PHY 359 2.0 / ASP 487 2.0
Telecommunication

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Modulation and Demodulation

Introduction

- For Radio Transmission, necessary to send an audio signal (Ex. music, speech etc.) from a broadcasting station over great distances to a receiver. And audio signals employ wireless communication.
- The audio signal cannot be sent directly over the air for appreciable distance. Even if the audio signal is turned into an electrical signal, it cannot be transmitted very far without using a significant amount of power.
- The energy of a wave is directly proportional to its frequency. At audio frequencies (20 Hz to 20 kHz), the signal power is small, and radiation level is not practicable.
- The radiation of electrical energy is practicable only at high frequencies (above 20 kHz). The high frequency signals can be sent thousands of km distance even with comparatively small power.

Introduction

- So, if the audio signal is to be transmitted properly, A method has to be developed that will allow for high-frequency transmission while still enabling the audio signal to be carried. Electrical audio signals can be superimposed over high frequency electrical carriers to achieve this task.

- The above resultant waves are known as modulated waves or radio waves and the process is called modulation.

- At the radio receiver, the audio signal is extracted from the modulated wave by the process called demodulation.

- Then the signal is then amplified and reproduced into sound by the loudspeaker.

Radio Broadcasting, Transmission and Reception

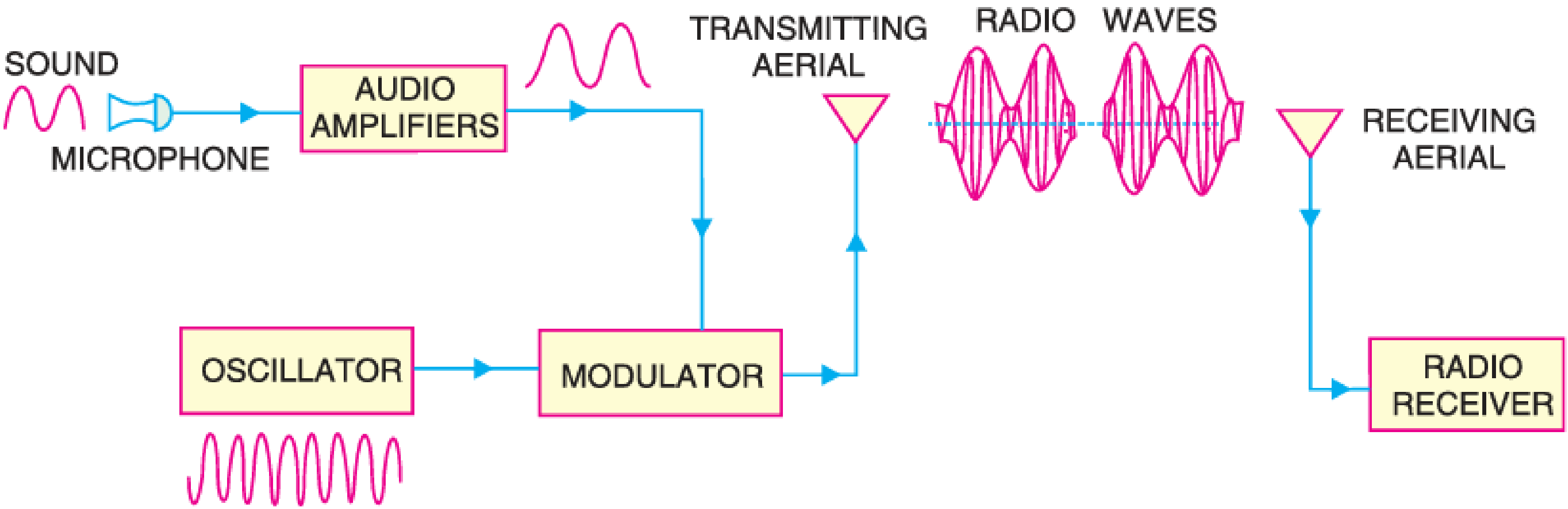


Figure: 01 Block diagram of a modern full-duplex communication system

Radio Broadcasting, Transmission and Reception

Transmitter

The transmitter’s purpose is to produce radio waves for transmission into space. The important components: **A microphone, audio amplifiers, oscillator, modulator, and transmitting antenna.**

Microphone

A microphone is a device which converts sound waves into electrical waves. The output of microphone is fed to a multistage audio amplifier for raising the strength of a weak signal.

Audio amplifier

Since the microphone's audio signal is so weak, it needs to be amplified. Audio amplifiers that are cascaded do this function. The modulator receives the amplified output from the final audio amplifier in order to perform the modulation process.

Radio Broadcasting, Transmission and Reception

Oscillator

- A carrier wave, which is a high frequency signal, is produced by an oscillator. For this, a crystal oscillator is typically employed.
- Radio frequency amplifier stages increase the carrier wave's power level to a suitable level. The majority of broadcasting stations have several kW (kilowatts) of carrier wave power. To send the signal over the required distances, such great power is required.

Modulator

- The modulator receives both the carrier wave and the amplified audio signal. In this case, the audio signal is superimposed on the carrier wave properly. The process is known as modulation, and the final waves are referred to as radio waves or modulated waves.
- The audio signal can be sent at the carrier frequency through the modulation procedure. The audio signal may travel great distances because the carrier frequency is so high.
- The transmitting antenna or aerial receives the radio waves from the transmitter and radiates them into space.

Radio Broadcasting, Transmission and Reception

radio waves Transmission

- The radio waves are sent into space in all directions by the transmitting antenna. The speed of these radio waves is 3×10^8 m/s, which is the speed of light.
- Electromagnetic waves and radio waves have many general characteristics.
- It is readily demonstrated that electrical energy may be emitted into space at high frequencies.

Radio receiver

- The radio waves cause a small e.m.f. to be induced in the receiving antenna upon reaching it.
- The radio receiver provides this small voltage. Here, the radio waves are amplified initially, and the signal is then extracted by the **Demodulation process**.
- Audio amplifiers amplify the signal before feeding it to the speaker so that sound waves can be produced.

modulation schemes – by Signals

- Modulation by Analog signals
- Modulation by Digital signals.

