VERIGY

Hideo Okawara's
Mixed Signal Lecture Series

DSP-Based Testing – Fundamentals 25
PM & FM Waveform Generation I

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Preface to the Series

ADC and DAC are the most typical mixed signal devices. In mixed signal testing, analog stimulus signal is generated by an arbitrary waveform generator (AWG) which employs a D/A converter inside, and analog signal is measured by a digitizer or a sampler which employs an A/D converter inside. The stimulus signal is created with mathematical method, and the measured signal is processed with mathematical method, extracting various parameters. It is based on digital signal processing (DSP) so that our test methodologies are often called DSP-based testing.

Test/application engineers in the mixed signal field should have thorough knowledge about DSP-based testing. FFT (Fast Fourier Transform) is the most powerful tool here. This corner will deliver a series of fundamental knowledge of DSP-based testing, especially FFT and its related topics. It will help test/application engineers comprehend what the DSP-based testing is and assorted techniques.

Editor's Note

For other articles in this series, please visit the Verigy web site at www.verigy.com/go/gosemi.

Preface

In mixed signal device testing, various modulated signals are required as well as sinusoids and multi-tones as stimulus signals, which are programmed and generated by arbitrary waveform generators (AWG). Amplitude, phase and frequency modulations are the most typical modulation. PM and FM is the topics of the month. There are some methods available to create PM and FM modulated waveforms. In this issue, straightforward methods are discussed.

Signal Modulation

Let's define a simple signal $v(t)$ as below;

$$v(t) = A\cos(\omega t + \phi) \tag{1}$$

where A is amplitude, ω is angular frequency and ϕ is phase offset. Each one of the parameters can be modified along time and convey information, so that the modulated signal can be expressed as below in general;

$$v(t) = A(t)\cos(\omega(t)t + \phi(t)) \tag{2}$$

Each parameter can be a function of time. When the amplitude A is modulated, it is called amplitude modulation (AM). When the phase ϕ is modulated, it is called phase modulation (PM). When the (angular) frequency ω is modulated, it is called frequency modulation (FM).

PM Waveform Generation

The blue arrow in Figure 1 shows a rotating vector. When the rotation speed is ω_p [rad/sec], the instantaneous phase of the vector is $\omega_p t$. The green arrow in Figure 1 is a shadow or projection of the rotating vector. The point of the arrow draws a sinusoidal waveform. The frequency of the sinusoid is $\omega_p/(2\pi)$ [Hz].

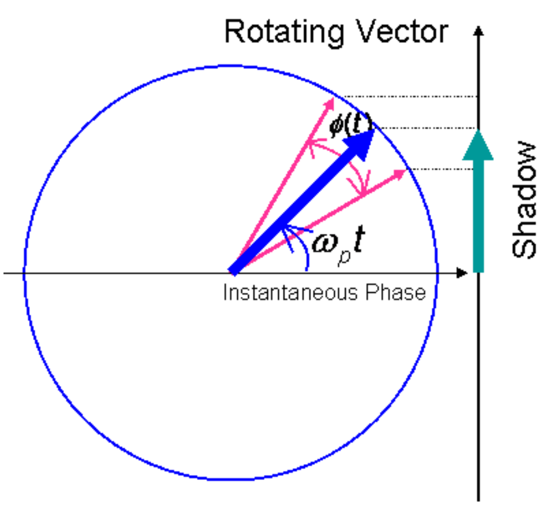

Figure 1: Rotating Vector: PM

PM is modulation to the instantaneous phase of the carrier signal so that it can be described easily by an equation as below;

$$\begin{aligned} v(t) &= A \sin\left(\omega_p t + \phi(t)\right) \\ \phi(t) &= R \sin\left(\omega_q t\right) \end{aligned} \tag{3}$$

