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SAR PROBE RESPONSE TO DIRECT SEQUENCE SPREAD SPECTRUM (DSSS) MODULATED SIGNALS

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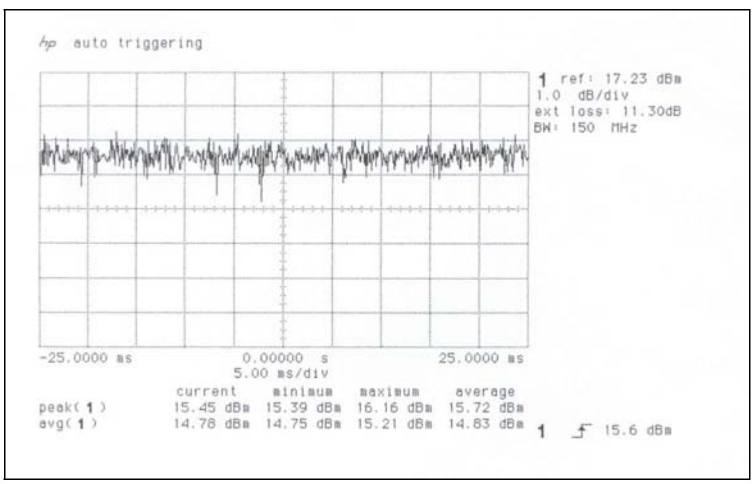

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Introduction

Direct sequence spread spectrum modulations are used in an increasing number of wireless devices. The modulation is complex being a mixture of frequency and time-varying modulation and it is necessary to perform laboratory testing to investigate the response of SAR probes to the modulation. The facility for producing test signals is not readily available on signal generators in most laboratories and so the tests reported here have used an actual wireless device as the signal source. The device employed has the facility to switch between CW and various different DSSS modulations in a maximum-transfer rate test modes.

Equipment used

The device used as a source was an Intermec Pocket PC working on the 802.11 protocol in the 2.45GHz frequency band (see Figure 1). This device was used with a test application installed, which enabled the device to be set to transmit at varying data rates using DSSS modulation as well as providing a CW test mode. The power output of the device was of low-level, 16dBm, and was of fixed (i.e. not variable) power level.

Figure 1. The test device employed as a DSSS source showing Intermec Pocket PC and Intel LAN card

The 2450MHz tissue-simulant body liquid used in the waveguide had properties within +/-5% of the P1528 target values (relative permittivity = 52.7 and conductivity = 1.95 S/m). The waveguide return loss at 2450MHz, when filled with this liquid, was 33.0 dB.

Tests over a range of signal power levels
To enable testing to be performed over a wider range of power levels, the transmitted signal from the source was picked off using a coax connector and fed via a variable-attenuator and an RF amplifier to a 2.45GHz waveguide, which was filled with tissue stimulant liquid for the testing. A bi-directional coupler was used to record the input power level and an Indexsar IXP-050 SAR

probe was used to measure the SAR levels as the input power level and modulation characteristics were varied. SAR measurements were performed at a fixed point in the centre of the waveguide. The arrangement is shown in Figure 2.

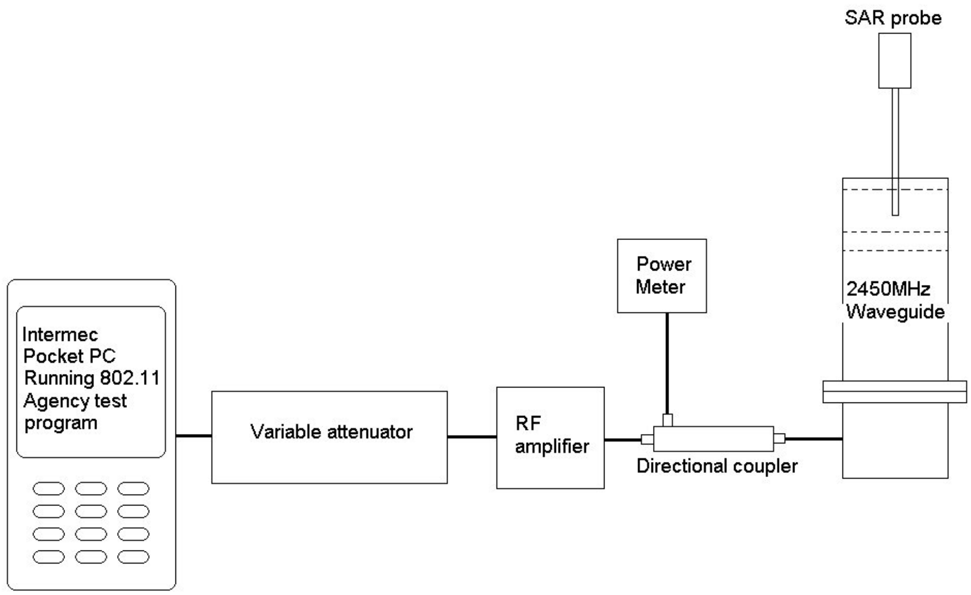


Figure 2. Test arrangement used to characterise SAR probe response to DSSS modulations.

