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3.0 Amplitude Modulation

<http://www.educatorscorner.com/experiments/spectral/SpecAn5.html>

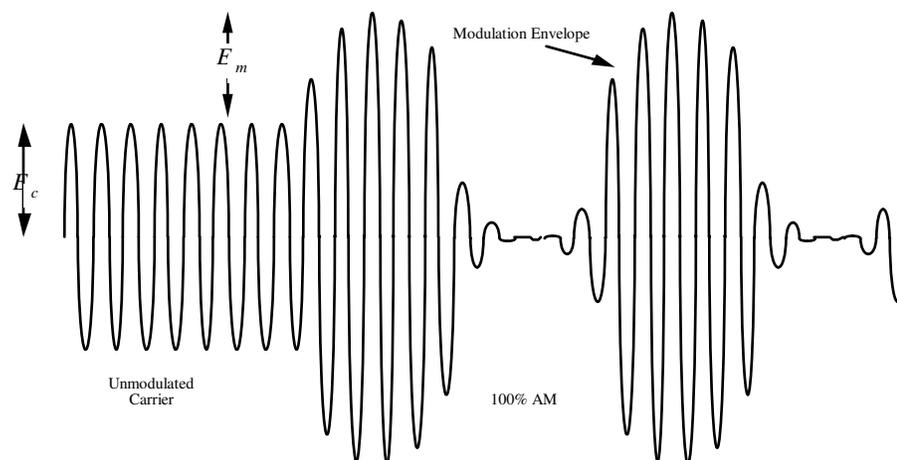
Information can be used to modulate a high frequency carrier in three principle ways: by varying the carrier amplitude, frequency or phase.

The simplest and most bandwidth efficient of these methods is amplitude modulation.

3.1 Theory

A sinewave carrier signal is of the form $e_c = E_c \sin \omega_c t$ and a sinewave modulation signal is of the form $e_m = E_m \sin \omega_m t$.

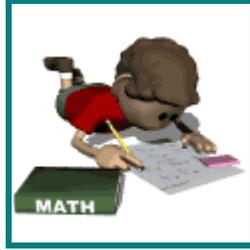
Notice that the amplitude of the high frequency carrier takes on the shape of the lower frequency modulation signal forming what is called a modulation envelope.



The modulation index is defined as the ratio of the modulation signal amplitude to carrier signal amplitude. $m = \frac{E_m}{E_c}$ where $0 \leq m \leq 1$.

The overall signal can be described by:

$$\begin{aligned} e_{am} &= (E_c + E_m \sin \omega_m t) \sin \omega_c t \\ &= (E_c + mE_c \sin \omega_m t) \sin \omega_c t \end{aligned}$$



A note on frequency multiplication:

The product of two sinewaves produces sum and difference frequencies:

$$\sin \omega_1 t \sin \omega_2 t = \frac{1}{2} \cos(\omega_1 - \omega_2)t - \frac{1}{2} \cos(\omega_1 + \omega_2)t$$

The subtraction of two frequencies does not result in a negative frequency. It is understood to really represent the absolute magnitude:

$$\sin \omega_1 t \sin \omega_2 t = \frac{1}{2} \cos(|\omega_1 - \omega_2|)t - \frac{1}{2} \cos(\omega_1 + \omega_2)t$$

One way to avoid a 'negative frequency' is to always subtract the smaller value from the larger one. However, when this expression refers only to angles, it is often necessary to retain the negative.

As a result, expanding the instantaneous AM expression results in:

$$\begin{aligned} e_{am} &= E_c \sin \omega_c t + mE_c \sin \omega_m t \sin \omega_c t \\ &= \underbrace{E_c \sin \omega_c t}_{\text{Carrier}} + \underbrace{\frac{mE_c}{2} \sin(\omega_c - \omega_m)}_{\text{LSB}} - \underbrace{\frac{mE_c}{2} \sin(\omega_c + \omega_m)}_{\text{USB}} \end{aligned}$$

From this we observe that upper and lower sidebands are created when using amplitude modulation. The sideband amplitude is: $\frac{mE_c}{2}$, and the total occupied spectrum is twice the bandwidth of the modulation signal or $2f_m$.

Often, the amplitude of the carrier is normalized and the expression is written:

$$e_{am} = (1 + m \sin \omega_m t) \sin \omega_c t$$

AM signals are often characterized in terms of power, since it is power, which is used to drive antennas. The total power in a 1Ω resistor is given by:

$$\begin{aligned}
 P_T &= E_c^2 + \left(\frac{mE_c}{2}\right)^2 + \left(\frac{mE_c}{2}\right)^2 \\
 &= P_c + \frac{m^2}{4} P_c + \frac{m^2}{4} P_c \\
 &= P_c \left(1 + \frac{m^2}{2}\right)
 \end{aligned}$$

From this we observe that with a modulation index of 0, the transmitted power is equal to the carrier power. However, when the modulation index is 1, the total transmitted power increases to 1.5 times the carrier power.

At 100% modulation, only 1/3 of the total power is in the sidebands or only 1/2 of the carrier power is in the sidebands.

In terms of voltages and currents:

$$E_T = E_c \sqrt{1 + \frac{m^2}{2}} \quad I_T = I_c \sqrt{1 + \frac{m^2}{2}}$$

If the carrier is modulated by a complex signal, the effective modulation can be determined by the combining the modulation index of each component.

$$m_{eff} = \sqrt{m_1^2 + m_2^2 + m_3^2 + \dots} \text{ (must not exceed 1)}$$

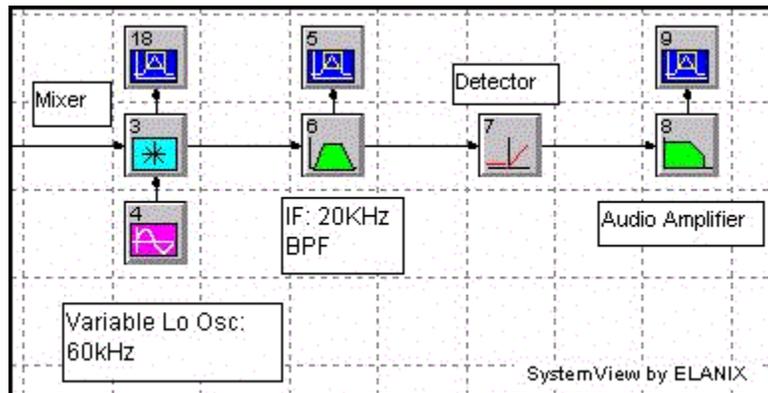
3.2 AM Receivers

[RF & IF Digitization in Radio Receivers by Wepman & Hoffman](#)

The most common receivers in use today are the super heterodyne type. They consist of:

- Antenna
- RF amplifier
- Local Oscillator and Mixer
- IF Section
- Detector and Amplifier

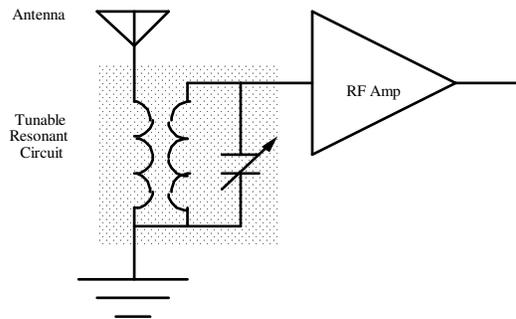
SystemView AM Receiver Model



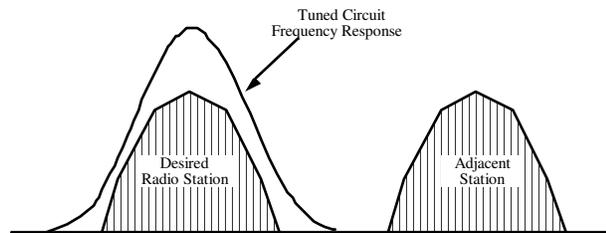
The need for these subsystems can be seen when one considers the much simpler and inadequate TRF or tuned radio frequency amplifier.

3.2.1 TRF Amplifier

It is possible to design an RF amplifier to accept only a narrow range of frequencies, such as one radio station on the AM band.



By adjusting the center frequency of the tuned circuit, all other input signals can be excluded.



The AM band ranges from about 500 KHz to 1600 KHz. Each station requires 10 KHz of this spectrum, although the baseband signal is only 5 KHz.

Recall that for a tuned circuit: $Q = \frac{f_c}{B}$. The center or resonant frequency in an *RLC* network is most often adjusted by varying the capacitor value.

However, the Q remains approximately constant as the center frequency is adjusted. This suggests that as the bandwidth varies as the circuit is tuned.

For example, the Q required at the lower end of the AM band to select only one radio station would be approximately:

$$Q = \frac{f_c}{B} = \frac{500\text{KHz}}{10\text{KHz}} = 50$$

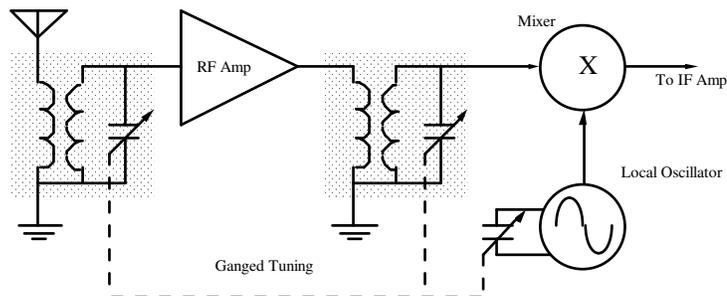
As the tuned circuit is adjusted to the higher end of the AM band, the resulting bandwidth is:

$$B = \frac{f_c}{Q} = \frac{1600\text{KHz}}{50} = 30\text{KHz}$$

A bandwidth this high could conceivably pass three adjacent stations, thus making meaningful reception impossible.

