The response of Indexsar SAR probes to amplitude modulated (pulsed) RF signals (IXS0211)

SAR probes are required to measure the effective value (RMS value) of the electric field strength. The averaging time is defined in the standards as being over 6 minutes but with most of the signals that occur in the real world, such a long averaging time is unnecessary since the fluctuations are eliminated with significantly shorter averaging times. With most signals, a much shorter averaging time is sufficient. For example the GSM frame rate is 120mS and averaging over this time period will remove the fluctuations.

In diode probes, a single Schottky diode is used as the detector for each of the three channels (X, Y and Z). For small field strengths, these offer a very good approximation to a true RMS rectifier. For higher field strengths, higher or lower values than the RMS value can be displayed - depending on the modulation frequency.

The theoretical maximum deviation from the RMS value can be derived based on the behavior of the two extremes [1]:

An average-value rectifier

- displays a value proportional to the average value of the magnitude of a measured quantity.

A peak-value rectifier

- displays a value proportional to the peak value of the magnitude of a measured quantity

The proportionality factor for a practical probe is chosen so that the probe reads the true RMS value for a continuous (CW) signal.

For pulsed signals, a diode rectifier must deliver a value lying somewhere between the two extremes of an average value rectifier and a peak value rectifier. By way of example, for a GSM signal with a 1 in 8 duty cycle (ratio of 'on' time to total time), the power measurement at higher powers can vary between being a factor of 8 too low (average value extreme) and a factor of 8 too high (peak-value extreme).

The actual behaviour is complex as it depends on the period of the modulation in relation to various time constants in the measuring system. These include the holding time of the diode (typically 50 uS), the time constant of the high-resistance leads and the time constant and integration periods of the measurement electronics. Also, the modulation periods are complex – GSM has a basic burst rate of 4.615mS, but the full modulation scheme only repeats every 120mS.

Keller [1] analysed how readings displayed by a diode probe vary from the correct values for a range of different modulation schemes and source combinations. He discounted simple models of the rectifier as being inadequate. Keller's solution was to devise a complex rectifier model the solution of which required the use of sophisticated numerical simulation techniques in the time domain.

He gives an example of a GSM source assuming that only one carrier frequency and one time slot of the source are active (as with a handset). Figure 1 illustrates the measurement errors of the diode rectifier used in an EMR20 E-field probe. For medium field strengths, a value is indicated that is too low by a maximum factor of 1.57 for E (2.46 for power). For very high field strengths, the result is too high by a factor of 1.66 for E (2.76 for power).

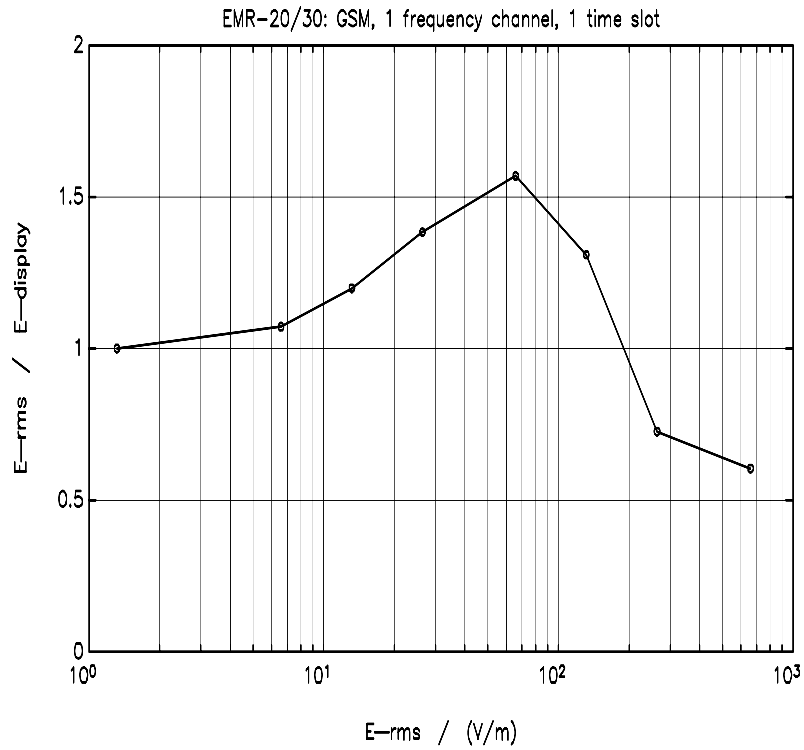

Figure 1: Display error for GSM signal (1 in 8), showing the situation with the greatest error in the direction of an average-value rectifier from Keller [1].

The basic characteristics of a diode sensor probe such as that illustrated in Figure 1 are such that it underestimates GSM signals at medium field strengths and overestimates GSM signals at very high field strengths.

