Communication Systems

Lecture 4

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Chapter 4

Amplitude Modulator
and Demodulator Circuits

Topics Covered in Chapter 4

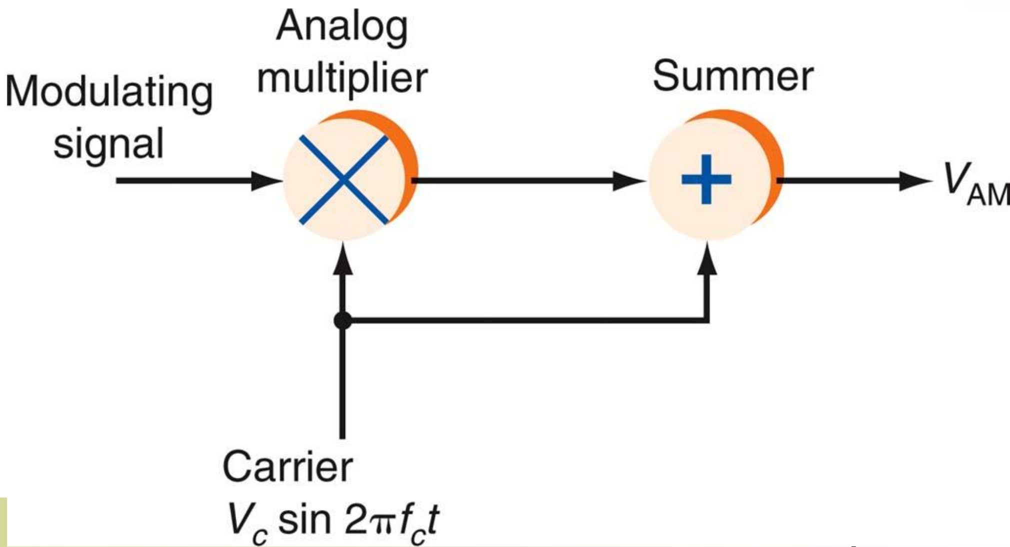
- 4-1: Basic Principles of Amplitude Modulation
- 4-2: Amplitude Modulators
- 4-3: Amplitude Demodulators
- 4-4: Balanced Modulators
- 4-5: SSB Circuits

4-1: Basic Principles of Amplitude Modulation

AM in the Time Domain

- Amplitude modulation voltage is produced by a circuit that can multiply the carrier by the modulating signal and then add the carrier.

$$v_{AM} = V_c \sin 2\pi f_c t + (V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$$
$$= V_c \sin 2\pi f_c t\,(1 + m \sin 2\pi f_m t)$$



4-1: Basic Principles of Amplitude Modulation

AM in the Frequency Domain

- The product of the carrier and modulating signal can be generated by applying both signals to a nonlinear component such as a diode.
- A diode gives a good approximation of a square-law response. Bipolar and field-effect transistors (FETs) can also be biased to give a square-law response.
- A **square-law function** is one that varies in proportion to the square of the input signals.

4-1: Basic Principles of Amplitude Modulation

- Diodes and transistors whose function is not a pure square-law function produce third-, fourth-, and higher-order harmonics, which are sometimes referred to as **intermodulation products**.

- **The current in a semiconductor diode can be approximated by**

$$i = av + bv^2$$

- **Diodes and transistors also have higher-order terms, such as c u^3 and cu^4**
- **however, these are smaller and often negligible and so are neglected in an analysis**
- **To produce AM, the carrier and modulating signals are added and applied to the nonlinear device**

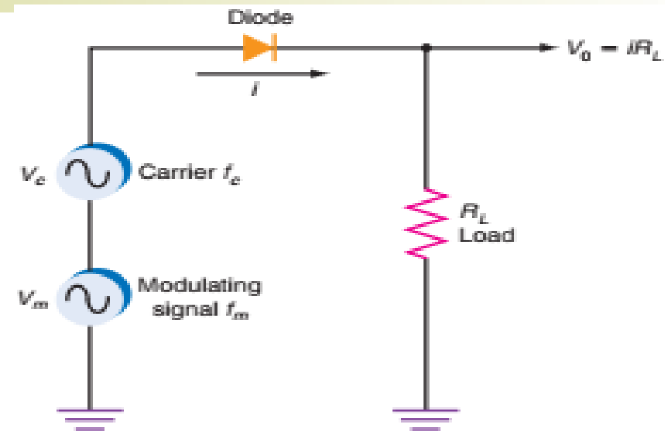
$$v = v_c + v_m$$

4-1: Basic Principles of Amplitude Modulation

- **The diode current in the resistor is**

$$i = a(v_c + v_m) + b(v_c + v_m)^2$$

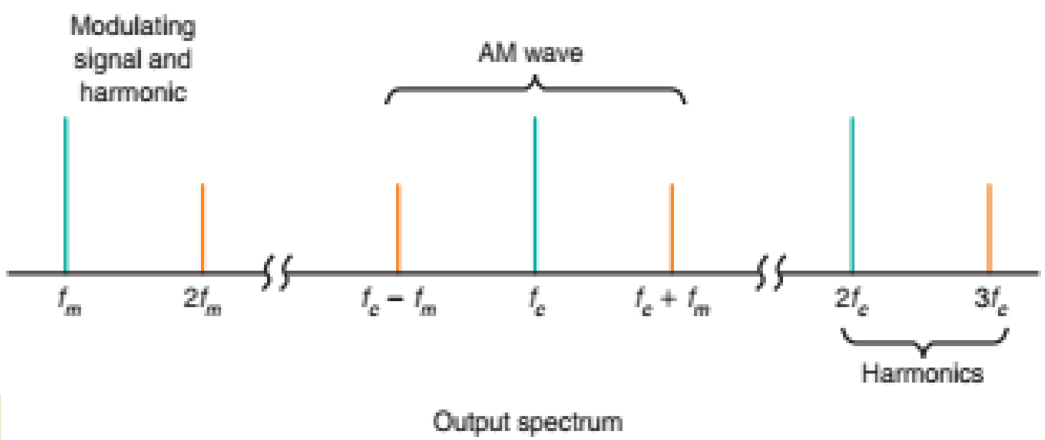
$$= a(v_c + v_m) + b(v_c^2 + 2v_c v_m + v_m^2)$$



- **By Substituting the trigonometric expressions**

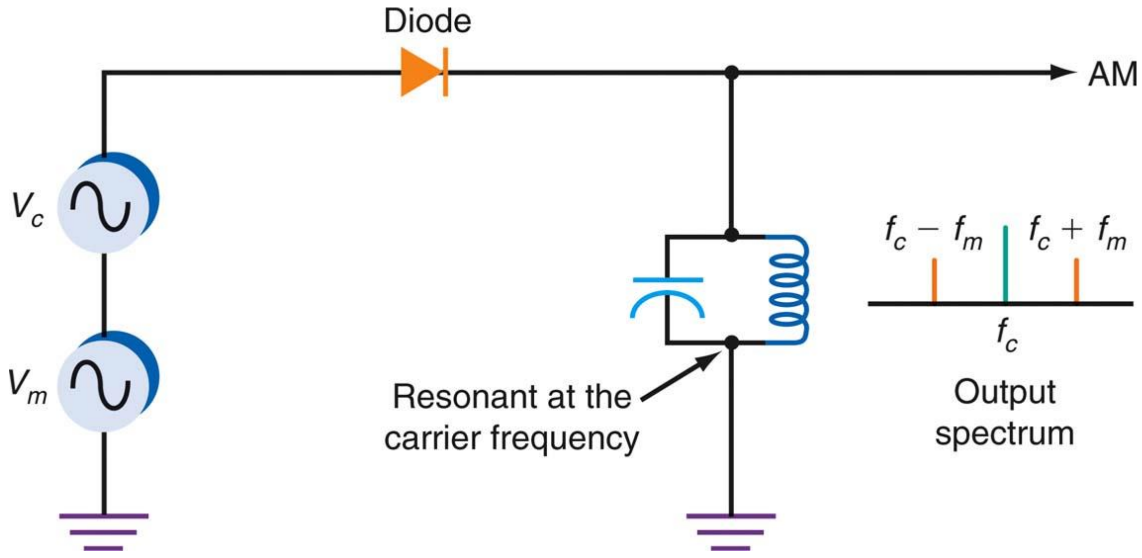
$$i = av_c \sin \omega_c t + av_m \sin \omega_m t + 0.5bv_c^2(1 - \cos 2\omega_c t) + 2bv_c v_m \sin \omega_c t \sin \omega_m t + 0.5bv_m^2(1 - \cos \omega_m t)$$

- **The first and fourth terms represent the AM signals**
- **Other intermodulation products terms can be filtered out**



4-1: Basic Principles of Amplitude Modulation

- **Intermodulation products are easy to filter out by a Tuned circuits filter out the modulating signal and carrier harmonics, leaving only carrier and sidebands.**
- **If a parallel resonant circuit is substituted for the resistor, we get an AM wave across the tuned circuit.**



