ACCURATE POWER MEASUREMENTS ON MODERN COMMUNICATION SYSTEMS

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This paper will take a look at the demands on measuring power on some modern communication systems. We will have a look at the technology of power measurement and the errors and uncertainties in making the power measurement.

Increased data rate demands from customers have driven the change from simple constant envelope modulation schemes such as FM, used on PMR equipment, first generation mobile phones and microwave links, to more complex schemes such as GMSK, CDMA and N-QAM.

This paper will concentrate upon RMS measurements on CDMA and N-QAM systems and will examine two different types of sensor technology that can be used to measure these types of signal.

CDMA signals such as IS-95 the north American 'narrow' band cdma standard or the 3GPP WCDMA standard have a considerable amount of amplitude content. Typically we might expect as a minimum 10dB peak to average power and possibly as high a peak to average ratio as 16dB. This amplitude variation renders the conventional CW linearity corrected diode sensor unsuitable for these types of measurements.

Radio links have adopted N-QAM, typically 64 QAM or 256 QAM to increase the data rate. Other systems such as some of the newer higher WLAN standards are also adopting 64QAM for their fastest data rate. The symbol rates for these systems are typically higher than the bandwidth of most commonly available peak power meters, and a RMS measurement makes an accurate and economical indication of the power of the system.

Power measurement technology has settled to three main types of power sensor design. Thermistors, Diodes and Thermopiles or Seebeck Effect devices.

Thermistors have traditionally been used for standards transfer and are not used for normal measurements on systems and equipment because of their limited power handling capability.

Diode based sensors have been available in two different formats, the square law only based sensors and the linearity corrected wide dynamic range sensors. Recently, a third type of diode sensor has been introduced, the multiple diode based sensor.

Thermopile or Seebeck effect sensors work on the thermocouple principle and rely on the heating effect of the input signal. This makes them ideal for measuring the true RMS power of complex waveforms such NQAM as they will always respond to the true RMS value of the input waveform regardless of the modulation imposed upon the carrier. Thermopile sensors have a good return loss, which reduces the measurement uncertainty. The only disadvantages that they have tend to be limited dynamic range and they are relatively slow compared with a diode sensor. The Anritsu fast thermal sensors have a response time of 4ms.

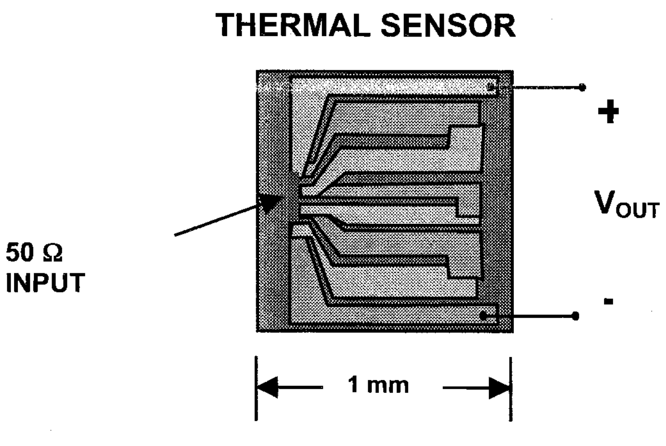

Figure 1:
Thermopile Sensor

Figure 2 shows the response of the thermopile element and of a diode detector. Conventional Diode detectors either work in the square law region, and are thus limited to 50dB dynamic range, or use linearity correction techniques to extend their dynamic range. This technique is limited by the speed of the power meter and is not suitable for applications where the system transmitted symbol rate far exceeds the sampling rate of the power meter.

