] \quad (1)$$

where I_{avg} is the average received photocurrent, $V_\pi(\omega)$ is the frequency-dependent halfwave voltage of the MZM, and $J_0(\cdot)$ and $J_1(\cdot)$ are the zero- and first-order Bessel functions of the first kind. It is important to note that the output current amplitude of the k -th signal has a $J_1(\cdot)$ dependence on the amplitude of the k -th input voltage and a $J_0(\cdot)$ dependence on the amplitude of all other signals present at the link input. Thus it is clear from Eq. (1) that we may tailor the magnitude of the k -th output signal by judicious choice of the ratio $|v_k(t)| / V_\pi(\omega_k)$ (e.g., through automatic gain control). When $J_1[\pi |v_k(t)| / V_\pi(\omega_k)] = 0$ the k -th signal is suppressed at the link output. All other signals see reduced --

though linear -- gain through the link. For each signal with an amplitude satisfying the suppression condition, all other signals experience a reduction in gain equal to $J_0^2[\pi |v_k(t)|/V_\pi(\omega_k)] = 0.1622$ ($\sim -8\text{dB}$).

3. Experiment

To demonstrate our technique we construct an IMDD link consisting of a distributed feedback laser, low-halfwave voltage Mach-Zehnder intensity modulator ($V_\pi \approx 1\text{ V}$), and high-speed photodiode. The average photocurrent varies in the experiments presented here (1 – 10 mA). In this technique it is the

Fig. 2: Demonstrations of interference mitigation. (a) Time-domain envelopes of 10 microsecond bandwidth-limited pulses at a center frequency of 450 MHz. (b) Power spectra corresponding to the time-domain waveforms in (a). (c) Time-domain signal amplitudes (black: input, red: output) and waveform spectrogram for a 455 MHz center frequency, 25 MHz bandwidth FMCW signal. (d) Power spectra corresponding to the signals in (c).

ratio of the magnitude of the time-domain envelope to the modulator halfwave voltage which determines the amount of suppression achieved. Any constant-magnitude waveform – including bandwidth-limited pulses or linear frequency-modulated continuous-wave (FMCW) signals -- may then be suppressed using this technique. To illustrate this, we apply a single 10-microsecond duration, 450 MHz center-frequency constant-amplitude pulse to the link input. The peak voltage is adjusted to achieve maximum suppression of the waveform at the link output. Figure 2(a) shows the input (black) and output (red) time-domain pulse envelopes. Comparison of the peak input voltage (1.3 V) to the constant-amplitude portion of the output waveform ($\sim 5\text{ mV}$) illustrates a peak power suppression of $\sim 48\text{ dB}$. The sharp features on the leading and trailing edges of the output waveform are due to the finite rise and fall-times of the input voltage pulse. The power spectra of the input and output waveforms [FFT of the time-domain data in Fig. 2(a)] are shown in Fig. 2(b). As expected, the output power-spectral density is decreased by 48 dB as calculated from the time-domain voltage amplitudes. Deep suppression is achieved across the waveform bandwidth – the sharp features in the time-domain waveform possess little of the waveform energy. As a second example, we apply a 25 MHz bandwidth, 455 MHz center frequency FMCW waveform to the link input. Figure 2(c) illustrates the waveform's instantaneous frequency (dashed black) and the waveform's input (black) and output (red) time-domain amplitudes. The input amplitude is again chosen to achieve strong suppression of the signal at the link output. Comparison of the mean time-domain amplitudes of the input and output waveforms (1.28 V and 29.2 mV, respectively) demonstrates $\sim 33\text{ dB}$ suppression of the FMCW waveform at the link output. This suppression is also clearly illustrated by the input (black) and output (red) power spectra shown in Fig. 2(d). Here, $\sim 33\text{ dB}$ suppression is observed across the waveform's 25 MHz bandwidth. It should be noted that the maximum suppression achieved for both the bandwidth-limited pulse and FMCW waveforms as compared to the CW case is due to amplitude fluctuations on the input waveforms. Decreasing the dependence on amplitude fluctuations represents a key area of future work.

4. Summary

We present a novel amplitude-based technique for interference mitigation in RF systems. Based on the power-dependent transmission function of an angle-modulated analog optical link, this technique provides strong suppression of unwanted signals without requiring intimate knowledge of the signals frequency or absolute phase.

5. References

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