Measurement of coupling loss between mobile handsets and DTT receive antennas at 700 MHz

A report for Ofcom

700 MHz coupling measurement report -issue 3a

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AEGIS spectrum engineering

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1 INTRODUCTION

On behalf of Ofcom, Aegis Systems undertook a modelling exercise to estimate the degree of interference that might be experienced by DTT services were the '700 MHz' band to be released for use by cellular services (Aegis Report 2523/SPP/R/4/5 *"Interference from LTE handsets to DTT services*", 15th May 2014).

The most likely bandplan would involve the user equipment (UE) handsets transmitting at frequencies immediately above the remaining broadcast allocation, with base stations assigned spectrum higher in the band. This implies that the most significant interference path is likely to be from UE devices in the street at a height of around 1.5m to rooftop TV aerials at 10m above ground.

No data on the statistics of loss for such paths currently exists, and a limited measurement campaign has therefore been undertaken, with the principal aim of informing the choice of suitable input parameters for coexistence studies.

The measurements conducted by Aegis seek to provide some information on the degree of coupling experienced in practice between handsets and the domestic DTT receivers. These measurements to capture both the variability of the propagation path between handset and antenna, and also that associated with the domestic system (downlead quality, amplifiers, splitters, etc). In an ideal world, these two variables would be measured separately, using standard gain rooftop antennas in addition to the actual domestic installation. Given the constraints of the project it was decided to adopt a pragmatic, engineering approach rather than to undertake a more fully comprehensive study.

2 METHOD

2.1 Overall approach

The path loss measurements involve the use of a low-power handheld (CW) transmitter (simulating an LTE UE handset) and a logging receiver connected to the standard TV wall outlet in a number of properties. The statistics of coupling are determined as the handset position is varied over a relatively wide area to accumulate path loss statistics.

This method exactly replicates the coupling path of interest, however the results include not only the variations due to the propagation path, but also those due to the characteristics of different receive systems (aerial type, cabling, amplifier and splitters).

2.2 Specific method

The position of the transmitter relative to the receiver must be logged together with the received power, so that the relationship between coupling loss and distance/bearing can be determined. In the arrangement adopted for the present measurements, a GPS receiver is used to modulate the transmitter, so that it broadcasts its location, which is then logged at the receiver together with the received power. The equipment is described in Annex A and has worked reliably in the measurements conducted to date.

Measurements were made with a Rohde & Schwarz EB200 test receiver, interfaced to a PC running Aegis' logging software.

2.3 Test frequency

It is clearly necessary that measurements be made at a frequency that is representative of potential LTE allocations in the 700 MHz band. As propagation effects change relatively slowly with wavelength, however, the exact frequency is immaterial and can be chosen to ensure compatibility with existing users.

Measurements have been carried out in Brighton, Brighton is primarily served by a high-power relay (Whitehawk Hill) operating in the higher UHF channels (48-60). The areas also has a number of lower-power relays that use a selection of interleaved channels. This makes it hard to identify a locally clear channel in the '700 MHz' band; a frequency, 702.0 MHz, has therefore been selected that lies on the boundary of channels 49 and 50. This is 8 MHz clear of Whitehawk Hill, ands care will be taken to avoid measurements in any areas served by the adjacent low-power relays (Patcham, Hangleton, Ovingdean).

2.4 Post-processing

In the modelling of 700 MHz UE interference, the coupling between the handset and the DTT antenna assumes:

- A handset with a defined eirp (maximum 23dBm) and an isotropic antenna
- A pathloss model, typically Okumura Hata (suburban), giving the isotropic path loss
- A DTT antenna with a gain of 9.2dBi and following the BT.419 pattern

The measurements cannot separate the effects of the propagation path and of the receive antenna. They are therefore normalised to give a coupling loss with the following assumptions:

- A correction is made for the actual transmitter power at any instant, as given by the telemetry from the transmitter.
- A correction (5.8dB) is made for the presence of the 75Ω-50Ω matching pad.

These corrections mean that the coupling loss reported represent the loss between the transmitter antenna socket and the domestic wallplate

The comparison curves given in this report make the same assumptions. If the modelling is accurate, one would expect the measured points to lie in an area between the curve and 9dB above it.