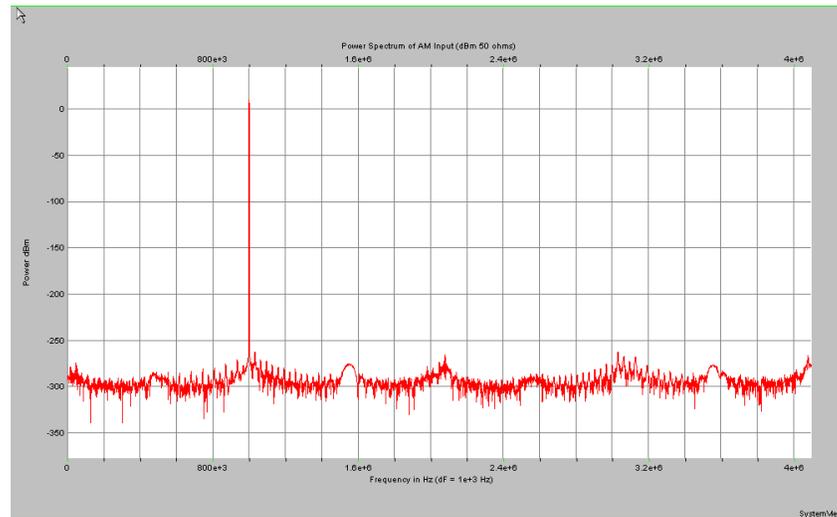
To prevent this, the incoming RF signal is heterodyned to a fixed IF or intermediate frequency and passed through a constant bandwidth circuit.

3.2.2 Superheterodyne Receiver



The RF amplifier boosts the signal into the mixer. In doing so, it may add some noise.

1 MHz AM Carrier into the mixer



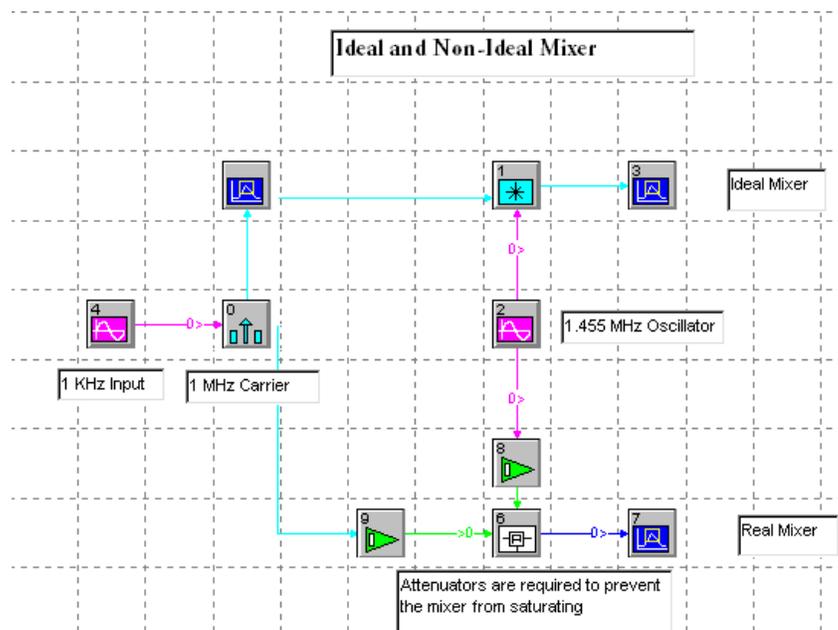
The other mixer input is a high frequency sinewave. In AM receivers, it is 455 KHz above the incoming carrier frequency.

An ideal mixer will combine the incoming carrier with the local oscillator to create sum and difference frequencies.

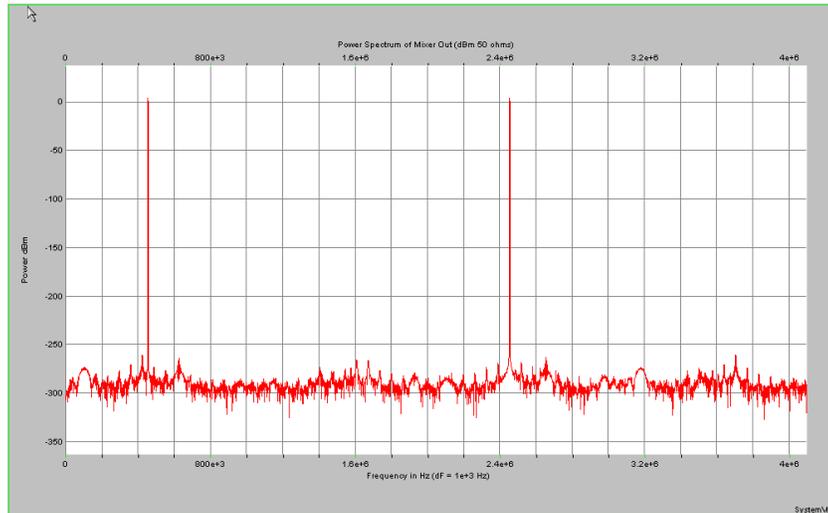
[Integrated LNA & Mixer Basics by National Semiconductor](#)

[Operating & Evaluating Quadrature Modulators for PCS Systems by National Semiconductor](#)

SystemView Mixer Models



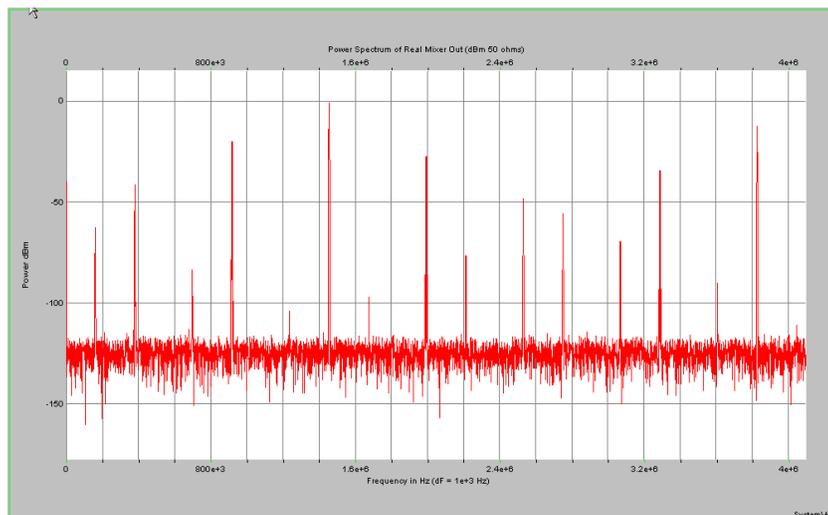
Ideal Mixer Output



A real mixer combines two signals and creates a host of new frequencies:

- A dc level
- The original two frequencies
- The sum and difference of the two input frequencies
- Harmonics of the two input frequencies
- Sums and differences of all of the harmonics

Non-Ideal Mixer Out



The principle mixer output signals of interest are the sum and difference frequencies, either of which could be used as an IF. However, the IF is generally chosen to be lower than the lowest frequency being received. Consequently, the IF in an AM radio has been standardized to 455 KHz.

3.2.2.1 Local Oscillator Frequency

Since the mixer generates sum and difference frequencies, it is possible to generate the 455 KHz IF signal if the local oscillator is either above or below the IF. The inevitable question is which is preferable.

Case I The local Oscillator is above the IF. This would require that the oscillator tune from (500 + 455) KHz to (1600 + 455) KHz or approximately 1 to 2 MHz.

It is normally the capacitor in a tuned RLC circuit, which is varied to adjust the center frequency while the inductor is left fixed. Since $f_c = \frac{1}{2\pi\sqrt{LC}}$,

solving for C we obtain $C = \frac{1}{L(2\pi f_c)^2}$. When the tuning frequency is a maximum, the tuning capacitor is a minimum and vice versa. Since we know the range of frequencies to be created, we can deduce the range of capacitance required.

$$\frac{C_{\max}}{C_{\min}} = \frac{L(2\pi f_{\max})^2}{L(2\pi f_{\min})^2} = \left(\frac{f_{\max}}{f_{\min}}\right)^2 = \left(\frac{2}{1}\right)^2 = 4$$

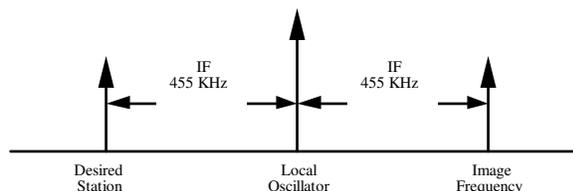
Making a capacitor with a 4:1 value change is well within the realm of possibility.