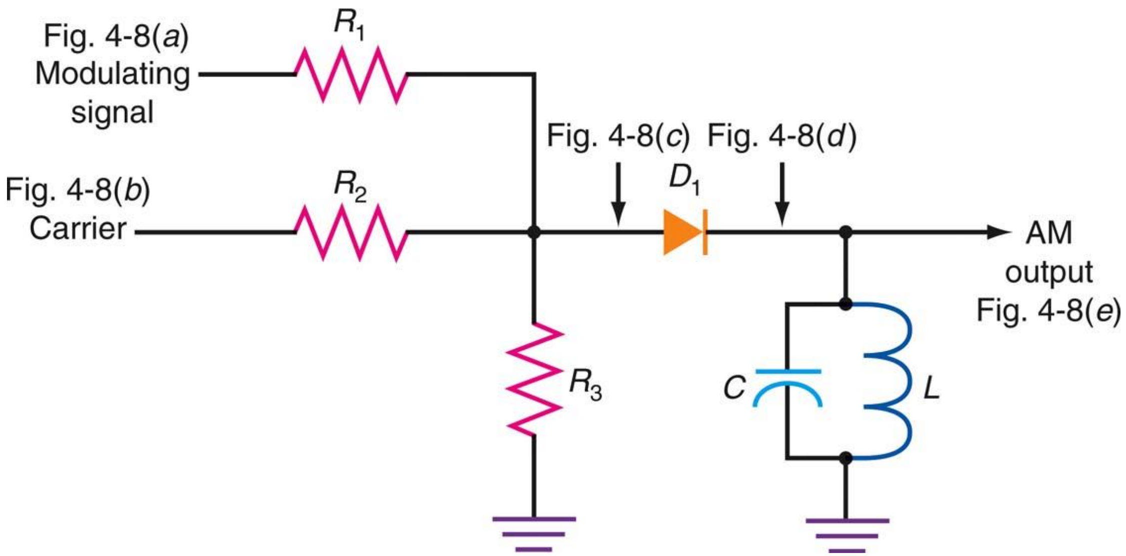
4-2: Amplitude Modulators

- There are two types of amplitude modulators. They are **low-level** and **high-level modulators**.
- Low-level modulators generate AM with small signals and must be amplified before transmission.
- High-level modulators produce AM at high power levels, usually in the final amplifier stage of a transmitter.

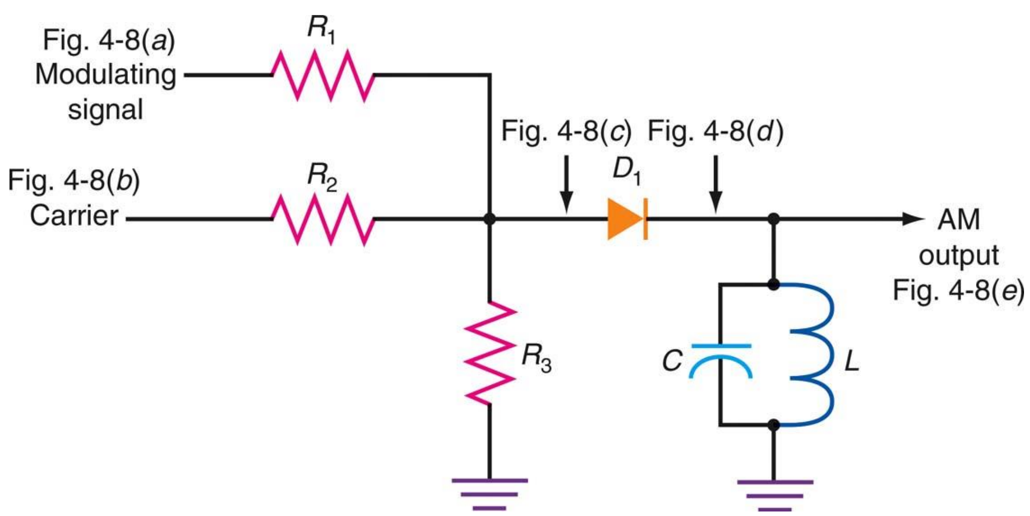
4-2: Amplitude Modulators

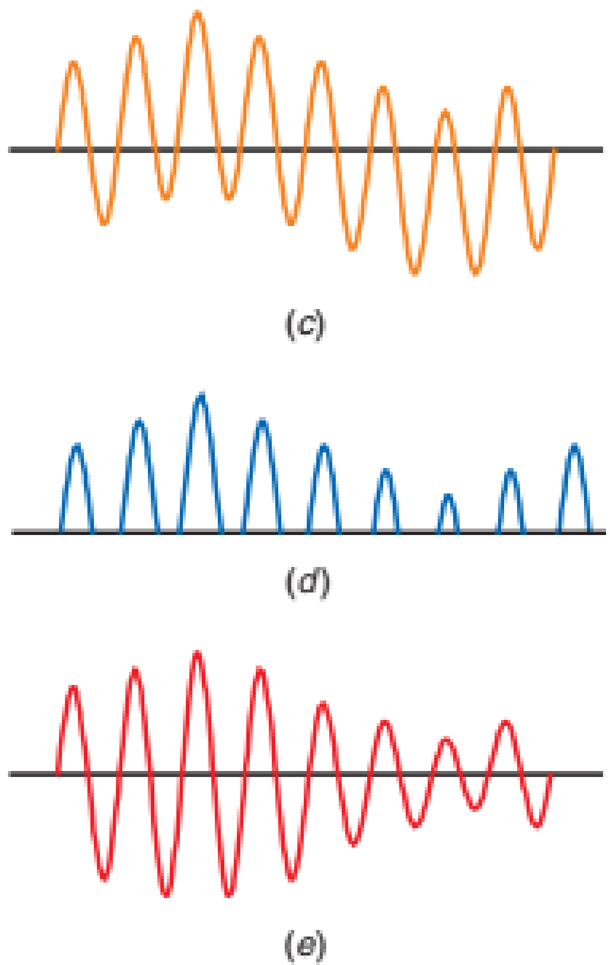
Low-Level AM: Diode Modulator

- **It** consists of a resistive network, a diode, and an *LC filter*.
- The carrier is applied to one input resistor and the modulating signal to another input resistor.
- This resistive network linearly mix the two signals



4-2: Amplitude Modulators





- A diode passes half cycles when forward biased.
- The coil and capacitor repeatedly exchange energy, causing an oscillation or ringing at the resonant frequency.

4-2: Amplitude Modulators

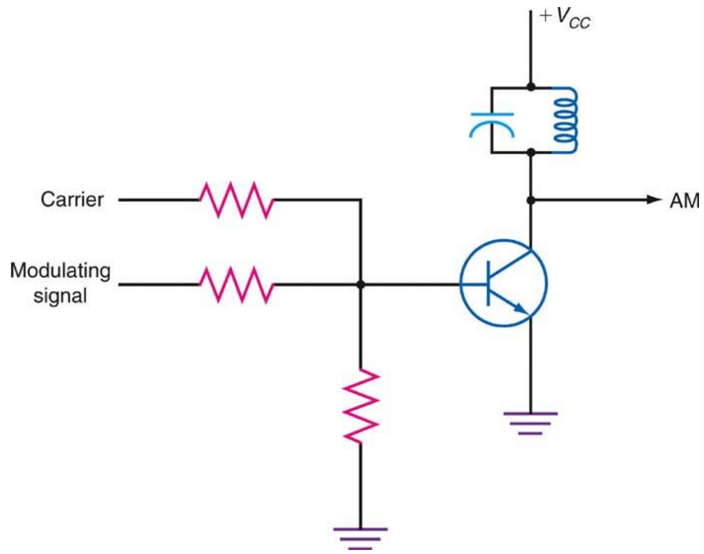
Low-Level AM: Diode Modulator

- Because the nonlinear portion of the diode's characteristic curve occurs only at low voltage levels, signal levels must be low, less than a volt, to produce AM. At higher voltages, the diode current response is nearly linear.
- The circuit works best with millivolt-level signals.

4-2: Amplitude Modulators

Low-Level AM: Transistor Modulator

- **Transistor modulation consists of a resistive mixing network, a transistor, and an *LC* tuned circuit.**
- **The emitter-base junction serves as a diode and nonlinear device.**
- **Modulation and amplification occur as base current controls a larger collector current.**
- **Because it uses a transistor instead of the diode, the circuit has gain.**



4-2: Amplitude Modulators

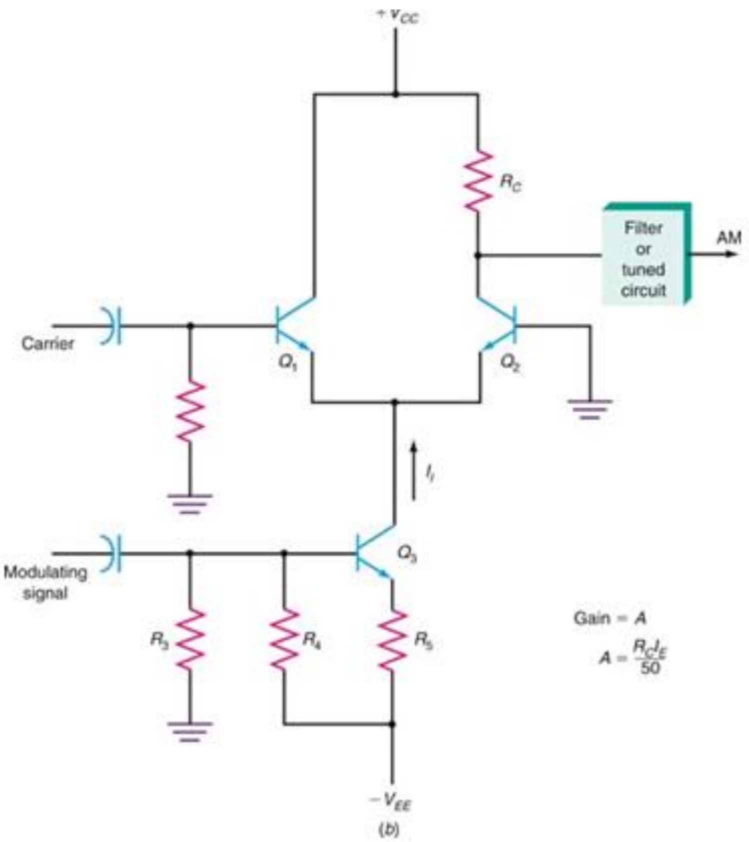
Low-Level AM: Differential Amplifier

- Differential amplifier modulators make excellent amplitude modulators because they have a high gain, good linearity and can be 100 percent modulated.