3 RESULTS - OUTDOOR AERIALS

A total of 8 households have been measured to date. The results are summarised in the plots below.

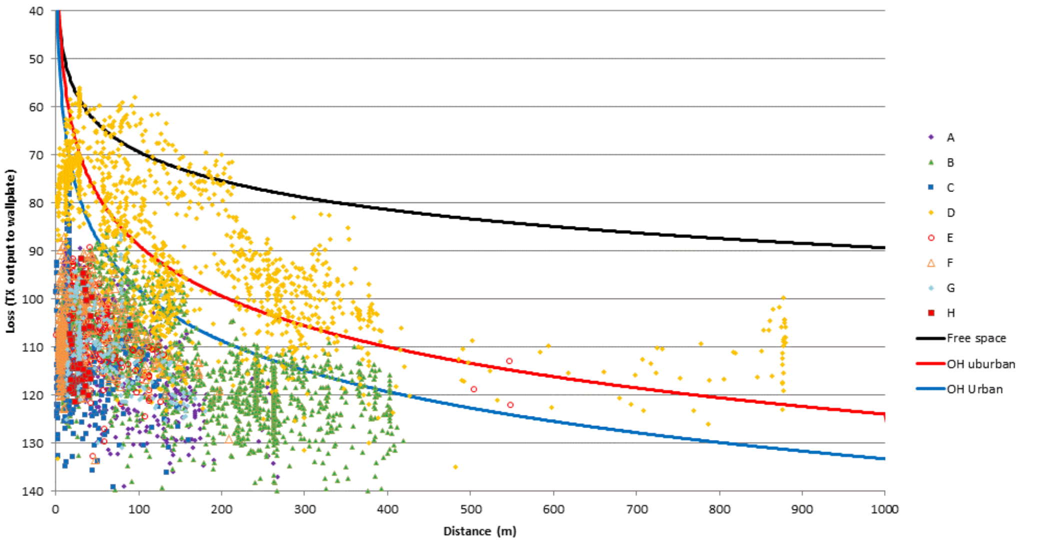


Figure 4.1: Coupling loss measurements

The figure below shows shorter paths in more detail.

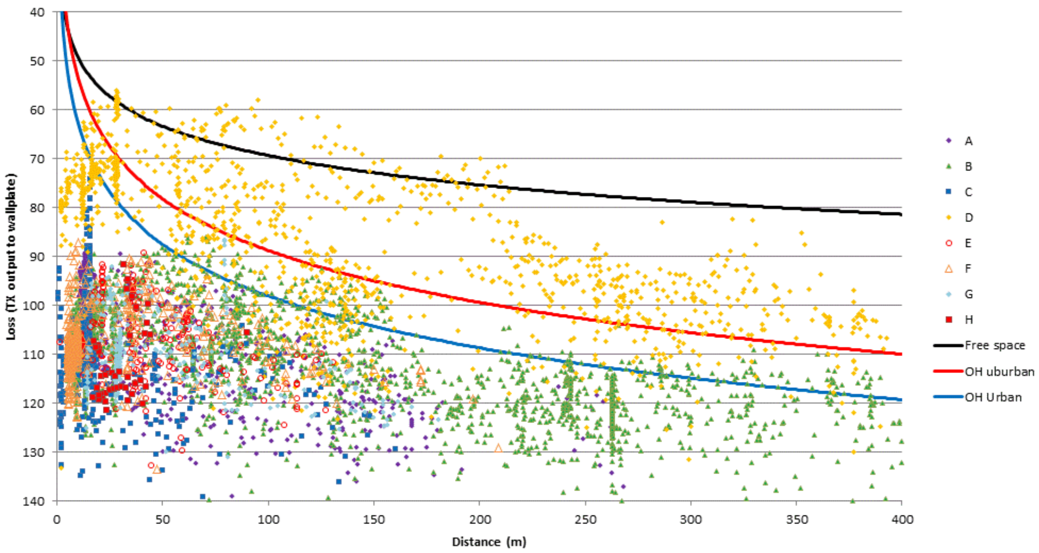


Figure 4.2: : Coupling loss measurements (detail)

Recalling that excursion of up to 9dB (representing the assumed DTT antenna gain) above an accurate model would be expected, the Hata 'urban' curve appears to offer a plausible model for all save one set of measurements.

