MEASUREMENTS

Sensor methods for converting RF power into an easy to measure DC voltage

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Doing measurements as a hobbyist on DC or audio circuits today is easy and cheap. Digital multi meters that are sold in the 20 to 50 Euro range measure voltage, current, resistance and often even frequency and transistor gain. Even oscilloscopes that show DC and audio signals graphically over time are affordable as new or used commercial equipment. Unfortunately for the radio amateur, measurements get more tricky once the frequencies rise higher into the so call radio frequency (RF) range. Multi meters are usually specified up to a some 10kHz only and reasonable oscilloscopes are usually limited to a couple of 10MHz. Above these frequencies it is not trivial for the budget limited amateur to measure the characteristics of a signal. Since measuring is the key to success for own developments or rebuilds, other ways for evaluating RF signals must be found. This article shows ways to overcome the states limitations of standard measurement devices by converting a RF signal power into an easy to measure DC voltage.

As initially stated, sampling a RF signal directly in the time domain (i.e. viewing the signal with an oscilloscope) is usually limited to frequencies below 20-100MHz, depending on the bandwidth of the oscilloscope. There are oscilloscopes on the market with sampling rates of 20-50Gs/s and bandwidths up to 10-20GHz. Their prices however are located in the 6-digit Euro range, so only very few amateurs will be able to afford that luxury. Another device that can show RF power (not in the time domain but in the frequency domain) is a spectrum analyzer. When it comes to the price, a spectrum analyzer is also much too expensive for most radio amateurs.

So if an amateurs wants to measure the signal power of a RF signal, there is no other way than to convert the amplitude of the signal into an equivalent DC voltage first. A piece of equipment that is able to do this conversion is usually referred to as a sensor. The DC voltage at the output of the sensor can be measured with a standard ADC (analog-digital-converter) or a cheap multimeter. If the transfer function of the sensor is known, the signal power of the input signal can be calculated from the measured DC voltage level.

There are basically three different principles that can be used to build a sensor that can convert RF signal power into a corresponding DC voltage level. All three principles have their pros and cons. So depending on the actual requirement, one or another sensor may be best suited.

Thermal Sensor

Within a thermal power sensor, the incoming RF signal is absorbed in a small dummy load. A standard 50 Ohms chip resistor (e.g. 0603) can be used up to 5-10GHz with very good results. Due to the power dissipation from the RF signal, the resistor warms up, the change in temperature can then be used to determine the power of the RF signal. If we glue a NTC (a resistor that changes its resistance depending on its temperature) on the dummy load and include it in an measurement bridge, we get a bridge voltage that is equivalent to the applied RF input power. A second NTC of the same kind can be used in the bridge to eliminate the ambient temperature influence.

The nice thing about this principle is that it is basically independent of the frequency of the input signal. The resistor does not care if it is warmed up by a noble 10GHz beacon signal or by a cheap DC signal that can also be measured by a standard multi meter. Therefore every amateur can calibrate his or her homemade thermal sensor by applying different DC voltages to the input and writing down the resulting bridge voltage. Whenever one applies a RF signal and sees the same DC output voltage as with a certain DC input signal, he or she knows that the power of the measured RF signal is the same, independent on the frequency or waveform of the signal.

The unfortunate thing with thermal power sensors is that the usable dynamic range is quite low. Signals in the mW range hardly warm up the dummy load. So very small changes in the ambient temperature can lead to much bigger DC output voltages than the signal that shall be measured. On the other hand, the small dummy load cannot withstand input powers of more than a couple of 10mW. That leaves the user with a usable input power range of roughly 1mW to 100mW, which is a dynamic range of only 20dB. In commercially available equipment, a dynamic range of over 40dB is achieved with thermal power sensors. But the effort for achieving .the required thermal isolation and very low drift in the DC amplification is well beyond what the average radio amateur can spend.

Also it should be mentioned that the response time of a thermal sensor is not arbitrarily short. The dummy load needs some time warm up after the RF signal is applied. For a average homemade thermal sensor, the response time is in the range of one to three seconds, which is well acceptable for the radio amateur. Only for fast changing signals this could be an issue, as the sensor would be able to follow the a very quick change in input power.

