Mixer Waveforms

Mixers are an integral part of a wide range of communication and RF devices. Because they shift a signal to a different frequency, mixers "tune" the center frequency of a narrow band amplifier – such as a radio receiver or a spectrum analyzer. This note includes a circuit that can be used to illustrate the operation of a mixer, an analysis of the circuit's operation, and an Excel Graph to illustrate the circuits theoretical operation

A Basic Mixer

There are a number of manufacturers that package "Transconductance Amplifiers" in DIP packages that are easily mounted on Laboratory Breadboards. These IC's are helpful in understanding the operation of a mixer. The operational characteristics of these devices are often included in the data sheets so they are only summarized here.

A simplified schematic (taken from an Intersil data sheet for the older CA3080) is shown below. You'll see the circuit includes a differential transistor pair (Q1 and Q2) that gets driven from the current source W. So the sum of the two emitter currents is set by the source W, and the current in each transistor is set by the differential input voltages at the bases. Also notice that the device outputs a CURRENT equal to the sum of the two Collector current.

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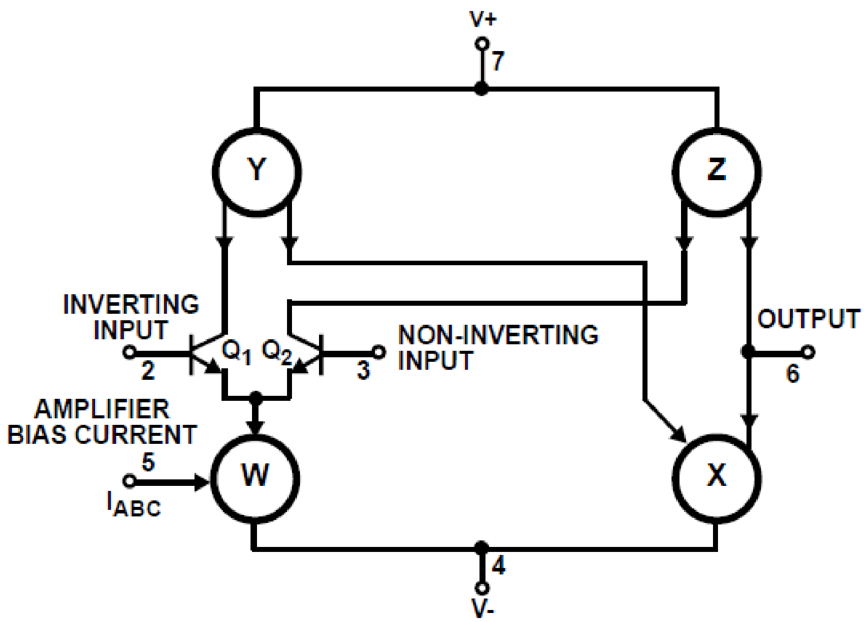


The Operation of this device can be illustrated like this.

The voltage on the two transistor bases can be expressed as

voltage on the base of Q1 = Ve + Vd/2

voltage on the base of Q2 = Ve -Vd/2

where Ve is a common mode voltage at the emitter
and Vd is the differential signal between the two bases.

Now keeping with the tradition of small signal analysis the collector current of the transistors can be approximated as

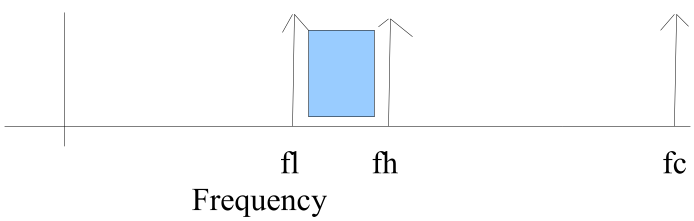
IC1 = gm(Vd/2)
IC2 = gm(- Vd/2)