That set ('D'), relates to a household with a (notionally) high-gain (horizontally-polarised) Yagi receiving signals from the Rowridge transmitter 80km distant. The installation include an amplifier, and the house is located in an elevated position, with potential line of sight to point along the entire route explored.

The remainder of the installations were all un-amplified, and used small Yagis or log-periodic antennas directed at the local relay. As this relay operates in Group C/D, one would expect the antenna to exhibit reasonable gain at the test frequency. It seems that clutter loss causes the signal to be lost in the noise beyond around 150-200m in most cases.

On the basis of these measurements, the Hata ‘suburban’ model has been used in most of the current modelling, but it would seem appropriate to make some comparisons using a free-space model.

3.1 Aerial system performance

In an unamplified installation, the interference potential of LTE handsets is largely determined by the ratio between the wanted and interfering signal, rather than the absolute power of the latter. It is therefore important to be able to predict the wanted DTT signal level.

In modelling, both in this study and in UKPM predictions generally, an aerial system gain of 7dBd is assumed (10dBd aerial gain and 3dB feeder loss); in previous surveys, it has been found that this value is seldom realised in practice, with the majority of installations showing a significantly lower gain.

The present measurements have not been intended to measure the absolute gain of domestic aerials, but an indication of performance can be obtained by comparing UKPM predictions with the voltage measured at the wall-plate at each property. The two figures can be used to determine the gain the aerial system would exhibit if the UKPM prediction were precise at that specific location. The results are tabulated below.

Table 4.1: Measured DTT signal level and implied aerial gain

Location	UKPM pixel	Service	Predicted field	Measured voltage	Implied system gain
A	TQ311062	WHH 60	101.4 dBµV/m	75.4 dBµV	-8.7 dBi
B	TQ311062	WHH 60	101.4 dBµV/m	80.4 dBµV	-3.7 dBi
C	TQ310061	WHH 60	101.0 dBµV/m	78.4 dBµV	-5.3 dBi
D	TQ309067	ROW 28	70.4 dBµV/m	66.9 dBµV	+10.8 dBi
E	TQ314064	WHH 60	102.3 dBµV/m	71.1 dBµV	-13.9 dBi
F	TQ312065	WHH 60	101.7 dBµV/m	74.9 dBµV	-9.5 dBi
G	TQ311062	WHH 60	52.3 dBµV/m	56.2 dBµV	+6.8 dBi
H	TQ311062	WHH 60	101.4 dBµV/m	51.9 dBµV	--32.2 dBi

4 RESULTS - COUPLING FROM INDOOR HANDSETS

It is increasingly the case that cellular user terminals are used seamlessly both outside and inside the home, so the possibility of interference coupled to a rooftop antenna from an indoor handset is important.

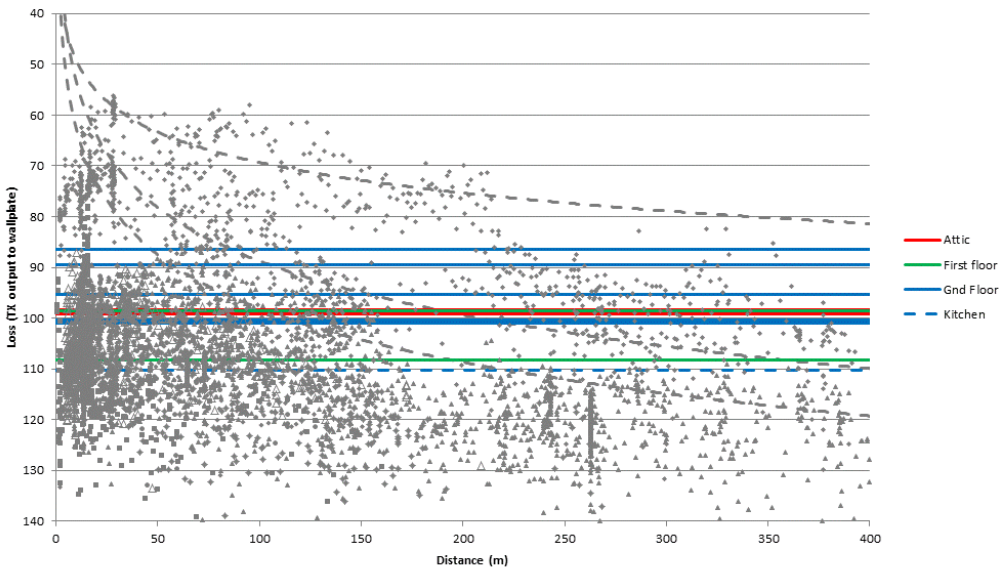
It might be expected that coupling on such paths would exhibit greater attenuation than for the outdoor case due to the loss through ceilings walls and roof (and perhaps due to the radiation pattern of the antenna). The coupling loss measurements were therefore expanded to determine if this was the case.