Case II The local Oscillator is below the IF. This would require that the oscillator tune from (500 - 455) KHz to (1600 - 455) KHz or approximately 45 KHz to 1145 KHz, in which case:

$$\frac{C_{\max}}{C_{\min}} = \left(\frac{1145\text{KHz}}{45\text{KHz}}\right)^2 \approx 648$$

3.2.2.2 Image Frequency

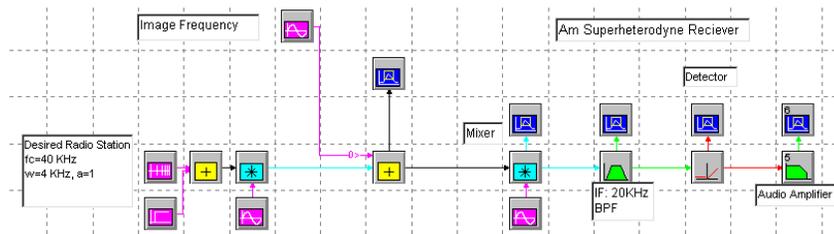
Just as there are two oscillator frequencies, which can create the same IF, two different station frequencies can create the IF. The undesired station frequency is known as the image frequency.



$$f_{\text{image}} = f_s + 2f_{IF} \text{ if } f_o > f_s$$

$$f_{\text{image}} = f_s - 2f_{IF} \text{ if } f_s > f_o$$

SystemView Image Frequency Model



If any circuit in the radio front end exhibits non-linearities, there is a possibility that other combinations may create the intermediate frequency.

3.2.3 AM Detection

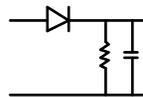
There are two basic types of AM detection, coherent and non-coherent. Of these two, the non-coherent is the simpler method.

Non-coherent detection does not rely on regenerating the carrier signal. The information or modulation envelope can be removed or detected by a diode followed by an audio filter.

Coherent detection relies on regenerating the carrier and mixing it with the AM signal. This creates sum and difference frequencies. The difference frequency corresponds to the original modulation signal.

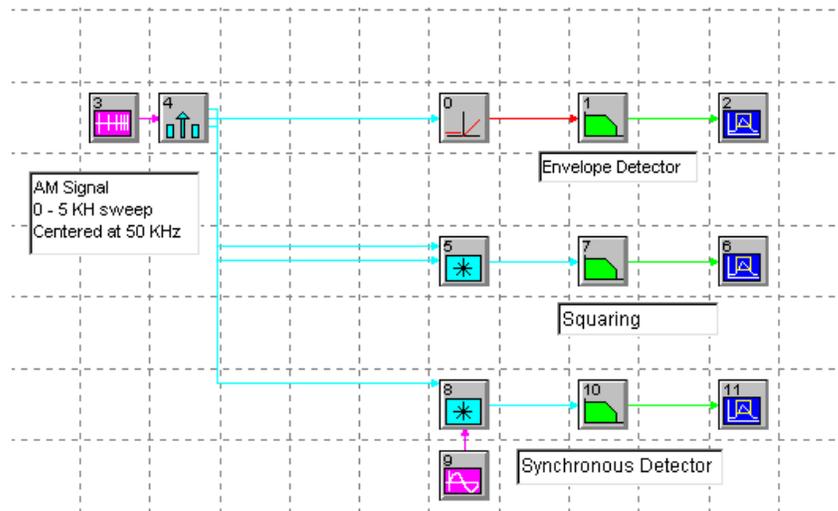
Both of these detection techniques have certain drawbacks. Consequently, most radio receivers use a combination of both.

3.2.3.1 Envelope Detector

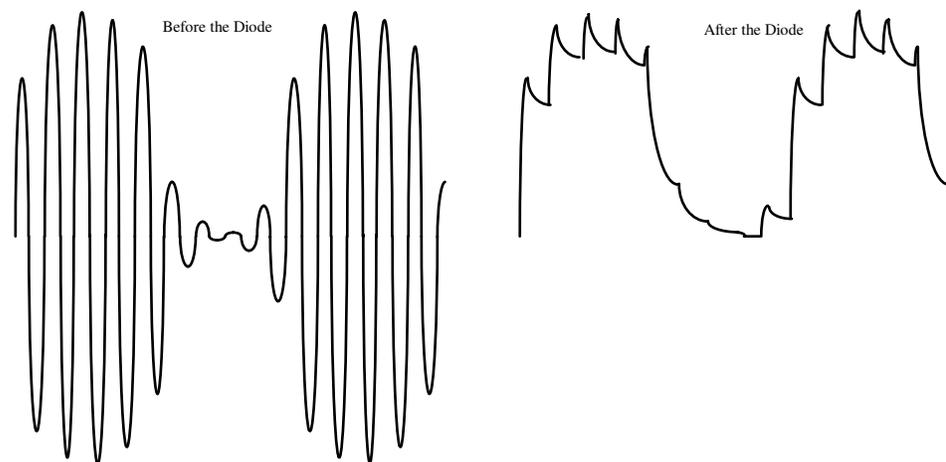


An envelope detector is simply a half wave rectifier followed by a low pass filter. In the case of commercial AM radio receivers, the detector is placed after the IF section. The carrier at this point is 455 KHz while the maximum envelope frequency is only 5 KHz. Since the ripple component is nearly 100 times the frequency of the highest baseband signal and is not passes through any subsequent audio amplifiers.

SystemView AM Detector Models

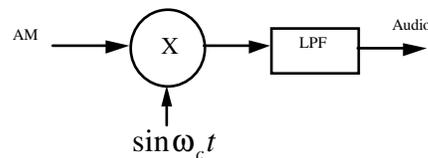


An AM signal where the carrier frequency is only 10 times the envelope frequency would have considerable ripple:



3.2.3.2 Synchronous Detector

In a synchronous or coherent detector, the incoming AM signal is mixed with the original carrier frequency.



SystemView Model

Since the AM input is mathematically defined by:

$$\sin \omega_c t + \frac{m}{2} \sin(\omega_c - \omega_m)t - \frac{m}{2} \sin(\omega_c + \omega_m)t$$

At the multiplier output, we obtain:

$$\left(\sin \omega_c t + \frac{m}{2} \sin(\omega_c - \omega_m)t - \frac{m}{2} \sin(\omega_c + \omega_m)t \right) \sin \omega_c t =$$

$$\underbrace{-\frac{m}{2} \sin \omega_m t}_{\text{original modulation signal}} - \frac{1}{2} \sin 2\omega_c t - \underbrace{\frac{m}{4} \sin(2\omega_c - \omega_m)t + \frac{m}{4} \sin(2\omega_c + \omega_m)t}_{\text{AM signal centered at 2 times the carrier frequency}}$$

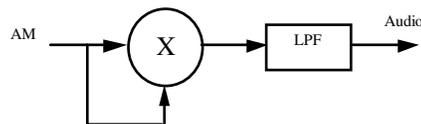
The high frequency component can be filtered off leaving only the original modulation signal.

This technique has one serious drawback. The problem is how to create the exact carrier frequency. If the frequency is not exact, the entire baseband signal will be shifted by the difference. A shift of only 50 Hz will make the human voice unrecognizable.

Consequently, most radio receivers use an oscillator to create, not the carrier signal, but another intermediate frequency. This can then be followed by an envelope detector.

3.2.3.3 Squaring Detector

The squaring detector is also a synchronous or coherent detector. It avoids the problem of having to recreate the carrier by simply squaring the input signal. It essentially uses the AM signal itself as a sort of wideband carrier.



SystemView Model

The output of the multiplier is the square of the input AM signal:

$$\left(\sin \omega_c t + \frac{m}{2} \sin(\omega_c - \omega_m)t - \frac{m}{2} \sin(\omega_c + \omega_m)t \right)^2$$

Since the input is being multiplied by $\sin \omega_c t$, one of the resulting terms is the original modulation signal.

The principle difficulty with this approach is trying to create a linear, high frequency multiplier.

3.3 AM Modulators

A basic equation describing amplitude modulation is:

$$e_{am} = (1 + m \sin \omega_m t) \sin \omega_c t$$

From this we notice that AM involves a process of multiplication. There are several ways to perform this function electronically. The simplest method uses a switch.

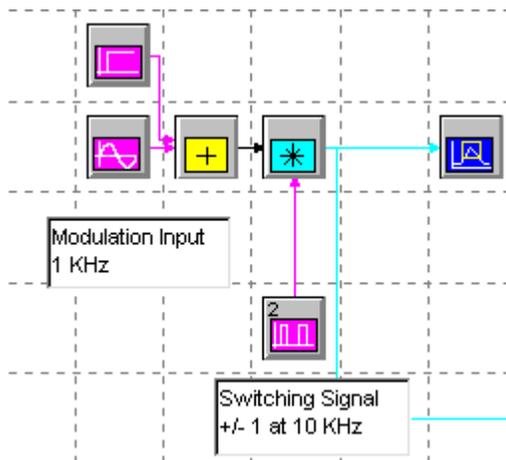
3.3.1 Switching Modulators

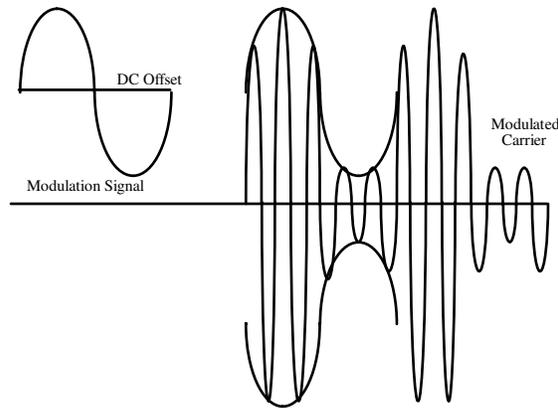
Switching modulators can all be placed into two categories: unipolar and bipolar.

