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Principles of Communication Systems

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Amplitude-modulation Systems

One of the basic problems of communication engineering is the design and analysis of systems which allow many individual messages to be transmitted simultaneously over a single communication channel. A method by which such multiple transmission, called *multiplexing*, may be achieved consists in translating each message to a different position in the *frequency* spectrum. Such multiplexing is called *frequency multiplexing*. The individual message can eventually be separated by filtering. Frequency multiplexing involves the use of an auxiliary waveform, usually sinusoidal, called a *carrier*. The operations performed on the signal to achieve frequency multiplexing results in the generation of a waveform which may be described as the carrier modified in that its amplitude, frequency, or phase, individually or in combination, varies with time. Such a modified carrier is called a *modulated* carrier. In some cases the modulation is related simply to the message; in other cases the relationship is quite complicated. In this chapter, we discuss the generation and characteristics of amplitude-modulated carrier waveforms.[1]

3.1 FREQUENCY TRANSLATION

It is often advantageous and convenient, in processing a signal in a communications system, to translate the signal from one region in the frequency domain to another region. Suppose that a signal is bandlimited, or nearly so, to the frequency range extending from a frequency f_1 to a frequency f_2. The process of frequency translation is one in which the original signal is replaced with a new signal whose spectral range extends from f_1' to f_2' and which *new* signal bears, in recoverable form, the same *information* as was borne by the original signal. We discuss now a number of useful purposes which may be served by frequency translation.

FREQUENCY MULTIPLEXING

Suppose that we have several different signals, all of which encompass the same spectral range. Let it be required that all these signals be transmitted along a single communications channel in such a manner that, at the receiving end, the signals be separately recoverable and distinguishable from each other. The single channel may be a single pair of wires or the free space that separates one radio antenna from another. Such multiple transmissions, i.e., multiplexing, may be achieved by translating each one of the original signals to a different frequency range. Suppose, say, that one signal is translated to the frequency range f_1' to f_2', the second to the range f_1'' to f_2'', and so on. If these new frequency ranges do not overlap, then the signal may be separated at the receiving end by appropriate bandpass filters, and the outputs of the filters processed to recover the original signals.

PRACTICABILITY OF ANTENNAS

When free space is the communications channel, antennas radiate and receive the signal. It turns out that antennas operate effectively only when their dimensions are of the order of magnitude of the wavelength of the signal being transmitted. A signal of frequency 1 kHz (an audio tone) corresponds to a wavelength of 300,000 m, an entirely impractical length. The required length may be reduced to the point of practicability by translating the audio tone to a higher frequency.

NARROWBANDING

Returning to the matter of the antenna, just discussed, suppose that we wanted to transmit an audio signal directly from the antenna, and that the inordinate length of the antenna were no problem. We would still be left with a problem of another type. Let us assume that the audio range extends from, say, 50 to 10^4 Hz. The ratio of the highest audio

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Fig. 3.2-1*a*. The pattern
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multiplication of $v_m(t)$ with

$$v_c(t) = A_c \cos \omega_c t = A$$

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frequency to the lowest is 200. Therefore, an antenna suitable for use at one end of the range would be entirely too short or too long for the other end. Suppose, however, that the audio spectrum were translated so that it occupied the range, say, from $(10^6 + 50)$ to $(10^6 + 10^4)$ Hz. Then the ratio of highest to lowest frequency would be only 1.01. Thus the processes of frequency translation may be used to change a "wideband" signal into a "narrowband" signal which may well be more conveniently processed. The terms "wideband" and "narrowband" are being used here to refer not to an absolute range of frequencies but rather to the fractional change in frequency from one band edge to the other.

COMMON PROCESSING

It may happen that we may have to process, in turn, a number of signals similar in general character but occupying different spectral ranges. It will then be necessary, as we go from signal to signal, to adjust the frequency range of our processing apparatus to correspond to the frequency range of the signal to be processed. If the processing apparatus is rather elaborate, it may well be wiser to leave the processing apparatus to operate in some fixed frequency range and instead to translate the frequency range of each signal in turn to correspond to this fixed frequency.

3.2 A METHOD OF FREQUENCY TRANSLATION

A signal may be translated to a new spectral range by *multiplying* the signal with an auxiliary sinusoidal signal. To illustrate the process, let us consider initially that the signal is sinusoidal in waveform and given by

$$v_m(t) = A_m \cos \omega_m t = A_m \cos 2\pi f_m t \tag{3.2-1a}$$

$$= \frac{A_m}{2} (e^{j\omega_m t} + e^{-j\omega_m t}) = \frac{A_m}{2} (e^{j2\pi f_m t} + e^{-j2\pi f_m t}) \tag{3.2-1b}$$

in which A_m is the constant amplitude and $f_m = \omega_m/2\pi$ is the frequency. The two-sided spectral amplitude pattern of this signal is shown in Fig. 3.2-1*a*. The pattern consists of two lines, each of amplitude $A_m/2$, located at $f = f_m$ and at $f = -f_m$. Consider next the result of the multiplication of $v_m(t)$ with an auxiliary sinusoidal signal

$$v_c(t) = A_c \cos \omega_c t = A_c \cos 2\pi f_c t \tag{3.2-2a}$$

$$= \frac{A_c}{2} (e^{j\omega_c t} + e^{-j\omega_c t}) = \frac{A_c}{2} (e^{j2\pi f_c t} + e^{-j2\pi f_c t}) \tag{3.2-2b}$$

in which A_c is the constant amplitude and f_c is the frequency. Using the trigonometric identity $\cos \alpha \cos \beta = \frac{1}{2}\cos(\alpha + \beta) + \frac{1}{2}\cos(\alpha - \beta)$, we

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