The equipment used is listed in Table 1below:

Table 1. List of the principal test equipment employed

Component	Manufacturer/ supplier	Model number/ serial no.
Test source	Intermec Pocket PC	700C with 802.11
802.11 WLAN card	Intel Compact Flash LAN radio	WCF2011BEWW
Control software	Intel F310-03	802.11 Agency Test program
Variable attenuator	Hewlett Packard	11713A with 2-off 8494H
RF amplifier	Vectawave 10W 0.8-3GHz	VTL 6450
Directional coupler	Narda 1-18GHz	Model 4222-16
Power Meter	Rohde & Schwarz	NRVS
Liquid-filled waveguide	Indexsar	2450MHz band
Tissue-simulant liquid	Indexsar	2450 body liquid
SAR probe	Indexsar	IXP-050 S/N 0131
SAR software	Indexsar	SARA2v1.5gVPM
Peak power analyser	Hewlett Packard	8990A (Inv. No 1670)
Power sensor	Hewlett Packard	84812A (Inv, No 1662)

Tests using a signal analyser displaying statistics of peak and average power
A Hewlett Packard (Model No. 8990A) peak power analyser was used to measure peak and average power levels from the 802.11 card using a coax connection to a test port on the card. The Agency test program on the Pocket PC was used to switch between the modulations on channel 6 (2437 MHz).

The procedures employed closely followed an existing BABT test method sheet, TMS-5-414, extracts from which are given in the Appendix along with an uncertainty analysis.

Results

Tests over a range of signal power levels

The Pocket PC was switched between CW and DSSS test signals with data rates of 1, 2, 5.5 and 11 MB/s. The tests were done on the mid frequency (Channel 6) which was 2437MHz. Using the variable attenuator, power was varied over a range giving CW SAR levels in the waveguide of between 0.14 and 13 W/kg. Input power levels were recorded using the directional coupler and SAR levels were measured using the probe S/N 0131, which had previously been calibrated for use in 2450MHz body liquid. The variable attenuator was switched in steps of 2dB and, at each setting, the SAR level for the CW and the 11MB/s modulated signals were noted along with readings of the power meter. Modulated signals at the other data rates were also checked at each attenuator setting. Whilst the power level drifted down somewhat after each test signal was first switched on, the SAR readings for each modulation level were the same within the uncertainty caused by the power drift. Excluding the two highest power settings, where the RF amplifier was beginning to saturate, the average difference between the waveguide input powers between the CW transmission and the modulated transmissions was -1.3dB. If both signals had the same peak power, then, since the duty cycle is defined as the difference between the peak and average power, this represents a duty cycle of 1.36. However, additional tests (described below) were undertaken to measure the duty cycle using a specialist power meter that measured statistics of both peak and average power levels. These measurements showed that the peak power levels were lower for the modulated signals compared to the CW test mode of the 802.11 card in the Pocket PC. The SAR readings were graphed against the setting of the variable attenuator to indicate the linearity of the SAR probe response versus source power for both modulated and un-modulated signals. For the modulated signals, 1.3 dB was added to the output prior to display in Figure 3. With this offset applied, the coincidence of the data for both signals in Figure 3 confirms that the SAR probes read in proportion to the true RMS signal level and that the probe response to both signals is proportional to the source power over a wide range of SAR values.

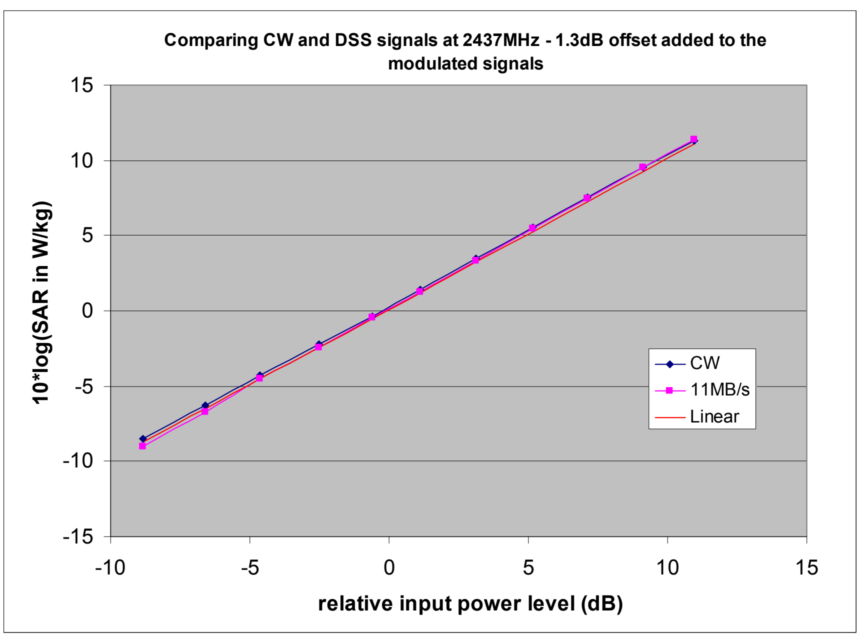


Figure 3a. Indicating that DSSS signals are measured correctly using a CW probe calibration over a wide range of power levels corresponding SARs from 0.14W/kg up to 13 W/kg.