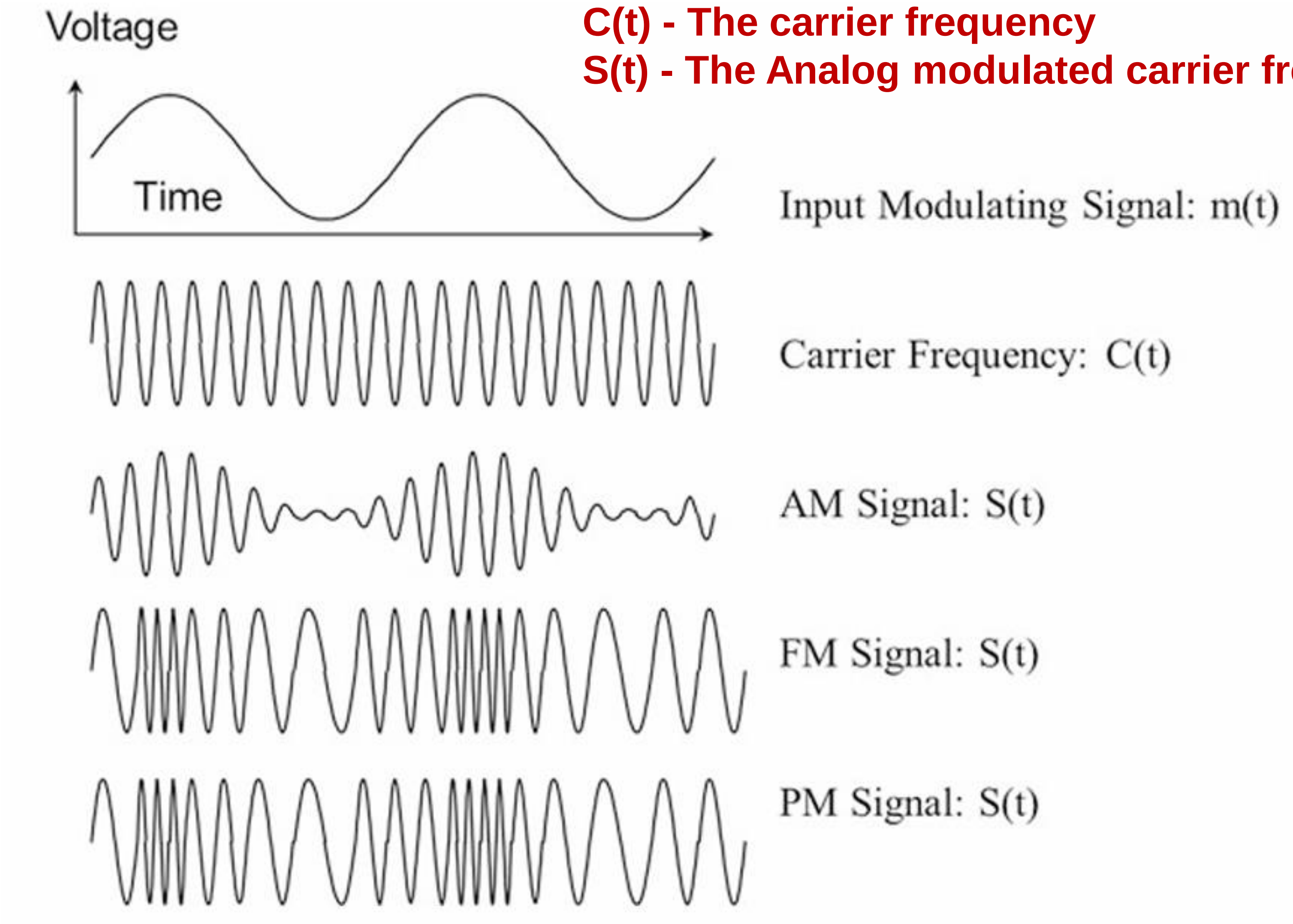
Modulation by Analog Signals

For analog signals, there are three well-known modulation techniques AM, FM, and PM.

- Amplitude Modulation (AM)
- Frequency Modulation (FM)
- Phase Modulation (PM)

Modulation by Analog Signals

m(t) - The input modulating audio signal
C(t) - The carrier frequency
S(t) - The Analog modulated carrier frequency



Modulation by Analog Signals

Amplitude Modulation (AM)
The amplitude of the carrier changes in accordance with the input analog signal, while the frequency of the carrier remains the same.

Frequency Modulation (FM)
The frequency of the carrier changes in accordance with the input modulation signal. In FM, only the frequency changes while the amplitude remains the same.

Phase Modulation (PM)
- The phase of the carrier changes in accordance with the phase of the carrier, while the amplitude of the carrier does not change. PM is closely related to FM.
- FM is derived from the rate of change of phase of the carrier frequency. Both FM and PM belong to the same mathematical Method.

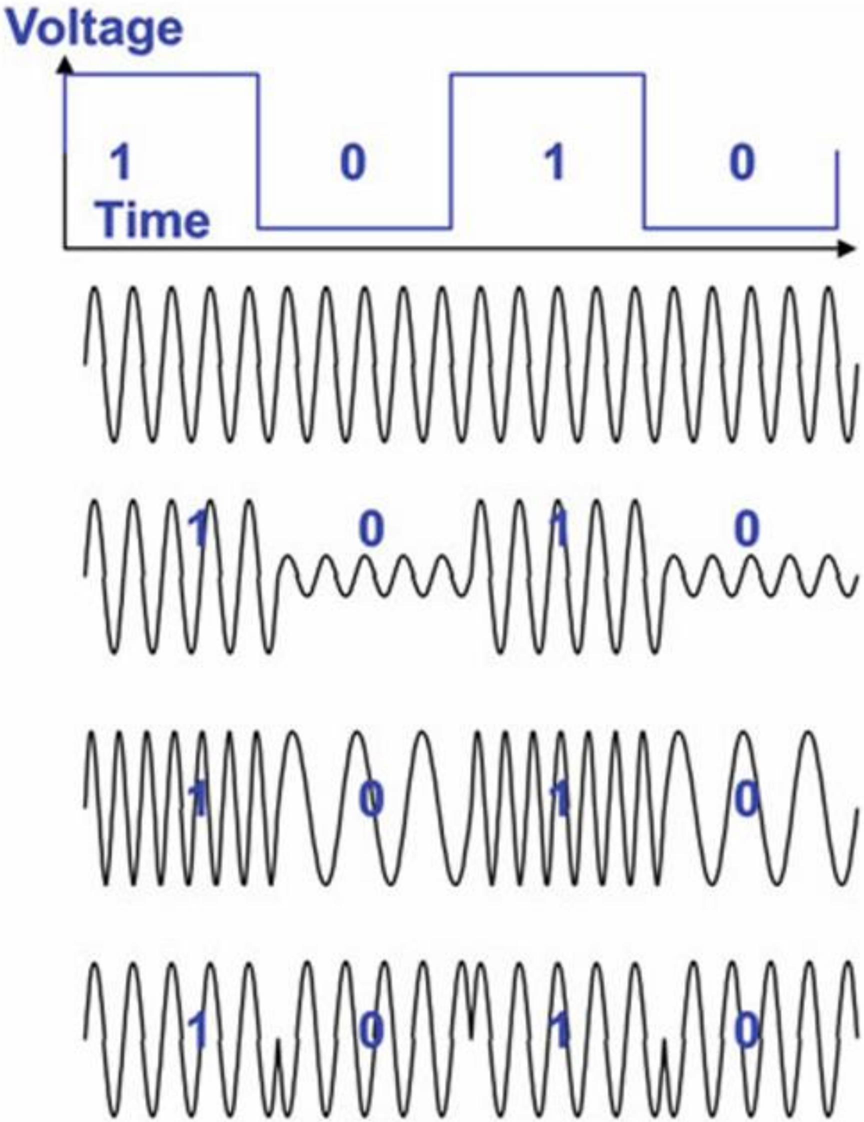
Modulation by Digital Signals

Modulation by Digital Signals

For digital signals, there are several modulation techniques available. The three main digital modulation techniques are:

- Amplitude shift keying (ASK)
- Frequency shift keying (FSK)
- Phase shift keying (PSK)

Modulation by Digital Signals



Input Modulating Digital Signal: m(t)

Carrier Frequency: C(t)

ASK Signal: S(t)

FSK Signal: S(t)

PSK Signal: S(t)

Modulation by Digital Signals

Amplitude shift keying (ASK)

- known as On–Off Keying (OOK), is a method of digital modulation that utilizes amplitude shifting of the relative amplitude of the career frequency.
- The signal to be modulated and transmitted is binary; this is referred to as ASK, where the amplitude of the carrier changes in discrete levels,
- In accordance with the input signal

Binary 0 (bit 0): Amplitude = Low
Binary 1 (bit 1): Amplitude = High

- Output of the ASK-modulated carrier, For binary signal 1, the carrier is ON. For the binary signal 0, the carrier is OFF. However, a small residual signal may remain due to noise, interference, etc.