4-2: Amplitude Modulators

Low-Level AM: Differential Amplifier

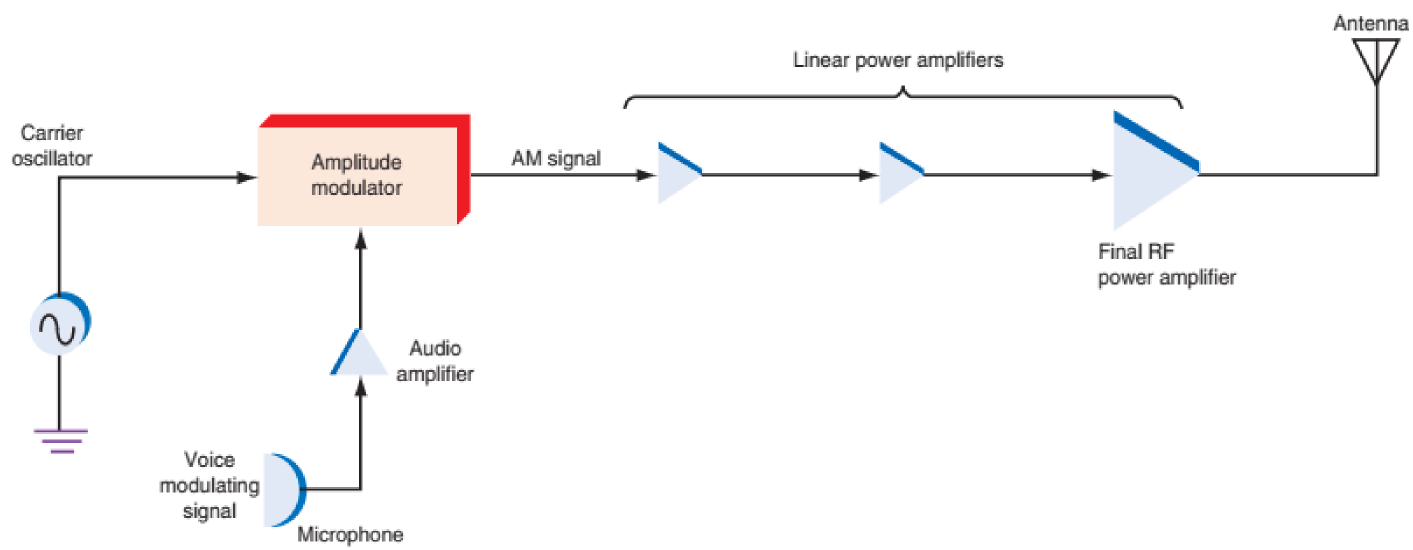
- The modulating signal is applied to the base of a constant-current source transistor.
- The modulating signal varies the emitter current and therefore the gain of the circuit.
- The AM output can be taken between two collectors, producing a **balanced,** or **differential,** output.
- The output can also be taken from the output of either collector to ground, producing a **single-ended output.**



4-2: Amplitude Modulators

Amplifying Low-Level AM Signals:

- In low-level modulator circuits, the signals are generated at very low voltage and power amplitudes. The voltage is typically less than 1 V, and the power is in milliwatts.
- The AM signal is applied to one or more linear amplifiers to increase its power level without distorting the signal.
- These amplifier circuits can be (class A, class AB, or class B)



4-2: Amplitude Modulators

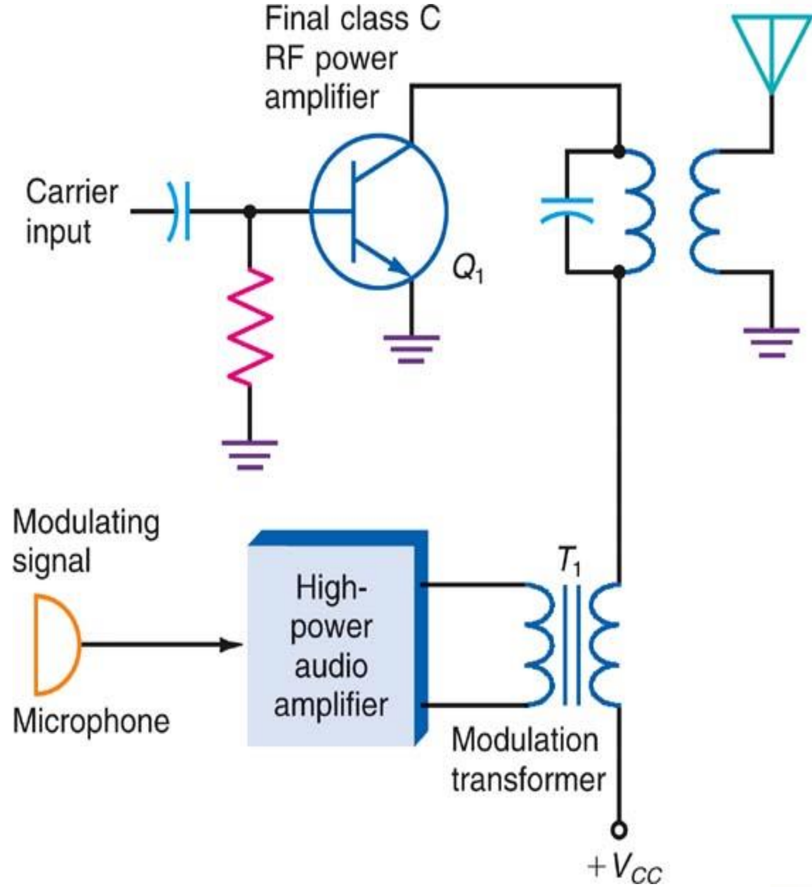
High-Level AM

- In **high-level modulation**, the modulator varies the voltage and power in the final RF amplifier stage of the transmitter.
- The result is high efficiency in the RF amplifier and overall high-quality performance.

4-2: Amplitude Modulators

High-Level AM: Collector Modulator

- A linear power amplifier takes the low-level modulating signals and amplifies them to a high-power level.
- The amplified modulating signal is coupled through a modulation transformer to a class C amplifier.
- The secondary winding of the modulation transformer is connected in series with the collector supply voltage of the class C amplifier.
- Howver,The higher the power, the larger and more expensive the transformer



4-2: Amplitude Modulators

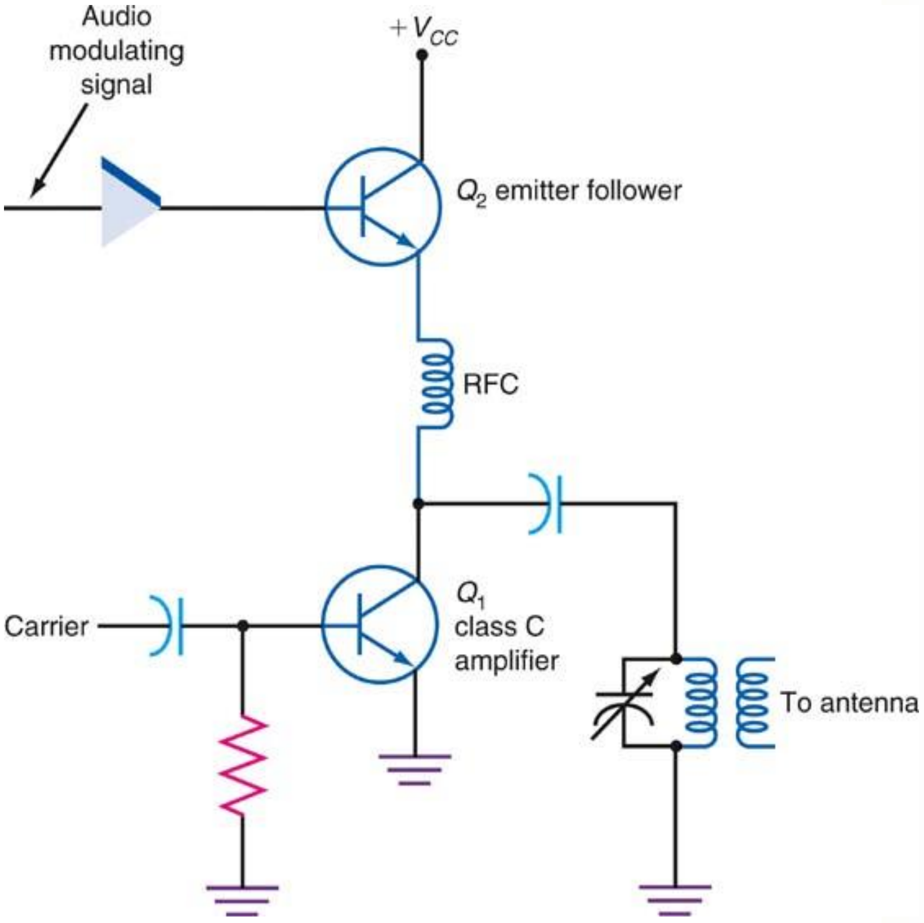
High-Level AM: Series Modulator

- A **series modulator** produces high-level modulation without a large and expensive modulation transformer used in collector modulators.
- A series modulator (emitter-follower) replaces the modulation transformer with an emitter follower
- It improves frequency response.
- It is, however, very inefficient since the emitter-follower modulator dissipates as much power as the class C RF amplifier.
- It is not practical for very high power AM, but it does make an effective higher-level modulator for power levels below 100W

