Pre-emphasis and De-emphasis in FM Modulation and Demodulation

EE 340: Prelab Reading Material for Experiment 5

August 22, 2018

As discussed in the reading material of Experiment 2, in FM signals, the instantaneous frequency of the carrier wave, $c(t) = \cos(2\pi f_c t)$, is varied with the amplitude of message signal $x(t)$, to get the FM signal with instantaneous frequency $f(t) = f_c + f_\Delta.x(t)$. Here f_Δ is called the maximum frequency deviation away from f_c if $x(t)$ is normalized such that the maximum value of $|x(t)| = 1$.

The phase of the FM signal can be written as

$$\phi(t) = \int_0^t 2\pi f(\tau) d\tau = 2\pi f_c t + 2\pi f_\Delta \int_0^t x(\tau) d\tau, \tag{1}$$

and the corresponding passbsand FM signal is

$$s_p(t) = cos\left(2\pi f_c t + 2\pi f_\Delta \int_0^t x(\tau) d\tau\right) = cos\left(2\pi f_c t + \phi_m(t)\right), \tag{2}$$

where $\phi_m(t)$ is the phase (in radians) added to the carrier wave due to the message signal $x(t)$. In your lab-sheets, a constant k_f has been used, where $k_f = 2\pi f_\Delta$.

1 Noise in FM transmission

The channel adds white Gaussian noise to the signal, which basically implies that the power spectral density (PSD) of the added noise is flat (i.e. independent of frequency) in the frequency band of interest, as shown in Fig. 1. Here, we denote the noise added by the channel in the FM signal's frequency band as $n_p(t)$, which can be written as (recall Experiment 4 reading material)

$$n_p(t) = n_I(t)\cos(2\pi f_c t) - n_Q(t)\sin(2\pi f_c t), \tag{3}$$

where $n_I(t)$ and $n_Q(t)$ are both independent of each other and also have flat PSDs. Ignoring scaling factors, the signal received at the FM demodulator input can be written as

$$s_r(t) = s_p(t) + n_p(t) = cos\left(2\pi f_c t + \phi_m(t)\right) + n_I(t)\cos(2\pi f_c t) - n_Q(t)\sin(2\pi f_c t). \tag{4}$$

Figure 1: Block diagram showing message transmission using FM through an AWGN (Additive White Gaussian Noise) channel.

It can be shown that for narrow-band FM, i.e. when $|\phi_m| \ll 1$, and when the noise level is much smaller than the signal level, i.e. $|n_I|, |n_Q| \ll |\phi_m|$, the carrier phase is $\phi_r(t) \approx \phi_m(t) + n_Q(t)$. The demodulated message signal, thus, is

$$x_r(t) = \frac{d}{dt}\phi_r(t) = \frac{d}{dt}\phi_m(t) + \frac{d}{dt}n_Q(t) = x(t) + \frac{d}{dt}n_Q(t). \tag{5}$$

Differentiation of a signal with respect to time results in peaking of high frequency components (differentiation in time domain implies multiplication by $j\omega$ in frequency domain). Since the demodulation process involves differentiation of $\phi_r(t)$, the high frequency components of noise part in it experience a large gain.

2 Use of pre-emphasis and de-emphasis to avoid noise peaking

The problem of noise peaking at high-frequencies in the demodulated signals can be avoided by applying a de-emphasis filter, which is basically a low pass filter with its gain decreasing with frequency. However, simply applying de-emaphasis to the demodulated signal will 'de-emphasize' the high frequency contents of the message signal as well, which will effectively distort the signal.

To avoid this problem, the message signal at the transmitter can first be pre-emphasized (i.e. passed through a high-pass filter) before frequency modulation, as shown in Fig. 2. The resultant signal can then be frequency modulated and transmitted via the wireless channel. The received FM signal is demodulated and passed through a low pass filter to get back the desired message signal. If the product of the pre-emphasis and de-emphasis transfer functions is a constant, message signal distortion as well as high-frequency noise peaking can be avoided.

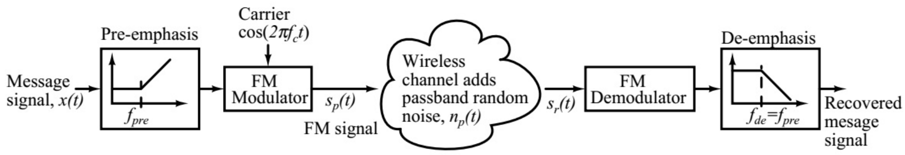

Figure 2: Block diagram showing message transmission using FM through an AWGN channel. Pre-emphasis and de-emphasis filters are used for avoiding noise peaking and getting undistorted signal as the final output.

Typically, the pre-emphasis filter is chosen as a first-order high-pass filter with corner frequency f_{pre}, and the de-emphasis filter as a first-order low-pass filter with corner frequency f_{de}, such that $f_{pre} = f_{de}$. The time constant τ of values 50 μs or 75 μs are commonly used for these filters, for which, the corresponding corner frequency values are given by $f_{\_3dB} = \omega_{\_3dB}/(2\pi) = 1/(2\pi\tau)$. The pre-emphasis and de-emphasis filters can be implemented using IIR filter blocks in GNU radio (please refer to prelab reading material of Experiment 2).

3 FM demodulation in GNU radio

Please again refer to the prelab reading material of Experiment 2. The demodulation of an FM signal (before de-emphasis) can be carried out in the following way. The incoming message signal $x_r[n]$ from RTL-SDR dongle can be multiplied with the conjugate of its one-sample-delayed copy, i.e. $x_r[n-1]$. Therefore, if the phase of $x_r[n]$ is $\phi_r[n]$, then the phase of the resultant signal becomes $\phi_r[n]-\phi_r[n-1]$, which is basically proportional to the desired demodulated signal (before de-emphasis). The proportionality constant $1/T$ (where T is the sampling period) can be multiplied to this resultant phase to get the correct differential value in the absolute sense.

Important note: In the discrete-time implementation in GNU radio, the phase value (which is obtained using the 'Complex to Arg' block) has an ambiguity of $2n\pi$, where n is an integer. Therefore, you need to be careful in your implementation to ensure that the $2n\pi$ jumps in the demodulated signal are avoided. When the noise level is high, these phase jumps are sometimes unavoidable, and as a result, shape of the noise spectrum in the demodulated spectrum changes. Try to observe this effect by increasing noise in your simulations when you are carrying out the experiment.