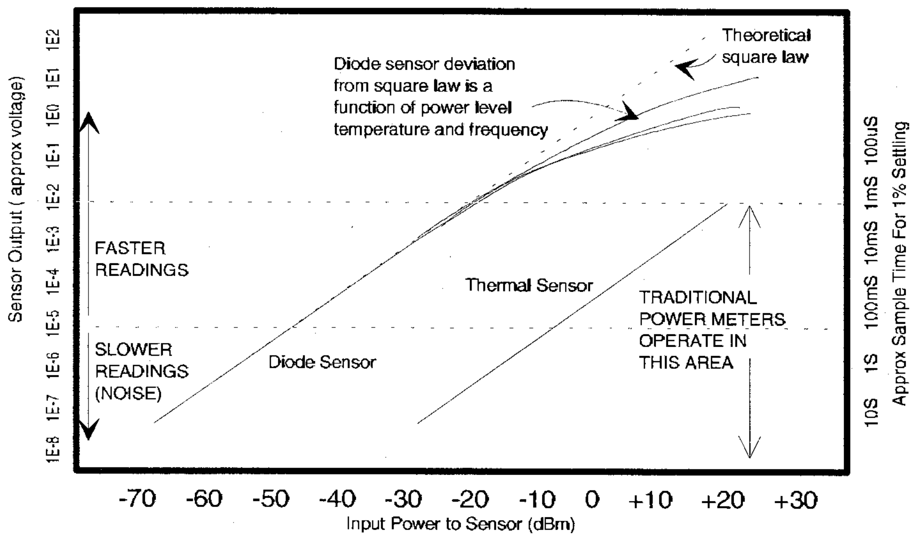

Diagram 2: Sensor Sensitivity vs Signal Level.

The MA2481B Universal Sensor

Taking a look at diagram 2, we can see that the diode square law extends from –70dBm to about –20dBm.
The universal sensor uses the square law regions of three diode paths to make a true RMS sensor that covers the dynamic range of +20dBm to –60dBm.
There are two change over points between the diode pairs, the first changeover is at approximately –3.5dBm and the second at –23.5dBm.

The path for Detector A has 40dB of attenuation and the detector is selected when the input power is in the range of +20dBm to –3.5dBm. The signal level on the diode varies therefore from-20dBm to –43.5dBm.

Detector B has 23dB of attenuation and is selected when the input power is between –3.5dBm and –23.5dBm.The signal level at the diodes varies from –26.5dBm to –46.5dBm.

The final diode pair, Detector C, has just 6dB of attenuation and operates when the input level falls below –23.5dBm . The signal level on the diodes varies between –29.5dBm and –66dBm.

See Figures 3 and 4 for the system diagram and the physical layout.