3.3.1.1 Bipolar Switching

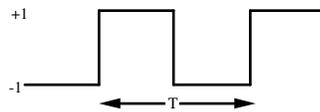
The bipolar switch is the easiest to visualize. Note that an AM waveform appears to consist of a low frequency dc signal whose polarity is reversing at a carrier rate.

SystemView Bipolar Switching Modulator Model





The AM signal can be created by multiplying a dc modulation signal by ± 1 .



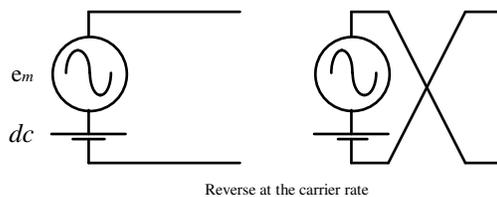
The spectrum of this signal resembles:

$$F\{f(t)\} = \sum_{n=1}^{\infty} \frac{4}{\pi n} \sin\left(\frac{\pi n}{2}\right) \cos\left(\frac{2\pi n t}{T}\right)$$

If the square wave switching function has a 50% duty cycle, this simplifies to:

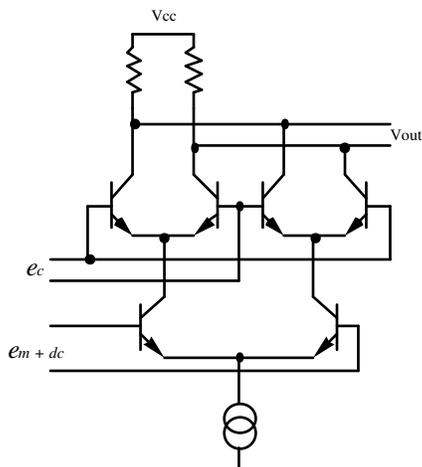
$$F\{f(t)\} = \frac{4}{\pi} \sum_{n=1,3,5\dots}^{\infty} \frac{1}{n} \cos\left(\frac{2\pi n t}{T}\right)$$

Physically this is done by reversing the signal leads:

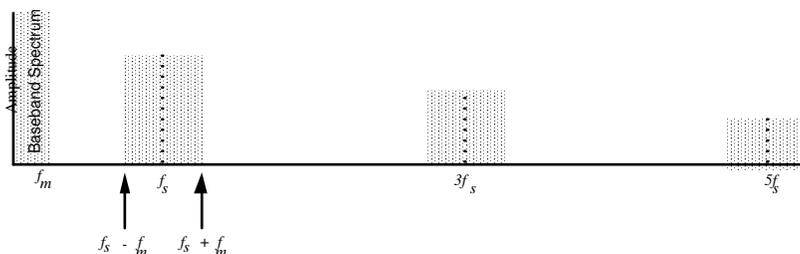


The process of reversing the polarity of a signal is easily accomplished by placing two switch pairs in the output of a differential amplifier. The MC1596 is an example of such a device.

[LM1596 Balanced Modulator-Demodulator by National Semiconductor](#)



As noted above, a square wave is comprised of an infinite number of odd harmonics. Consequently multiplying the baseband or modulation signal by a square wave creates an infinite number of sum and difference frequencies, each of which constitutes an AM signal.

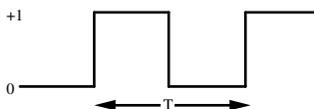


A band pass filter can be used to select any one of the AM signals. The number of different output frequencies can be significantly reduced if the multiplier accepts sinewaves at the carrier input.

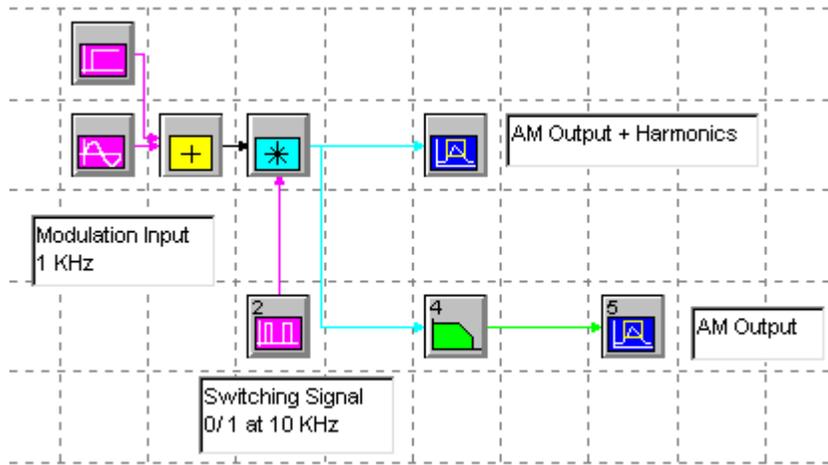
Removing the DC component from the input eliminates the carrier signal and creates DSBSC modulation.

3.3.1.2 Unipolar Switching

An AM signal can be created by multiplying a dc modulation signal by 0 & 1.



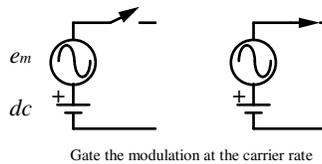
SystemView Unipolar Switching Modulator



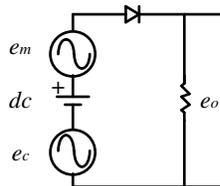
The spectrum of this signal is defined by:

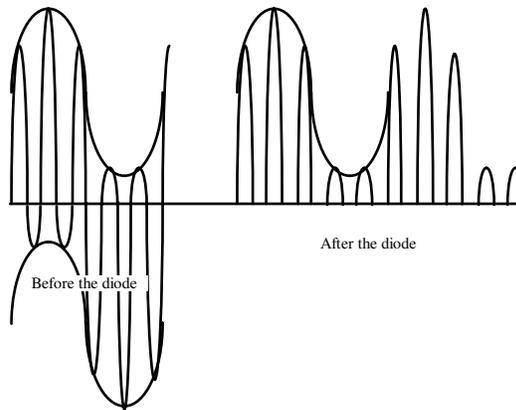
$$F\{f(t)\} = .5 + \sum_{n=1}^{\infty} \frac{2}{\pi n} \sin\left(\frac{\pi n}{2}\right) \cos\left(\frac{2\pi n t}{T}\right)$$

Physically this is done by turning the modulation signal on and off at the carrier rate:



A high amplitude carrier can be used to turn a diode on and off. A dc bias is placed on the modulation signal to make certain that it cannot reverse bias the diode.

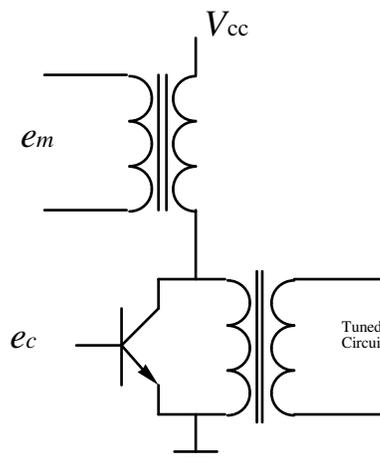




It may not seem obvious, but the output of this circuit contains a series of AM signals. A bandpass filter is needed to extract only one.

3.3.1.3 Collector Modulator

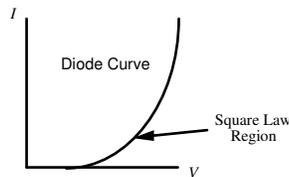
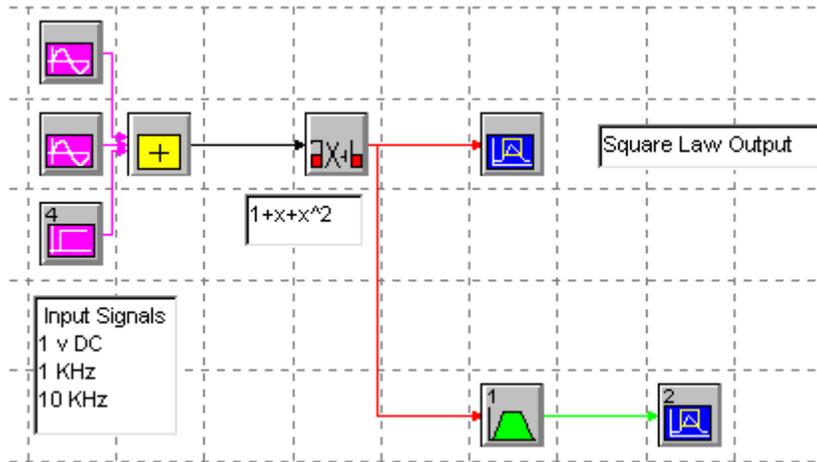
The diode switching modulator is incapable of producing high power signals since it is a passive device. A transistor can be used to overcome this limitation.