4-2: Amplitude Modulators

Series Modulator Circuit

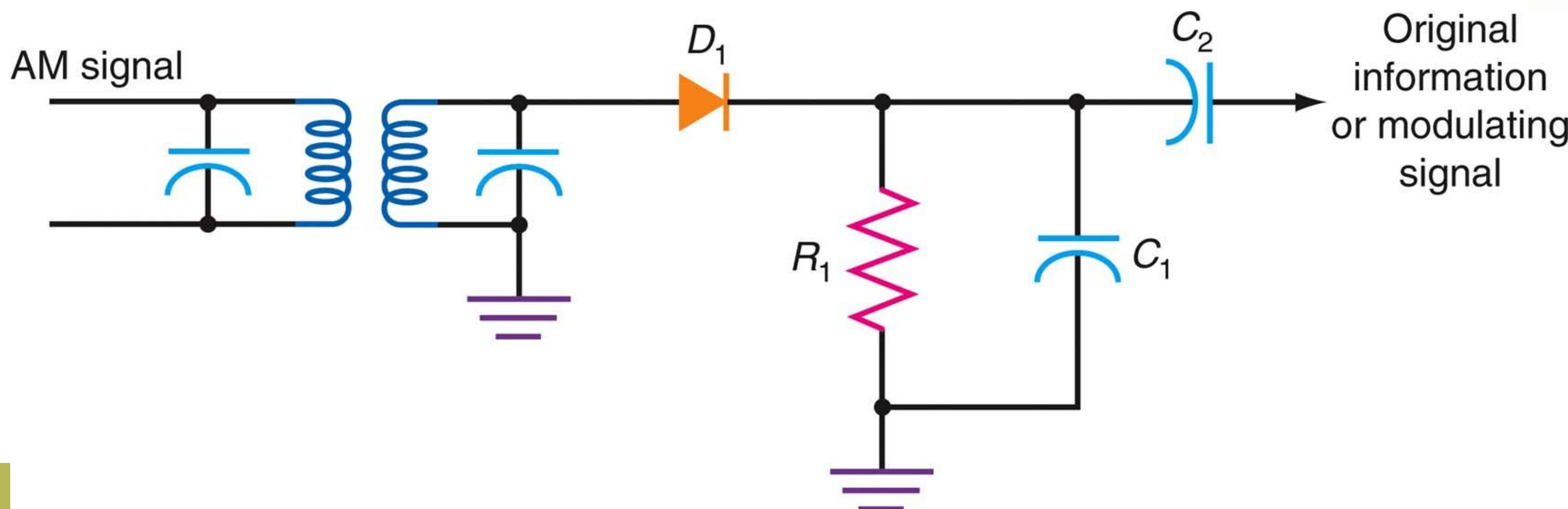
- The modulating signal is applied to the emitter follower.
- The emitter follower is in series with the collector supply voltage.
- The collector voltage changes with variations in the amplified audio modulating signal.



4-3: Amplitude Demodulators

- **Demodulators**, or detectors, are circuits that accept modulated signals and recover the original modulating information.

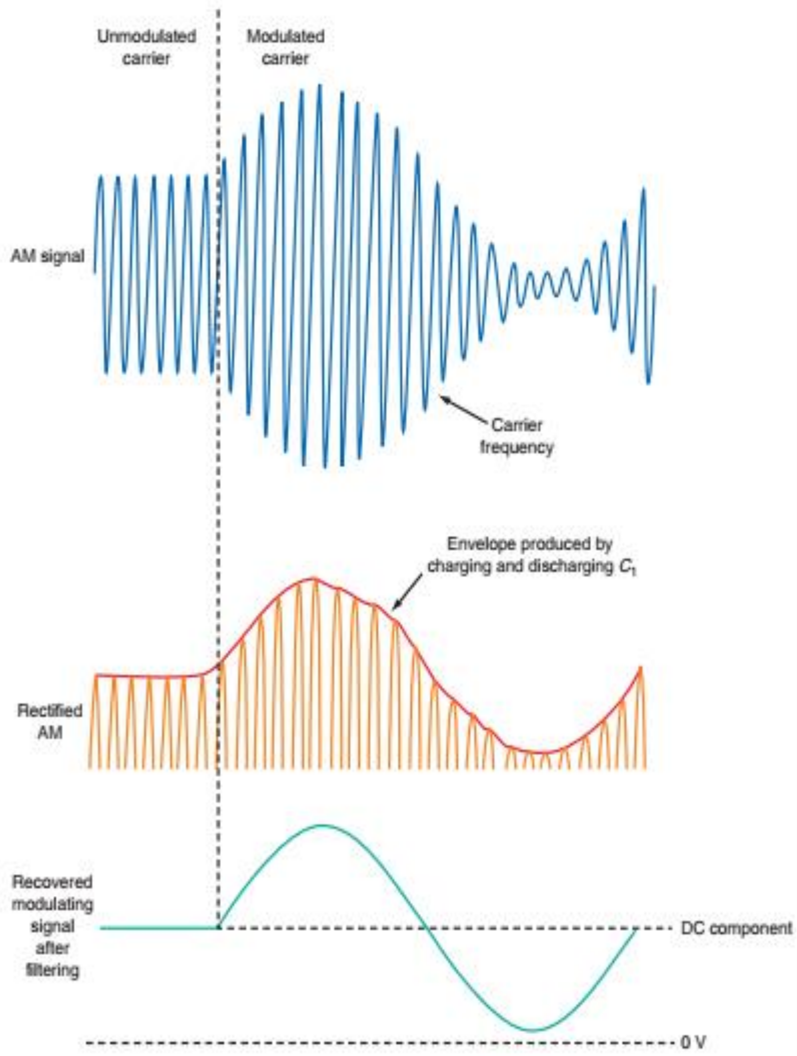
Diode Detector: the diode detector recovers the envelope of the AM (modulating) signal, the circuit is sometimes called an envelope detector.



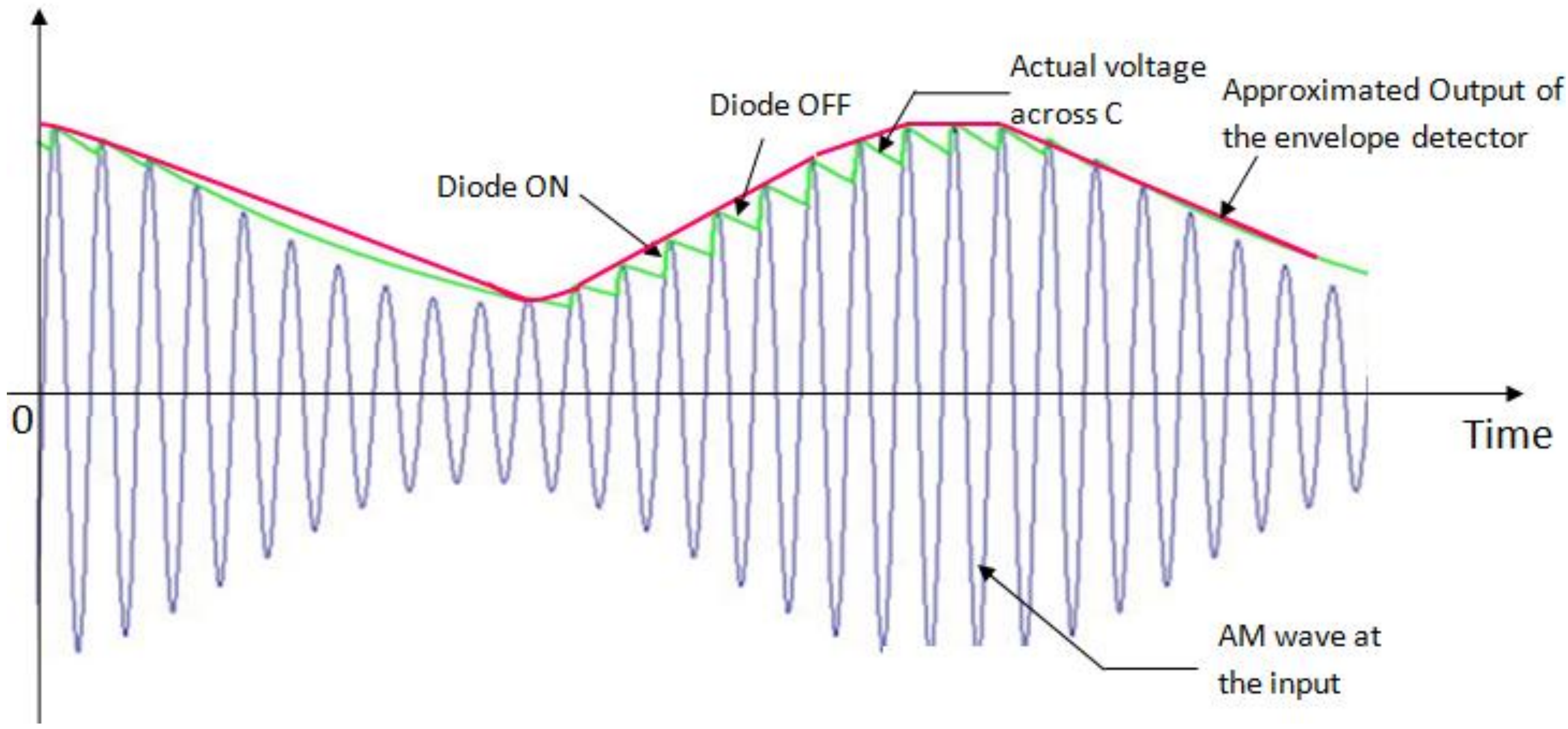
4-3: Amplitude Demodulators

Diode Detector

- On positive alternations of the AM signal, C1 charges quickly to the peak value of diode rectified pulses
- When the pulse voltage drops to zero, C1 discharges into R1
- The RC time constant is long compared to the period of the carrier.
- The capacitor discharges only slightly when the diode is not conducting.
- The resulting waveform across the capacitor is a close approximation to the original modulating signal.