The vector is rotating at the speed of ω_p. $\phi(t)$ is the phase variation of the vector that is modulated by the (angular) frequency of ω_q. The phase deviation is $+/-R$ [rad]. Consequently the modulated instantaneous phase of the signal is $\omega_p t + \phi(t)$. From the program coding's point of view, PM is as simple as AM which is discussed in the previous Newsletter article. Basically there are two independent sinusoids. One is the carrier signal and the other is modulation phase offset. The waveform programmed in an AWG is usually looped many times so that the number of sinusoidal waveform cycles in the unit waveform period should be a whole number. List 1 is an example program code. The phase variation is calculated at Line 14, and the modulation can be performed at Line 17, where the phase variation is enclosed in the instantaneous phase.

```
01:   INT      i,Nawg,Np,Nq;
02:   DOUBLE   dFawg,dA,dFp,dFq,dP,dQ,dR;
03:   ARRAY_D dU,dV;
04:
05:   dFawg=102.4 MHz;  Nawg=1024;                 // AWG Condition
06:
07:   dA=1.0;                                      // Amplitude
08:   dFp=5.1 MHz; Np=51; dP=2.0*M_PI*Np/Nawg;  // Carreir Frequency
09:
10:   dFq=0.3 MHz; Nq=3;  dQ=2.0*M_PI*Nq/Nawg;  // Modulation Frequency
11:   dR=1.5*M_PI;                                 // Phase Offset Amplitude
12:
13:   dU.resize(Nawg);
14:   for (i=0;i<Nawg;i++) dU[i]=dR*sin(dQ*i);  // Phase Offset Trend
15:
16:   dV.resize(Nawg);
17:   for (i=0;i<Nawg;i++) dV[i]=dA*sin(dP*i+dU[i]); // Modulated Signal
18:
```

List 1:   PM Program Example

Figure 2 illustrates the PM waveforms generated by List 1. The carrier is 5.1MHz signal. The 300kHz modulation signal is generated with the amplitude of +/-1.5π [rad] as (a). The PM modulated signal is generated as (b). By performing FFT to the PM signal, the frequency spectrum looks as (c). The waveform (b) is PM signal, but it looks as a frequency modulated signal. By analyzing frequency of the waveform (b), the frequency trend is figured out as (d).