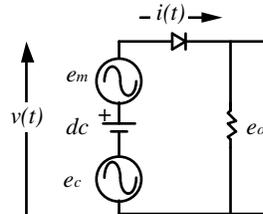
3.3.1.3 Square Law Modulator

The voltage-current relationship of a diode is nonlinear near the knee and is of the form: $i(t) = av(t) + bv^2(t)$. The coefficients a and b are constants associated with the diode itself.

SystemView Square Law Modulator



Amplitude modulation occurs if the diode is kept in the square law region when signals combine.



Let the injected signals be of the form:

$$k = \text{dc bias}$$

$$e_m = E_m \sin \omega_m t = \text{modulation signal}$$

$$e_c = E_c \sin \omega_c t = \text{carrier signal}$$

The voltage applied across the diode and resistor is given by:

$$v(t) = k + e_m + e_c$$

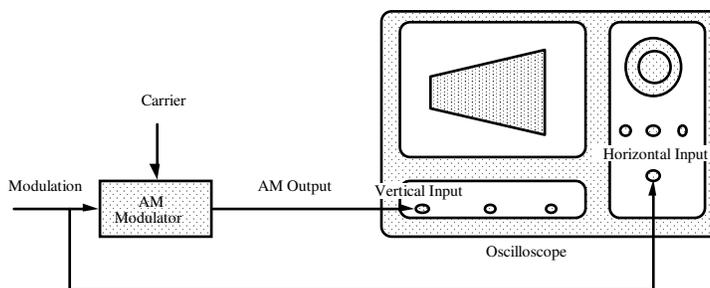
The current in the diode and hence in the resistor is given by:

$$\begin{aligned}
 i(t) &= a[k + e_m + e_c] + b[k + e_m + e_c]^2 \\
 &= \underbrace{k[a + bk]}_{\text{dc}} + \underbrace{[a + 2bk]e_m}_{\substack{\text{original modulating} \\ \text{signal}}} + \underbrace{[a + 2bk]e_c}_{\text{carrier}} + \underbrace{2be_me_c}_{\substack{2 \text{ sidebands} \\ 2 \times \text{the modulation} \\ \text{frequency}}} + \underbrace{be_m^2}_{\substack{2 \times \text{the modulation} \\ \text{frequency}}} + \underbrace{be_c^2}_{\substack{2 \times \text{the carrier} \\ \text{frequency}}}
 \end{aligned}$$

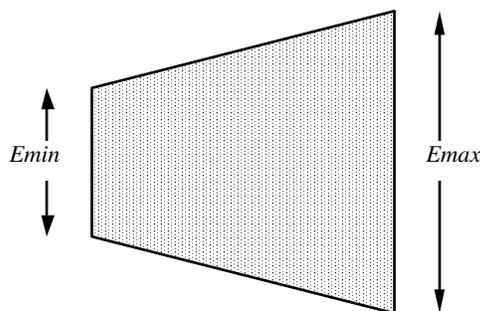
From this we observe that passing signals through a nonlinear device creates a wide range of new signals. Therefore, a band pass filter is needed to select only the frequencies of interest.

3.3.2 Modulation Index Measurement

It is sometimes difficult to determine the modulation index, particularly for complex signals. However, it is relatively easy to determine it by observation.

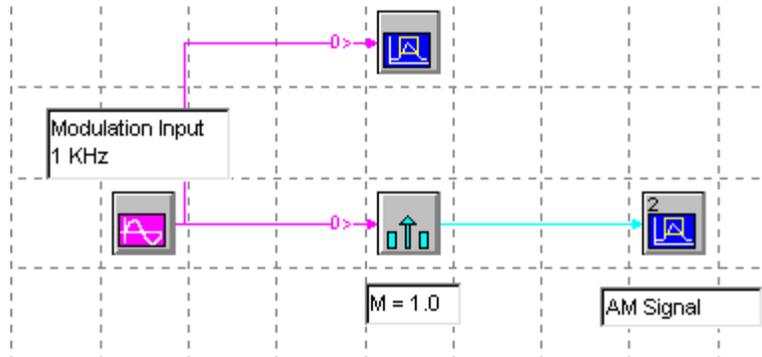


The trapezoidal oscilloscope display can be used to determine the modulation index.

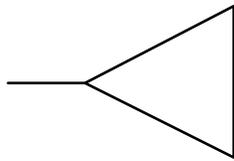


modulation index $m = \frac{E_{\max} - E_{\min}}{E_{\max} + E_{\min}}$

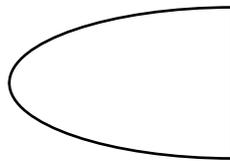
SystemView Trapezoidal Pattern



The trapezoidal display makes it possible to quickly recognize certain types of problems, which would reduce the AM signal quality.



Over Modulation



Nonlinearities

The highest authorized carrier power for AM broadcast in the US is 50 kilowatts, although directional stations are permitted 52.65 kilowatts to compensate for losses in the phasing system. The ERP can be much higher

3.3.3 Quadrature AM Stereo

AM broadcast is inherently monaural, however there are ways to make it stereophonic.

<http://www.inetarena.com/~alfredot/exciter-theory.html>

<http://www.fcc.gov/mmb/asd/bickel/amstereo.html>

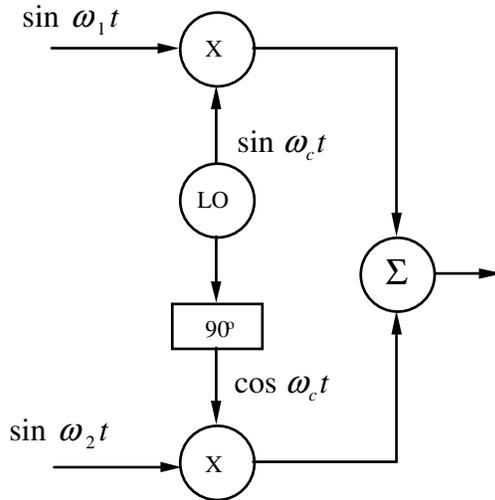
At one time, there were five competing systems: Harris, Magnavox, Motorola, Belar, and Kahn and Hazeltine.

In 1993 the FCC picked C-Quam system. Of the stations then broadcasting in AM stereo, 591 used Motorola C-Quam, 37 used the Harris system, and less than 20 used the Kahn system.

There were already 24 million C-Quam receivers.

3.3.3.1 AM stereo and Vector Modulation

A simple AM stereo system can be made using a vector modulator, unfortunately, it is not backward compatible with monophonic AM receivers. However, its operating principles form the basis of those systems in use.



Output of the top mixer:

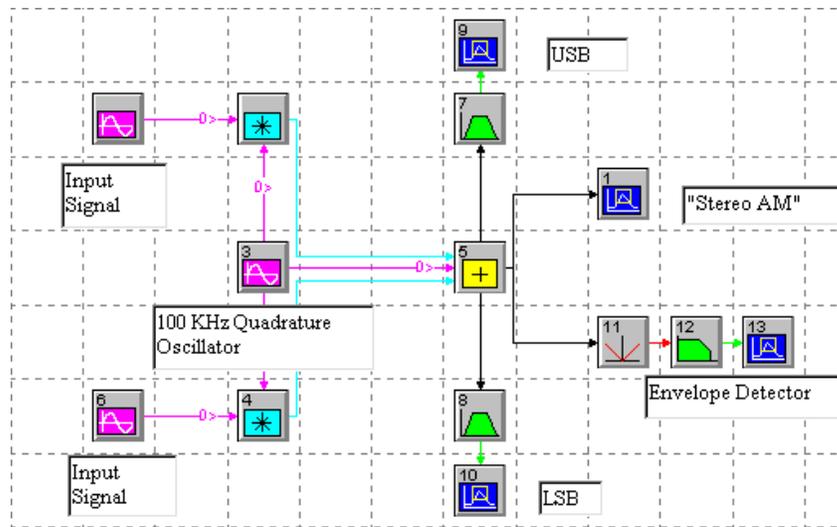
$$\sin \omega_1 t \sin \omega_c t = \frac{1}{2} \cos(\omega_c - \omega_1)t - \frac{1}{2} \cos(\omega_c + \omega_1)t$$

Output of the bottom mixer:

$$\sin \omega_2 t \cos \omega_c t = \frac{1}{2} \sin(\omega_c - \omega_2)t + \frac{1}{2} \sin(\omega_c + \omega_2)t$$

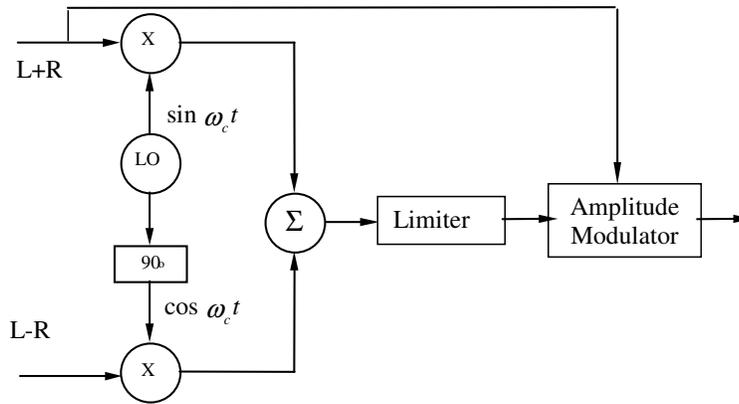
Although the sum of these two signals can easily be detected, the uncorrelated phase changes between the two sidebands cause amplitude variations, which cause distortion in a standard envelope detector.