In most of the houses surveyed, a measurement run was carried out moving the transmitter throughout the room where the wall-plate was situated (invariably the living room, on the ground floor at the front of the house).

Loss values (TX antenna connector to wall-plate) of 100.9 - 86.5 dB were measured from living rooms. The lowest loss was measured in the house (H) with an anomalously low DTT signal perhaps suggesting a degraded downlead

The loss to the two attic rooms was found to be in the middle of the range, despite the proximity of the test transmitter to the rooftop aerial.

Figure 5.1 summaries the result of the coupling loss measurements, superimposed on the outdoor loss plot of Figure 4.2.



. Figure 5.1: Coupling loss from indoor transmitter to rooftop antenna.

5 RESULTS - INDOOR RECEIVE AERIALS

Tests have been made to understand the degree of coupling likely to be experienced between indoor UEs and indoor aerials.

Three domestic indoor TV aerials were purchased from a high street retailer. One was a simple unamplified loop. The other two aerials included amplifiers – one a fixed gain ('38dB gain') amplifier in a small 'flat-plate' package, the other integrated with a loop antenna similar to the amplified version (but integrated with a 'rabbit-ears' antenna for VHF radio and DAB). The larger antenna had a variable gain control offering 'up to 45dB' gain. This was set to a position at ¾ of the full travel of the control[1].

Figure 4.1: The indoor antennas tested in the study

Each of the antennas was placed on a bookshelf close to both the TV, adjacent to an external wall facing the transmitter, and close to a window (the transmitter is not line-of-sight, and the window is not in the direction of the transmitter when seen from the antenna position). Table 4.1 records the signal recorded from each aerial, compared with that from the wall-plate, and the signal characteristics reported by the DTT receiver.

[1] This was the point at which no further improvement in signal quality reported by the DTT receiver wa obtained.

Table 4.1: terminated voltages (75Ω) measured at receiver input

	Wall-plate	Unamplified	Small amplified	Large amplified
Voltage	75.4 dBµV	48.9 dBµV	57.4 dBµV	69.4 dBµV
Difference		-26.5 dB	-18.0 dB	-6.0 dB
'signal strength'	100%	90%	95%	100%
'Quality'	100%	100%	100%	100%

For each aerial, the test transmitter was then walked around rooms throughout the house, following a random pattern in each, but exploring the floor area fairly evenly. The results are tabulated below.

Table 4.2: Coupling from indoor TX to indoor aerial (dB worse than coupling to rooftop aerial)

	Unamplified	'Small' amplified	'Big' amplified
Living room	14.6	36.3	46.2
Kitchen	9.7	34.1	48.2
Back bedroom	4.9	20.2	41.2
Front bedroom	13.1	17.4	40.7
Attic	5.4	23.6	34.7

In all cases, the coupling loss was lower than for the rooftop aerial, and dramatically so in the amplified cases.

The most significant problem is likely to arise with amplified aerials, however; For both models of amplified aerial it was found that operating the transmitter in the same room caused picture breakup or loss. This was relatively modest with the smaller aerial, but complete loss of signal occurred throughout the room with the larger model. Some reception could be restored by reducing the gain to near the minimum position, but the signal was then prone to intermittent 'pixellation' or freezing, even in the absence of interference. No issues were noted with the unamplified device.

6 SUMMARY CONCLUSIONS

Measurements have been made of the coupling loss between a 700 MHz handheld transmitter and DTT receive aerials. No attempt has been made to separate propagation effects from those relating to the quality of the receive aerial system, so the resulting statistics simply represent the loss between the input to the transmit antenna and the DTT receiver input.

