Design of a Noise and Jamming Resistent FM Transmitter/Receiver System

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***Abstract*—FM transmission and reception is a well established field. This report summarizes the effect of noise interference in FM signals, and explains the methodologies used to reduce the impact of noise. The consequences of capture effect has been studied, particularly its significance in signal jamming. A frequency-hopping jamming avoidance scheme has been implemented for a FM broadcast transmitter and receiver.**

I. Introduction

Apart from classical modulation and demodulation, we also have to take care of other factors while modeling the FM transmitter/receiver. The channel introduces noise which is mixed with the modulated signal. Receivers need to be immune to jamming as well. Jamming occurs when two signals modulated with the same carrier frequency reaches the receiver. The signal which is stronger in amplitude will be heard. This is known as *capture effect*. We investigated into various noise reduction and anti-jamming techniques. Noise affects the SNR of the modulated signal. The noise we used to model our channel was Additive White Gaussian Noise(AWGN). Since AWGN is not constrained to a particular frequency range, classical filtering techniques won't help as we end up losing message information as well. Thus, we used techniques which improve the SNR, thus ensuring that the message signal stays in the forefront. To achieve this, we used a pre-emphasis filter before modulation and a de-emphasis filter after demodulation. This was followed by a matched filter. This gave us a decent rise in SNR.

The capture effect is a phenomenon associated with FM reception in which only the stronger of two signals at, or near, the same frequency or channel will be demodulated. It occurs due to the complete suppression of the weaker signal at the receiver limiter. This phenomenon can be used by potential jammers who transmit a stronger signal which is demodulated by the receiver instead of the original message signal. A jammer can thus completely disrupt FM communication, provided the frequency of modulation is known. To avoid jamming, a frequency hopping scheme has been implemented. This is a method of transmitting signals by switching the carrier among many frequency channels using a pseudo random sequency known only to the transmitter and receiver. This makes it harder for a jammer to jam the transmitted signal. A suitable hopping frequency was chosen, keeping in mind that the signals to be transmitted are mostly audio signals. In case the duration of the message to be transmitted is longer than the hop duration, the message is divided into frames and transmitted accordingly.

II. Design

The FM transmitter/receiver were modelled using MATLAB's Communications Toolbox. A 9 second audio clip was used to test the system. The audio message signal is shown in Figure 1. The audio signal was first band limited to $10KHz$ using a low pass filter. The Frequency Spectrum of the signal is shown in Figure 2. The communication channel was modelled by creating a function which adds Additive White Gaussian

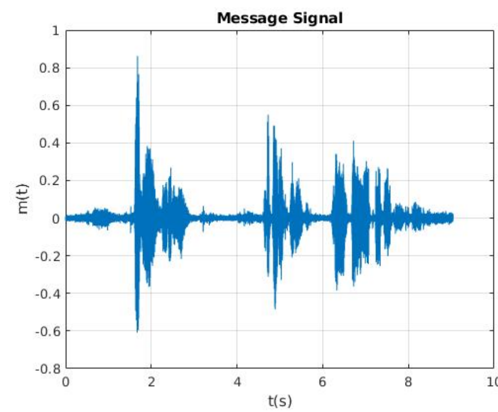

Fig. 1. Temporal Analysis of the message signal

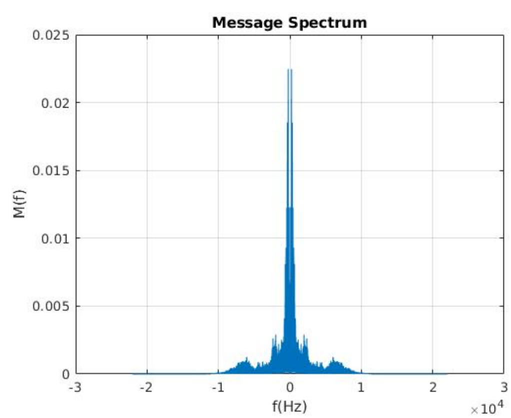

Fig. 2. Spectral Analysis of pre-processed message signal

Noise (AWGN) of a specified Signal-to-Noise Ratio (SNR) to the modulated signal.

A. Frequency hopping

The FM transmitter was designed to hop among 5 different carrier frequencies, the lowest of them being $4KHz$. Hopping is undertaken at multiples of the lowest frequency, reaching a maximum of $20KHz$. Thus, the overall bandwidth used by the system is $20KHz$. A pseudo-random sequence of hopping is decided by the transmitter and receiver. The transmitter hops with a duration of $2s$ and the receiver is synchronized to the same hopping frequency. This scheme provides a simple layer of protection from a potential jammer, since a jammer may not be aware of the sequence of frequency hopping. The frequency spectrum of a modulated signal for a sequence of $1-2-3-4-5$ is shown in Figure 3. The spectrum consists of the message signal modulated at carrier frequencies of multiples of $4KHz$.