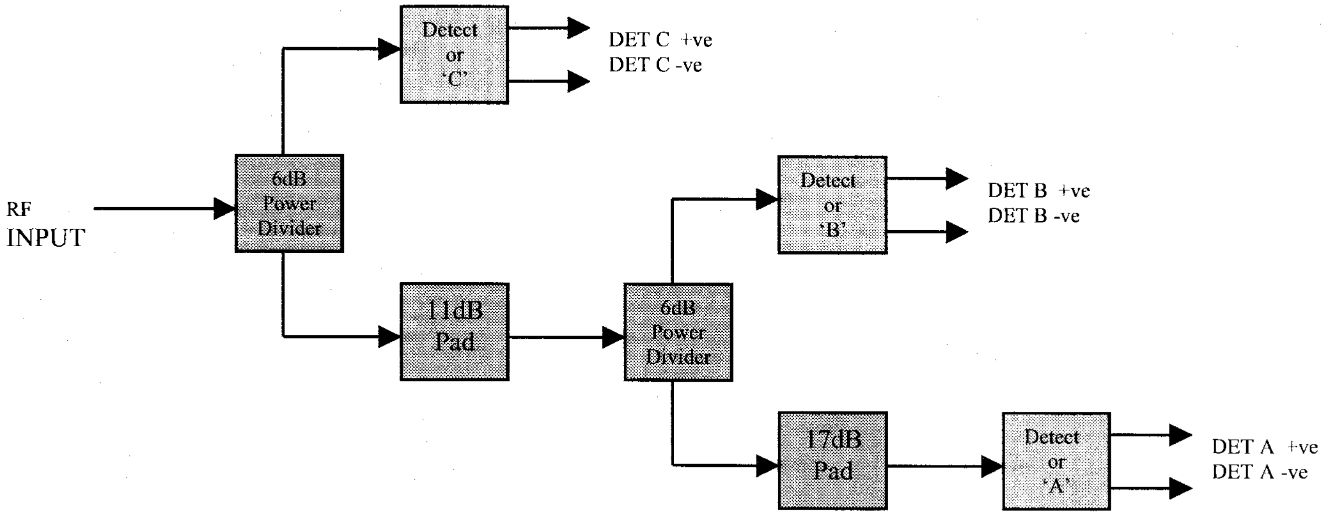

Fig 3: The MA2481B Universal Sensor

So what are the advantages of operating three diode pairs?
We have a sensor with a true RMS range of 80dB. This is very useful for measuring WCDMA signals produced by UEs which are expected to cover a wide dynamic range.
It's possible of course to produce a similar sensor with just two diode paths. The square law region of the diodes is 50dB, so if we had two paths operating over a range of 40dB each, then this would be sufficient to produce a 80dB dynamic range sensor.
However let's compare the noise performance of the two sensors. For the two path sensor, at the midway changeover point of –20dBm, the input power would be equivalent to –60dBm on the diode, at which point noise would become a serious influence on the measurement. For the three path sensor, the lowest signal at either changeover point is –46dBm, so the signal to noise ratio is considerably better than on the two path approach, which leads to a faster and less inaccurate measurement.

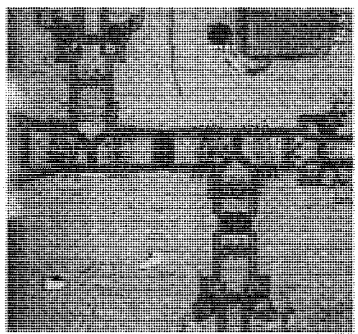

Fig 4: The Universal Sensor Physical Layout

The measurement errors and uncertainties can be divided up into four main areas of influence, the power meter, the calibrator, the sensor, and some of the properties of the device under test such as the match and spurious signal output. We will look at each of these areas in turn to examine their contribution to the power measurement.