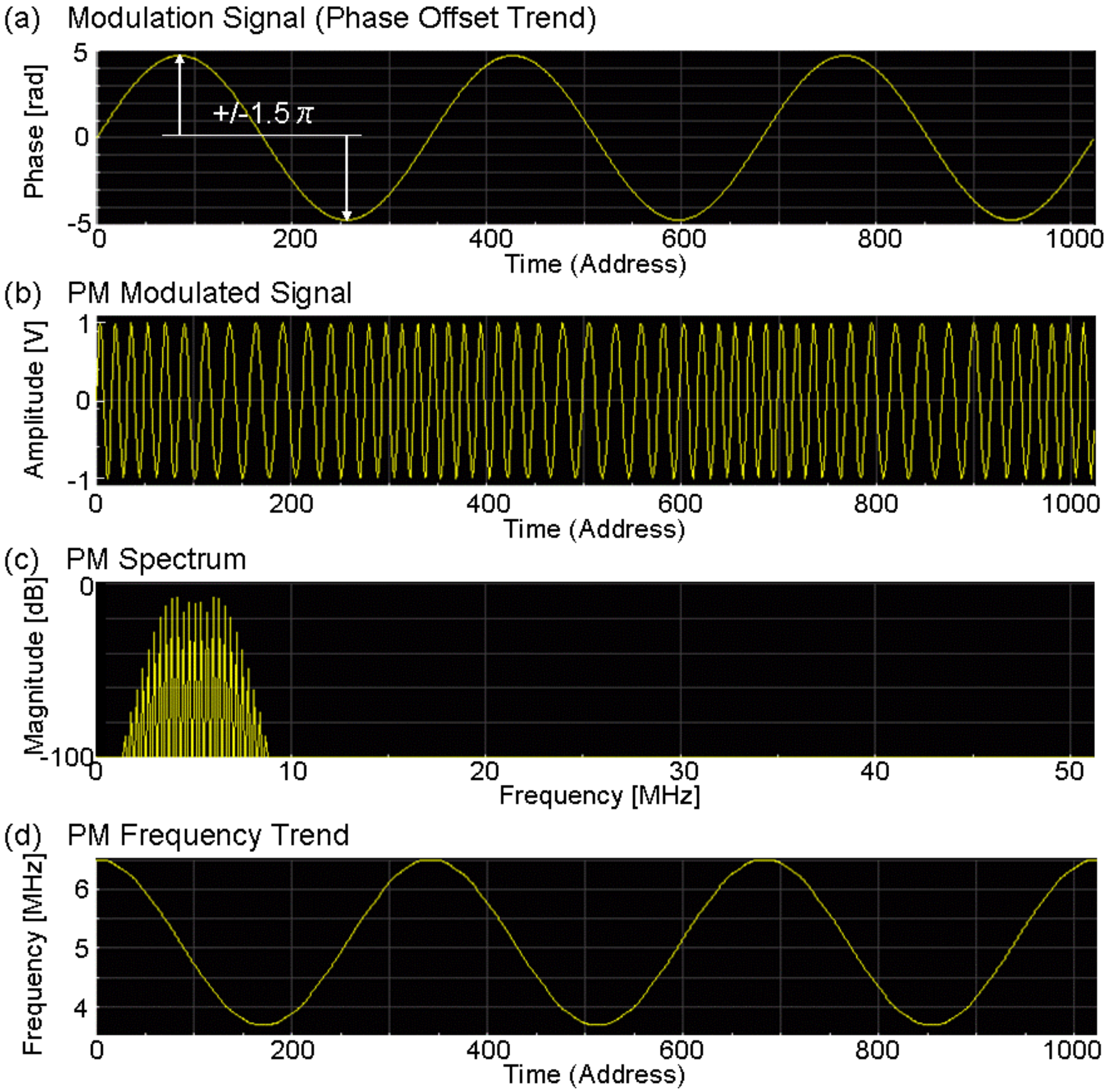

Figure 2 PM Signal

FM Waveform Generation

In terms of FM, the situation is slightly complex than PM.

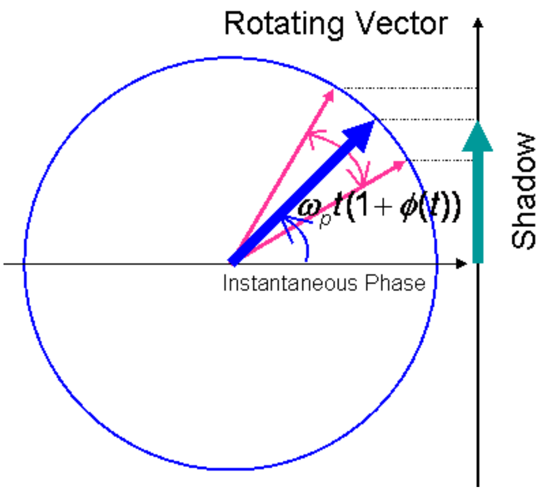

Figure 4: Rotating Vector: FM

FM is modulation to the angular frequency so that it can be described by the equation as below;

$$\begin{aligned} v(t) &= A\sin\left(\omega(t)\cdot t\right) \\ &= A\sin\left(\omega_p(1+u(t))\cdot t\right) \\ u(t) &= R\sin\left(\omega_q t\right) \end{aligned} \tag{3}$$

The vector is rotating at the nominal speed of ω_p. The center frequency ω_p is modulated by the fractional frequency of sinusoid $u(t)$. The frequency deviation is $+/-R/\omega_p$. There are two independent sinusoids. One is the carrier signal and the other is modulated frequency deviation. From the program coding's point of view, FM is not as simple as PM. The deviation sinusoid is nested inside the instantaneous phase of carrier. List 2 is an example program code.