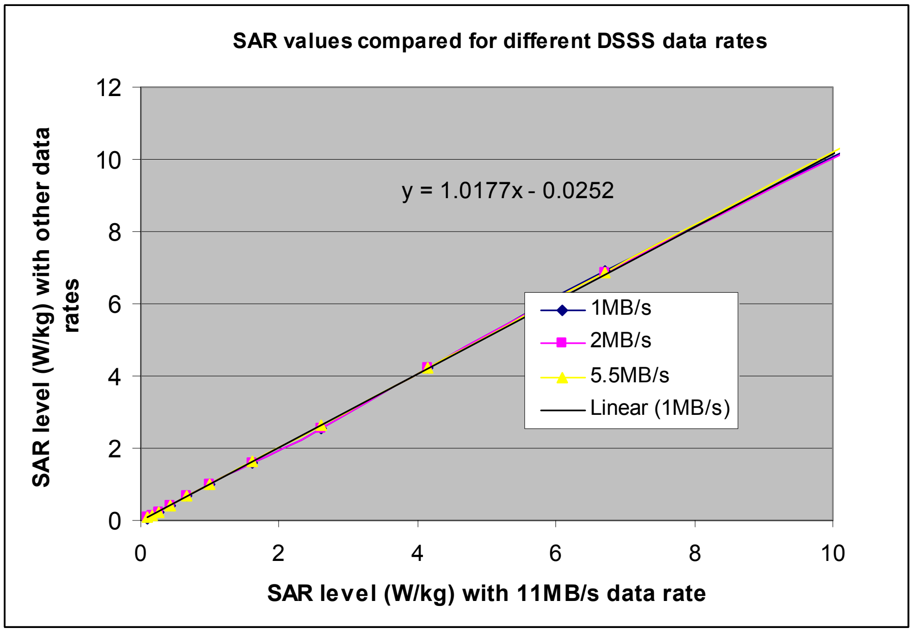


Figure 3b. Indicating that DSS signals at other data rates give the same SAR measurements as with the 11MB/s test signal

Tests using a signal analyser displaying statistics of peak and average power

The test set-up is shown in Figure 4. The following screen shots from the peak power analyser record the modulation statistics for each mode of transmission (Figs. 5 to 9). Summary data are presented in Table 2.

Figure 4. Photograph of test set-up used for obtaining statistics on peak and average power