SystemView Theoretical AM Stereo



3.3.3.2 C-QUAM

AM C-QUAM by Harris



The basic idea behind the C-Quam modulator is actually quite simple. The output stage is an ordinary AM modulator however; the carrier signal has been replaced by an amplitude limited vector modulator. Therefore, the limiter output is really a phase-modulated signal.

A standard AM receiver will detect the amplitude variations as L+R. A stereo receiver will also detect the phase variations and to extract L-R. It will then process these signals to separate the left and right channels.

To enable the stereo decoder, a 25 Hz pilot tone is added to the L-R channel.

3.4 DSBSC

Double side band suppressed carrier modulation is simply AM without the broadcast carrier. Recall that the AM signal is defined by:

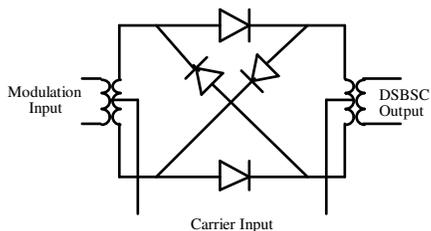
$$e_{am} = (1 + m \sin \omega_m t) \sin \omega_c t = \sin \omega_c t + \frac{m^2}{2} \cos(\omega_c - \omega_m)t - \frac{m^2}{2} \cos(\omega_c + \omega_m)t$$

The carrier term in the spectrum can be eliminated by removing the dc offset from the modulating signal:

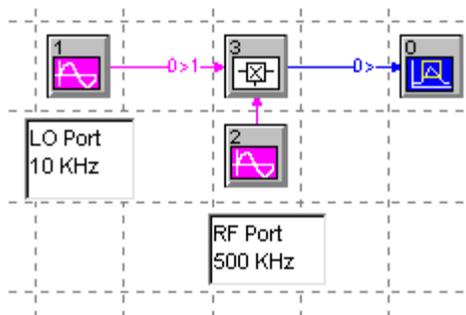
$$e_{DSBSC} = m \sin \omega_m t \sin \omega_c t = \frac{m^2}{2} \cos(\omega_c - \omega_m)t - \frac{m^2}{2} \cos(\omega_c + \omega_m)t$$

One of the circuits which is capable of doing this is the double balance ring modulator.

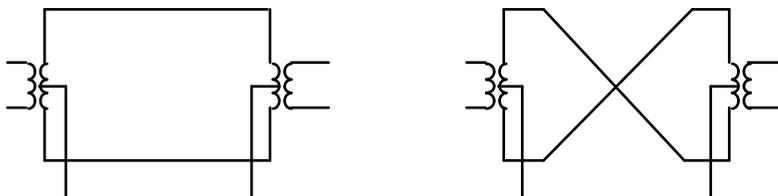
3.4.1 Double Balanced Ring Modulator



SystemView Double Balanced Ring Modulator



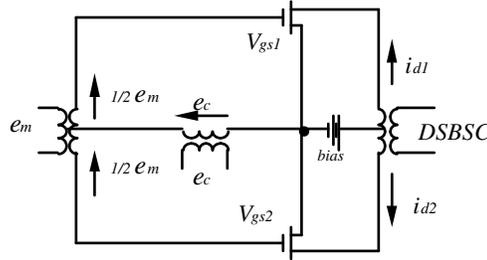
If the carrier is large enough to cause the diodes to switch states, then the circuit acts like a diode switching modulator:



The modulation signal is inverted at the carrier rate. This is essentially multiplication by ± 1 . Since the transformers cannot pass dc, there is no term which when multiplied can create an output carrier. Since the diodes will switch equally well on either cycle, the modulation signal is effectively being multiplied by a 50% duty cycle square wave creating numerous DSBSC signals, each centered at an odd multiple of the carrier frequency. Bandpass filters are used to extract the frequency of interest.

Some IC balanced modulators use this technique, but use transistors instead of diodes to perform the switching.

3.4.2 Push Pull Square Law Balanced Modulator



This circuit uses the same principles as the diode square law modulator. Since dc cannot pass through the transformer, it would be expected that there would be no output signal at the carrier frequency.

The drain current vs. gate-source voltage is of the form:

$$i_d = i_o + av_{gs} + bv_{gs}^2$$

The net drain current in the output transformer is given by:

$$\begin{aligned} i_{net} &= i_{d1} - i_{d2} \\ &= i_o + av_{gs1} + bv_{gs1}^2 - (i_o + av_{gs2} + bv_{gs2}^2) \\ &= a(v_{gs1} - v_{gs2}) + (v_{gs1}^2 - v_{gs2}^2) \\ &= a(v_{gs1} - v_{gs2}) + b(v_{gs1} + v_{gs2})(v_{gs1} - v_{gs2}) \end{aligned}$$

By applying KVL around the gate loops we obtain:

$$v_{gs1} = \frac{1}{2} e_m + e_c \quad v_{gs2} = -\frac{1}{2} e_m + e_c$$

Putting it all together we obtain:

$$\begin{aligned} i_{net} &= a\left(\frac{1}{2} e_m + e_c + \frac{1}{2} e_m - e_c\right) + b\left(\frac{1}{2} e_m + e_c - \frac{1}{2} e_m + e_c\right)\left(\frac{1}{2} e_m + e_c + \frac{1}{2} e_m - e_c\right) \\ &= ae_m + b2e_c e_m \end{aligned}$$

From this we note that the first term is the originating modulation signal and can easily be filtered off by a high pass filter. The second term is of the form:

$$\sin \omega_m t \sin \omega_c t = \frac{1}{2} \sin(\omega_c - \omega_m) t - \frac{1}{2} \sin(\omega_c + \omega_m) t$$

3.5 SSB

Single sideband is a form of AM with the carrier and one sideband removed. In normal AM broadcast, the transmitter is rated in terms of the carrier power.

SSB transmitters attempt to eliminate the carrier and one of the sidebands. Therefore, transmitters are rated in PEP [peak envelope power].

$$PEP = \frac{(\text{peak envelope voltage})^2}{2R_L}$$

With normal voice signals, an SSB transmitter outputs 1/4 to 1/3 PEP.

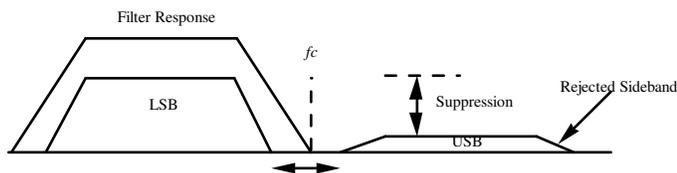
Modulation	Comments
SSB	Single sideband - amateur radio
SSSC	Single sideband suppressed carrier - a small pilot carrier is transmitted
ISB	Independent sideband - two separate sidebands with a suppressed carrier. Used in radio telephone
VSB	Vestigial sideband - a partial second sideband. Used in TV broadcasting
ACSSB	Amplitude companded SSB

There are several advantages of using SSB:

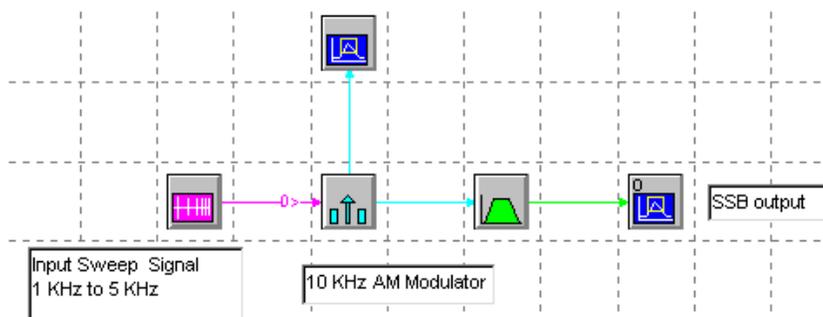
- More efficient spectrum utilization
- Less subject to selective fading
- More power can be placed in the intelligence signal
- 10 to 12 dB noise reduction due to bandwidth limiting

3.5.1 Filter Method

The simplest way to create SSB is to generate DSBSC and then use a bandpass filter to extract one of the sidebands.