Diode Detector Ripples



Selection of the RC time Constants

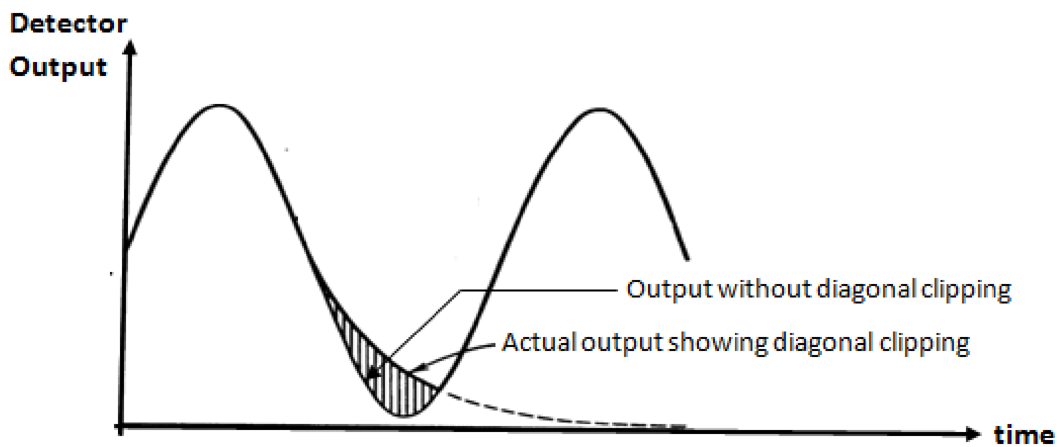
- The time constant RC should be short compared to the carrier period 1/fc (i.e., RC << 1/fc)
- On the other hand, the discharging time constant RC should be long enough so that the capacitor discharges slowly through the load resistance R .
- But, it should not be too long which will not allow the capacitor voltage to discharge at the maximum rate of change of the envelope **.**

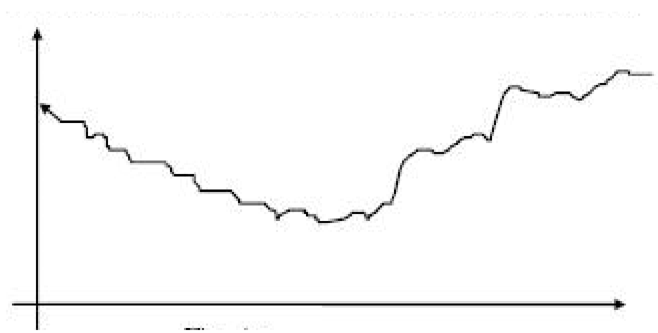
$$1/f_c << RC << 1/W$$

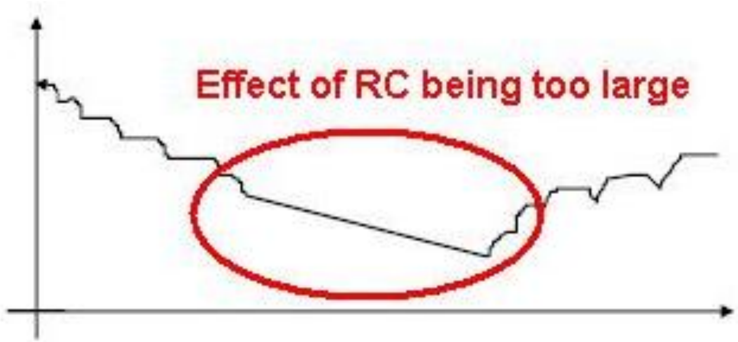
where, W = Maximum modulating frequency

Diode Diagonal Clipping

- If the RC time constant is too long, the RC circuit cannot follow the fast changes in the modulating envelope and diagonal distortion occurs



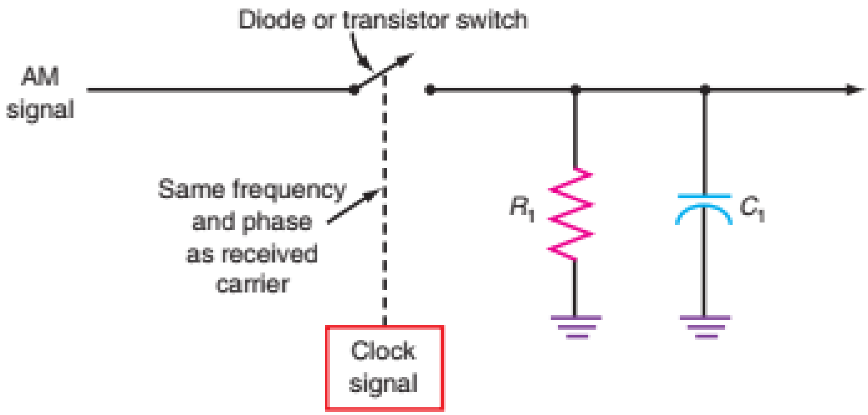


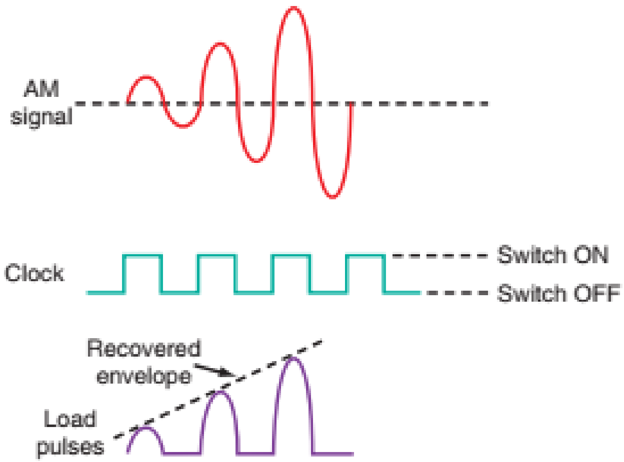


4-3: Amplitude Demodulators

Synchronous Detection (**coherent detectors**)

- **Synchronous detectors** use an internal clock signal at the carrier frequency in the receiver to switch the AM signal off and on, producing rectification similar to that in a standard diode detector.
- The AM signal is applied to a series switch that is opened and closed synchronously with the carrier signal.