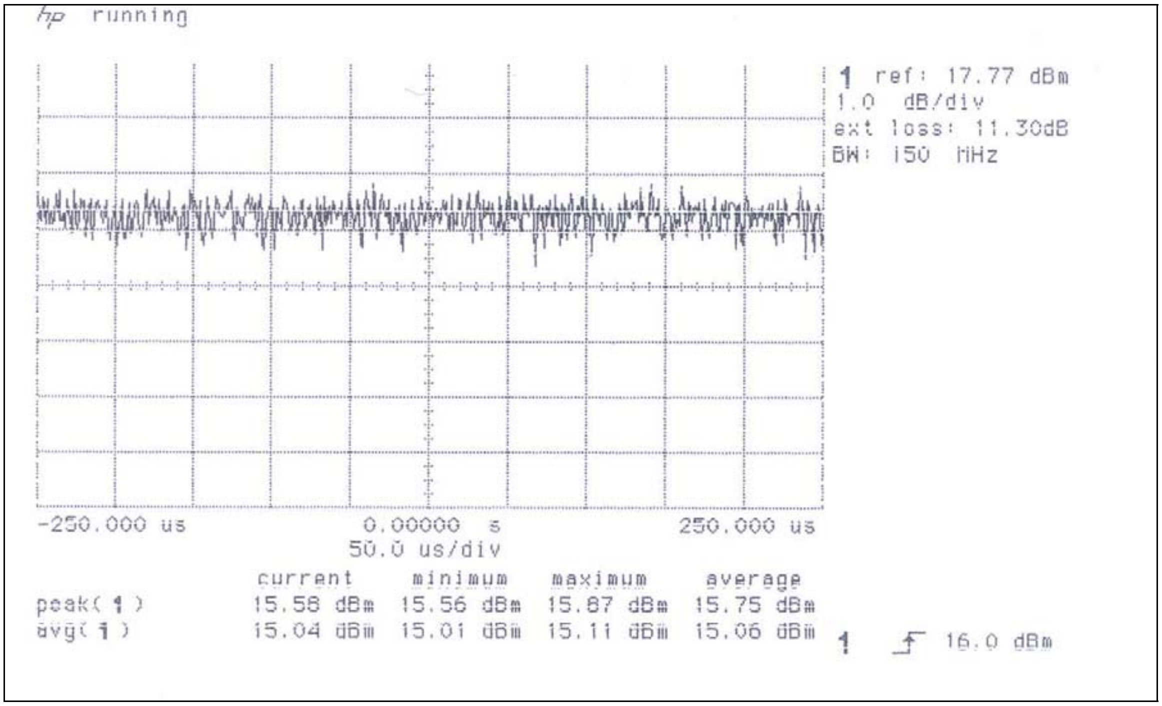


Figure 5. Modulation statistics for 1MB/s data rate

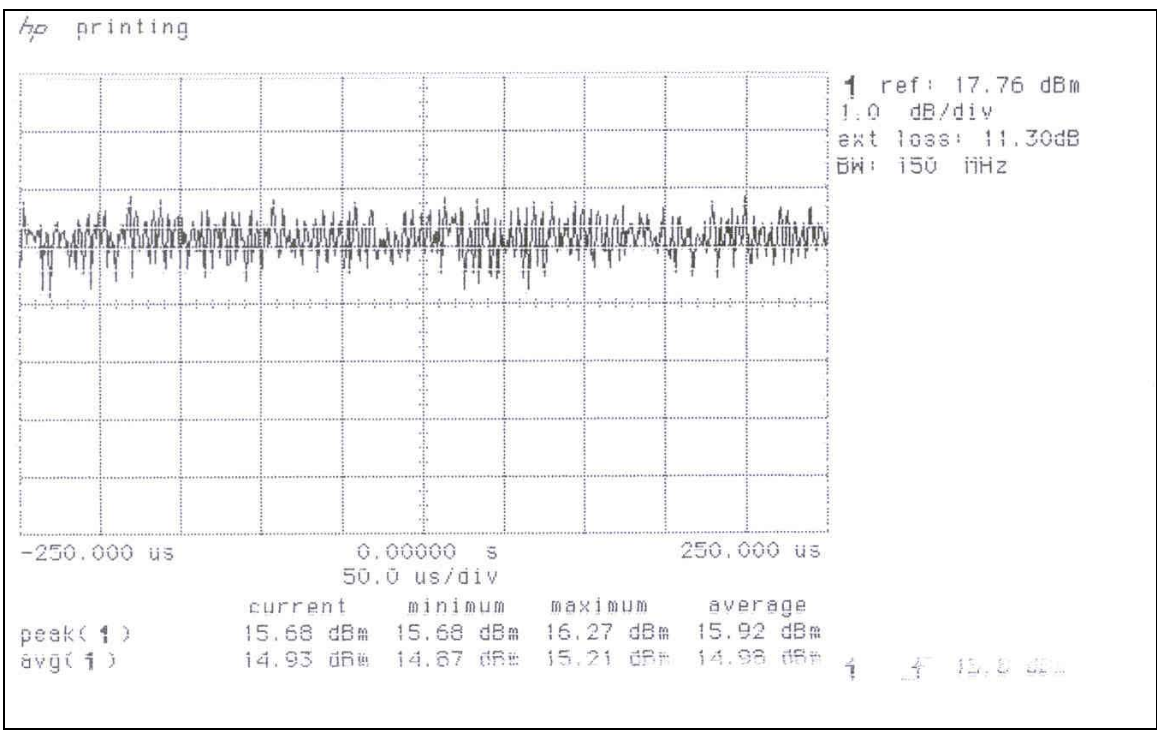


Figure 6. Modulation statistics for 2MB/s data rate

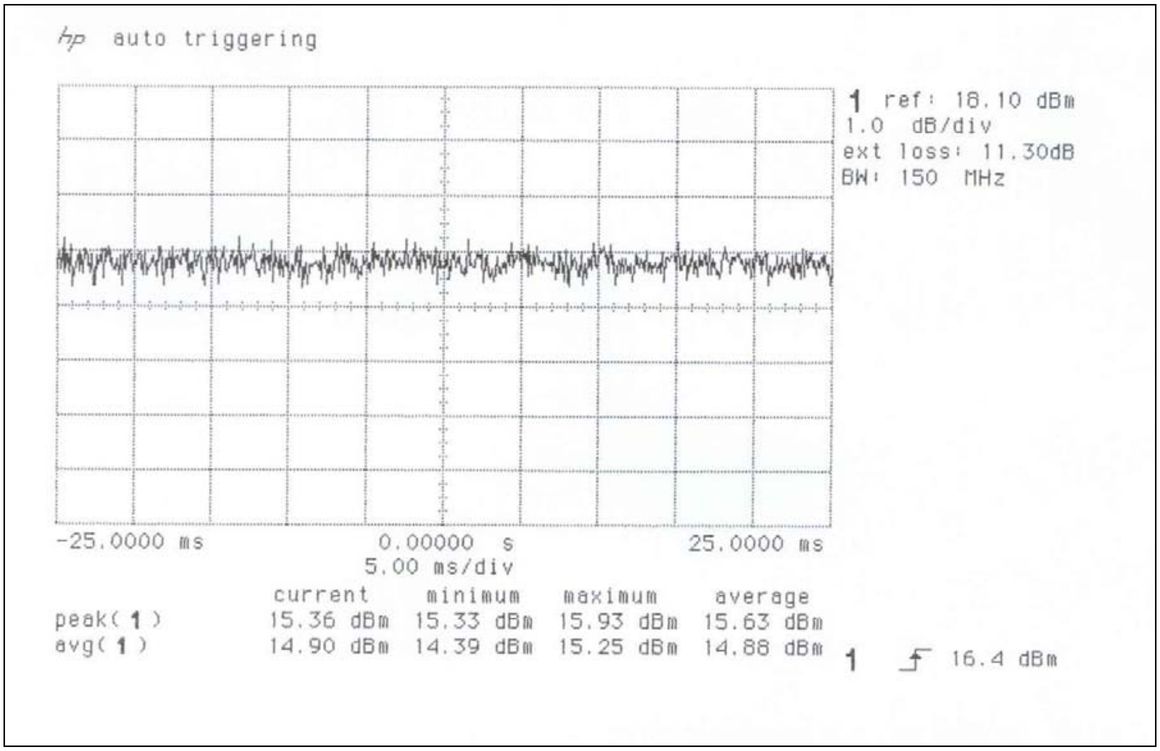


Figure 7. Modulation statistics for 5.5MB/s data rate

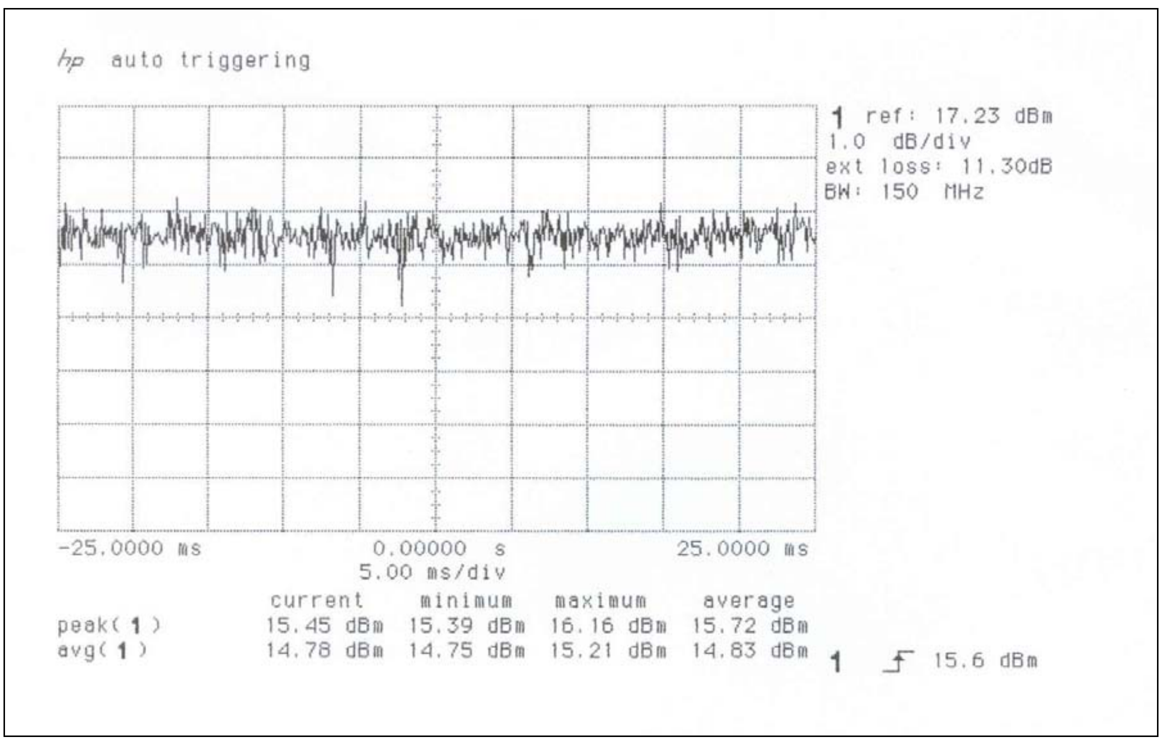


Figure 8. Modulation statistics for 11MB/s data rate

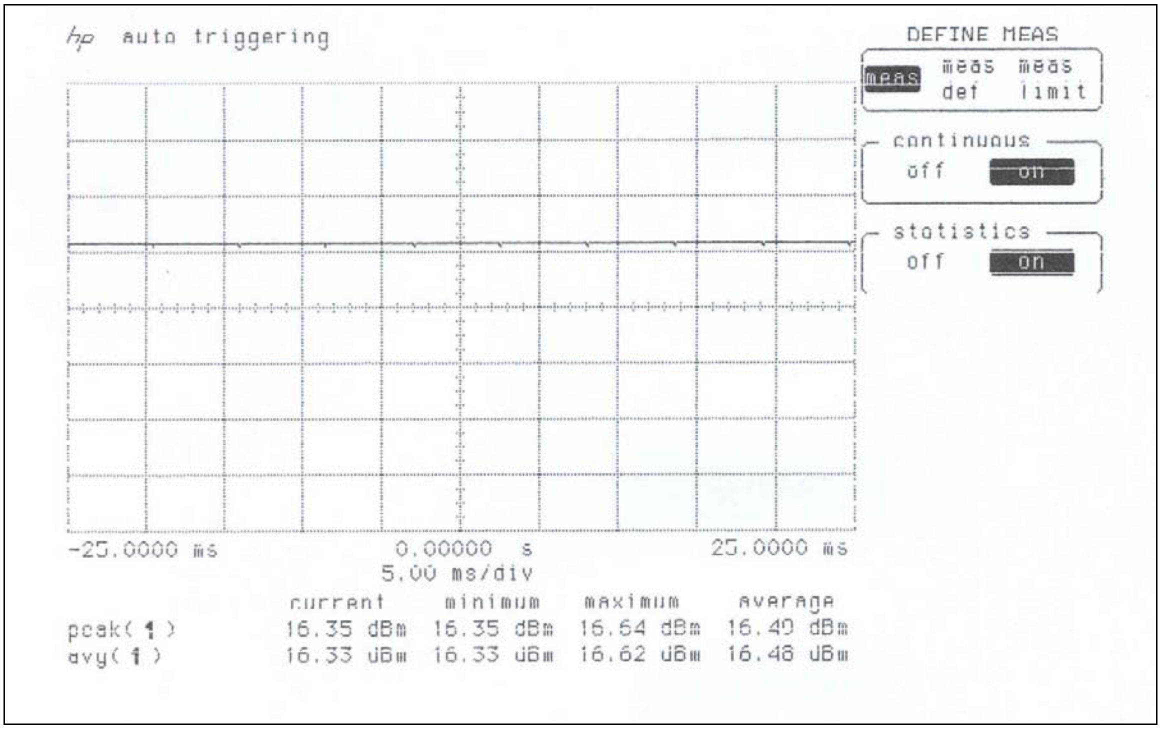


Figure 9. Modulation statistics for CW transmission mode

Table 2 Summary of modulation statistics data

Modulation (data rate – MB/s)	Peak power (dBm)	Average power (dBm)
CW	16.49	16.48
11	15.72	14.83
5.5	15.63	14.88
2	15.92	14.98
1	15.75	15.06

Based on the results above, the modulated signals from the device tested have only 70% of the output power delivered in CW test mode.

Also, the duty cycle of the modulated signals, which is given by the ratio of the peak power to the average power, is deduced to be 1.2.

Analysis of the errors arising from the use of CW probe calibrations for the measurement of DSSS modulated signals

An analysis of the appropriate DCP factors for use with DSSS signals for a duty cycle of 1.2 indicates that SARA2 CW DCPs of 20 (V*200) could be reduced to 19 (V*200) to optimise the linearity of probe response to DSSS signals. However, the magnitude of this correction is insignificant for low SAR levels and, indeed, no non-linearity is apparent in Figure 3. The errors that would be expected by using CW calibrations for the measurement of DSSS signals are indicated in the graph of Figure 10.