SystemView SSB Filter Method



This technique can be used at relatively low carrier frequencies. At high frequencies, the Q of the filter becomes unacceptably high. The required Q necessary to filter off one of the sidebands can be approximated by:

$$Q \approx \frac{f_c \sqrt{S}}{4\Delta f}$$

where f_c = carrier frequency

Δf = sideband separation

S = sideband suppression [not in dB]

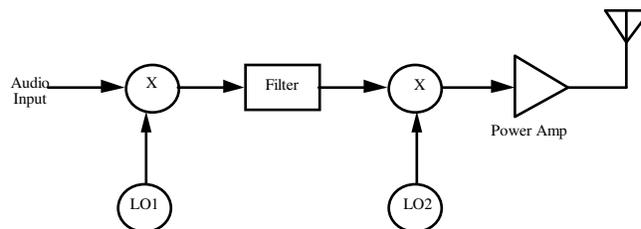
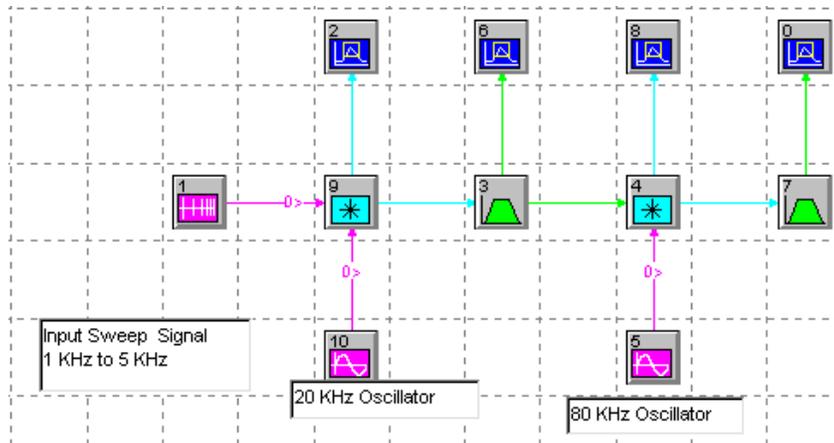
Several types of filters are used to suppress unwanted sidebands:

Filter Type	Maximum Q
LC	200
Ceramic	2000
Mechanical	10,000
Crystal	50,000

Standard Crystal Filters

In order to reduce the demands placed upon the filter, a double heterodyne technique can be used.

SystemView SSB Filter Method with Double Mixer



The first local oscillator has a relatively low frequency thus enabling the removal of one of the sidebands produced by the first mixer. The signal is

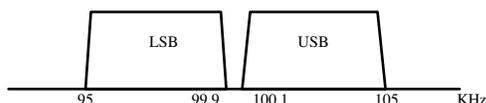
then heterodyned a second time, creating another pair of sidebands. However, this time they are separated by a sufficiently large gap that one can be removed by the band limited power amplifier or antenna matching network.

Example

Observe the spectral distribution under the following conditions:

- Audio baseband = 100 HZ to 5 KHz
- LO₁ = 100 KHz
- LO₂ = 50 MHz

The spectral output of the first mixer is:



If the desired sideband suppression is 80 dB, the Q required to filter off one of the sidebands is approximately:

$$S = \log^{-1} \frac{80}{20} = 10^4$$

$$Q \approx \frac{f_c \sqrt{S}}{4\Delta f} = \frac{100 \times 10^3 \sqrt{10^4}}{4 \times 200} = 12500$$

It is evident that a crystal filter would be needed to remove the unwanted sideband.

After the filter, only one sideband is left. In this example, we'll retain the USB. The spectrum after the second mixer is:



The Q required to suppress one of the side bands by 80 dB is approximately:

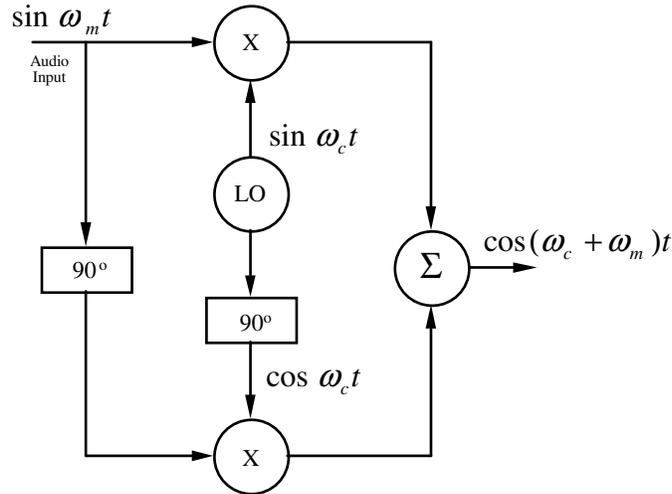
$$S = \log^{-1} \frac{80}{20} = 10^4$$

$$Q \approx \frac{f_c \sqrt{S}}{4\Delta f} = \frac{50 \times 10^6 \sqrt{10^4}}{4 \times 200.2 \times 10^3} = 6244$$

Thus, we note that the required Q drops in half.

This SSB filter technique is used in radiotelephone applications.

3.5.2 Phase Shift Method



The output from the top mixer is given by:

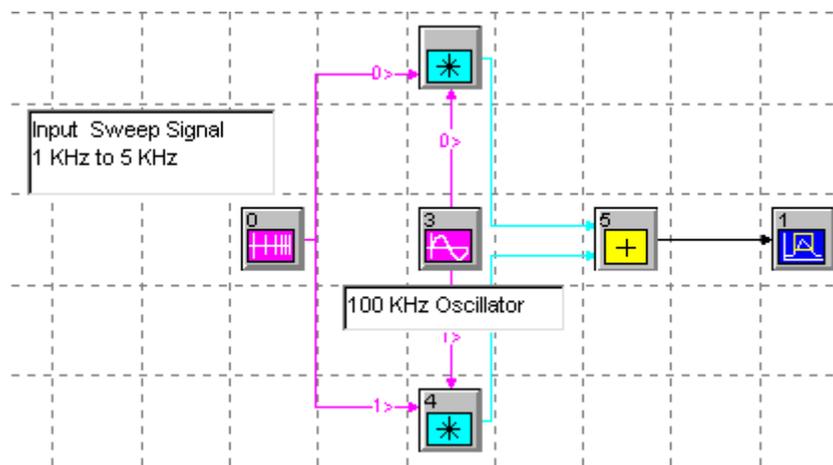
$$\sin \omega_m t \sin \omega_c t = \frac{1}{2} \cos(\omega_c + \omega_m)t - \frac{1}{2} \cos(\omega_c - \omega_m)t$$

The output from the bottom mixer is given by:

$$\cos \omega_m t \cos \omega_c t = \frac{1}{2} \cos(\omega_c + \omega_m)t + \frac{1}{2} \cos(\omega_c - \omega_m)t$$

The summer output is: $\cos(\omega_c + \omega_m)t$. This corresponds to the upper sideband only.

SystemView SSB Phase Shift Model

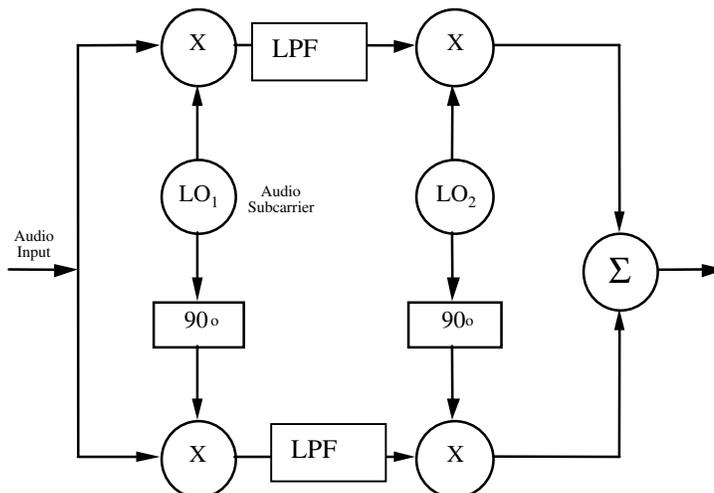
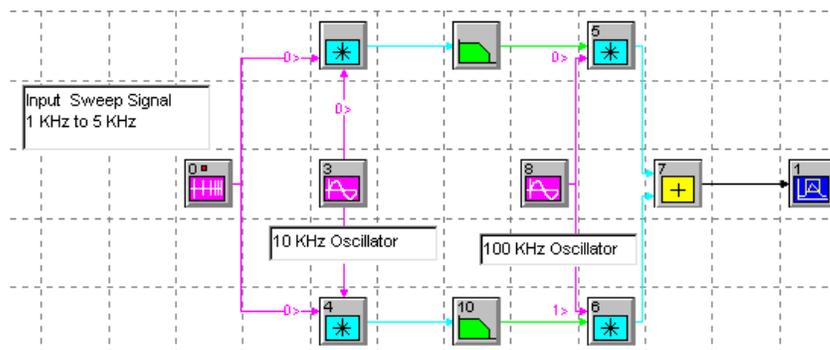


The major difficulty with this technique is the need to provide a constant 90° phase shift over the entire input audio band. To overcome this obstacle, the Weaver or third method uses an audio sub carrier, which is phase shifted.