```
01:   INT      i,Nawg,Np,Nq;
02:   DOUBLE  dFawg,dA,dFp,dFq,dFd,dP,dQ,dR,dS;
03:   ARRAY_D dU,dV;
04:
05:   dFawg=102.4 MHz;  Nawg=1024;                    // AWG Condition
06:
07:   dA=1.0;                                          // Amplitude
08:   dFp=5.1 MHz; Np=51; dP=2.0*M_PI*Np/Nawg;  // Carreir Frequency
09:
10:   dFq=0.3 MHz; Nq=3;  dQ=2.0*M_PI*Nq/Nawg;  // Modulation Frequency
11:
12:   dFd=2.0 MHz;        dR=(dFd/2.0)/dFp;     // Freq. Dev. Amplitude
13:
14:   dU.resize(Nawg);
15:   for (i=0;i<Nawg;i++) dU[i]=dR*sin(dQ*i);  // Freq. Shift Trend
16:
17:   dV.resize(Nawg);
18:   dS=0.0;                                          // Instantaneous Phase
19:   for (i=0;i<Nawg;i++) {
20:      dV[i]=dA*sin(dS);                             // Modulated Signal
21:      dS=dS+dP*(1.0+dU[i]);                         // Next Vector Angle
22:      if (dS>(2.0*M_PI)) dS=dS-(2.0*M_PI);   // Phase Wrapping
23:   }
```