- In an area of strong DTT signals, the majority of aerial systems show substantially less gain than the 7dBd assumed in the UKPM. This is in line with earlier studies.
- Measurements made to all but one of the installations tested suggested that the Hata 'urban' model would be a reasonable fit to the envelope of the data (i.e. would represent a worst-case situation). The outlier, which was an amplified Group A installation, showed significantly lower (20dB) coupling loss. Such installations might be quite typical in fringe areas.
- From the limited data currently available, the use of the Hata 'urban' model in the associated modelling seems reasonably conservative.
- The coupling loss from an indoor transmitter to the rooftop antenna has also been measured in most of the properties surveyed. The greatest degree of coupling was found for transmitters in the same room as the DTT receiver and for attic rooms close to the rooftop aerial.
- The coupling between indoor transmitters and indoor DTT aerials has been investigated. As might be expected, the DTT signal is between 6-26dB lower than from a rooftop aerial (depending on the degree of amplification offered by the indoor antenna), and the coupling loss from the indoor transmitter much lower (typically by 10-40dB). These factors would result in a severe loss of available protection ratio, but the greatest issue may be that of amplifier overload.

It would seem worthwhile to extend the present measurements to cover an area of significantly lower DTT field strength.

A ANNEX A: MEASUREMENT EQUIPMENT

A.1 Transmitter

A transmitter is required that will operate at 702 MHz and is capable of being modulated in some fashion with GSP data. No commercially available radio transceivers (i.e. walkie talkies) operate at this frequency for obvious reasons.

Consideration was given to the hire or purchase of an analogue (FM) radio microphone; a belt-mounted device, as used with a tie-clip microphone would be very suitable, and professional devices are available that will tune to the required frequency. It would be possible to use audio frequency shift keying to modulate the transmitter with GPS data without modifying the device. Unfortunately., such devices typically cost over £2,000 and it proved difficult to hire one under suitably flexible terms. It was therefore decided to construct a suitable low-power transmitter tailored to the task.

A suitable IC was identified, intended for use as an analogue TV modulator (to allow VCRs or CCTV cameras to be connected to sets with no separate video input). This device includes a PLL-controlled oscillator capable of tuning across the UHF band in 250 kHz steps, controlled by an I2C serial bus.

As the device is intended for TV use, only amplitude modulation[2] is catered for; for measurement purposes, a fixed amplitude output is preferred, and a modification was therefore made to allow for frequency modulation. This involved injecting audio into the phase locked loop (at pin 14) of the synthesiser - if the audio frequency is above the corner of the low pass loop filter, the modulation will appear on the synthesiser output.

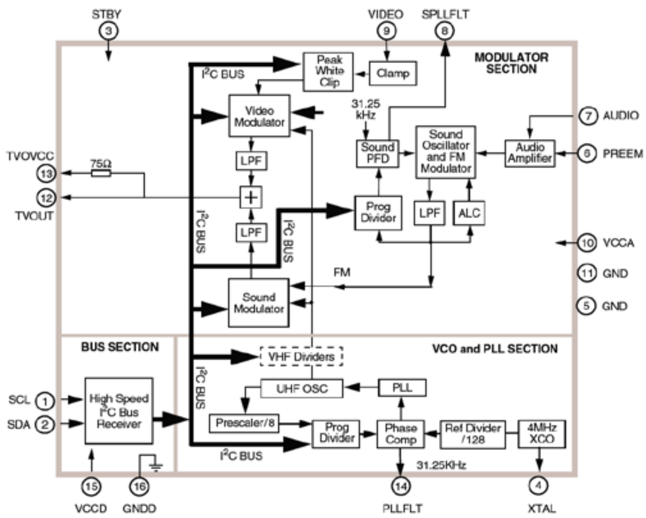


Figure A1: The MC44BC374T modulator IC (Freescale Semiconductor, Inc)

[2] The FM sound is implemented as a subcarrier on the video output

The output of the synthesiser is at a level of -30 dBm, and cascaded, pre-packaged amplifiers (Mini Circuits types ZFL1000 and ZHL3010+) are used to raise the power to a maximum of around 24dBm. The first amplifier has a variable gain and a preset resistor is used to set the overall gain to give the required output power. The power to the antenna is sampled with a directional coupler and the instantaneous value, in dBm, is added to the telemetry string.

