

# **Non-Linear Circuit Elements Square-Law Detector, Mixer**

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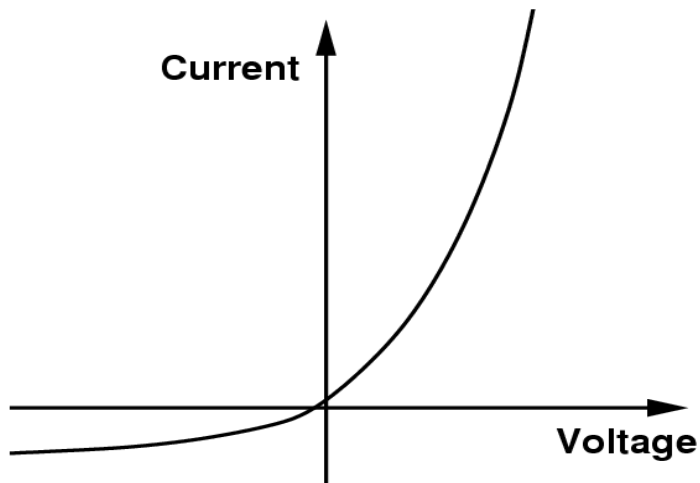
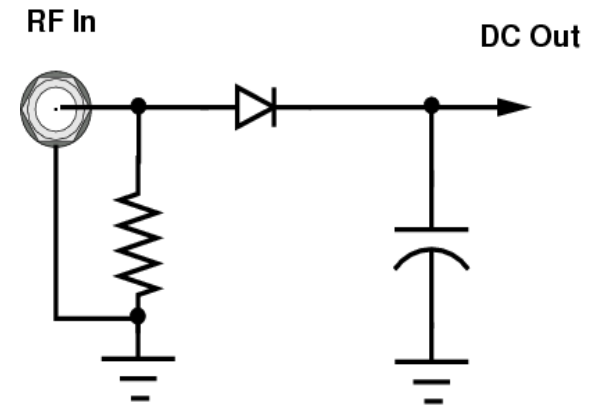
November 2007

## Square-Law Diode Detector

A solid-state diode rectifies an RF signal and produces a DC voltage that is integrated by a capacitor.

The diode is not an ideal rectifier: the forward drop at high current is 0.3-0.7 volts, depending on the semiconductor material.

The rectification efficiency varies widely over the range of input voltage.



At very low RF voltage, below the knee of the diode characteristic, the diode exhibits a **square law** response, where

$$V_{out} = k P_i$$

At higher RF voltage, above the knee, the output voltage is approximately the peak of the RF voltage, proportional to the square of the power.

## Experiments with Non-linear Circuit Elements

1. Measure the diode characteristic and determine over which range of input power the diode exhibits the square-law response.
2. The diode is a non-linear circuit element and can therefore be used as a mixer. Two frequencies will be passively mixed and directed to the diode. A spectrum analyzer will be used to look at the output frequency and amplitude spectrum.
3. The double-balanced mixer (DBM) uses a ring of four matched diodes to multiply together two input signals. As in experiment 2, two frequencies will be directed to the DBM and the output spectrum analyzed.

## Experiment 1. Square-Law Detector

Attach the output of a signal generator to the SMA input terminal of an Agilent 8474C crystal detector. Connect the BNC output connector of the detector to a digital voltmeter and to a 47,000 ohm resistor.

Set the signal generator to some frequency in the VHF or UHF spectrum, 80 MHz for example.

Measure the output voltage for input power over the range of -40 dBm to at least +10dBm.

Over what input power range does the diode exhibit good square-law behavior?  
How accurately does it rectify the peak voltage in the above-the-knee region?

RF goes  
in this end.



## Experiment 2. Diode as a Mixer

Connect the outputs of two signal generators together with a Minicircuits passive mixer module. Connect the output of the mixer to a spectrum analyzer.

Set the signal generators at 8 MHz and 10 MHz, with an output level of 0 dBm. Observe with the spectrum analyzer the spectrum from 1 to 30 MHz, noting any signals in addition to the 8 and 10 MHz signals.

Insert the Agilent 8474C crystal detector in the line from the mixer to the spectrum analyzer.

Measure the frequencies and amplitudes of the observed spectrum. Change the output levels of first one, and then the other signal generator from -40 to +10 dBm and note the change of all the mixing products.

If the diode were a pure square-law device, what frequencies would you expect to be present? Show with a simple calculation. (Below are some handy identities)

Is it a good square-law device?

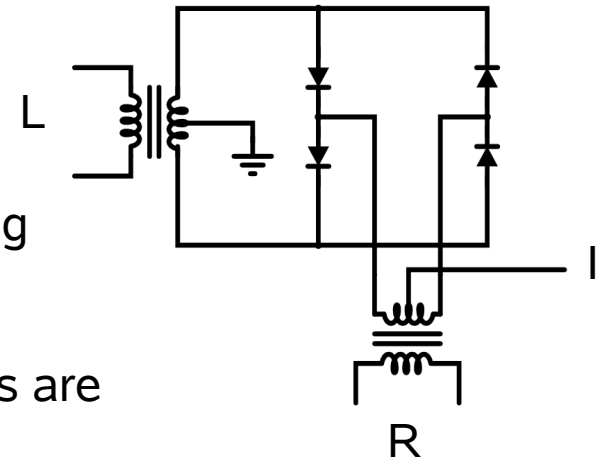
$$\cos^2(A) = \frac{1 + \cos(2A)}{2} \quad \cos(A) \cos(B) = \frac{1}{2} [\cos(A-B) + \cos(A+B)]$$

### Experiment 3. Double-Balanced Mixer (DBM)

The DBM mixer is a more ideal modulator. The vector product of the two input signals is presented at the output.

The mixer operates as a switch, with one input (L) commutating the other input (R) at the rate of L.

The output (I) contains the *mixer products*. These frequencies are combinations of harmonics of the inputs.



$$f_I = m \times f_L + n \times f_R$$

Where  $m$  and  $n$  are positive or negative integers.

If either  $m$  or  $n$  are zero, the output is a *feed-through product*. In an ideal DMB, the feedthrough products are zero. (Why?)

## DBM Experiment

Connect the L (local oscillator) and R (RF input) to two signal generators tuned to 8 and 10 MHz. The I (Intermediate Frequency) output is connected to a spectrum analyzer. Set the range of the spectrum analyzer to cover 1 to 50 MHz.

Set the L input level to +7 dBm at a frequency of 8 MHz. (A DBM has a specified LO level at which it works best. These units are rated for +7 dBm.)

Measure the frequencies and amplitudes of the observed output spectrum. Change the level of the 10 MHz generator from -20 to +10 dBm and record the level of all the mixing products.

For a fixed L input level, does the output level follow the R input level? Plot the conversion gain (output - input level) for the mixing products. Identify  $m$  and  $n$  for each of the mixing products. How can you be sure of the values of  $m$  and  $n$ ?

If you were designing a superheterodyne receiver, which mixer would you prefer? Diode or DBM? Why? What do most receivers use, such as TV receivers in their VHF/UHF tuners?