List 2: FM Program Example

The frequency deviation is normalized by the carrier frequency at Line 12. The frequency modulation trend is calculated at Line 15. Modulation is performed at Line 20. The instantaneous phase is dynamically calculated at Line 21, which indicates the next vector location.

Figure 5 illustrates the FM waveforms generated by List 2. The carrier signal is 5.1MHz sinusoid. The 300kHz modulation signal is generated with +/-1[MHz] of amplitude as (a). The FM modulated signal is shown as (b). The frequency spectrum of (b) looks as (c). By analyzing the instantaneous frequency of the FM signal (b), the actual frequency is shown as (d). The signal frequency deviates +/-1MHz from the center 5.1MHz.

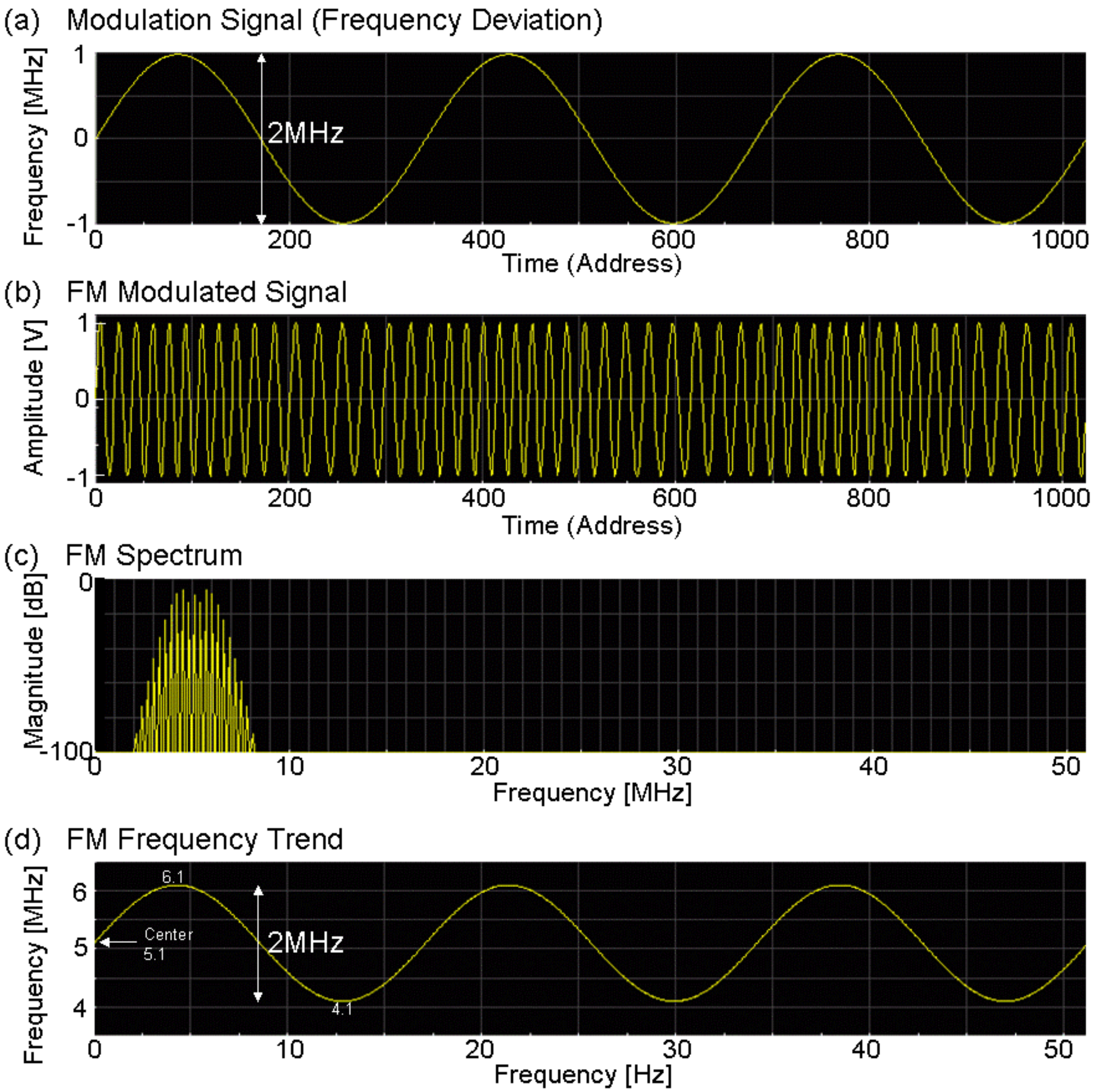

Figure 5: FM Signal

PM vs. FM

As examining Figures 2 and 5, PM and FM waveforms look very similar because they contain dense ranges and sparse ranges alternately. The modulation signal, PM and FM modulated signals, and their frequency trends are put together in Figures 6 and 7. Then you can find that the difference of PM and FM waveforms. FM frequency is proportional to the instantaneous level of modulation signal, while PM frequency is proportional to the gradient of the modulation signal. Consequently FM frequency trend looks 90 degree delayed than PM frequency trend. This fact suggests that FM signal could be generated through PM programming procedure that is simpler than FM programming procedure. This topic will be discussed in the future newsletter issues.

