Communication Signal Analysis Using MATLAB

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Abstract

In electronic communications one of the most important concepts that students must learn is that of time and frequency representation of communication signals. Examples in most text books do not convey some of the important characteristics of complex communication signals. Students must be able to analyze the time and frequency representation of a signal, modify parameters, and immediately see the effect. An effective way of doing this is using a numerical computation and graphics program such as MATLAB.

Introduction

Time and frequency domain representation of signals are concepts that is essential in understanding the characteristics of amplitude and frequency modulated signals. Many electrical engineering technology communications text books do not convey some of the important characteristics of complex signals [1], [2], [3]. The ability to modify parameters and immediately see their effect on the time and frequency representation of a signal is invaluable in understanding communication signals.

MATLAB is a numerical computation and graphics program that has been designed specifically to manipulate matrices of any dimension as easily as scalar quantities [4]. This makes processing of sequences of sampled time data as simple as working with a single number. A communication signal can be sampled in time, plotted in time, then be transformed into the frequency domain and plotted. The students enter the mathematical representation of a communication signal and create graphs of the signal's time and frequency representation. Then the student may easily vary parameters of the signal and analyze the results of the time and frequency components of the signal.

Sampling a Time Signal

Time domain representation of signals in MATLAB is analogous to a discrete time signal. Each increment of time represents a sample of a continuous waveform. The size the of time increments, nT, determines the maximum unambiguous frequency of the sampled signal.

The Nyquist rate is the sampling frequency required to unambiguously sample a signal of maximum frequency content f_{max} [5]. The Nyquist rate is defined below:

$$f_s > 2 * f_{\max}$$

The time increment is $T=1/f_s$. In these simulations, the carrier is displayed at the center of the plot, therefore the sampling rate will be:

$$f_s = 4 * f_c$$

The Fast Fourier Transform

The frequency content of a discrete signal may be determined by its discrete Fourier transform.

$$X(k) = \sum_{j=1}^{N} x(j) \quad {}_{N}^{(j-1)(k-1)}$$

The FFT transform routine in MATLAB is implemented two ways. If the number of samples N is a power of 2, the FFT routine used a radix-2 fast Fourier transform algorithm. If N is not a factor of two, a slower mixed radix algorithm is used. An n-point FFT may also be specified. If $n < N$ then the samples are truncated, if $n > N$ then the samples are padded with zeros [4].

The number of samples N determines the frequency resolution of the Fast Fourier Transform (FFT). The frequency resolution of the FFT is:

$$\Delta f = \frac{f_s}{N}$$

The amplitude of the FFT must be properly scaled. The amplitude depends on the number of samples.

$$A = \frac{A_{FFT}}{N/2}$$

The result of the FFT operation is a vector of length N, only half of the vector is needed to covey the frequency content of the signal, the other half is symmetrical.

AM Waveforms

The time domain representation of a signal is familiar to students. It is the most common way to represent a time varying signal. An amplitude modulated (AM) waveform in the time domain has the following form

$$V_{AM}(t) = (E_c + E_m \sin(\quad_m t)) \cdot \sin(\quad_c t)$$

This is for a single frequency modulating signal. This example is what most texts use in explaining AM modulation. In practice however, most modulating signals are composed of many frequencies each with a unique amplitude. Using MATLAB is easy to create such a signal and analyze its time and frequency representations.

Time Domain Representation

A carrier wave of frequency 500 Hz is modulated by a signal made up of three sinusoids with the following amplitudes and frequencies:

f_{m1} = 400 Hz, E_{m1} = 5V
f_{m2} = 250 Hz, E_{m2} = 2V
f_{m3} = 125 Hz, E_{m3} = 8V

This may be written as:

$$V_{AM}(t) = (E_c + E_{m1}\sin(\quad_{m1}t) + E_{m2}\sin(\quad_{m2}t) + E_{m3}\sin(\quad_{m3}t)) \cdot \sin(\quad_c t)$$

This is the type of signal that students have difficulty visualizing. MATLAB can evaluate this expression as shown below:

```
A= Ec + Em1*sin(2*pi*fm1*t) + Em2*sin(2*pi*fm2*t) +Em3*sin(2*pi*fm3*t);
%
vam=A.*[sin(2*pi*fc*t)];
```

A plot of the time domain representation is shown below in Figure 1.

