Application Note

Central Semiconductor Corp.

RF Frequency Mixer: Ideal Discrete Devices

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Introduction

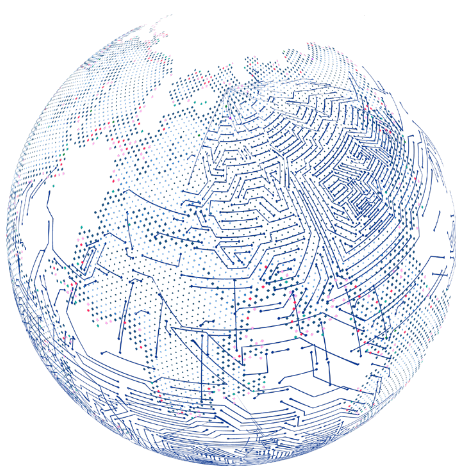
Central Semiconductor manufactures a wide range of switching and Schottky diodes, which can serve a frequency mixer circuit particularly well. Such circuits multiply signals supplied by a radio frequency (RF) and local oscillator (LO) input; and return the sum and difference between those two frequencies (collectively called beat frequencies), as well as their harmonics, without amplification. A single diode can be used in an unbalanced mixer, which shows both the beat frequencies and the original RF and LO signals in its output.

Passive mixers, like those shown, have found widespread use in superheterodyne receivers. Until the advent of software-tuned radios in recent years, superheterodyne receivers were almost the only receiver type found in both consumer and professional grade radios. For this application, the desired frequency from the mixer is called the intermediate frequency (IF), the standard being 455 kHz in the United States.

Mixer theory

Semiconductor mixers are possible thanks to their nonlinear relationship between voltage and current, meaning that the frequency of its forward voltage isn't reflected in the current though it. This relationship is expressed as $I = I_S\left(e^{\frac{qV_F}{kT}} - 1\right)$ where I_S is the saturation current (a constant device parameter), V_F is the forward voltage, k is Boltzmann's constant, q is the elementary charge, and T is the ambient temperature in Kelvin. The exponential function can be expanded to $e^x = \sum_{n=0}^{\infty} \frac{x^n}{n!} = 1 + x + \frac{x^2}{2} + \frac{x^3}{6} + \cdots$, meaning $e^{\frac{qV_F}{kT}} - 1 \approx \frac{qV_F}{kT} + \frac{1}{2}\left(\frac{qV_F}{kT}\right)^2$ for lesser voltages.

One can assume that the output voltage of a diode will be proportional to the current expressed above, if the diode is connected to a resistive load. The q/kT and I_S constants can be ignored for simplicity. If sinusoids of two different frequencies are passed through the diode (sin(at) and sin(bt)), the voltage at the output can be approximated as $v_o = (\sin at + \sin bt) + \frac{1}{2}(\sin at + \sin bt)^2$. Since multiplying the frequencies is the desired purpose, we can isolate the term produced from the square. Using trigonometry, this can be rewritten as $\sin at \sin bt = \frac{1}{2}[\cos(at - bt) - \cos(at + bt)]$, with beat frequencies a+b and a-b. Typically, one of the beats is the desired I_F, and the other is called the image frequency (as it is the "mirror image" of the other), which can cause noise.



Application: Single diode, unbalanced mixer

A simple frequency mixer is shown below, utilizing a Central Semiconductor CTLSH01-30L switching diode. Since the device does not amplify the signals, the voltage of the DC supply and resistor values aren't important. A negative to this mixer is the presence of the original RF and LO frequencies at the output, which must be filtered out at a future stage (such as the IF filter in the superheterodyne receiver below). Additionally, the presence of a DC power supply complicates the circuit somewhat, but that's not a problem for the double balanced mixer.

