simultaneously in the correct way. This is generally difficult and cumbersome in comparison with building a filter whose characteristics are fixed. An alternative to varying the filter characteristics is to use a fixed frequency-selective filter and shift the signal spectrum appropriately, using the principles of sinusoidal amplitude modulation discussed in Section 7.1.

For example, consider the system shown in Figure 7.16. The spectra of the signals $x(t)$, $y(t)$, $w(t)$, and $f(t)$ are illustrated in Figure 7.17. We observe that the

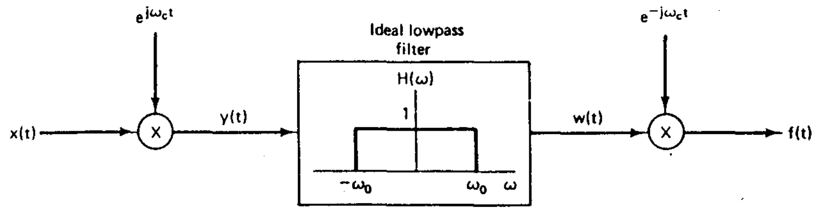


**Figure 7.16** Implementation of a bandpass filter using amplitude modulation with a complex exponential carrier.

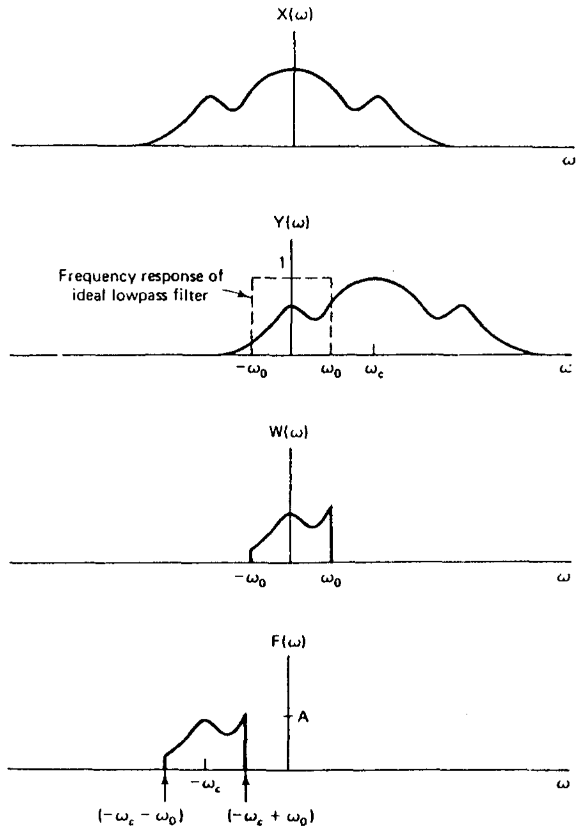


**Figure 7.17** Spectra of the signals in the system of Figure 7.16.

overall system of Figure 7.16 is equivalent to an ideal bandpass filter with center frequency $-\omega_c$ and bandwidth $2\omega_0$, as illustrated in Figure 7.18. As the frequency $\omega_c$ of the complex exponential oscillator is varied, the center frequency of the bandpass filter varies.

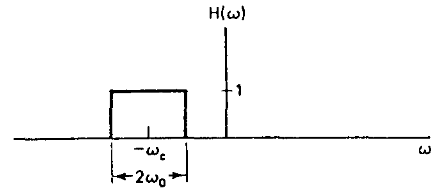


**Figure 7.18** Bandpass filter equivalent of Figure 7.16.

In the system of Figure 7.16, with $x(t)$ real, the signals $y(t)$, $w(t)$, and $f(t)$ are all complex. If we retain only the real part of $f(t)$, the resulting spectrum is that shown in Figure 7.19 and the equivalent bandpass filter passes bands of frequencies

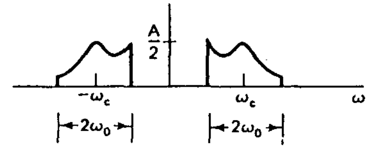


**Figure 7.19** Spectrum of $\Re e\{f(t)\}$ associated with Figure 7.16.

centered around $\omega_c$ and $-\omega_c$, as indicated in Figure 7.20. Under certain conditions it is also possible to use sinusoidal rather than complex exponential modulation to implement the system of Figure 7.20. This is explored further in Problem 7.12.

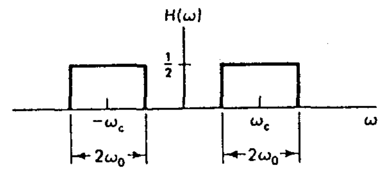


**Figure 7.20** Equivalent bandpass filter for $\Re e\{f(t)\}$ in Figure 7.19.

### *7.2.2 Sinusoidal Amplitude Modulation for Communications: Frequency-Division Multiplexing*

One of the most widespread areas of application of sinusoidal amplitude modulation is in communications and information transmission systems. The basic need for modulation arises for two reasons. Different transmission media that are used for transmission of signals are generally suited to a particular frequency range that might not match the frequency range of the signals to be transmitted. In telephone transmission systems, for example, long-distance transmission is often accomplished over microwave or satellite links. The individual voice signals are in the frequency range 200 Hz to 4 kHz, whereas a microwave link requires signals in the range 300 megahertz (MHz) to 300 gigahertz (GHz), and communication satellite links operate in