Diode Sensor

In order to convert an AC-signal level (i.e. our RF signal) to an analog DC voltage that we can measure, we can also use a diode. Of course we have to use a special RF diode that is fast enough, has very little capacitance and is housed in a very small package to keep the series inductance as small as possible.

There is a big prejudice on diodes stating that an diode only starts to conduct (hence to rectify) when the voltage is above the diodes threshold voltage (0.3-0.7 Volts, depending on the technology of the diode). If this was true, we would indeed be in trouble if we tried to measure RF-signals in the mW range. (1mW on 50Ohms is only 223mV). However, the diode is always a nonlinear component, so even with the tiniest AC-signal, there is an DC output voltage. There is indeed a change in behavior around a few hundred mV, but it is just a soft transition from the so called square law region to the linear region.

In the square law region (roughly speaking below the threshold voltage) the diode already exhibits a different resistance in forward and backward direction. The difference is not as distinct as above the threshold voltage, but it is still there. The result is a DC-voltage that is proportional to the power of the signal, i.e. it is proportional to the square root of the peak voltage of the signal.

In the linear region the diode simply conducts at the positive half wave and isolates at the negative half wave. That is exactly the behavior that is well known from large signal rectifiers like in power supplies. The result is an DC voltage that is directly proportional to the peak voltage level of the input signal, therefore the name linear region.

There is a very good application note diode sensors from Alpha Industries [1]. Their zero-bias Schottky detector diode SMS 7630 can be used to build really good diode sensors. The easy-to-get BAT62 from Infineon also gives a very flat frequency response, but the video resistance (the differential source resistance of the DC output voltage) is higher. If a high-impedance multimeter or ADC is used to measure the DC output voltage, this does not really matter.

Logarithmic Amplifier Sensor

A logarithmic amplifier is an active form of a converter from an AC amplitude to a DC level. The principle they work on is based on a chain of amplifiers that amplify the inputs signal until it is driven into compression. The supply current of all single amplifiers is summed up and converted into a voltage. The very nice thing about logarithmic amplifiers is the fact that the DC voltage is proportional to the logarithm of the input level. In other words, the DC level is proportional to the input level measured in dB. For every dB the input amplitude raises, the DC output raises for some millivolts. Therefore we can measure over a very wide dynamic range (from very small input signals to rather big ones) without the need for a high amplification of the DC voltage. Even with amateur means we can measure over at least 50-60dB dynamic range. That means signal power factors of 1 million from the smallest to the largest signal that we can measure.

The disadvantage is that the precision is not very high, especially when we measure at different frequencies. Like every amplifier, the log amp changes its behavior over frequencies. Of course the manufacturers of integrated log amps try to eliminate this effect as much as possible.

For some time now there are very nice integrated log amps available on the market. For frequencies up to 2.5GHz the AD8313 from Analog Devices is one good example. The external component count is very low and unless one uses components that don't work to 2.5GHz, the results are very repeatable. So if one copys a log amp sensor with similar components, the DC output level for a certain RF input power will be quite the same.

A very good and extensive article on the theory of logarithmic amplifier can be found on pages 7 to 10 in the data sheet of the AD8307 from Analog Devices [2].

[1] Alpha Industries, Inc., A Level Detector Design for Dual-Band GSM-PCS Handsets, APN1014, Application Note

[2] Analog Devices, Low Cost DC-500 MHz, 92 dB, Logarithmic Amplifier, Data Sheet

Sensor Type	Advantages	Disadvantages
Thermal Sensor	◆ can be calibrated with DC signals ◆ almost no variation over frequency ◆ can be homemade up to 10GHz ◆ high accuracy ◆ shows the true RMS value of the input signal	◆ low dynamic range ◆ slow sensor response
Diode Sensor	◆ good accuracy ◆ reasonable dynamic range ◆ good compromise for all kind of applications	◆ signals with a lots of harmonics (none sinusoidal signals) can lead to inaccurate power readings
Logarithmic Amplifier	◆ high dynamic range	◆ high variation over frequency ◆ needs frequency correction for reasonable accuracy