For CW signals, the probe channel output signals are linearised in the manner set out in Refs [2] and [3]. The following equation is utilized for each channel:

$$U_{lin} = U_{o/p} + U_{o/p}^{\,2} / DCP \qquad (1)$$

where U_{lin} is the linearised signal, $U_{o/p}$ is the raw output signal in voltage units and DCP is the diode compression potential in similar voltage units. DCP is determined from fitting equation (1) to measurements of U_{lin} versus source feed power over the full dynamic range of the probe. The DCP is a characteristic of the schottky diodes used as the sensors. For the IXP-050 probes the DCP values are typically 0.10V (or 20 in the voltage units used by Indexsar software, which are V*200).

To correct for the errors due to the diode response to pulsed signals, a multiplier can be added to the second term of Equation 1. In principle, this multiplier can have a range for a GSM signal of between 8 and 1/8. The correction scheme will

$$U_{lin} = U_{o/p} + U_{o/p}^{2} * PCF / DCP \qquad (2)$$

Where PCF is a pulse correction factor ranging between the duty cycle and the reciprocal of the duty cycle.

Indexsar SAR probes show a qualitatively similar behaviour in respose to GSM signals, but with a much lesser degree of over or underestimation than for the probe shown in Figure 1. Indeed, for many Indexsar probes, the PCF has been established by measurement to be close to unity. A probe with a unity PCF reads true RMS for a pulsed signal without correction.

Typically, the PCF for an individual probe is established by a series of measurements comparing pulsed and CW signals generated with a suitably-featured signal generator with allowance being made for the RMS power difference (8 for GSM). The procedure is described in the Indexsar probe calibration documents. A typical measurement comparison is shown in Figure 2. The PCF has the effect of altering the effective diode compression potential and a modification to the DCP value is how the GSM correction is implemented in the Indexsar probe calibration scheme.

The modified DCP values for GSM are now included in the standard probe calibration report. The recommendation is that tests to establish the PCF for other RF signal modulation schemes should be undertaken using a suitable test set. If the transmit power level of a handset can be controlled with sufficient accuracy, the handset itself can be used to check the linearity of the probe calibration scheme with the assumption that the probes read true RMS at output levels well below the DCP.

Non-amplitude modulated carriers can be considered as CW as far as the probe calibration is concerned.

The effects of amplitude modulation of the CDMA signal on SAR measurements has been considered in a draft paper [4] submitted to IEEE SCC-34.

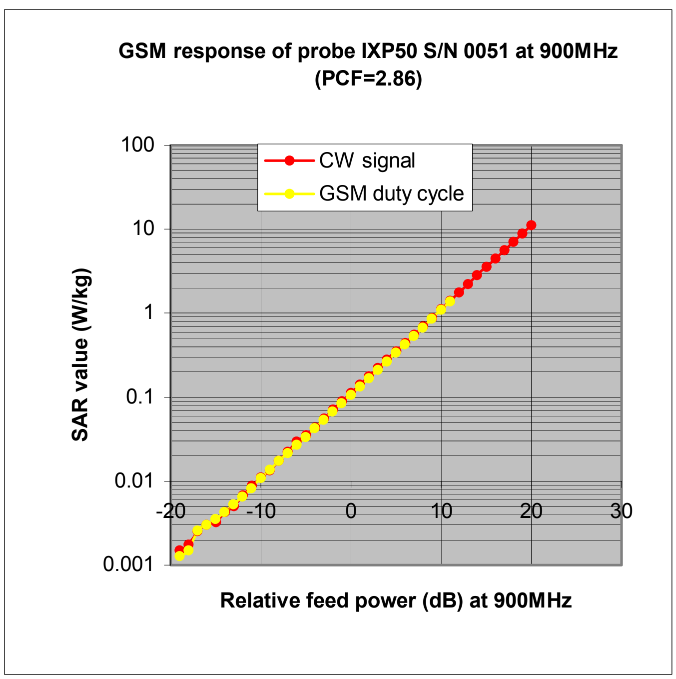

Figure 2: Comparison of GSM response with CW response for a particular probe. In this case, a PCF of 2.86 optimises the GSM probe linearity.

References

[1] Helmut Keller, ‘Standardized Personal Safety Measurements in the RF and Microwave Range with the EMR-20 / EMR-30 Field Strength Meters’ Application note by Wandel & Goltermann GmbH & Co.

[2] CENELEC, EN 50361, July 2001. Basic Standard for the measurement of specific absorption rate related to human exposure to electromagnetic fields from mobile phones.

[3] IEEE 1528, Recommended practice for determining the spatial-peak specific absorption rate (SAR) in the human body due to wireless communications devices: Experimental techniques.

[4] Carlo di Nallo, ‚Effect of amplitude modulation of the CDMA signal on SAR measurements, Motorola draft report for IEEE SCC-34, april 2002.