Multipath Mitigation from FM-AM Correlation

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***Abstract*— Multipath is one of the limiting factors for an accurate outdoor and indoor localization. We proposed an approach that uses a multipath mitigation derived from the undesired frequency-to-amplitude conversion of a frequency modulated (FM) signal experiencing multipath.**

Keywords*— *fading; frequency modulation; indoor location; multipath

I. Introduction

Multipath propagation is one of the limiting factors for an accurate outdoor and indoor localization [1, 2]. It introduces multipath fading due to the interference of the direct line-of-sight (LOS) signal with reflected signals from objects such as buildings, ground, trees, and other obstacles. The destructive interference of LOS and the reflected signals can create frequency dependent spectral nulls. Indoors, multipath fading occurs frequently and makes it quite difficult to accurately estimate the direct path length. Different multipath compensation schemes have been proposed and implemented over the years to tackle the effect of multipath propagation for accurate location [3, 4]. In this paper, we describe a method of multipath correction that uses correlation between frequency modulation (FM) and amplitude modulation (AM) signals due to frequency-to-amplitude conversion of a FM signal experiencing multipath. The simulation result of the proposed multipath mitigation method is presented.

II. Methods/Results

The proposed approach of multipath mitigation utilizes the undesired frequency-to-amplitude conversion of a frequency modulated (FM) signal experiencing multipath. The basic concept is to measure correlation between the demodulated FM and AM of the received signal under multipath environment and create a control signal for feed-forward correction. One advantage of measuring AM is its simplicity, it requires an AM detector which is a simpler, smaller, and less expensive device.

The block diagram of the scheme used for reducing multipath effects on FM signals is shown in Fig. 1. We implemented this configuration in a LabVIEW simulation. First, the TX signal was generated by frequency modulating a carrier with white Gaussian noise. A model for a simple multipath channel was created by adding a single delayed, attenuated version of the TX signal to itself.

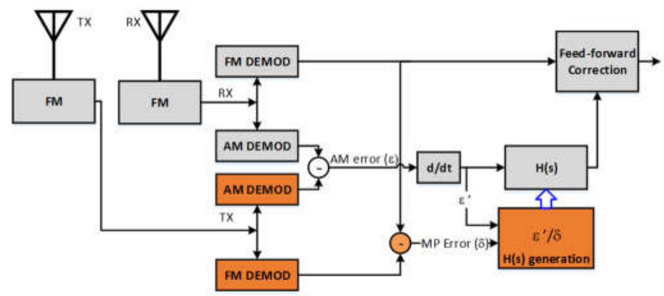

Fig. 1. Block diagram of the FM-AM correlation measurement and compensation technique. The orange blocks are required only for H(s) generation. H(s) is the control transfer function that maps amplitude fluctuations to multipath (MP) error. In case of two-way ranging known modulation symbols can be used for H(s) generation.

Sending the TX signal through this multipath channel generates the received signal RX. The received signal is simultaneously FM and AM demodulated. In addition, the TX signal is also FM and AM demodulated at the transmitter end. The instantaneous multipath error, $\delta(t)$ is determined by subtracting the received FM demodulated signal from the transmitted FM demodulated signal. Similarly, the AM error, $\varepsilon(t)$ is obtained by subtracting the received and transmitted AM demodulated signals. The cross-power spectral density (CPSD) which is a measure of correlation between two time- series, is calculated between $\delta(t)$ and $\varepsilon(t)$ and is given by

$$S_{\delta\varepsilon}(f) = \frac{2}{T}\left\langle \Delta(f)\,\mathrm{A}^*(f) \right\rangle_m , \tag{1}$$

where, $\Delta(f)$ and $\mathrm{A}(f)$ are the Fourier transforms of $\delta(t)$ and $\varepsilon(t)$ respectively, T is the measurement time normalizing the power spectral density (PSD) to 1 Hz, "*" indicates the complex conjugate, and $\langle\ \rangle_m$ denotes an ensemble of m averages. The simulation results in decibels (dB) of $S_{\delta\varepsilon}$ along with S_δ (= PSD of $\delta(t)$) and S_ε (= PSD of $\varepsilon(t)$) are shown in Fig. 2. The degree of correlation between S_δ and S_ε can be described by a correlation function, ρ [5]

$$\rho = \frac{S_{\delta\varepsilon}}{\sqrt{S_\delta S_\varepsilon}} , \tag{2}$$

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where $\sqrt{S_\delta S_\varepsilon}$ is the geometric mean of S_φ and S_α. The values of ρ range from 0 to 1 and $\rho = 1$ represents 100 % correlation. Fig. 2 shows that the cross-spectrum is almost the expected geometric mean between 10 kHz and 1 MHz offset frequencies indicating almost a 100 % correlation. Further, it can be seen from Fig. 2 that the slope of S_ε is f^0 and S_δ is f^2, so if we generate a control signal utilizing S_ε that is of same magnitude, the same noise slope, and opposite phase as the S_δ, then this control signal can be used in a feedforward approach to reduce the error due to multipath.

