

Frequency Modulation Frequency modulation (FM) was introduced by E.A. Armstrong in the 1930's as an alternative to the AM commonly in use at the time for broadcasting. The advantage to frequency modulation is that, for a given transmitted power, the signal-to-noise ratio is much higher at the receiver output than it is for AM. The digital version of FM, frequency-shift keying, has been in use since an even earlier date. In FM, the frequency of the carrier is modulated to follow the amplitude of the message signal. To be more specific, if $m(t)$ with peak value p_m is a message signal, then the instantaneous frequency $f(t)$ is given by $f(t) = f_c + k_f m(t)$, where f_c is the carrier frequency and k_f is a proportionality constant called the "frequency sensitivity." The term $k_f p_m$ is called the "frequency deviation" of the instantaneous frequency from the carrier frequency, and the peak frequency deviation f_p is an important FM system parameter. Given the instantaneous frequency, we can find the total instantaneous angle $\theta(t)$ of the carrier by integrating the instantaneous frequency. That is, $\theta(t) = 2\pi \int_{-\infty}^t f(\tau) d\tau$. (18) Since the initial angle $\theta(0)$ is of no consequence, we can simplify the equations by taking $\theta(0) = 0$. The transmitted FM signal is then given by $s(t) = A_c \cos(\theta(t))$. (19) Figure 1 shows a 2 kHz carrier frequency modulated by a 200 Hz sinusoidal message. Figure 1. Frequency Modulated Signal To create an FM signal using the USRP, the message signal is normalized to a peak value of one, multiplied by $2\pi f_p$ and integrated to form the complex-valued signal $e^{j\theta(t)}$, where $\theta(t) = 2\pi \int_{-\infty}^t m(\tau) d\tau$. The complex-valued signal $e^{j\theta(t)}$ is sent to the Write Tx Data vi, and the USRP produces the FM signal. The only tricky step in generating an FM signal is integrating the message. In discrete time we have $m[n]$, nT is the reciprocal of the IQ sample rate. If we write $\theta[n] = 2\pi \sum_{k=0}^{n-1} m[k] T$ (22) then $\theta[n] = 2\pi T \sum_{k=0}^{n-1} m[k]$ (23) Equation (23) is the difference equation of an IIR filter. This filter can be implemented using the IIR Filter vi found in the Signal Processing>Filters>Advanced IIR Filtering palette. Use a "forward coefficients" array of T and a "reverse coefficients" array of 1 .