Power Meter

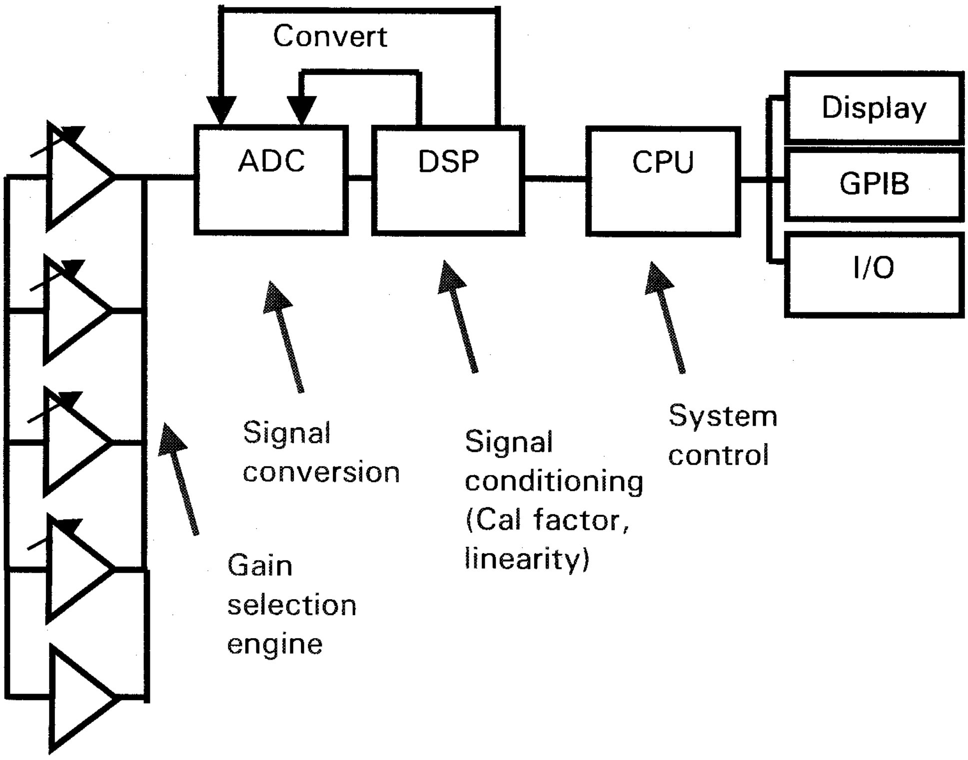

Figure 5: Simplified Block Diagram of the Anritsu ML2437A power meter

This is a typical block diagram of a modern power meter. The incoming signal is amplified , converted by the ADC and then processed by the DSP.

In traditional power meters each of the range settings of the amplifiers used to be dedicated to a decade range. The requirement for wide dynamic range power sensors has led to the use of greater dynamic range AD converters and the ranges generally cover more than 10dB. The Anritsu power meter has five amplifier ranges. The two lowest gain ranges are DC coupled and have the advantage of a quick response time for GSM type applications. The other three ranges are AC amplifiers which are used in conjunction with a chopper located in the sensor. These ranges are used for low level signals where stability, noise and drift are the key parameters. The bandwidth on these ranges is reduced, which improves the noise performance.

Instrumentation Accuracy

The instrumentation accuracy of the power meter is <0.5% and can treated a universal error. This is the performance of the power meter when considered as a baseband voltage measurement system. Some of the parameters that used to affect this figure such as quantisation error and zero carry over have been greatly reduced by the adoption of AD converters with greater resolution.

The lowest gain range often has the largest dynamic range. Let's examine the effect of quantisation on this gain range as the effects will be the most significant.

The maximum input voltage to the AD converter on this range is 4.5 volts. The converter is a 16bit AD converter so the resolution is 68.6uV per bit. The smallest signal that the range has to deal with is approximately 80mV. This would correspond to approximately 1,200 bits on the A/D converter. So the quantisation error is less than 0.09% and need not be treated as a separate item. The other amplifier ranges have a much smaller dynamic range and so the quantisation error is considerably smaller.

Zero set and drift
This is the residual from the zeroing process and its drift over one hour, measured with maximum averaging. The specification for this parameter is that the error term is less than 0.5% of full scale on the most sensitive range. For the two sensors discussed in this paper, the most sensitive ranges cover 10dB. For the fast thermal sensor the zero set is equivalent to 0.05 microwatts and for the universal diode sensor, the zero set is equivalent to 0.05 nanowatts. The effect of the zero set and drift becomes more significant as the power level decreases on the bottom range. For a signal at the lowest end of the published dynamic range, the contribution is <5%

Calibrator Power Reference

The power reference provides the power meter with a traceable 0dBm reference level for calibrating the sensors. The calibration of the reference is traceable to national standards and can be considered to be accurate to within +/-1.2% peak, or 0.9% RSS in one year. The other error we need to take into account is the mismatch between the sensor under calibration and the reference. The Reference has a VSWR of <1.04 and this helps reduce this error. For the two sensors under consideration this error term is 0.31%.

Power Sensor

The power sensor contributes five factors to the uncertainty budget.

- Linearity. The sensor has a linearity specification which is the measurement deviation from an ideal power measurement device.
- Temperature Coefficient. Both the thermopile and the diode elements have a temperature coefficient. The Anritsu sensors are individually calibrated for temperature drift and have a small thermistor located on the substrate which the power meter uses to calculate the correction. The correction is not perfect so there is still a residual error. Typically this is less than 1% over a wide temperature range.
- Mismatch Uncertainty at the time of the measurement between the sensor and the device under test. Often this is the largest single factor in the error budget, even with the relative good match of the sensors.
- Cal Factor Uncertainty. This is a function of the mismatch between the sensor and the cal factor calibration system. This is influenced by the sensor being tested. So for example a fast thermal sensor at 38GHz has a cal factor uncertainty of 3.62% and the universal sensor at 2.2 GHz has a cal factor uncertainty of 0.6%.
- Noise. This is dependent upon the type of sensor and the signal level applied. For the Thermopile element the noise contribution increases as the signal level decreases. In the case of the universal sensor we need to take into account the increase in noise on each set of diodes towards the range change points. After the range change the signal to noise ratio improves. The power meter signal channel contributes relatively little to the overall noise performance of the sensor. Averaging can reduce noise and the Anritsu ML234X power meter offers several averaging schemes. There is a facility to increase the averaging automatically at lower powers, keeping the fast response at higher power levels.