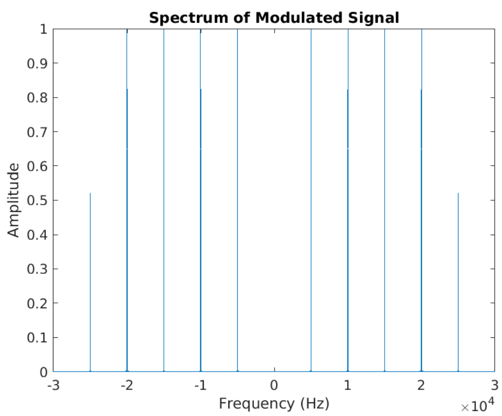

Fig. 3. Spectral Analysis of modulated signal

B. Noise Reduction

A white Gaussian Noise of specific SNR was added to the signal. The initial approach taken to remove this noise was classical pre-emphasis and de-emphasis techniques. This gave us minimal increase in SNR. We then tried to use matched filtering to increase SNR. This corrupted the audio signal itself. We speculate that this happened because matched filtering works best in the case of digital communication. Here, we are dealing with analog communication. We also tried median filtering, but this attenuated the audio content as well. Thus, we proceeded to focus on filters which try to compute a statistical estimate of the original signal.
Gaussian noise is added in order to mimic any random processes that occur in nature. A Gaussian Random Process can be completely characterized by its mean and auto-correlation function. It is also a Wide Sense Stationary Process. Thus, the receiver noise is modelled as a random process with zero mean (Normal Distribution) and a 'Flat' or 'White' Power Spectral Density (PSD). Our next attempt was then to find a technique to reduce this noise. Low pass filtering would remove the high frequency noise but not the white Gaussian Noise. Further research into signal processing techniques to handle white noise led us to special filters such as the Wiener filter, Kalaman filter and few adaptive filters. The Wiener filter is a commonly used filter for speech and image enhancement applications. It used to produce an estimate of a desired or target random process by linear time-invariant (LTI) filtering of an observed noisy process. The goal of the Wiener filter is to compute a statistical estimate of an unknown signal using a related signal as an input and filtering that known signal to produce the estimate as an output. The statistical method used is the Minimum Mean Squared Error Estimator (MMSE). The mean squared error which is to be minimised is given by -

$$MSE : E[e^2[n]] = E[(x[n] - s[n])^2]$$

The following assumptions are required to use a Wiener filter -

- The additive noise is a stationary stochastic process.
- The statistical characteristics of the noise is known, such as mean and auto-correlation.

The White Gaussian Noise satisfies these characteristics, which encouraged us to use the Wiener filter.

III. Experimental Results

A. Noise Reduction

An audio clip sampled at 44.1KHz and of 9 seconds duration was chosen for testing. It is shown in Figure 1. The signal was frequency modulated and transmitted through the channel, which added White Gaussian Noise of 75 SNR to the signal. The resulting noisy demodulated signal is shown in Figure 4.

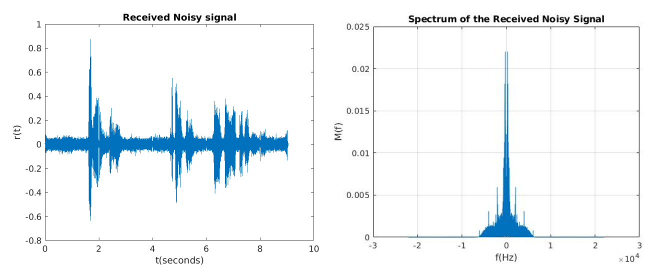

Fig. 4. Received noisy signal and its spectrum

The noisy signal was then filtered using the Wiener filter. The noise-reduced message signal which was obtained is shown in Figure 5.

B. Jamming Avoidance

A simple frequency hopping scheme was implemented with $2seconds$ hopping duration. A pseudo-random sequence of five integers ranging from 1 to 5 was used by the transmitter and receiver. The carrier frequencies were chosen as these integer multiples of the base frequency. The base frequency was chosen to be $4KHz$. Thus, the maximum carrier frequency

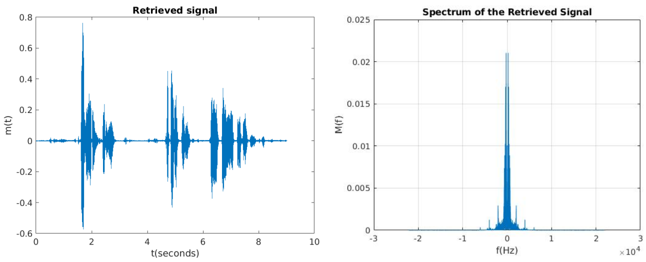

Fig. 5. Noise reduced signal and it's spectrum

used is $20KHz$. Although the pre-emphasis and de-emphasis mechanism did not work well in the noise reduction, we retained them because an increased SNR is another jamming precaution. The audio was then -

1) Frequency modulated according to the hopping scheme.
2) Transmitted via the channel which adds White Gaussian noise.
3) Received and frequency demodulated.
4) Filtered to reduce the noise.

IV. Conclusion

After a lot of literature survey and the given time frame, the most plausible approach to the jamming problem was frequency hopping in a random sequence which is known by the transmitter and the receiver.

For the AWGN reduction, after a lot of investigation, we found out that the wiener filter worked best and reduced almost all of the noise, even the noise present in the input signal. Pre-emphasis and de-emphasis helped improve it marginally. We also tried increasing the SNR of the signal using matched filtering, but this approach did not give us a good output. We are trying to investigate into this.