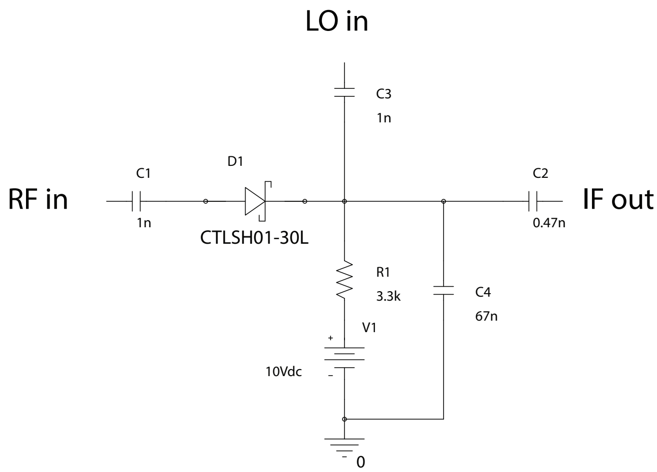


Figure 1:
Single diode, unbalanced mixer

Application: Multiple diode, double balanced mixer

To achieve the best RF and LO rejection at the output, a double balanced mixer is recommended. This is noticeably more complex than the unbalanced mixer, due to the use of transformers and four diodes. However, this complexity is well worth the effort, since image frequency is the only component required to be filtered from the output. The diodes appear in a shape similar to a full bridge rectifier, but are arranged in a clockwise or counterclockwise pattern, rather than being parallel to its opposite. In the example below, the circuit is comprised of Schottky diodes. This circuit is similar to a ring modulator, but with inputs and outputs taken at different points.

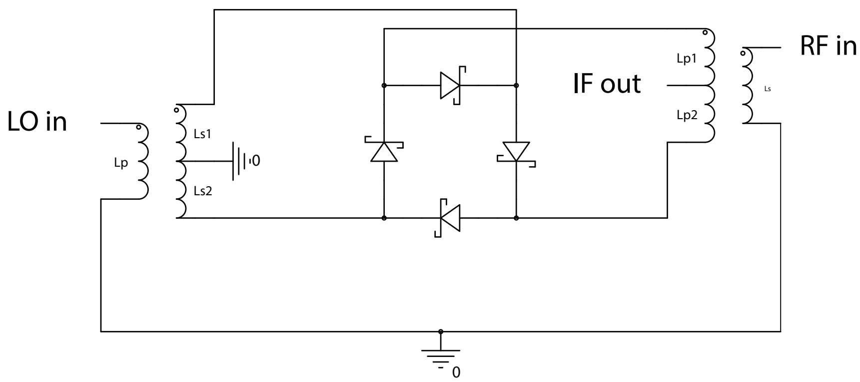


Figure 2:
Multiple diode, double balanced mixer

Application: Superheterodyne receiver

The RF amplifier is technically optional, but highly recommended to bring the signal from the microvolt to millivolt range. A single tuning capacitor controls the frequency of the local oscillator signal in addition to the center frequency of the RF filter passband. Due to the image frequency (which would also appear in the IF filter), the RF filter is required. It can use a large passband, as long as the image frequency is outside.

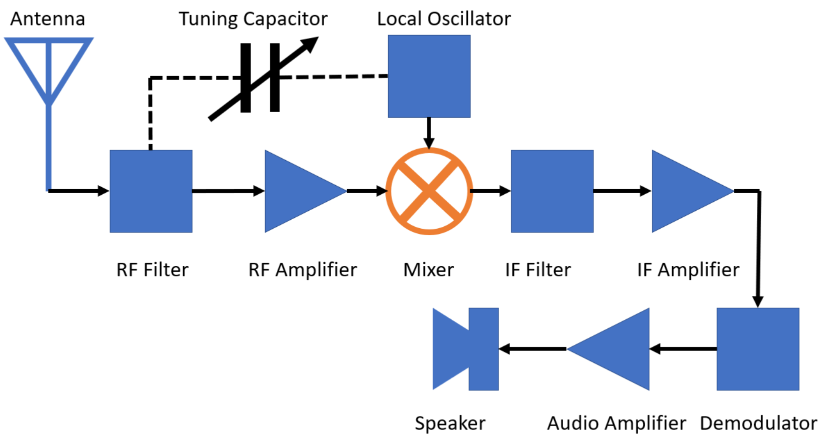


Figure 3:
Superhereodyne receiver

Central Semiconductor diodes

The two preferred diode types for frequency mixers are switching and Schottky diodes. Schottky diodes, without a PN junction, have the lowest forward (activation) voltage of any diode, as well as the fastest switching speeds. However, they are crippled by a large reverse current, which can cause thermal runaway in high voltage applications. While switching diodes have a slightly higher forward voltage, they have the fastest reverse recovery time (the length of time to completely shut off) of any PN junction diode, making switching diodes the next best choice to Schottky diodes.

Schottky diodes		
Central Item No.	**Type**	**Package**
CTLSH01-30L	Surface Mount	TLM2D3D6
CFSH2-3L	Surface Mount	SOD-882L
1N5817	Through-hole	DO-41

Switching diodes		
Central Item No.	**Type**	**Package**
CFD4448	Surface Mount	SOD-882L
1N5817	Through-hole	DO-35
BAX12	Through-hole	DO-35

Conclusion

Frequency mixing is one of many signal operations made available to designers with the invention of semiconductor devices. It has made its impact known by powering radios for the past century, and still does to this day. Central Semiconductor's switching and Schottky diodes offer fast switching times and low forward voltage, making them ideal for this operation.

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