Mismatch

This can be the single largest contribution to the error budget when making a measurement. The mismatch error is caused by the differing impedances of the sensor and the source. In general terms the sensors, which are passive terminations, tend to have a better match than active sources. The reflected wave combines vectorially with the transmitted wave to produce a standing wave. The sensor will detect this, but it is not possible to guess the position of the maxima and minima. Consequently we should always take the worst case when considering mismatch error.

The equation describing mismatch is

$$\% \text{ Mismatch Uncertainty} = 100\left[(1 \pm \Gamma s \Gamma l)^2 - 1\right]$$

where s is the source and l is the load, which in this case is the sensor.

Mismatch error can be improved with an attenuator. There is a facility in the Anritsu Power meter that allows the user to enter a table with attenuator values that can be applied to the measurement. A precision attenuator is capable of being calibrated to 0.05dB or 1.15%. If a non-precision attenuator is used, then the calibration error could be larger than the mismatch improvement you are looking for.

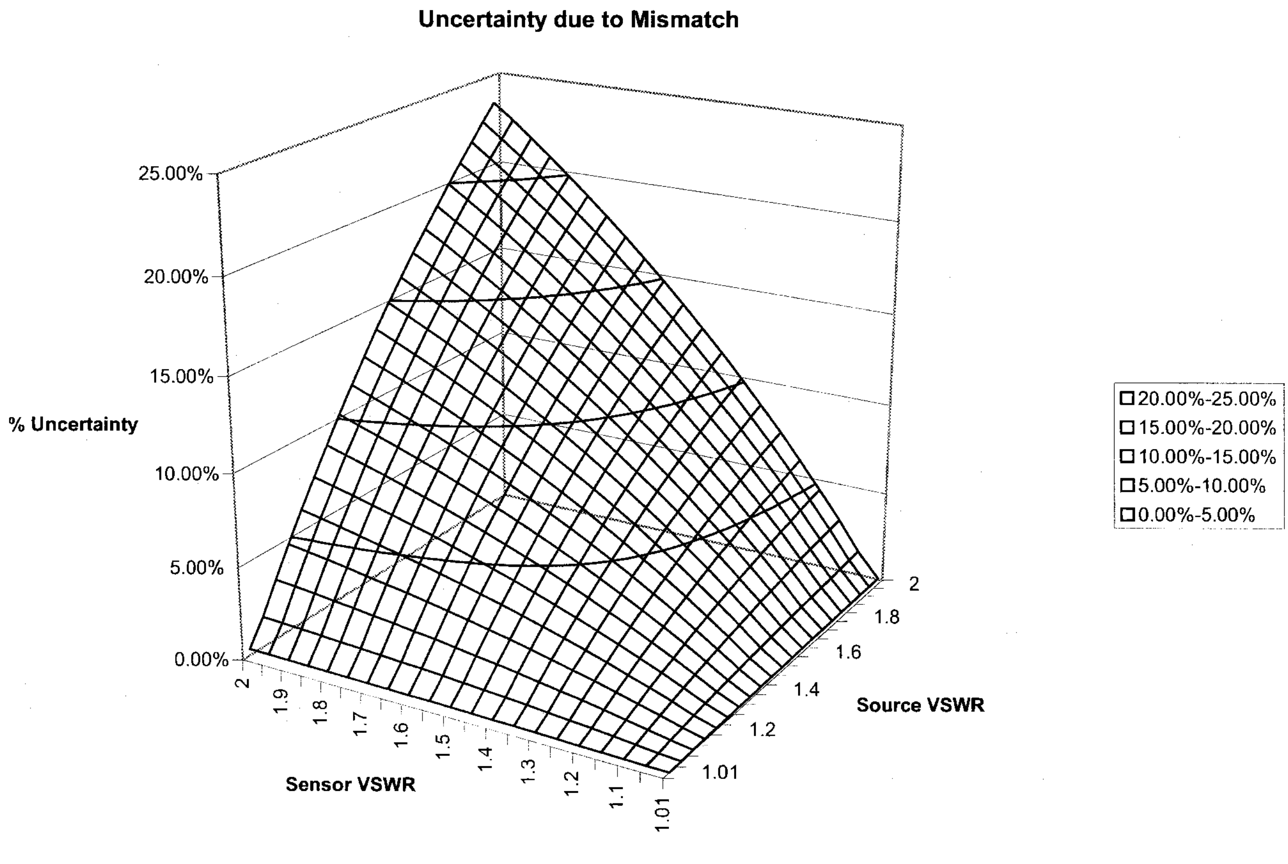

Figure 6: Error Surface due to the mismatch between the Source and Sensor

Harmonics and Spurious Signals

Another source of errors on the power measurement are harmonics and spurious signals. Square law sensors will add the powers of all the signals within its passband. For most finished systems designed to meet with Government or international specifications, the influence of these signals is negligible on the measurement. However for measurements made on uncompleted systems or parts of subsystems where the filtering is not in place, these signals can lead to extra errors. For example, suppose that a local oscillator is leaking through a mixer and that this component is only 20dB down on the main signal. The sensor will add the two powers together, so there will be an additional 1% error due to the presence of the two signals. If we take another example, this time of an amplifier which is being run into compression. In this case the harmonic output may only be 10dB down from the carrier, and so this will add an extra 10% on the reading, significant compared with the rest of the errors in the system.