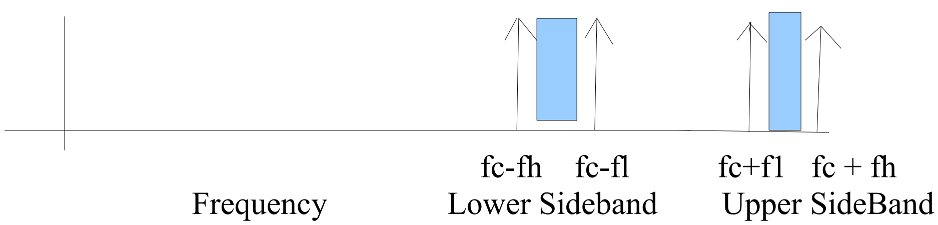
where gm (the transistor transconductance) *can be set by controlling the emitter current* in the device. When these two currents are added the result is Iout = gm(Vd)

Because the current IABC sets the total emitter current, it can be used to set the circuits "gain" or transconductance.

When both inputs of the Transconductance amplifier are sine waves, the current output has a sin(W1t) sin(W2t) term and (as illustrated at the end of this note) when two sinusoidal signals are multiplied the result is the sum of two sine wave – one has a frequency equal to the sum of the input frequencies and the other has a frequency equal to the difference of the two frequencies.   There are no signals at either of the input frequencies.

To visualize how this “Transconductance” amplifier can move one frequency band to another consider the situations illustrated below.





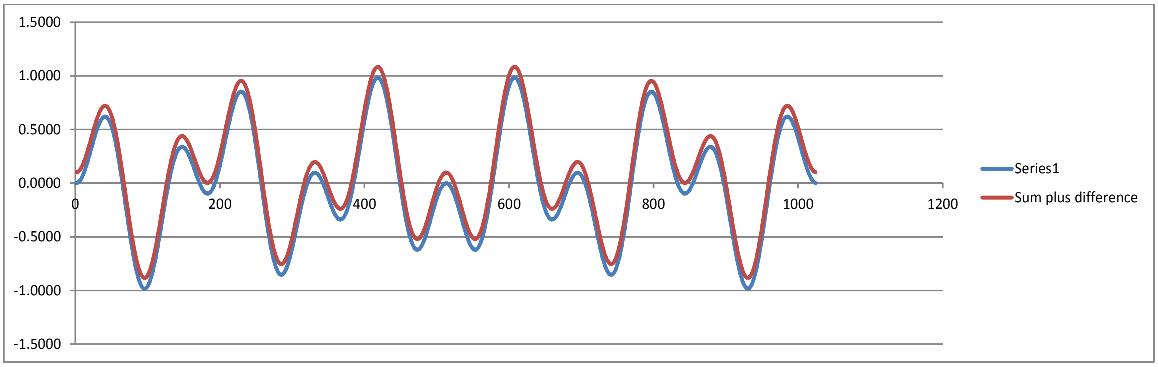
the input to the multiplexer consists of a band of frequencies (between fl and fh) on one input and a higher frequency (fc) on the other. As the signal pass through the “Mixer” notice how the band of frequencies gets mapped into two “bands” of frequencies. Also observe that the width of the band doesn't change – it gets moved. The amplitude of signals in each band is reduced to ½ their original value.

It should also be noted that each band has a complete copy of the information in the original signal (remember this system has no errors or noise) and only one of them is required to recover the original signal. Indeed, Ham radio operators that transmit Single Side Band signals regularly make use of this fact.

Interpretation of Sin(W1*T) * Sin(W2*T)

Like many mathematical expressions, the expression Sin(W1*t)*Sin(W2*t), has multiple equivalent representations. In the study of Mixers, one interesting representation expresses the product of two sine waves as the sum of two sine waves – one with a frequency equal to the sum of the two frequencies and the other with a frequency equal to the difference between the two frequencies. Like the analysis of the Transconductance Amplifiers this relationship is well documented all over the web.

$$\sin(W1 \cdot t) \cdot \sin(W2 \cdot t) = 1/2[\cos(W2 + W1) \cdot t - \cos(W2 - W1) \cdot t]$$



The graph shown here indicates that when the four waveforms are combined as indicated by the equation its difficult to see any differences in the two sides of the equations – indeed a small offset was added to one of the resulting waves so that, indeed, two distinct waves could be seen on the graph.