Modulation by Digital Signals

Frequency shift keying (FSK)

- FSK is a method of digital modulation that utilizes frequency shifting of the relative frequency content of the signal. The signal is to be modulated and transmitted in binary; this is referred to as binary FSK (BFSK).
- Where the carrier frequency changes in discrete levels, in accordance with the input signal:

Binary 0 (bit 0): Frequency = $f + \Delta f$
Binary 1 (bit 1): Frequency = $f - \Delta f$

- Output is the FSK-modulated carrier, which has two frequencies f_1 and f_2, corresponding to the binary input signal

- These frequencies correspond to the messages binary 0 and 1, respectively.

Modulation by Digital Signals

Phase shift keying (PSK)

- PSK is a method of digital modulation that utilizes the phase of the carrier to represent the digital signal. The signal to be modulated and transmitted is binary; this is referred to as binary PSK (BPSK).

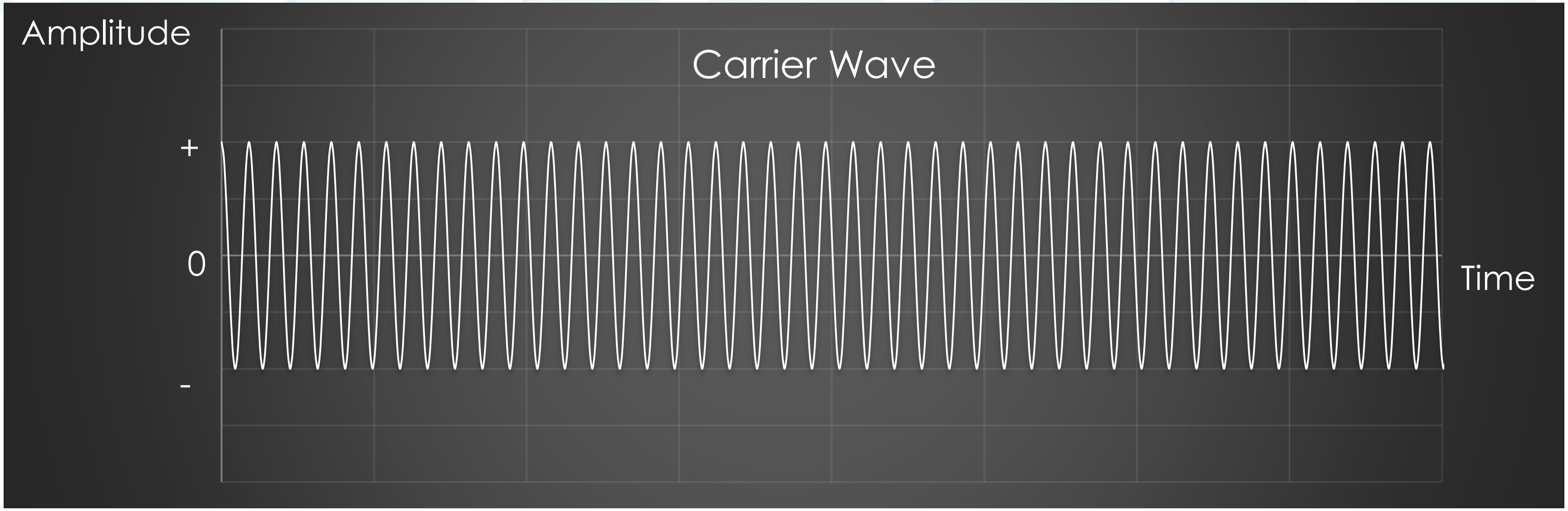
- Where the phase of the carrier changes in discrete levels, in accordance with the input signal:

Binary 0 (bit 0): Phase1 = 0°
Binary 1 (bit 1): Phase2 = 180°

- Output is the BPSK-modulated carrier, which has two phases ϕ_1 and ϕ_2 corresponding to the two information bits.

Amplitude Modulation
and
Demodulation

Carrier Wave



$c(t) = A_c \cos(\omega_c t + \Phi_c)$

$c(t)$= instantaneous carrier amplitude (volts)
A_c = carrier amplitude (peak volts)
ω_c = angular frequency in radians and $\omega_c = 2\pi f_c$
f_c = carrier frequency (hertz)
Φ_c = carrier phase delay (radians)

Amplitude Modulation

- Amplitude Modulation (AM) is used in short and medium wave radio transmission
- AM is varying the amplitude of a carrier wave, c(t), about a mean value, linearly with the baseband (message) signal, m(t)
- Carrier wave is given by:

$$c(t) = A_c \cos(\omega_c t + \Phi_c)$$

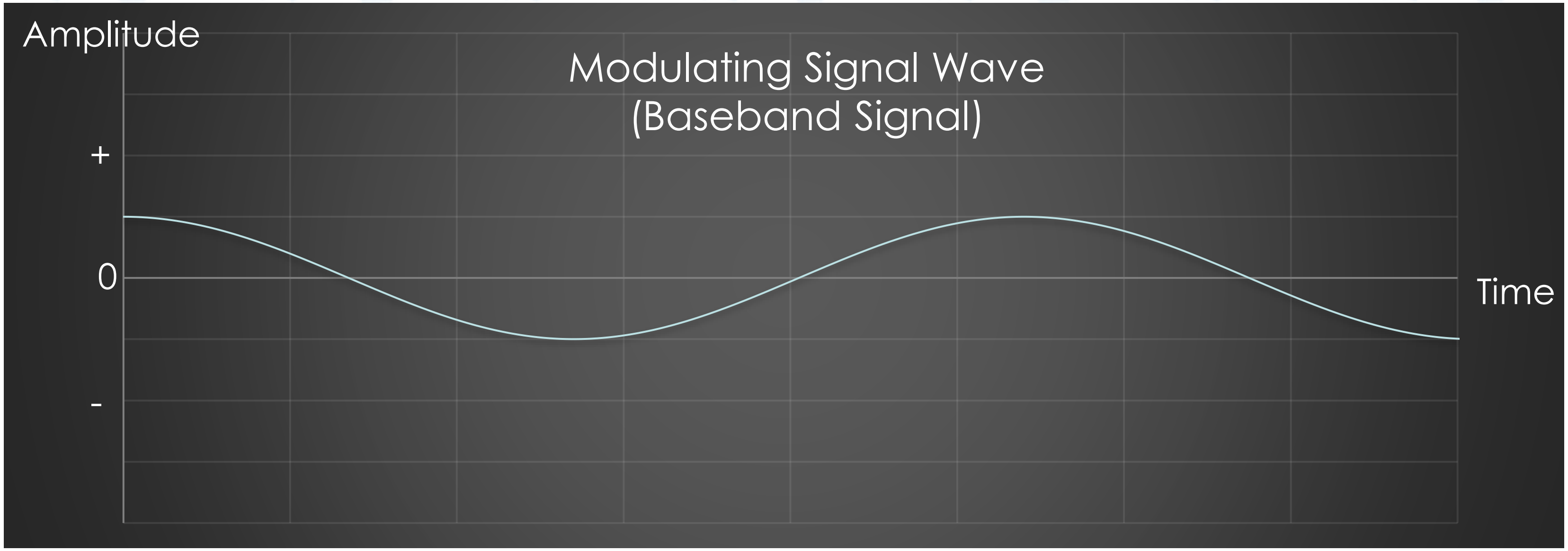
- AM modulated wave is given by:

$$s(t) = A_c[1+k_a m(t)] \cos(\omega_c t + \Phi_c)$$

- k_a is the amplitude sensitivity of the modulator
- For simplicity:

$$s(t) = A_c[1+m(t)] \cos(\omega_c t)$$

A Simple Baseband Signal



$$m(t) = A_m \cos(\omega_m t)$$

$m(t)$ = instantaneous modulating amplitude (volts)
A_m = modulating amplitude (peak volts)
ω_m = angular frequency in radians and $\omega_m = 2\pi f_m$
f_m = modulating frequency (hertz)

Amplitude Modulation..

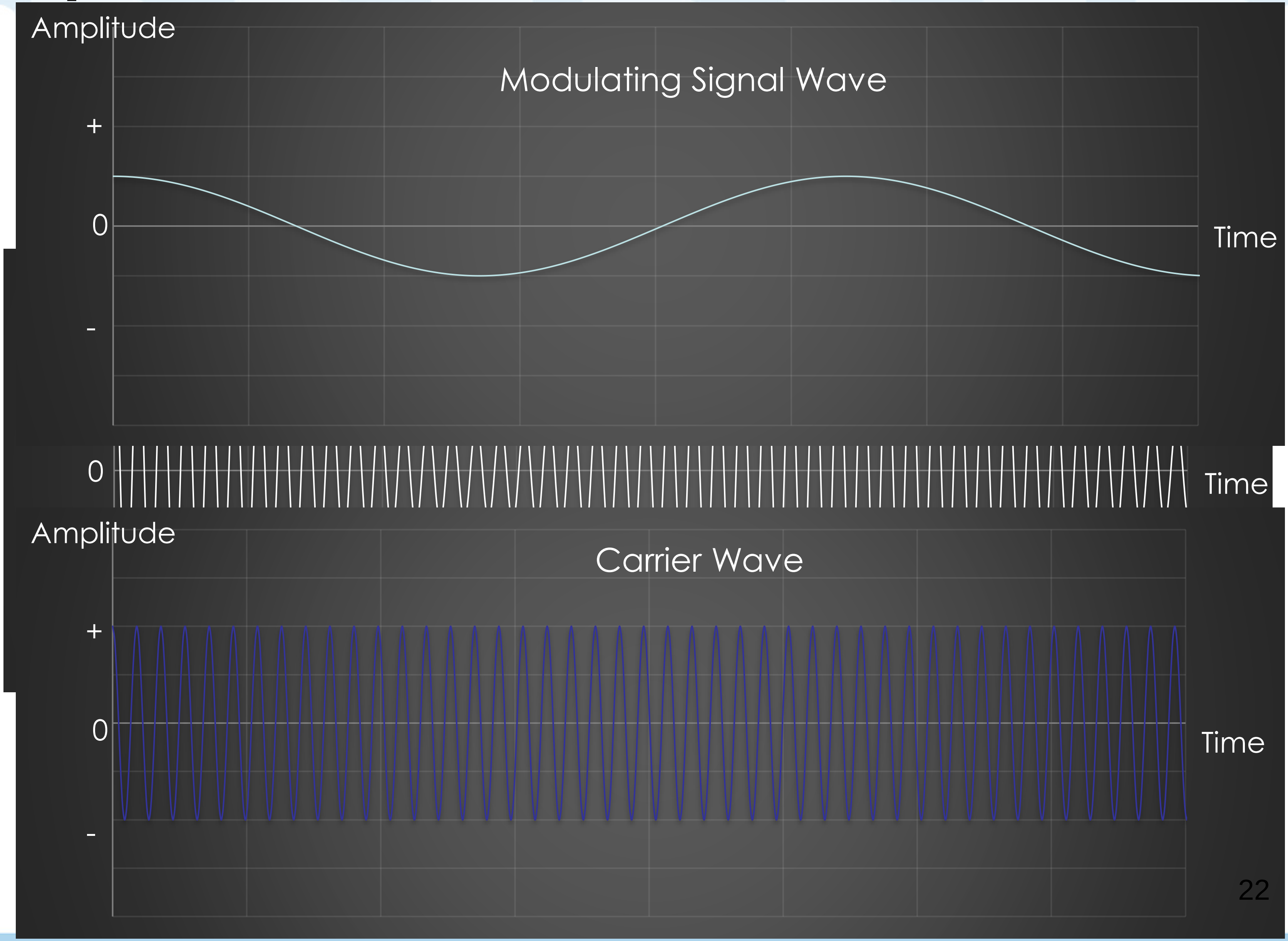
- Amplitude of carrier is made to vary about A_c by the message signal m(t)

$$m(t) = A_m \cos(\omega_m t)$$

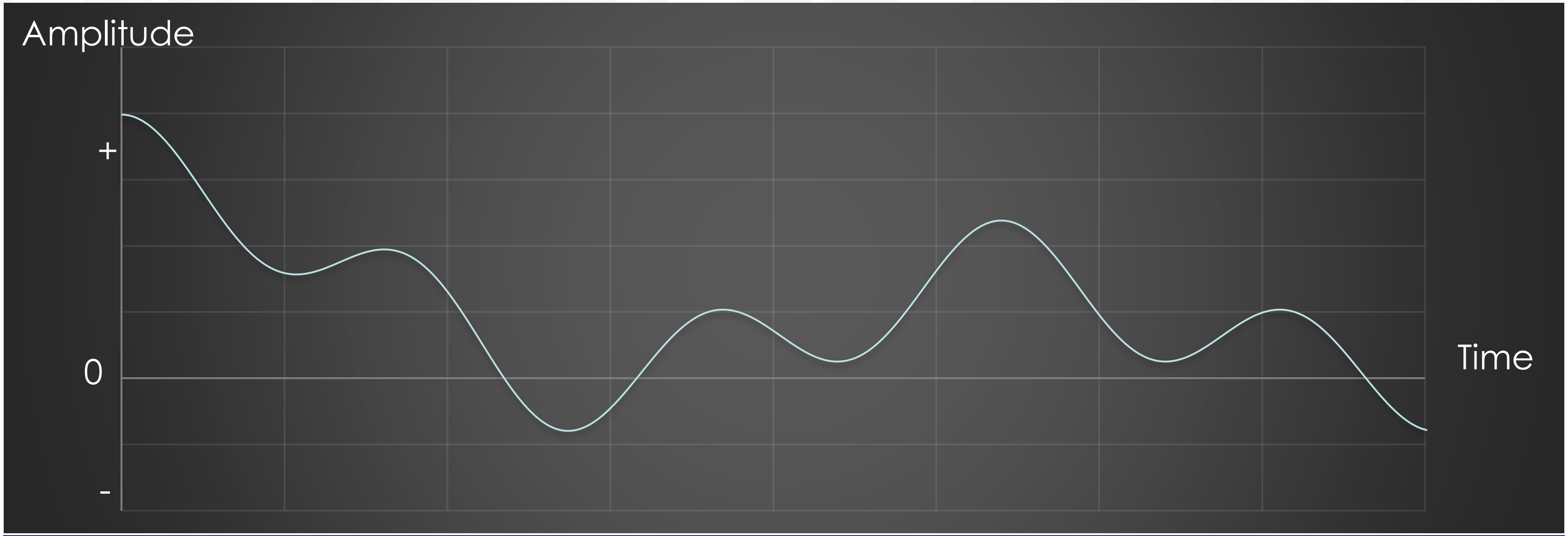
- Modulated signal becomes:

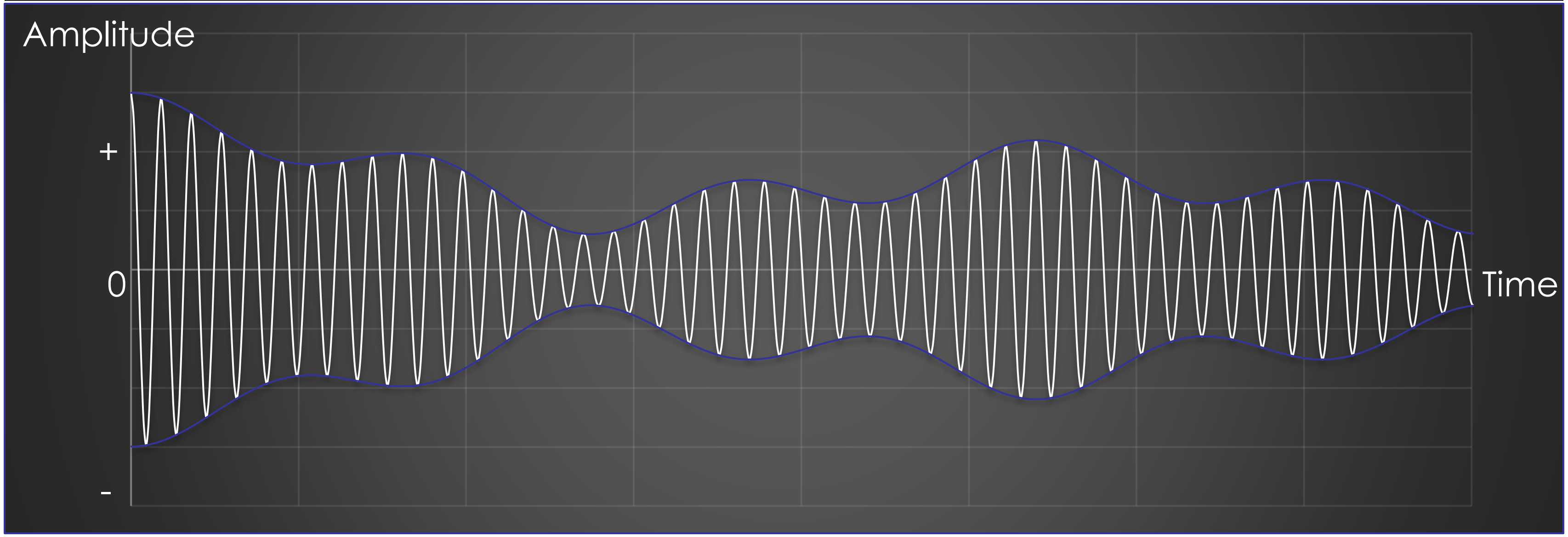
$$s(t) = A_c[1+m(t)] \cos(\omega_c t)$$
$$s(t) = A_c[1+A_m \cos(\omega_m t)] \cos(\omega_c t)$$

Amplitude Modulation..



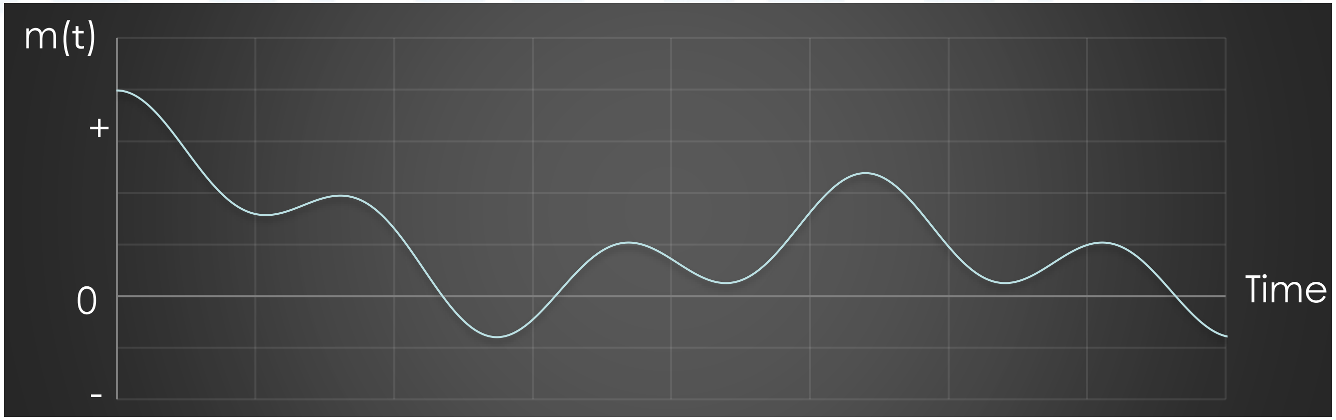
A Realistic Baseband Signal





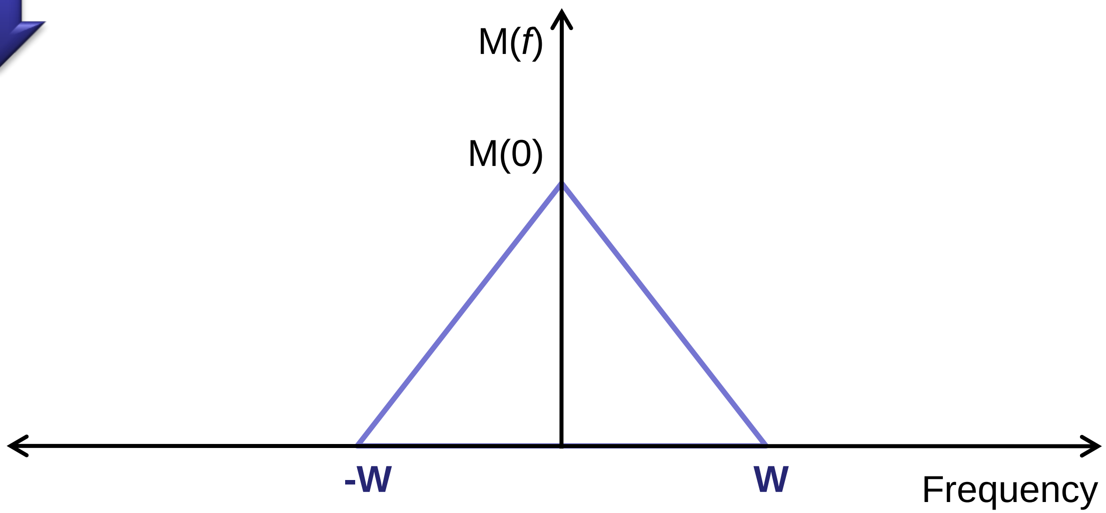
Frequency Domain Representation

Time Domain



Fourier Transform

Frequency Domain



Frequency Domain Representation

- AM signal:

$$s(t) = A_c[1+m(t)]\cos(\omega_c t)$$

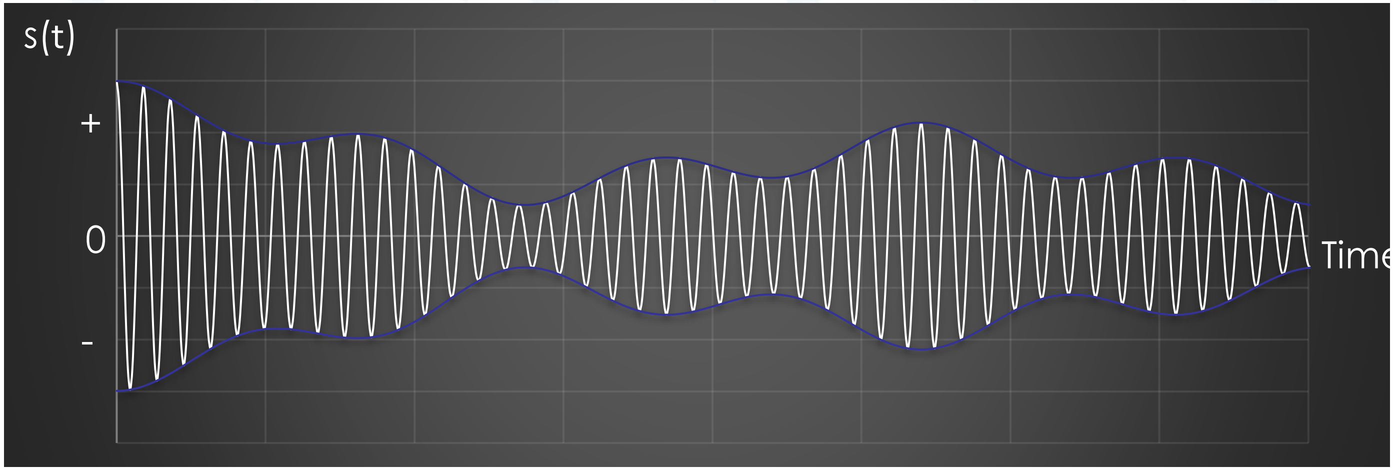
$$s(t) = A_c\cos(\omega_c t) + A_c m(t)\cos(\omega_c t)$$

- Fourier transform S(f) of AM signal s(t):

$$S(f) = \tfrac{1}{2} A_c [\delta(f-f_c) + \delta(f+f_c)] + \tfrac{1}{2} A_c [M(f-f_c) + M(f+f_c)]$$

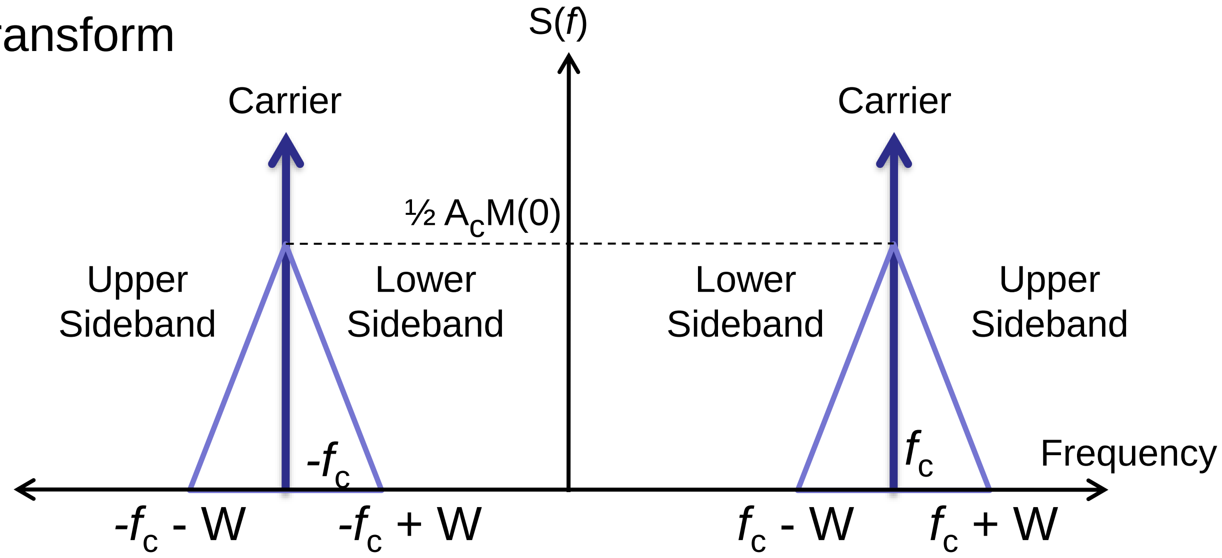
Frequency Domain Representation

Time Domain



Fourier Transform

Frequency Domain



Results of Amplitude Modulation

- Spectrum consists of:
  - two delta functions weighted by $A_c/2$ (occur at $\pm f_c$)
  - Two versions of the baseband spectrum transformed by $\pm f_c$, scaled in amplitude by $A_c/2$

- As a result of modulation, negative frequencies of m(t), from –W to 0, become visible as positive (i.e. measurable) frequencies

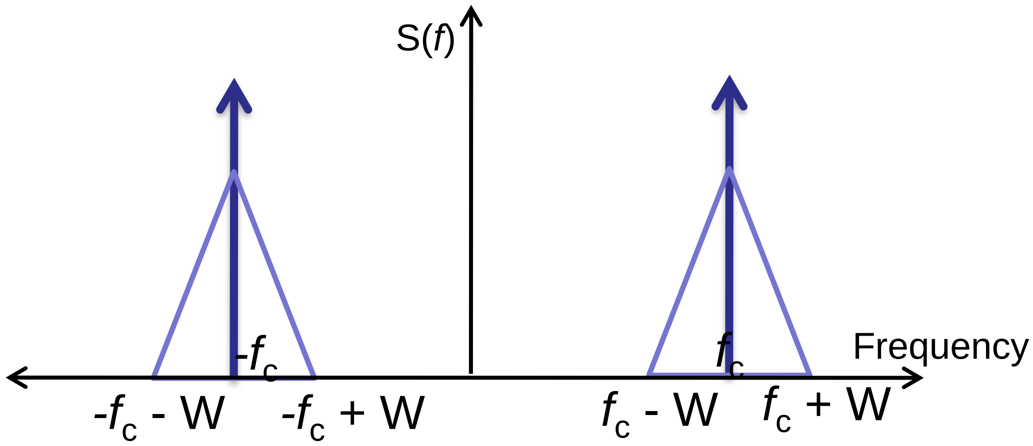
- Transmission Bandwidth

= Highest frequency – Lowest frequency

$$B_T = f_c + W - (f_c - W)$$

$$B_T = 2W$$

Carrier Frequency Selection



- Carrier frequency, f_c, should be much higher than the highest frequency component, W, of the message signal
- $f_c >> W$ is not satisfied an envelop cannot be detected satisfactorily