This property of true RMS sensors can be used to considerable advantage during multi-carrier tests. If we take two carriers spaced a few MHz apart, then the peak voltage will be 2V. A diode based peak power meter would then read this as 4xPower, whereas the true RMS sensor will correctly identify the combined signals as 2P.

So let's look at the influence of these errors on the two measurement scenarios. In both cases we will assume a source VSWR of 1.5, and that the signal spurious output is negligible.

1. A 2.2GHz WCDMA signal measured with a universal Sensor at +10dBm

2. A thermal sensor measuring a 38GHz radio link at +10dBm

In both these cases we can assume that the effect of noise and zero drift on the measurement is negligible.

Parameter	2.2GHz WCDMA Signal	38GHz N-QAM Link Signal
Instrumentation	0.5%	0.5%
Noise	0.0%	0.0%
Zero Set and Drift	0.0%	0.0%
Reference Power Uncertainty	1.2%	1.2%
Reference to Sensor Mismatch	0.31%	0.31%
Sensor Linearity	3.0%	1.5%
Sensor Cal Factor Uncertainty	0.6%	3.62%
Mismatch Uncertainty	2.28%	5.29%
Temperature Accuracy	1.0%	1.0%
Sum@ Room Temperature	7.89%	12.42%
RSS@ Room Temperature	4.04%	6.72%
Sum-across temperature	8.89%	13.42%
RSS-across temperature	4.16%	6.79%

Table 1: Uncertainties for two measurement scenarios

The table shows the uncertainties added in linear and RSS mode.
The linear summation assumes that the worst case errors will always add. The RSS summation takes the view that as the sources for the errors are derived from different physical mechanisms, it is legitimate to assume that on average they will not add in worst case fashion.
Many companies and uncertainty schemes adopt this approach when dealing with the summation of non-physically related uncertainties.

If we want to expand our view of the uncertainties away from these frequencies and power levels, then the best way to demonstrate this is via 3-D graphs.