3.5.3 Weaver Method

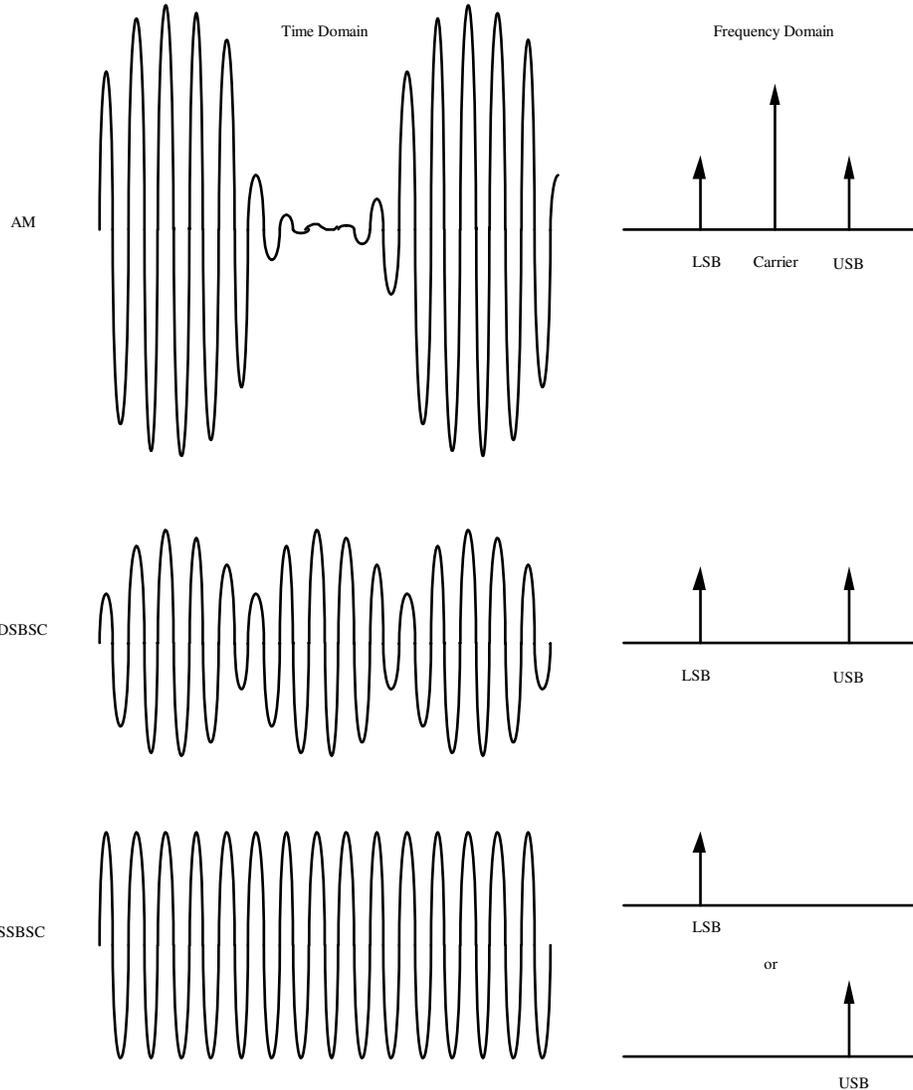
The Weaver or 'third' method places the baseband signal on a low frequency quadrature carrier.

SystemView Model – Weaver Method



This has the advantage of not requiring a broadband phase shifter however; the use of four mixers makes it awkward and seldom used.

AM Modulation Waveforms



3.5.4 SSB Receivers

These receivers require extremely stable oscillators, good adjacent channel selectivity, and typically use a double conversion technique. Envelope detectors cannot be used since the envelope varies at twice the frequency of the AM envelope.

Stable oscillators are needed since the detected signal is proportional to the difference between the untransmitted carrier and the instantaneous side band. A small shift of 50 Hz makes the received signal unusable.

SSB receivers typically use fixed frequency tuning rather than continuous tuning as found on most radios. The receiver uses crystal oscillators to select the fixed frequency channels.

Assignment Questions

Quick Quiz

1. Double heterodyning cannot be used in SSB transmitters based on the filter technique. [True, False]

Analytical Questions

1. Determine the carrier power in an AM signal if the total power is 100 kW and the modulation index is 0.89.
2. Since the voltage-current relationship of a diode is of the form:

$$i(t) = av(t) + bv^2(t)$$

it can be used to make an AM modulator or demodulator.

- a) State the necessary conditions for this to happen.
 - b) Create a SystemView model to demonstrate this phenomenon.
 - c) What impact does this phenomenon have on circuit design?
3. An AM transmitter has the following characteristics:

Carrier frequency = 27 MHz

Carrier power = 10 W

Modulation frequency = 2 KHz sine wave

Modulation index = 90%

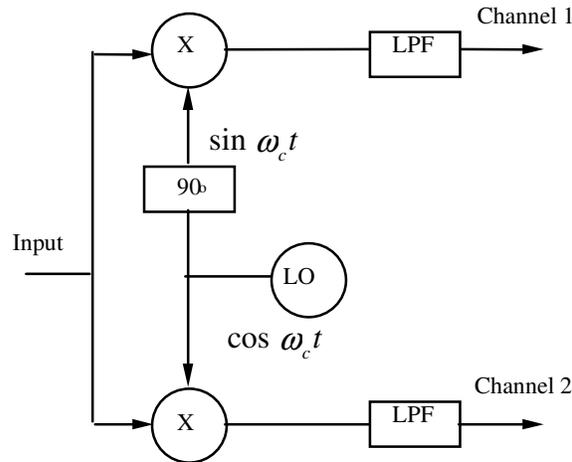
Load impedance = 50 Ω

Determine:

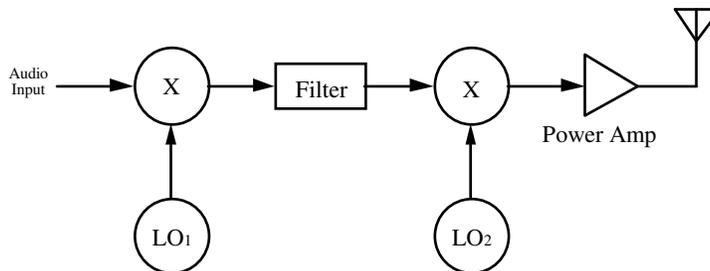
- a) Component frequencies in the AM signal
- b) Minimum and maximum voltage of the AM waveform
- c) Sideband signal voltage and power
- d) Load current
- e) Sketch the time domain, frequency domain, and trapezoidal waveforms

Composition Questions

1. Prove mathematically that under the right set of circumstances, a switching diode can be used to create AM.
2. Create a SystemView model to show that the following receiver can detect pure AM stereo.



3. List the components of an AM signal at 1 MHz when modulated by a 1 KHz sinewave. What are the component(s) if it is converted to an USB transmission? If the carrier is redundant, explain why must it be “reinserted” at the receiver.
4. Draw the block diagram of a superheterodyne AM receiver. Assume it is tuned to receive a station centered at 1200 KHz, and explain in detail what happens at each stage. Use sketches to supplement your explanations.
5. Given the following SSB transmitter:



with the following characteristics:

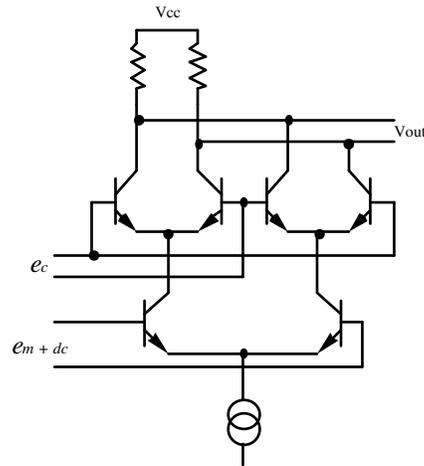
1. Audio input = 100 Hz to 5 KHz
2. $LO_1 = 100$ KHz
3. $LO_2 = 50$ MHz
4. Sideband suppression = 40 dB

5. The filter and power amp only pass the upper sidebands out if their respective mixers.

Find:

- a) The required Q in the filter
- b) Sketch and label the expected spectrum at every point in the circuit
- c) Create a SystemView model to verify your answer [Note: it will be necessary to scale the 50 MHz oscillator frequency]

6. Given the following device:



- a) Identify the circuit
- b) Explain its operation using mathematics
- c) Illustrate its operation using time and frequency domain sketches
- d) Suggest applications

For Further Research

Amateur Radio

<http://www.purchon.co.uk/radio/>

<http://www.alltel.net/~kj5ag/>

<http://www.qsl.net/w5ami/>

<http://www.thebizlink.com/am/>

Vintage

<http://www.antique-radio.org/>

<http://www.liveline.com/~w7gmk/vlinks.html>

National Association of Broadcasters

<http://www.nab.org/>

<http://www.gate.net/~dlung/rf.html>

Radio Theory

<http://murray.newcastle.edu.au/users/staff/eemf/ELEC351/SProjects/Bastian/index.htm>

CBC Radio

<http://radioworks.cbc.ca/>

Slide Tutorial

<http://www.telecommunication.msu.edu/classes/tc201/slides/Modulation/index.htm>

Modulation Tutorial

http://www.ece.utexas.edu/~bevans/courses/realtime/lectures/13_Modulation/lecture13/lecture13.html

Broadcast Equipment

<http://www.bdcast.com/home.html>

<http://www.rfspec.com/>

Harris

<http://www.comsyst.com.au/harris1.htm>

HP AM/FM Tutorial

<http://www.tmo.hp.com/tmo/Notes/interactive/an-150-1/download/hp-am-fm.zip>