Amplitude Sensitivity of Modulator

- AM waveform is given by:

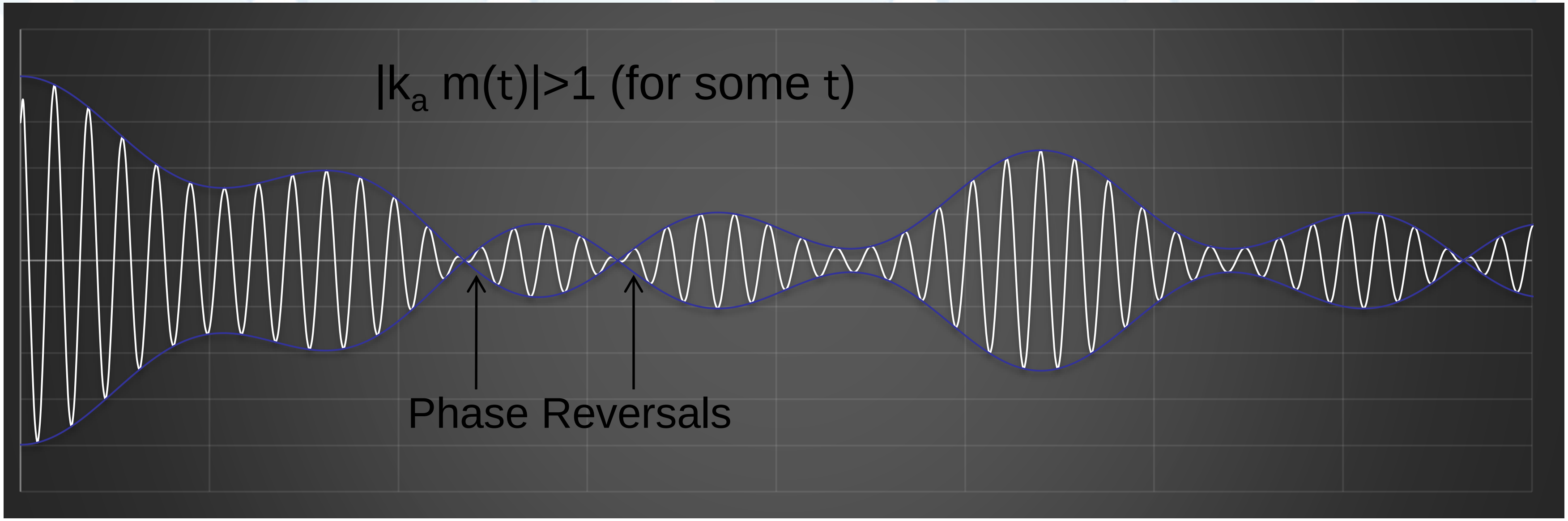
$$s(t) = A_c[1+k_a m(t)] \cos(\omega_c t)$$

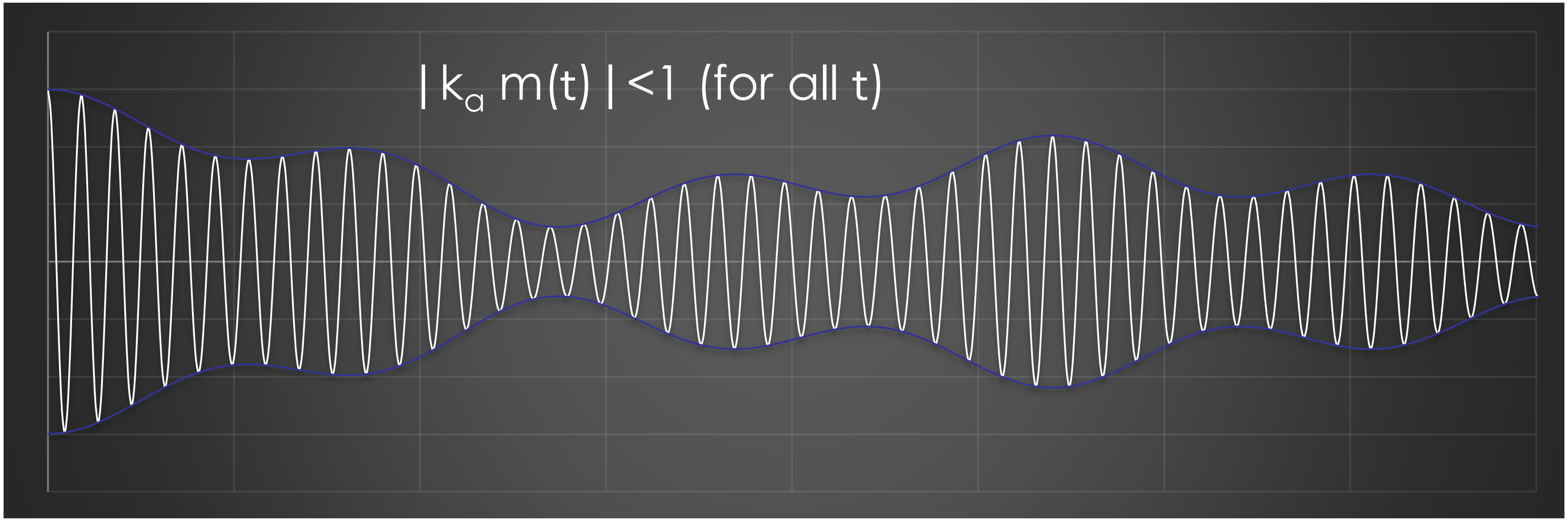
- For all t, $|k_a m(t)|<1$ to ensure $[1+k_a m(t)]$ is always positive

- If k_a of the modulator is large enough to make $|k_a m(t)|>1$ for any t, the carrier wave becomes over modulated, resulting in carried phase reversals whenever the factor $|k_a m(t)|$ crosses 0