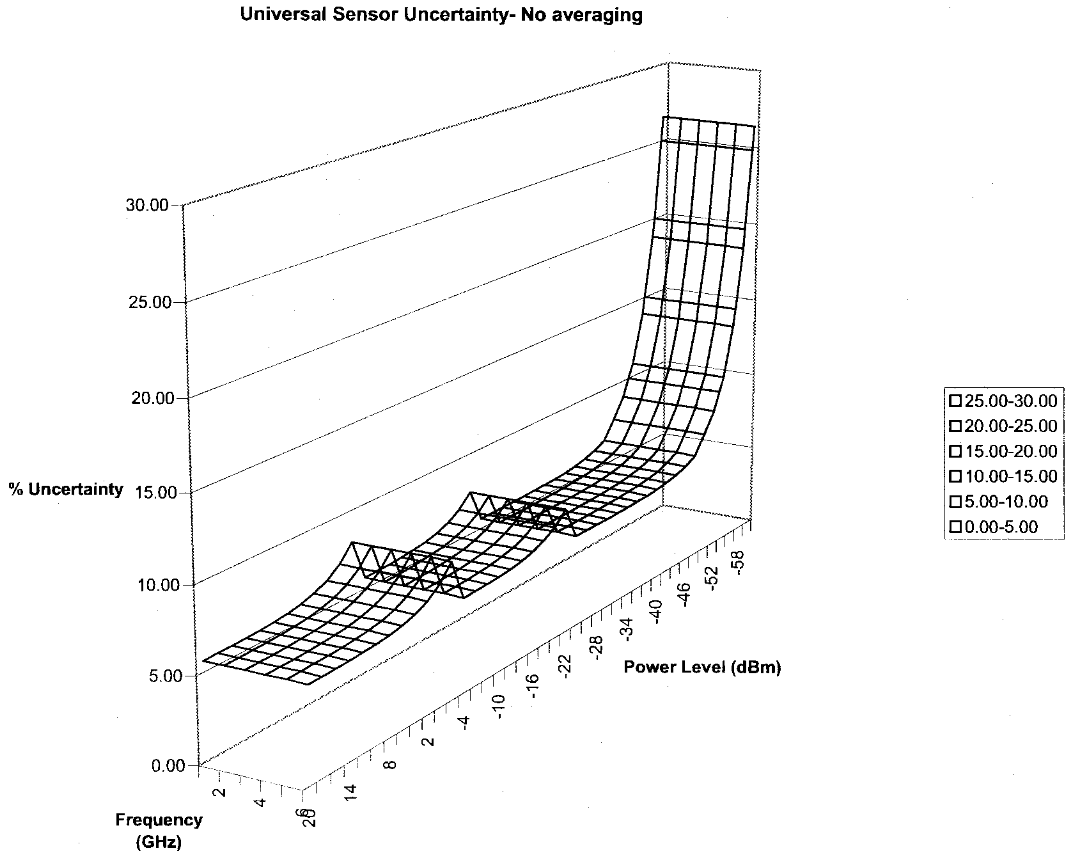

Figure 7: The Universal Sensor MA2481B Uncertainty Surface, Worst Case Addition.

This graph shows the sum of the uncertainties at room temperature for the universal sensor with no averaging applied. Worst case addition has been used. The influence of noise on each of the diode paths can be seen. With a modest amount of averaging the noise at the changeover points can be reduced to negligible levels. Noise is the biggest single influence at low power levels.