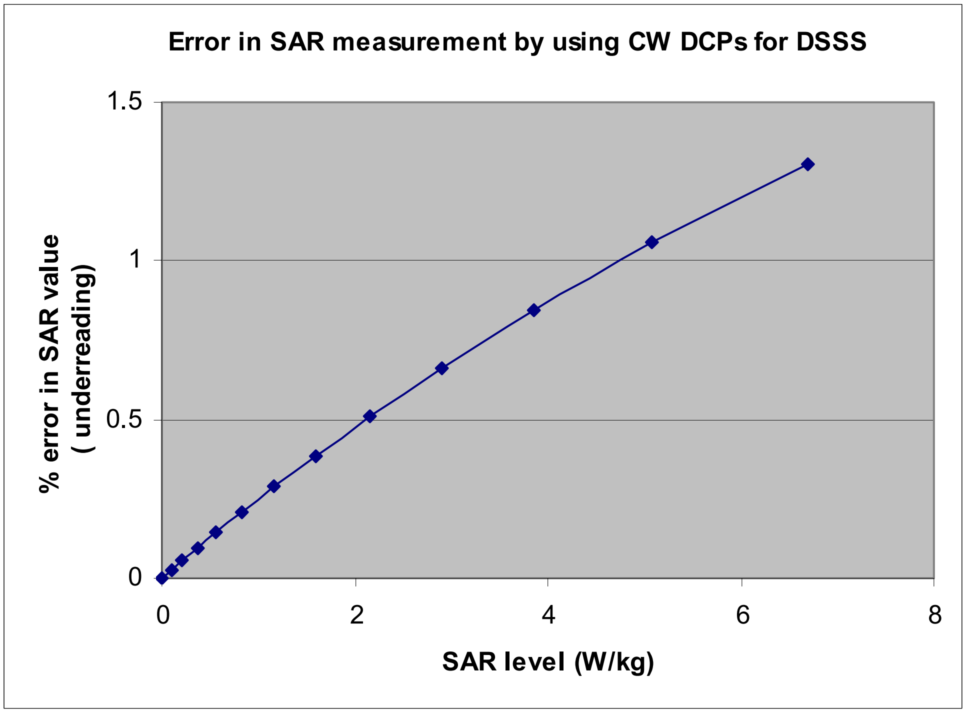


Figure 10. Estimated errors in SAR measurements caused by using CW calibration factors for the measurement of DSSS signals.

Conclusions

Using an 802.11 card in a pocket PC, SAR levels for the DSSS signals were found to be approximately 1.3dB lower than for the CW signal setting in the Test Mode.

DSSS test signals for varying data rates between 1MB/s and 11MB/s all appear to have similar duty cycles (ratio of peak to average power) of 1.2.

This is a level of duty cycle that is close to continuous and the CW diode compression potentials (DCPs) do not need to be altered significantly to optimise the linearization of such signals. For Indexsar probes, it appears that the correct DCPs to use for DSSS signals would be 19 (V*200) rather than 20 (V*200) used for CW probe calibrations. A maximum error from using CW probe calibrations for measuring DSSS modulated signals is only a fraction of one percent at SAR levels within the P1528 limits (see Fig. 10).

In the comparative measurements reported here, the CW probe calibration measured the correct power levels for the DSSS signals within expected measurement errors and the response of the probes to both modulated and CW signals was linear over the range 0.14 W/kg to 10 W/kg.

Appendix 1: BABT test method for determining the statistics of peak and average power

This is an extract from TMS-5-414 September 2002

TEST EQUIPMENT USED:

HEWLETT PACKARD 8990A PEAK POWER ANALYSER
Inv No: 1670

HEWLETT PACKARD 84812A Power Sensor
Inv No: 1662

HEWLETT PACKARD ESG4000A Inv No
Inv No: 3470

10dB Attenuator Lucas Weinschel Inv No
Inv No: 2652

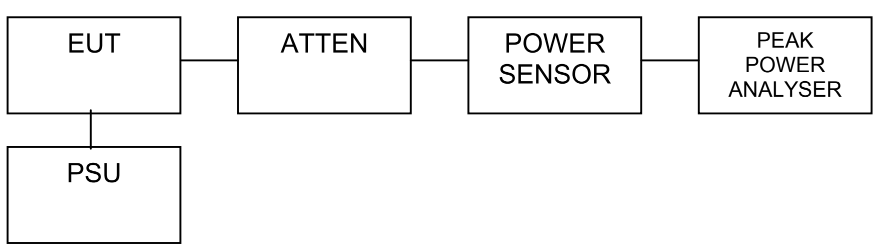
HEWLETT PACKARD Power Meter 436A
Inv No EMC 757

HEWLETT PACKARD 8482A Power Sensor
Inv No: 1529

CONDITIONS FOR TEST:

1. NORMAL: Within +15ºC to +35ºC at 20% RH to 75% RH at normal test source voltage or as stated in the relevant specification.

Peak Power Analyser, (8990A) and Sensor, (For measuring Average & Peak Power)



PATH LOSS CALIBRATION

1. The Power Meter and Sensor were calibrated in accordance with the manufacturer's instructions.

2. A 10dB attenuator was chosen to:

    a) protect the power sensor and power meter from damage from the EUT.

b) ensure that the attenuated power is within the dynamic range of the sensor.

3. Using a signal generator and a power meter, the path losses between points A and B were established and recorded.

AVERAGE AND PEAK POWER MEASUREMENT

1. The equipment was set- up as shown above

2. The EUT was set to transmit in its modulated mode.

3. The measured path loss was entered into the Peak Power Analyser as an offset.

4. The instrument settings were adjusted to measure the signal present at the sensor for average and peak power. .A statistical result showing the average power maximum, minimum, average and current peak powers were displayed.

MEASUREMENT UNCERTAINTY BUDGET FOR PEAK AND AVERAGE POWER

To establish the path loss of the measurement set-up, a power meter, sensor and signal generator is used. The sensor is connected to the signal generator output and the power meter reading is zeroed, (dB relative). The cables and attenuator are positioned between the sensor and signal generator and the resultant reading recorded as the path loss. This is entered into the peak power analyser as an offset. The EUT then replaces the signal generator and the peak power anlayser sensor replaces the power meter sensor.