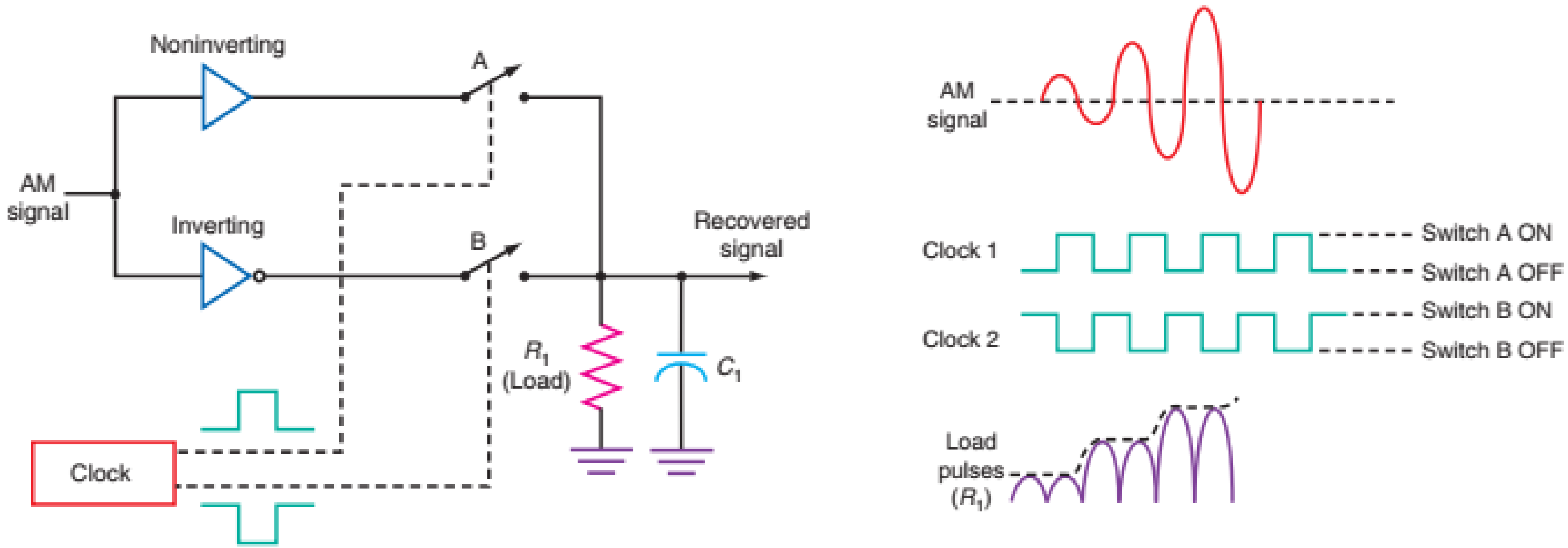




4-3: Amplitude Demodulators

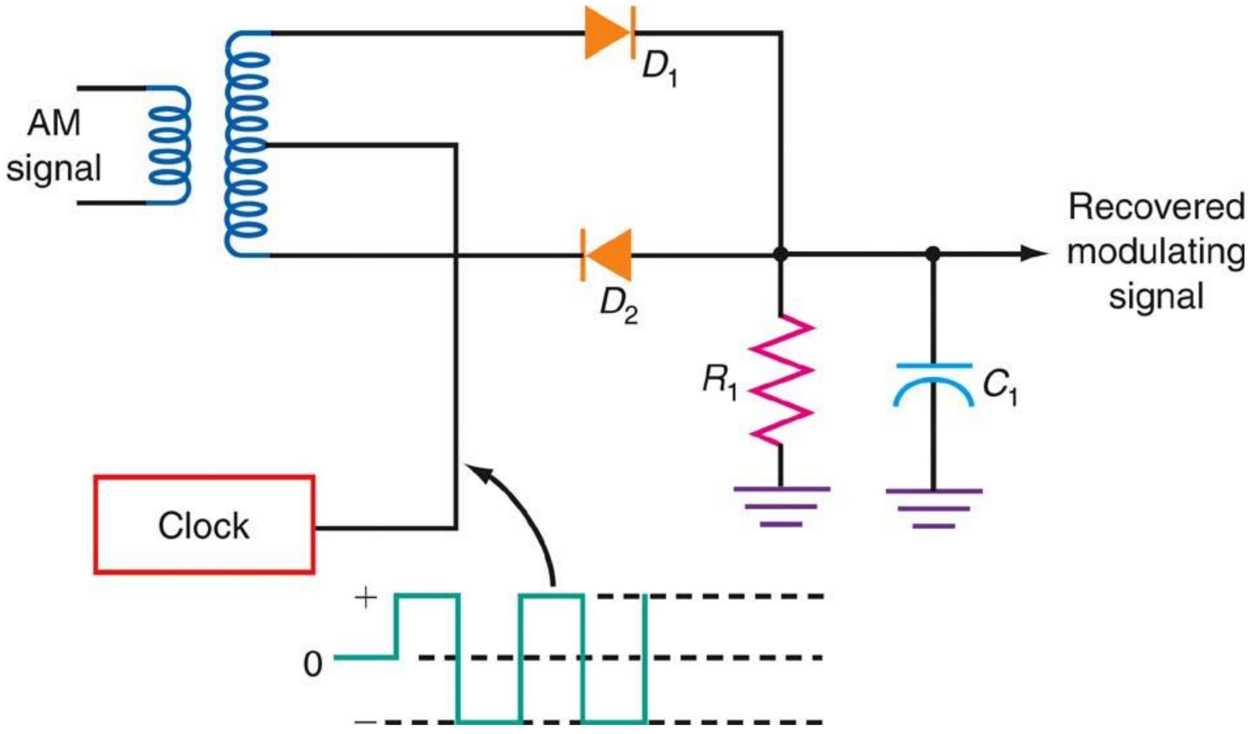
Full wave synchronous detector

- The AM signal is applied to both inverting and noninverting amplifiers.
- The internally generated carrier signal operates two switches A and B. The clock turns A on and B off or turns B on and A off (single-pole, double-throw (SPDT) switch).



4-3: Amplitude Demodulators

Practical Full wave synchronous detector



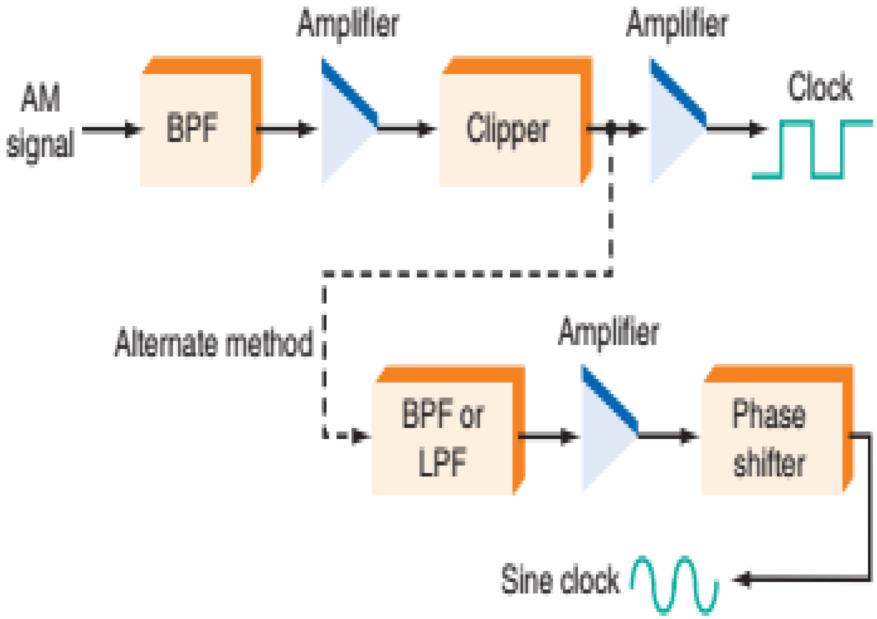
4-3: Amplitude Demodulators

- Synchronous detectors have less distortion and a better signal-to-noise ratio than standard diode detectors.
- The key to making the synchronous detector work is to ensure that the signal producing the switching action is perfectly in phase with the received AM carrier.
- An internally generated carrier signal from an oscillator will not work, which raises the need to have a carrier recovery circuits that can be used to generate a switching signal that has the correct frequency and phase relationship to the carrier.

Carrier recovery circuit

- The AM signal is applied to a highly selective bandpass filter that picks out the carrier and suppresses the sidebands
- This signal is amplified and applied to a clipper or limiter that removes any remaining amplitude variations from the signal, leaving only the carrier.
- The clipper circuit typically converts the sine wave carrier into a square wave that is amplified and thus becomes the clock signal.

- In some synchronous detectors, the clipped carrier is put through another bandpass filter to get rid of the square wave harmonics and generate a pure sine wave carrier.
- This signal is then amplified and used as the clock.
- A small phase shifter may be introduced to correct for any phase differences that occur during the carrier recovery process.



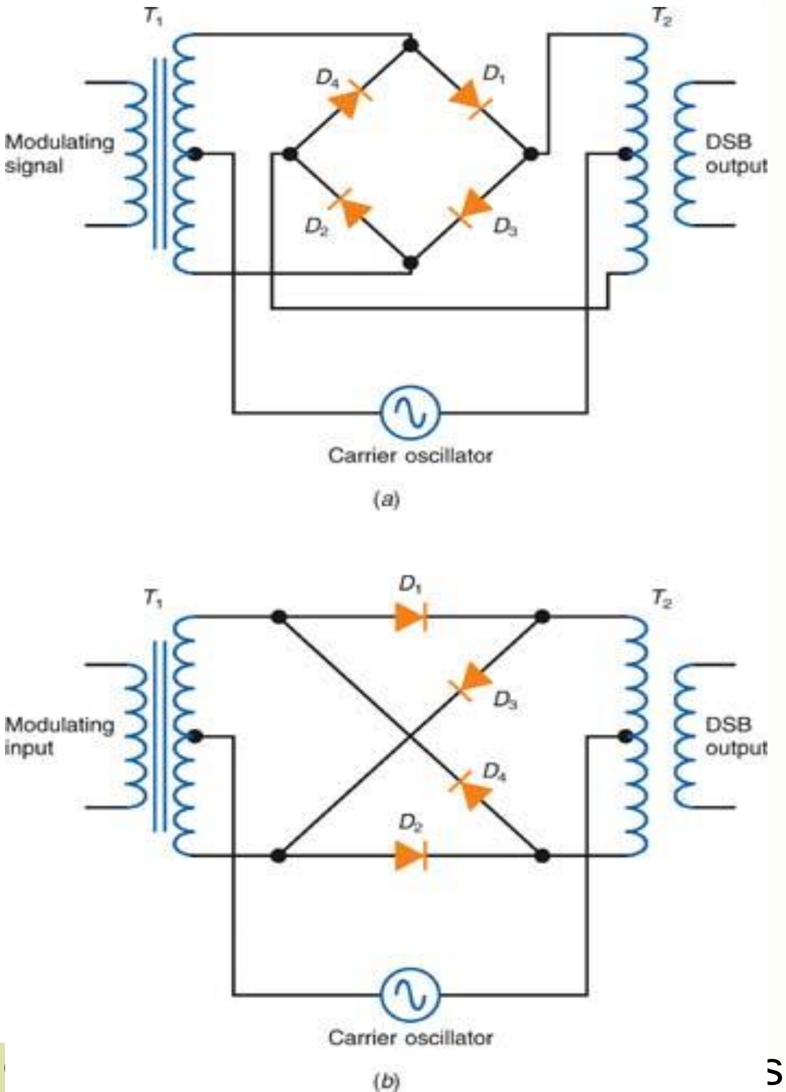
4-4: Balanced Modulator

- A **balanced modulator** is a circuit that generates a DSB signal, suppressing the carrier and leaving only the sum and difference frequencies at the output.
- The output of a balanced modulator can be further processed by filters or phase-shifting circuitry to eliminate one of the sidebands, resulting in a SSB signal.
- Types of balanced modulators include lattice, 1496/1596 IC, and the analog multiplier.