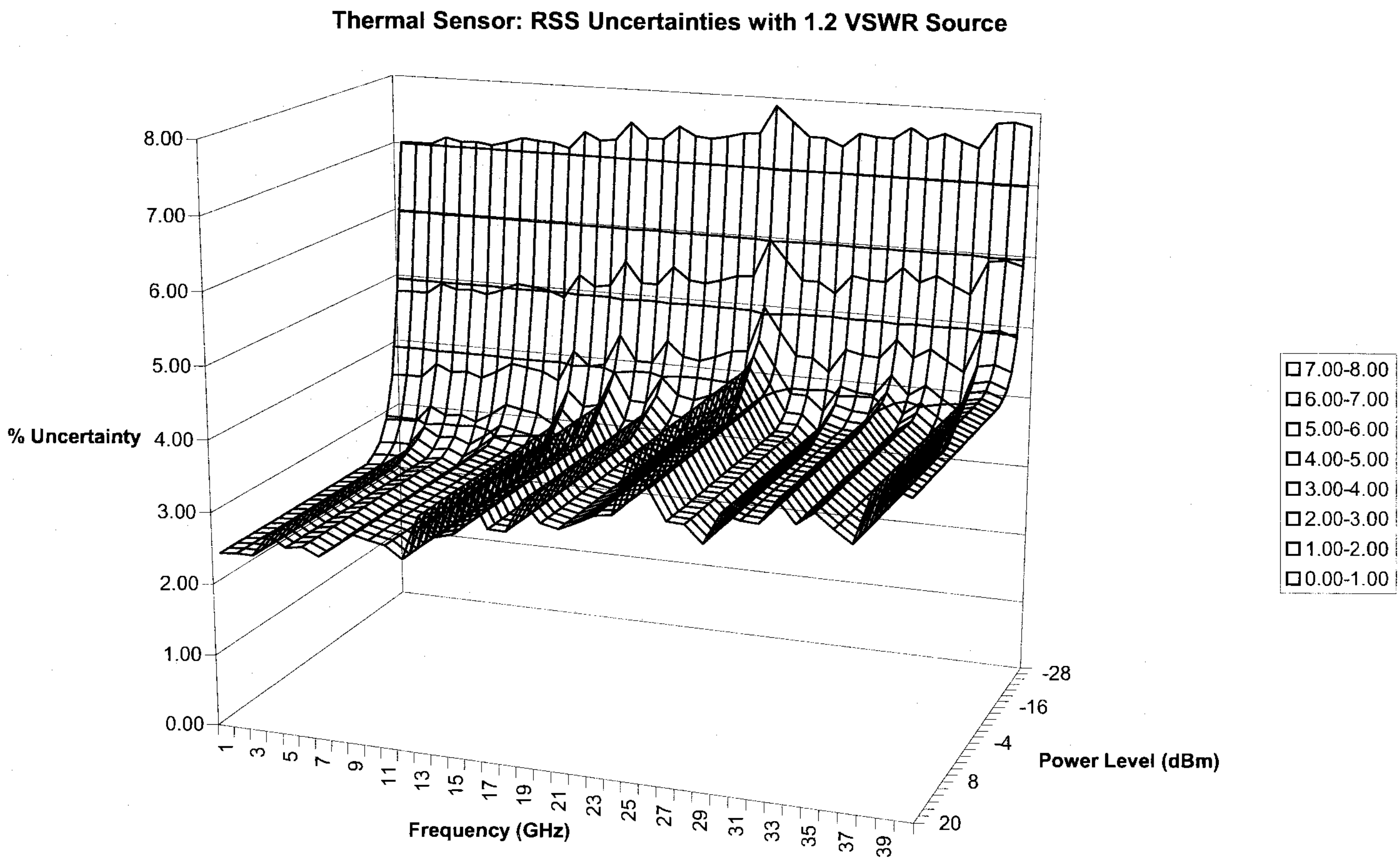

Figure 8: Thermal Sensor Uncertainty Surface, Averaging Applied, RSS Error Addition

This graph shows the uncertainty surface for the thermopile sensor across its operating frequency range. The source match in this case has been put at 1.2, so that the uncertainty due to mismatch has been reduced. The uncertainties have been added as RSS terms. The increase in uncertainty at low power levels is mainly due to the influence of the zero set parameter. The frequency related ripple is due to the cal factor uncertainty varying across the range.
2.5% uncertainty, which is the lowest uncertainty on the graph is just over +/-0.1dB, and 8%, the largest figure on the uncertainty graph is +0.33/-0.36 dB.

Conclusion

Accurate true RMS measurements can be made on signals with complex modulation using the appropriate sensor technology. This paper shows the various contributions that need to be taken into account in calculating the uncertainty budget when measuring power.
The most significant single influence at high signal power levels is mismatch, and this can be managed by the use of matching techniques such as precision attenuators. The most significant influence at low power levels is noise and this can be managed by the selection of the appropriate averaging conditions on the power meter.