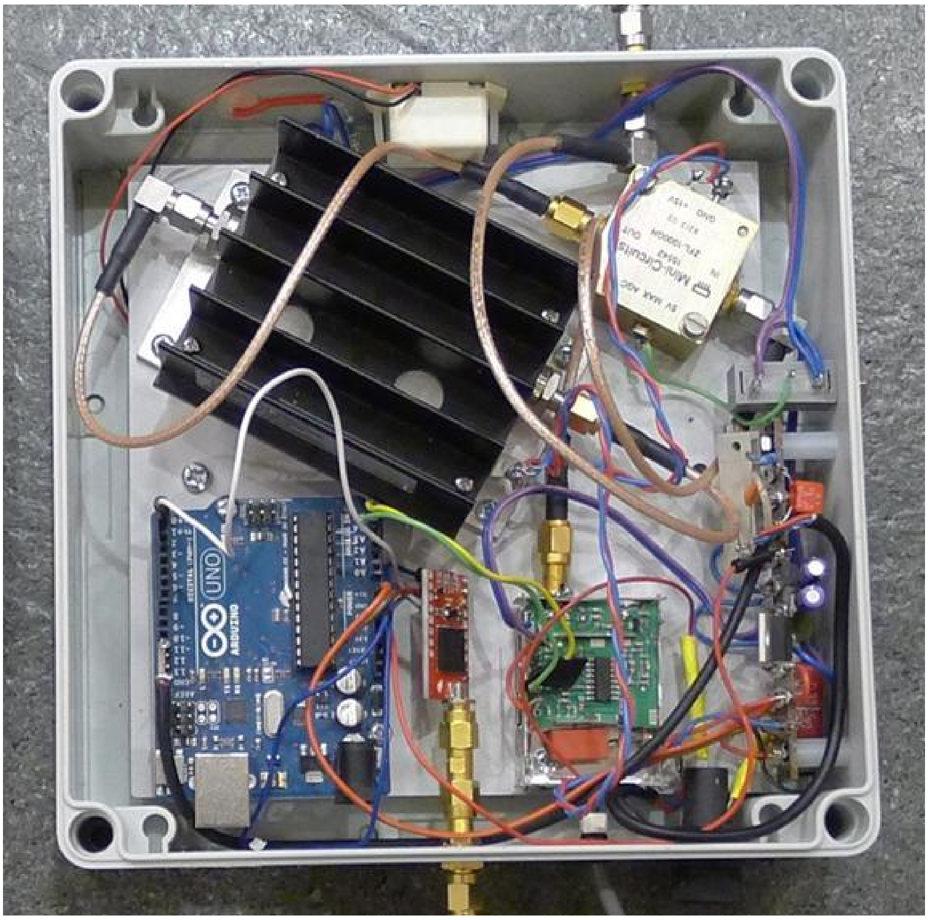


Figure A2: The transmitter unit

The synthesiser is set using an Arduino microcontroller. This was also used to read GPS data from a small receiver module, and to generate an audio frequency shift keyed (AFSK) signal carrying the GPS data and power output data at 1200 baud.

The unit is normally powered from a 3.2Ah sealed lead-acid battery (carried in a backpack on which the GPS antenna is mounted) which provides around 2 hrs of operating time.