4-4: Balanced Modulator

Lattice Modulator (Diode ring)

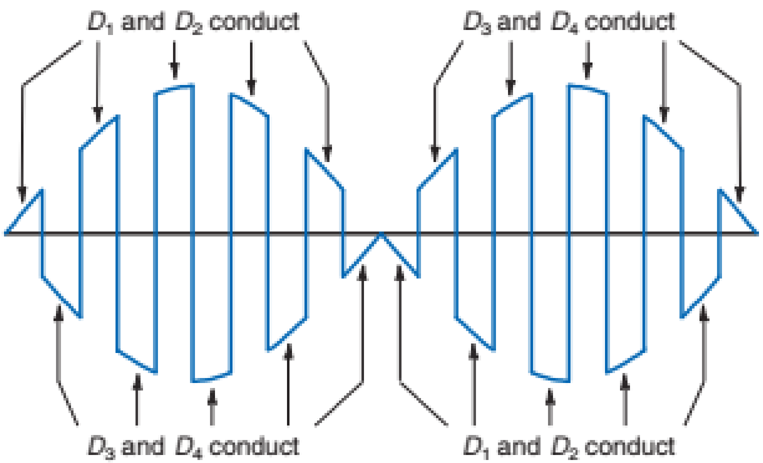
- A popular type, which consists of an input transformer, an output transformer and four diodes connected in a bridge circuit.
- The carrier signal is applied to the center taps of the input and output transformers.
- The modulating signal is applied to the input transformer.
- The output appears across the output transformer.



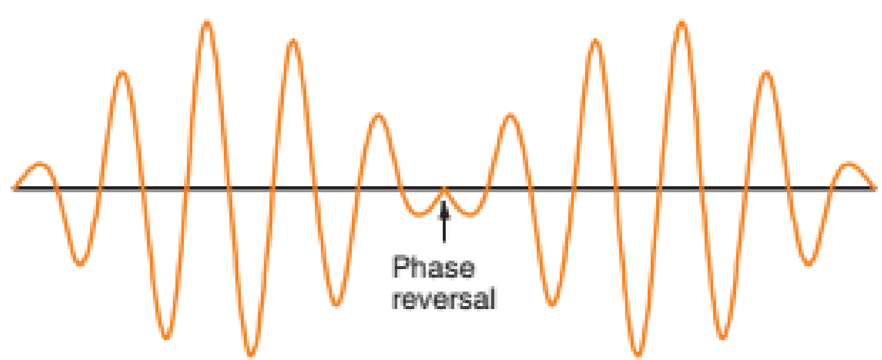
4-4: Balanced Modulator

Lattice Modulators

- The carrier sine wave is used as a source of forward and reverse bias for the diodes.
- The carrier turns the diodes off and on at a high rate of speed.
- The diodes act like switches that connect the modulating signal at the secondary of T_1 to the primary of T_2.



DSB signal—primary T_2



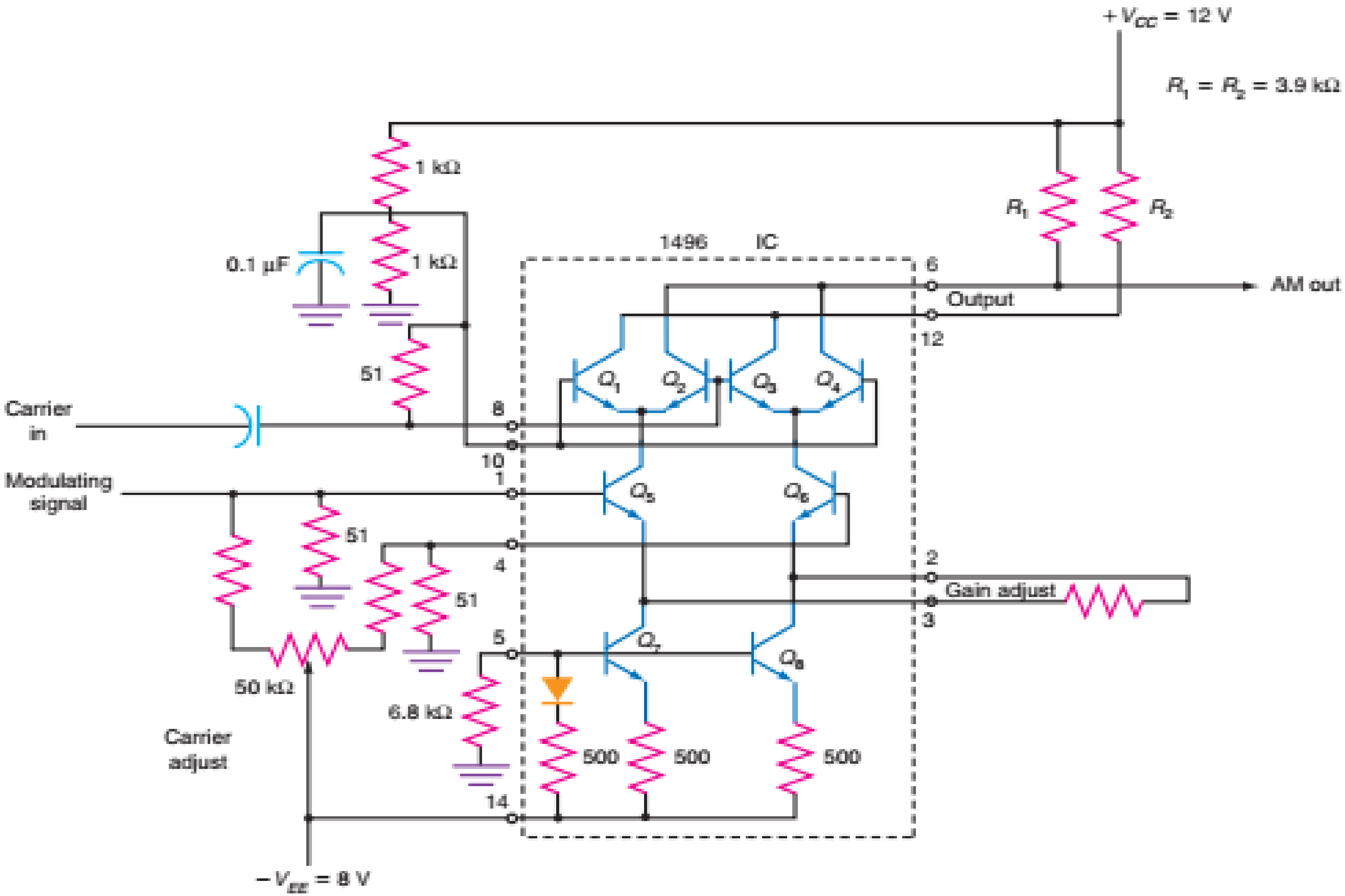
DSB output signal

4-4: Balanced Modulator

IC Balanced Modulators

- The 1496/1596 IC can operate as a balanced modulator or configured to perform as an amplitude modulator, a product detector, or a synchronous detector It can work at carrier frequencies up to 100 MHz.
- It can achieve a carrier suppression of 50 to 65 dB.
- It is available in standard 14-pin dual in-line package (DIP) IC in addition to several types of surface-mount packages

4-4: Balanced Modulator



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4-4: Balanced Modulator

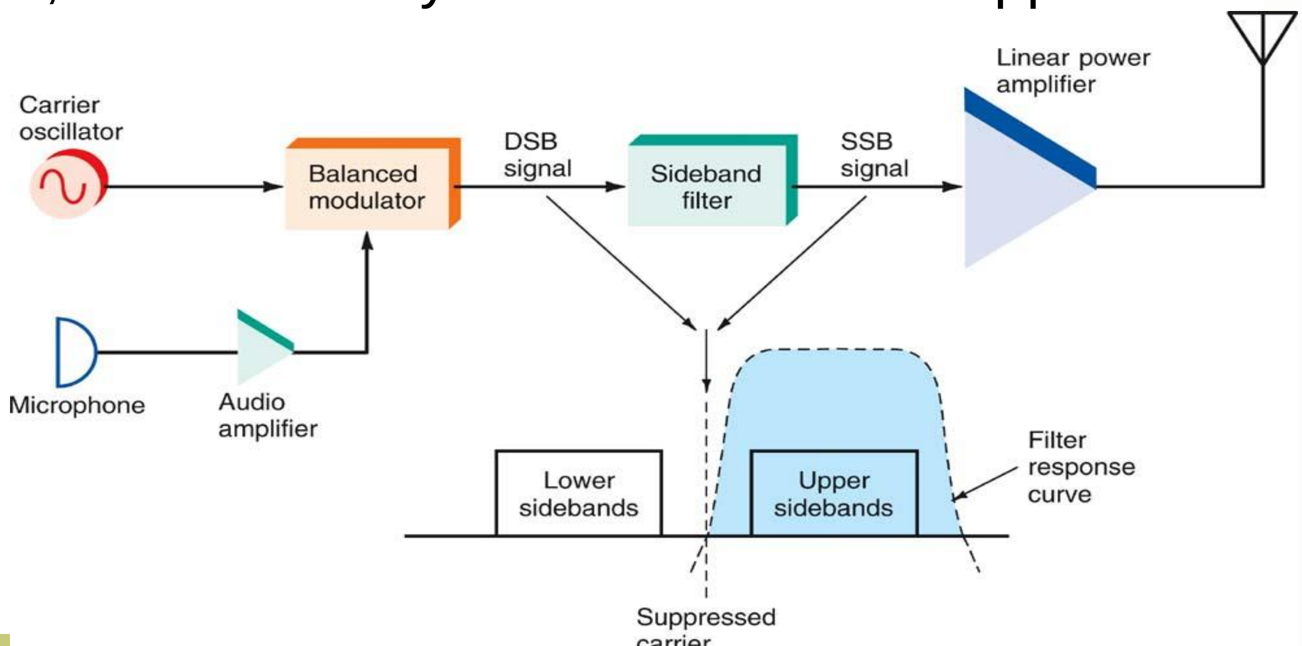
IC Balanced Modulators: Analog Multiplier

- An **analog multiplier** is a type of integrated circuit that can be used as a balanced modulator to generate DSB signals.
- The analog multiplier is not a switching circuit like the balanced modulator.
- The analog multiplier uses differential amplifiers operating in the linear mode.