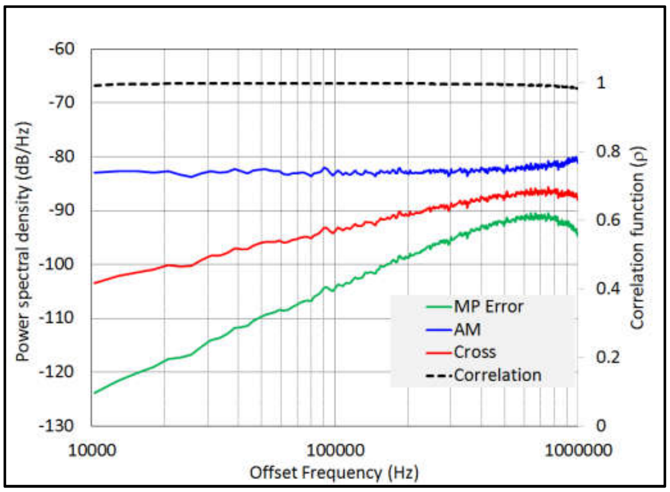
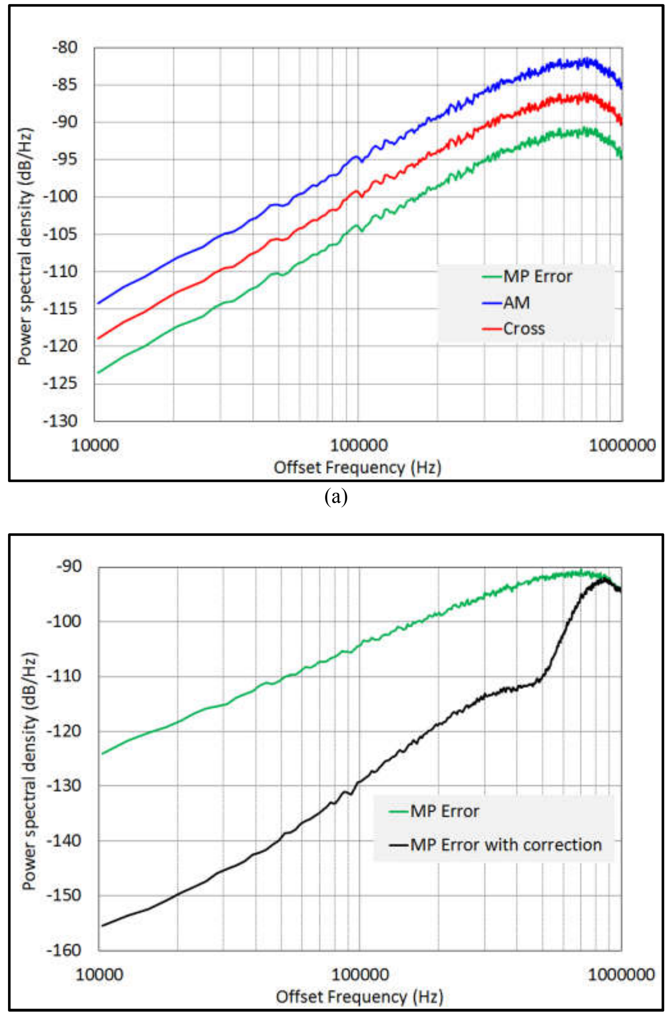


Fig. 2. Plot of the power spectral density $S_{\delta\varepsilon}$ (cross) along with S_δ (multipath error) and S_ε (AM) (left axis). The plot shows almost 100 % correlation ($\rho = 1$) as shown on the right axis. For this simulation, a 100 MHz carrier frequency modulated with white noise (standard deviation = 0.1, noise bandwidth = 1.0 MHz, modulation index = 0.3) and multipath delay, $\tau = 13$ ns was used. MP – Multipath.

To simplify the control transfer function, H(s), the slopes between S_δ and S_ε can easily be matched by taking the time derivative of $\varepsilon(t)$ to produce $\varepsilon'(t) = d\varepsilon(t)/dt$. This is shown in Fig. 3 (a) indicating that S_δ, $S_{\varepsilon'}$ and $S_{\delta\varepsilon'}$ all now have the same slope. Here, $S_{\varepsilon'}$ is the PSD of $\varepsilon'(t)$ and $S_{\delta\varepsilon'}$ is the CPSD between $\delta(t)$ and $\varepsilon'(t)$. H(s), which maps amplitude fluctuations to multipath error is generated with the LabVIEW frequency response function (FRF). For calculating H(s), $\varepsilon'(t)$ is used as the stimulus signal and $\delta(t)$ as the response signal. Once the transfer function is created, $\varepsilon'(t)$ is filtered with the transfer function and applied to the FM demodulated signal in a feedforward fashion. The PSD of the multipath error $\delta(t)$ is measured with and without the control signal and is shown in Fig. 3 (b). An improvement of greater than 20 dB over two decades of offset frequencies can be seen. However, this scheme works for a fixed multipath condition and requires re-calculation of the transfer function when multipath environment changes (i.e. the antennas positions move). This problem can possibly be addressed with an adaptive control system. Also, in case of two-way ranging conditions a known modulation symbols can be used for H(s) generation.



(b)

Fig. 3. (a) Plot of the power spectral density $S_{\delta\varepsilon'}$ (cross) along with S_δ (multipath error) and $S_{\varepsilon'}$ (derivative of AM). (b) Plot of S_δ (multipath error) with and without feedforward correction. MP – Multipath.

III. Conclusions

We proposed a new multipath mitigation technique suitable for narrowband systems. It relies on FM-AM correlation when the FM signal experiences multipath, we reported more than 20 dB reduction of multipath distortion.

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