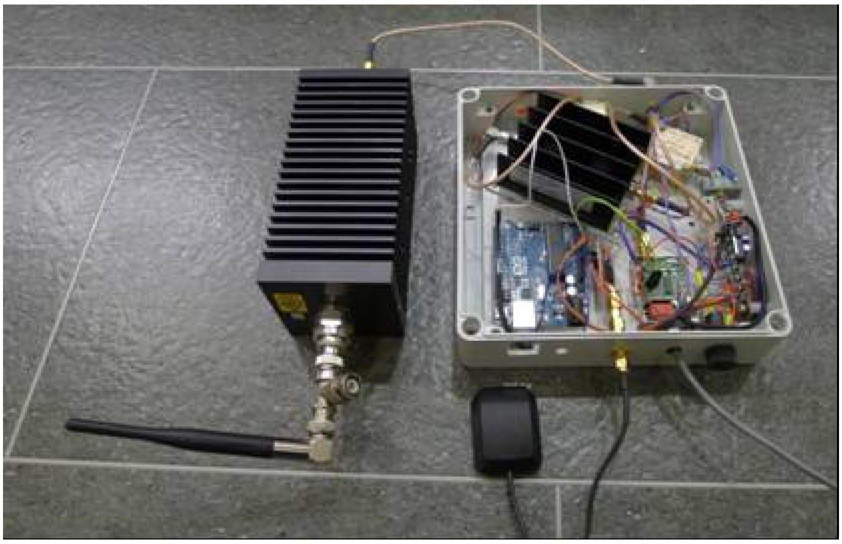


Figure A3: The transmitter with GPS antenna and load for testing

A.2 Antenna

The requirement for the transmit antenna was simply that it should have a predictable and stable gain and a broad pattern. A simple sleeve dipole was constructed from semi-rigid coaxial cable and tuned to give a return loss of some 15dB at 702 MHz.

Figure A4: The test antenna

A.3 Receiver and demodulator

The receiver is a Rohde and Schwarz EB200 unit, controlled from a laptop via an Ethernet connection. The Aegis Systems logging software polls the receiver every second and stores the received voltage.

The audio output of the receiver is fed to a second Arduino board, on which an AFSK demodulator has been implemented in software. This is used to recover the telemetry bitstream, with each received packet being subject to a cyclic redundancy check, before being passed over a USB connection to the logging computer. The position information is polled alongside the received voltage, and the two are time-stamped and saved to an XML file for processing and analysis.

B ANNEX B: MEASUREMENT LOCATIONS

B.1 House A

This house is in a row of Victorian terraced housing on a road running downhill to the south.

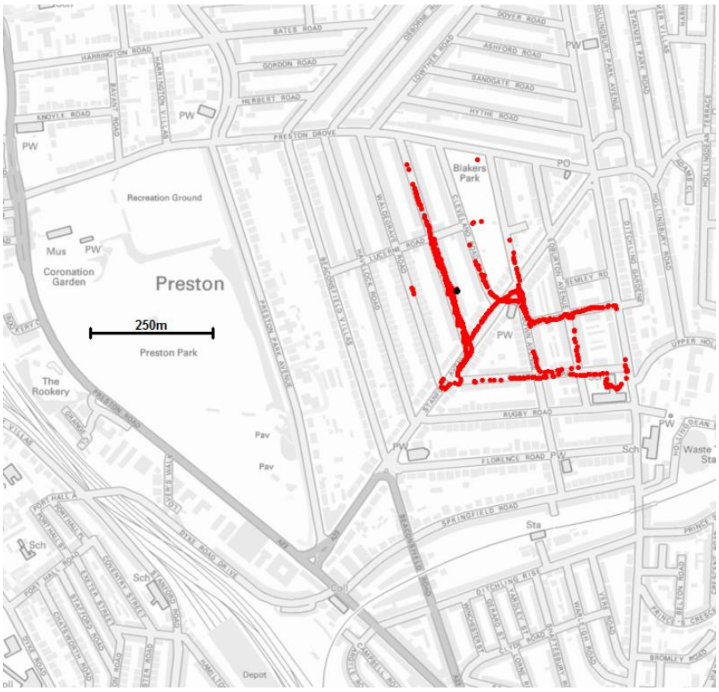
The rooftop DTT aerial is a Triax group C/D yagi, some 10years old but apparently in good condition, directed at Whitehawk Hill. The UHF aerial is diplexed with the output from a Band II FM aerial, and the signals split again at the wallplate. The voltage measured at the wallplate, 75.4dBμV, is 8.7dB less than would be expected on the basis of the UKPM prediction and an assumption of a 7dBd gain aerial system.

The portion of the measurement route for which the signal was above the noise level is shown below.

B.2 House B

Of identical construction to House A, on the other side of the road and 50m downhill. The aerial is a recently-installed log-periodic with no devices between the aerial and the wallplate. The voltage measured at the wallplate, 80.4 dBµV, is 3.7dB less than would be expected on the basis of the UKPM prediction and an assumption of a 7dBd gain aerial system.