- Modulated wave shows envelope distortion

Modulation Sensitivity

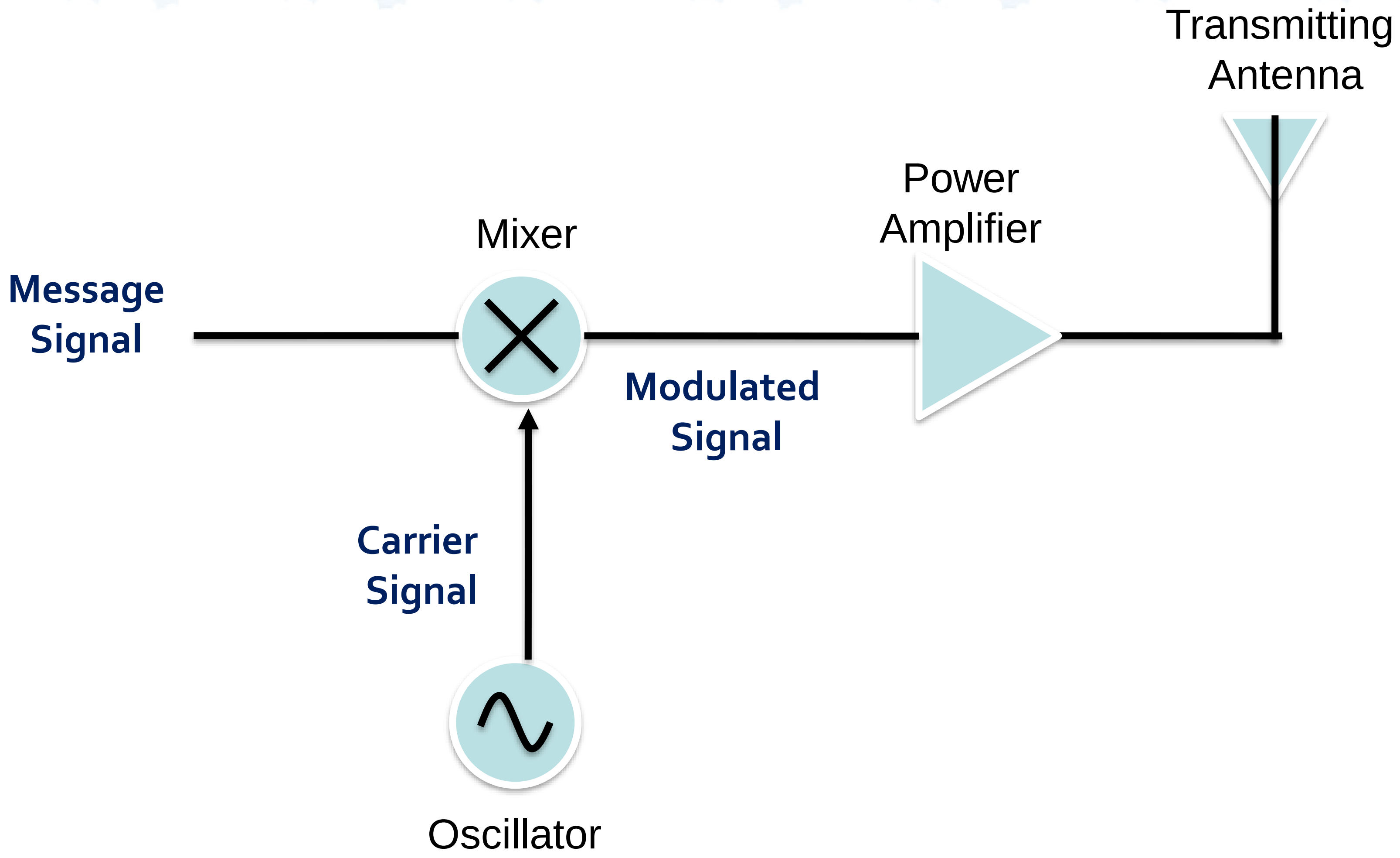




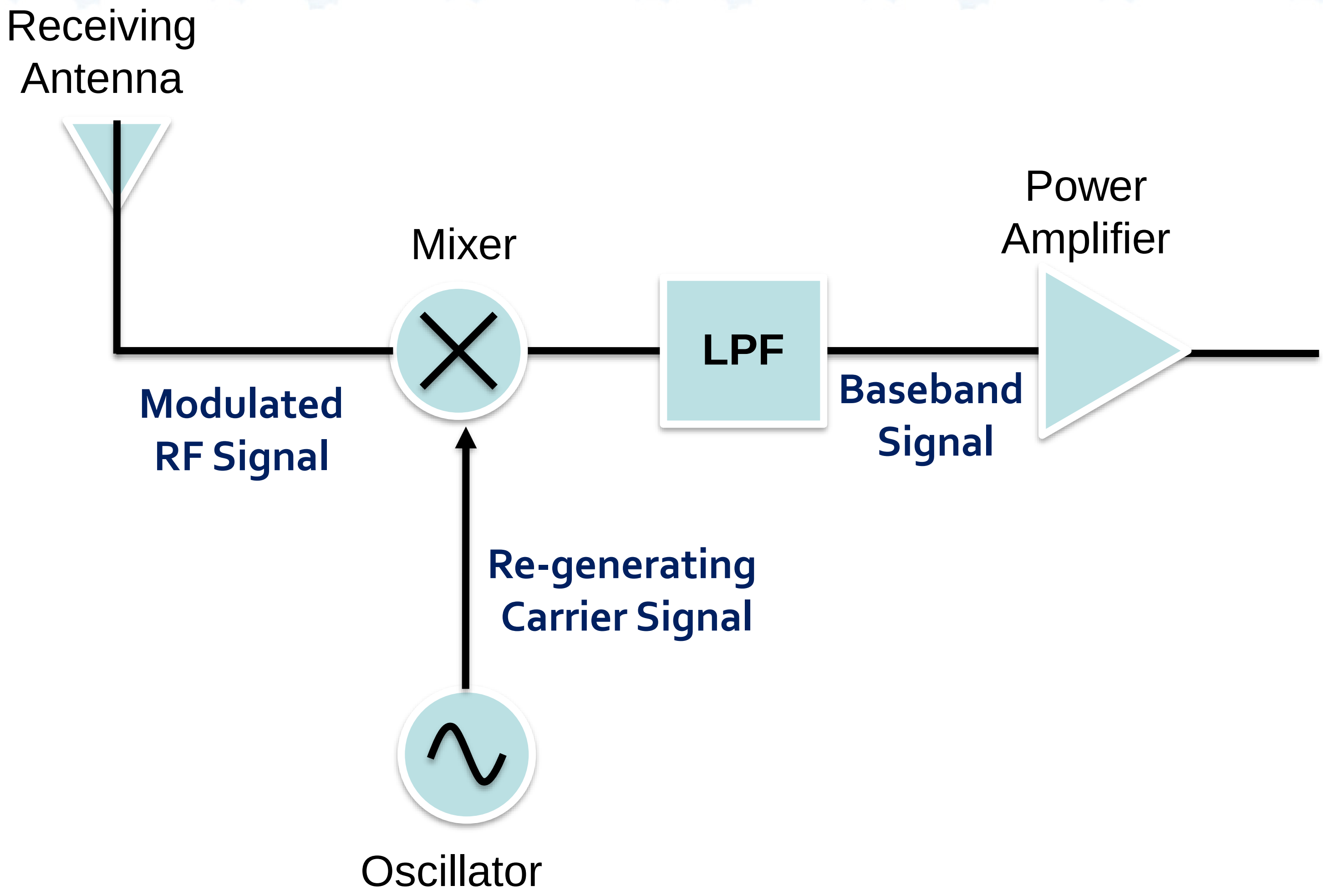
Limitations of AM & Remedies

- Transmitted power and channel bandwidth are primary communication resources
- AM has two major limitations:
  - Wasteful of power – only a fraction of power carries m(t)
  - Wasteful of bandwidth – only one sideband is necessary
- Suppressing the carrier and modifying sidebands overcomes these inefficiencies
- Double-sideband suppressed-carrier(DSBSC), single-sideband(SSB), double-sideband reduced-carrier (DSBRC), vestigial sideband(VSB) are some such technologies
- Removing carrier signal increases transmitter efficiency by three times
- Carrier must be regenerated, using a beat frequency oscillator, to use conventional demodulating techniques for DSBSC and DSBRC

AM Transmitter



AM Receiver


Receiving
Antenna
Mixer
Power
Amplifier
LPF
Modulated
RF Signal
Baseband
Signal
Re-generating
Carrier Signal
Oscillator