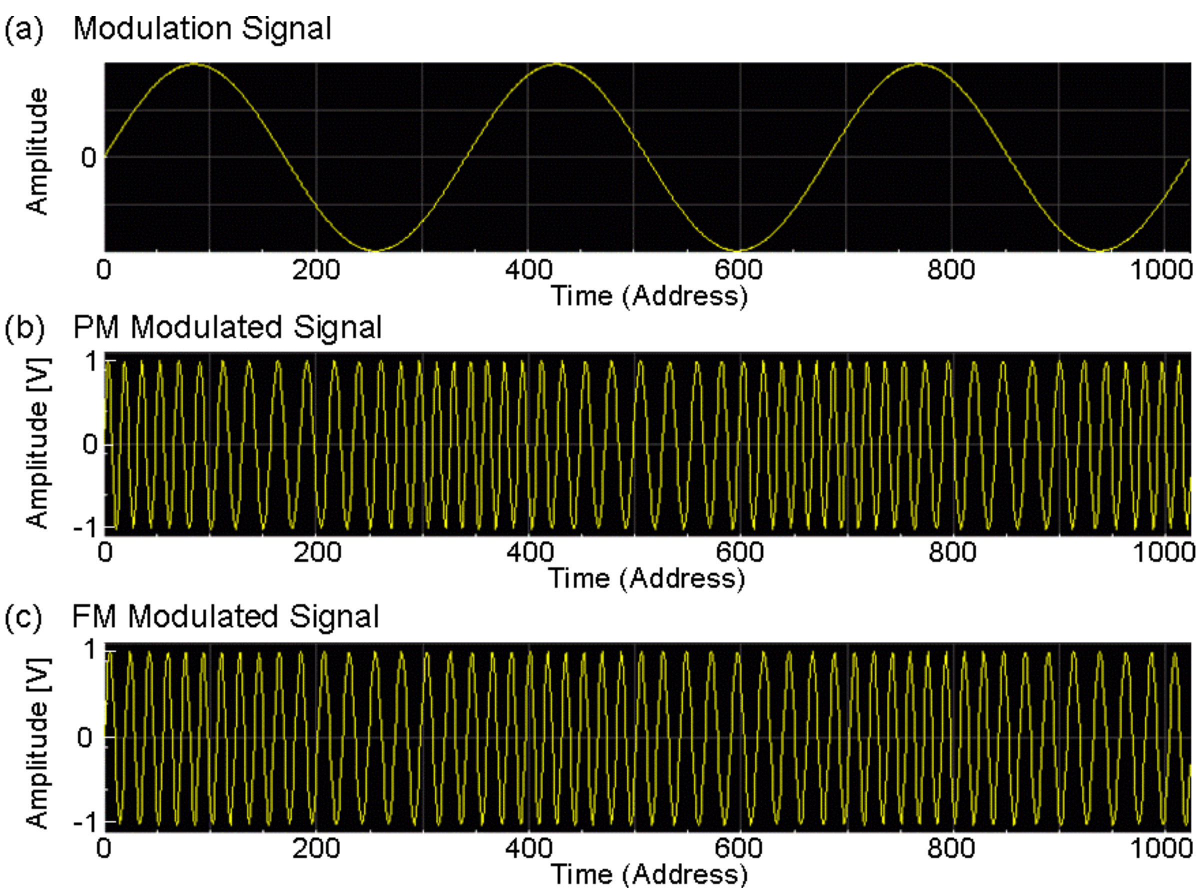

Figure 6: PM vs. FM Signals

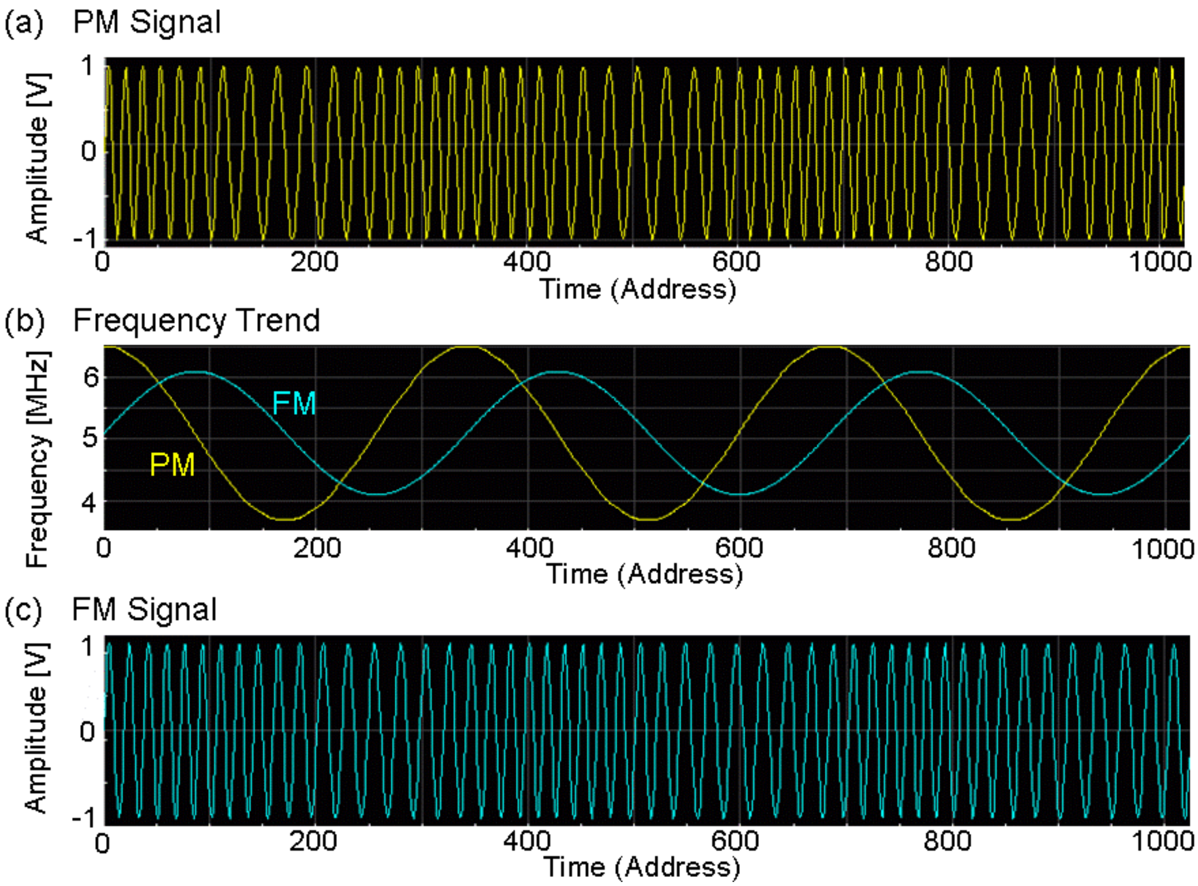

Figure 7: PM vs. FM Signals Modulated by the Same Modulation Signal