As the path loss calibration is a relative measurement, the following contributions can be ignored:

Power Meter Calibration Reference Source
Zero Set
Signal Generator Amplitude Level Accuracy

The testing is carried out in an air conditioned laboratory where the temperature change is ±2ºC. However, the temperature change is gradual and over the time period that the measurement is performed from calibration to final measurement, the temperature effects have been accounted for under the relative accuracy contribution from the manufacturer's declared drift of ±0.001dB/ºC. Thus a drift of 2ºC adds ±0.002dB to the specified ±0.02dB drift figure.

POWER METER MEASUREMENT OF REFERENCE LEVEL

The standard uncertainty of the Power Meter Reference from the manufacturer's specification is :

$$\frac{0.7}{\sqrt{3}} = 0.4\%^{**}$$

** This contribution is ignored as the measurement being performed is relative and therefore the calibration reference source is not applicable.

The standard uncertainty of the accuracy from manufacturer's specification is ± 1.2%

$$\frac{1.2}{\sqrt{3}} = 0.69\%$$

The standard uncertainty of the Sensor Drift from manufacturer's specification is ± 0.001dB which equates to linear values of ± 0.023%

$$\frac{0.023}{\sqrt{3}}$$ = 0.013%

The standard uncertainty of the Zero set from manufacturer's specification is ± 0.01dB which equates to linear values of ±0.23%

$$\frac{0.23}{\sqrt{3}}$$ = 0.13%**

** This contribution is ignored as the measurement being performed is relative and therefore the calibration reference source is not applicable.

The standard uncertainty of the Zero Carry Over from manufacturer's specification is ± 0.001dB which equates to linear values of ± 0.23%

$$\frac{0.23}{\sqrt{3}}$$ = 0.013%

The standard uncertainty of the mismatch between signal generator and power meter sensor:

$$\frac{0.17 \times 0.048 \times 100}{\sqrt{2}}$$ = ± 0.58%

$$\sqrt{0.69^2 + 0.013^2 + 0.013^2 + 0.58^2}$$ = ± 0.90%

PATH LOSS OF CABLE AND ATTENUATOR

The standard uncertainty of the mismatch between signal generator and cable:

$$\frac{0.17 \times 0.091 \times 100}{\sqrt{2}}$$ = ± 1.09%

The standard uncertainty of the mismatch between cable and attenuator

$$\frac{0.091 \times 0.13 \times 100}{\sqrt{2}}$$ = ± 0.84%

The standard uncertainty of the mismatch between attenuator and cable

$$\frac{0.13 \times 0.091 \times 100}{\sqrt{2}}$$ = ± 0.84%

The standard uncertainty of the mismatch between cable and sensor

$$\frac{0.091 \times 0.048 \times 100}{\sqrt{2}}$$ = ± 0.31%

Standard uncertainty of the mismatch between signal generator and sensor

$$\frac{0.17 \times 0.048 \times 0.32^2 \times 100}{\sqrt{2}}$$ = ± 0.059%

Standard uncertainty of the power meter relative accuracy from manufacturer's specification is ± 0.022dB, (see introduction), which equates to linear values of ± 0.051%

$$\frac{0.051}{\sqrt{3}}$$ = 0.029%

$$\sqrt{1.09^2 + 0.84^2 + 0.84^2 + 0.31^2 + 0.059^2 + 0.029^2}$$ = 1.64%

MEASUREMENT OF TRANSMITTER PEAK AND AVERAGE POWER USING 8990A

Standard Deviation for a Transmitter with unknown VSWR from TR100 028 is 0.2

Standard uncertainty of the mismatch between EUT and Cable:

$$\frac{0.2 \times 0.091 \times 100}{\sqrt{2}}$$ = 1.29%

The standard uncertainty of the mismatch between cable and attenuator:

$$\frac{0.091 \times 0.13 \times 100}{\sqrt{2}}$$ = 0.84%

The standard uncertainty of the mismatch between attenuator and cable:

$$\frac{0.13 \times 0.091 \times 100}{\sqrt{2}}$$ = 0.84%

The standard uncertainty of the mismatch between cable and sensor:

$$\frac{0.091 \times 0.11 \times 100}{\sqrt{2}}$$ = 0.71%

The standard uncertainty of the instrumentation uncertainty including noise and offset (from manufacturer's user manual)

$$3.5 + \left(\left(\frac{(0.07 \text{ x } 10^{-6})}{1 \times 10^{-3}} \right) x100 \right) \quad = 3.507\%$$

$$\sqrt{1.29^2 + 0.84^2 + 0.84^2 + 0.71^2 + 3.507^2} \quad = 3.98\%$$

Therefore combining all the contributions for each stage:

$$\sqrt{0.90^2 + 1.64^2 + 3.98^2} \quad = 4.4\%$$

Therefore, at 95% confidence, (k = 2):

2.00 x 4.4 = 8.8% = ±0.4dB