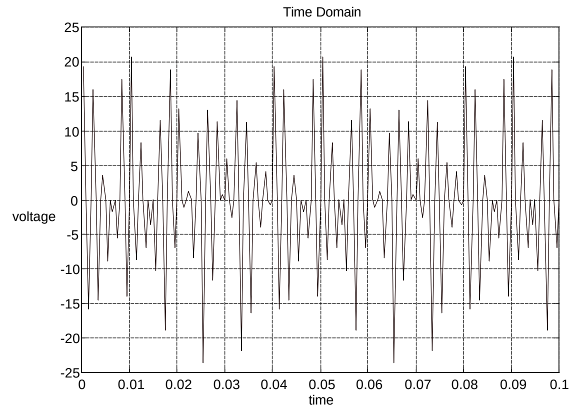

Figure 1. Time domain representation of AM with a modulation signal composed of three sinusoids.

Frequency Representation

The frequency representation of the complex AM signal above is easily obtained by taking the FFT of the time domain signal. The expression for evaluating the FFT is shown below:

```
Vf = abs(fft(vam,2048))/1024;
```

The absolute value or magnitude of the FFT is taken and the expression is also scaled to reflect the proper amplitude values.

The result is then plotted on the frequency scale. This shown in Figure 2.

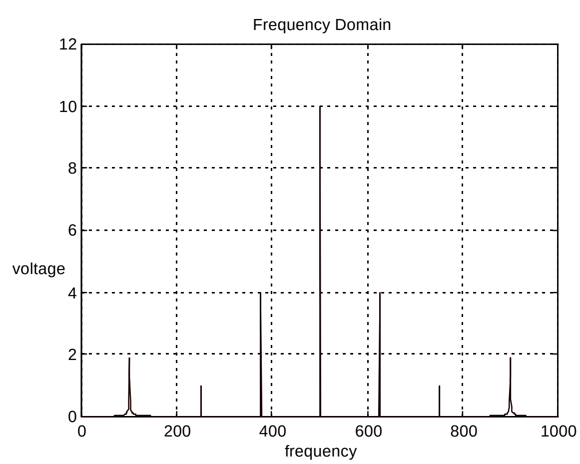

Figure 2. Frequency domain representation of AM with a modulation signal composed of three sinusoids.

The FFT result shows the three separate frequency components of the modulation signal. Their frequency and amplitude characteristics are present of the frequency representation. This information is not evident in the time domain representation.

FM Waveforms

A frequency modulated waveform has the following form:

$$V_{FM}(t) = E_C \cos[\omega_c t + \int K_1 v_m(t)dt]$$

Where K_1 is the deviation sensitivity

$$K_1 = \frac{radians/\sec}{volt}$$

and $v_m(t)$ is the modulation signal.

If

$$v_m(t) = E_m \cos(\omega_m t)$$

then the equation for $V_{FM}(t)$ reduces to:

$$V_{FM}(t) = E_c \cos[\omega_c t + \frac{K_1 V_m \sin(\omega_m t)}{\omega_m}]$$

This is the form used to describe FM in most text books.

In practice most modulation signals are composed of several sinusoidal signals each with a unique amplitude. For example given the modulation signal below:

$$v_m(t) = E_{m1} \cos(\omega_{m1} t) + E_{m2} \cos(\omega_{m2} t) + E_{m3} \cos(\omega_{m3} t)$$

The FM signal will be:

$$V_{FM}(t) = E_c \cos\{\omega_c t + K_1(\frac{E_{m1} \sin(\omega_{m1} t)}{\omega_{m1}} + \frac{E_{m2} \sin(\omega_{m2} t)}{\omega_{m2}} + \frac{E_{m3} \sin(\omega_{m3} t)}{\omega_{m3}})\}$$

Time Representation

The time domain representation for frequency modulation shows the frequency being changed at a rate proportional to the modulating signal. As an example the modulating signal may consist of the same three sinusoids as in the AM example. The deviation sensitivity, K_1 , will be equal to 20. The time domain signal may be evaluated in MATLAB with the expression:

```
vfm=Ec*cos(2*pi*fc*t+(k1*((Em1/(2*pi*fm1))*sin(2*pi*fm1*t) +...
(Em2/(2*pi*fm2))*sin(2*pi*fm2*t) + (Em3/(2*pi*fm3))*sin(2*pi*fm3*t))));
```

A plot of the time domain representation is shown in Figure 3.