4-5: SSB Circuits

Generating SSB Signals: The Filter Method

- The **filter method** is the simplest and most widely used method of generating SSB signals.
- An SSB signal is produced by passing the DSB signal through a highly selective bandpass filter.
- With the filter method, it is necessary to select either the upper or the lower sideband.

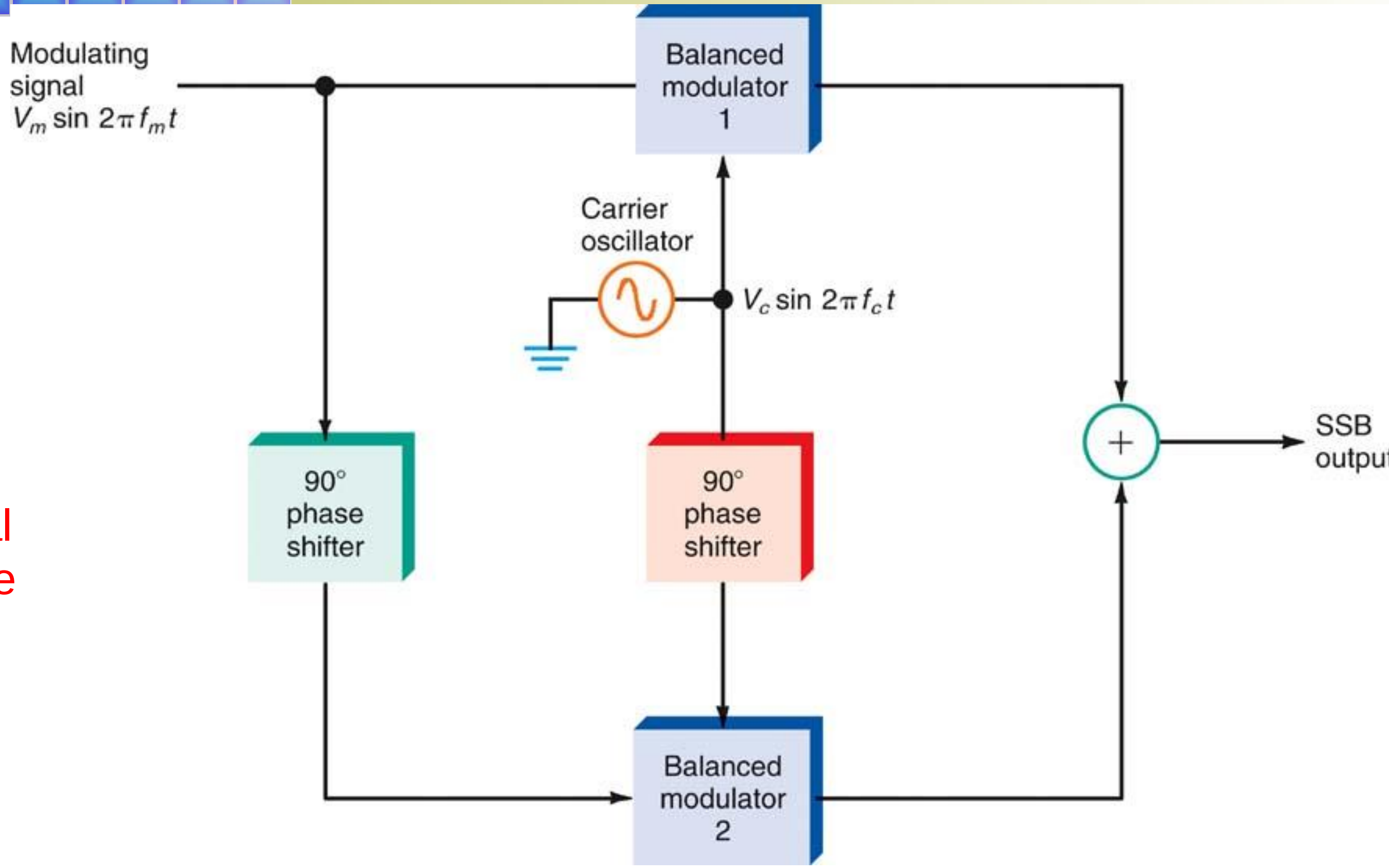


4-5: SSB Circuits

Generating SSB Signals: Phasing Method

- The **phasing method** uses a phase-shift technique that causes one of the sidebands to be canceled out.
- The phasing method uses two balanced modulators which eliminate the carrier.
- The carrier oscillator is applied to the upper balanced modulator along with the modulating signal.
- The carrier and modulating signals are both shifted in phase by 90 degrees and applied to another balanced modulator.
- Phase-shifting causes one sideband to be canceled out when the two modulator outputs are added together.

4-5: SSB Circuits



Check the Mathematical proof in page 144

Figure 4-33 An SSB generator using the phasing method.

4-5: SSB Circuits

DSB and SSB Demodulation

- To recover the intelligence in a DSB or SSB signal, the carrier that was suppressed at the receiver must be reinserted.
- A **product detector** is a balanced modulator used in a receiver to recover the modulating signal.
- Any balanced modulator can be used as a product detector to demodulate SSB signals.

4-5: SSB Circuits

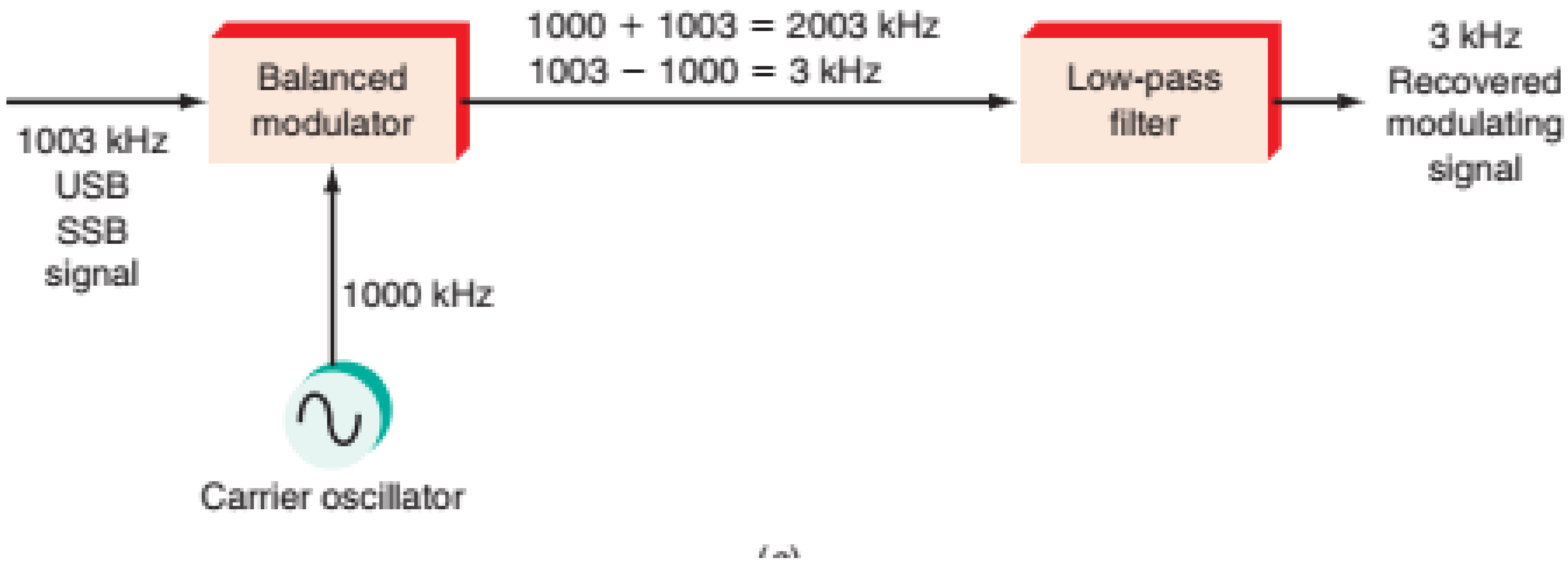


Figure 4-38 A balanced modulator used as a product detector to demodulate an SSB signal.