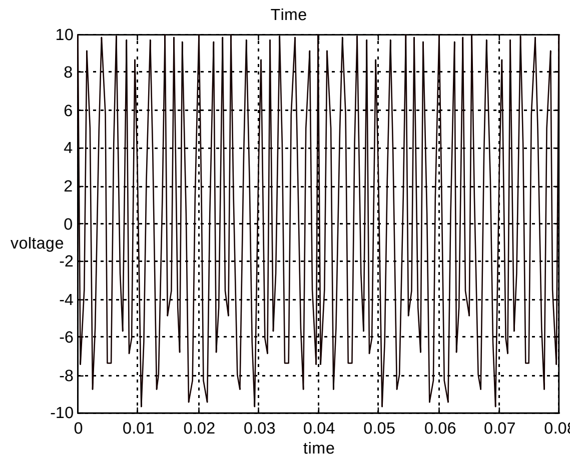

Figure 3. Time Domain Representation of an FM signal modulated by three sinusoidal.

Frequency Representation

The frequency representation of an FM signal is not a simple expression as the AM signal. Instead it must be expressed in terms of the Bessel function of the first kind. Complex sinusoidal modulation signals are not easily analyzed by the student. Using MATLAB to perform an FFT on the time signal allows the frequency representation to be evaluated simply:

```
Vf = fft(vfm,512);
```

The resulting plot is shown in Figure 4.

Unlike the AM signal, the frequency domain representation does not convey the same information about the composition of the FM signal. It does provide important information about the bandwidth of the signal.

What happens to the bandwidth of the signal when the deviation sensitivity changes from 20 to 10? This can be accomplished quickly by using MATLAB to recalculate the frequency components. The result is shown in Figure 5 for $K_1 = 10$.

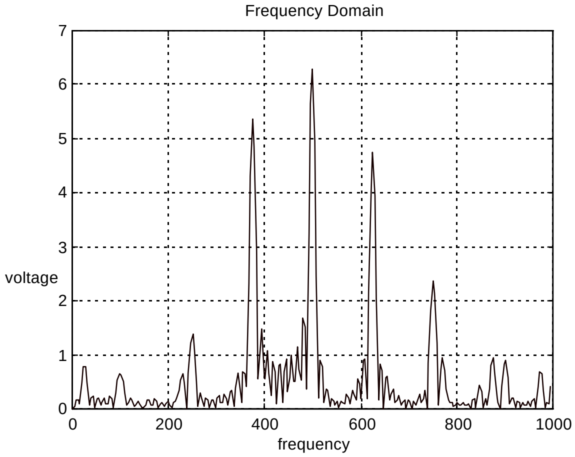

Figure 4. Frequency Domain Representation of an FM signal modulated by three sinusoidal.

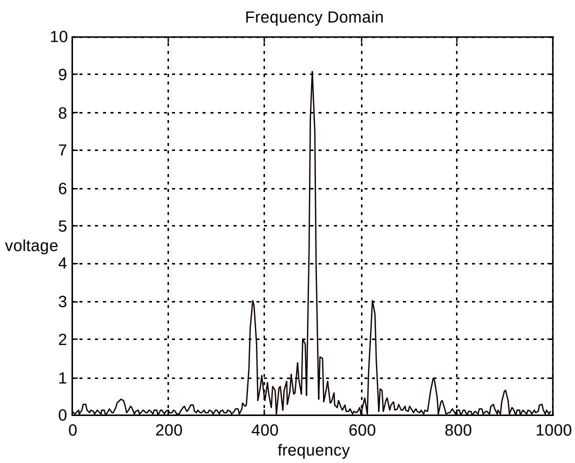

Figure 5. Frequency Domain Representation of an FM signal modulated by three sinusoids with $K_1 = 10$.

Figure 5 shows that the carrier power increased and the sidebands are reduced. This type of analysis is very important for the students to visualize and understand. Using MATLAB in this manner enables the student to experiment with many combinations of modulating waveforms and deviation sensitivities.

Conclusions

Signals may be represented in the time and frequency domain. Using a numerical and graphical program such as MATLAB enables the student to easily plot both the time and frequency representations of a signal. Parameters may be changed easily and the resulting change in the time and frequency characteristics of signal may quickly be analyzed. It is only necessary to define a signal in the time domain. Using the FFT capability of MATLAB, the frequency representation of a signal may be quickly calculated.

References

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