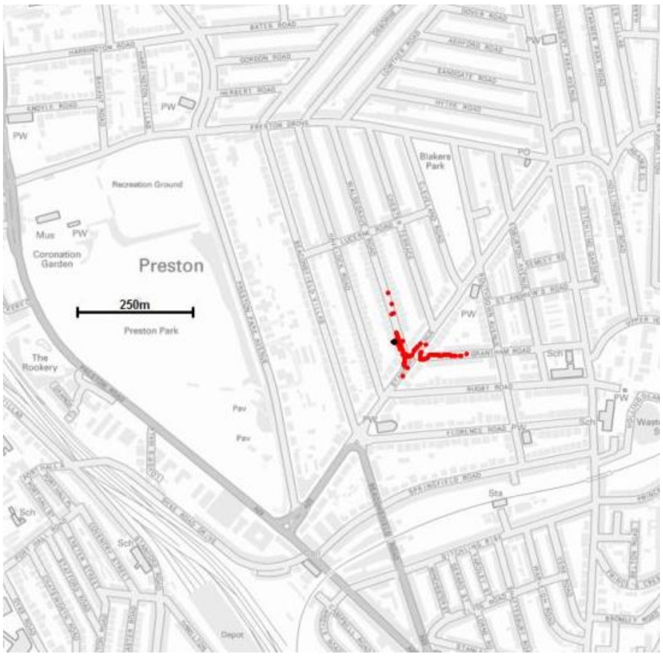
The portion of the measurement route for which the signal was above the noise level is shown below.



B.3 House C

Towards the bottom of another street of Victorian houses (semi-detached, in this case), the aerial is a ‘contract’ type, apparently in good condition and well-installed. The aerial is directed at Whitehawk Hill. The voltage measured at the wallplate, 78.4dBμV, is 5.3dB less than would be expected on the basis of the UKPM prediction and an assumption of a 7dBd gain aerial system.

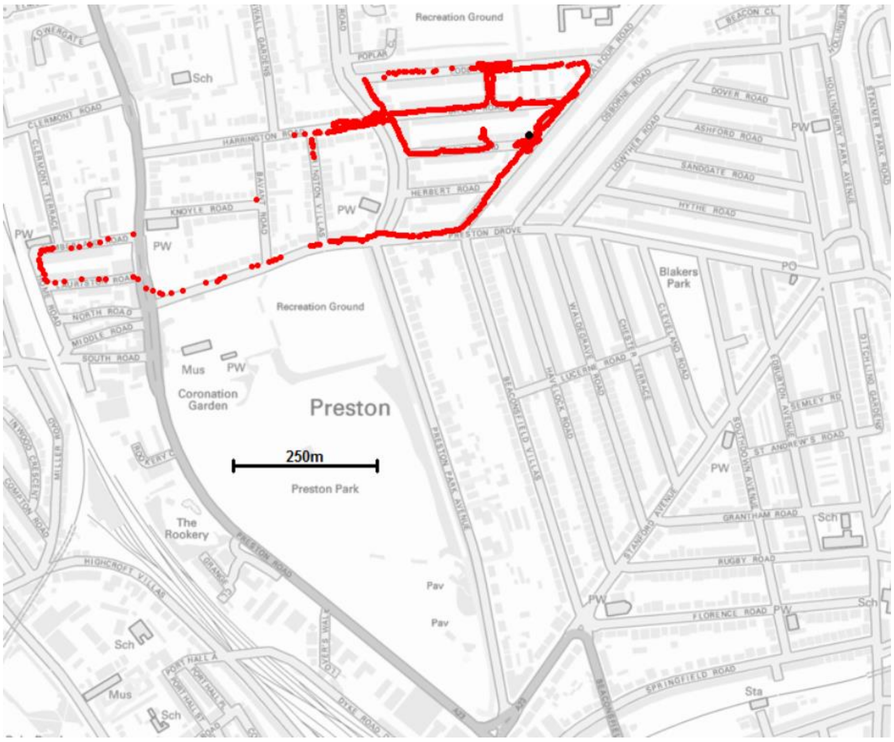
The portion of the measurement route for which the signal was above the noise level is shown below.



B.4 House D

Some 700m north of the previous locations, this corner property is screened from Whitehawk Hill by rising ground immediately to the East, and uses the Rowridge transmitter. The voltage measured at the wallplate is more than would be expected on the basis of the UKPM prediction and an assumption of a 7dBd gain aerial system. As can be seen in the photograph, the aerial ha a line-of-sight over a large area.

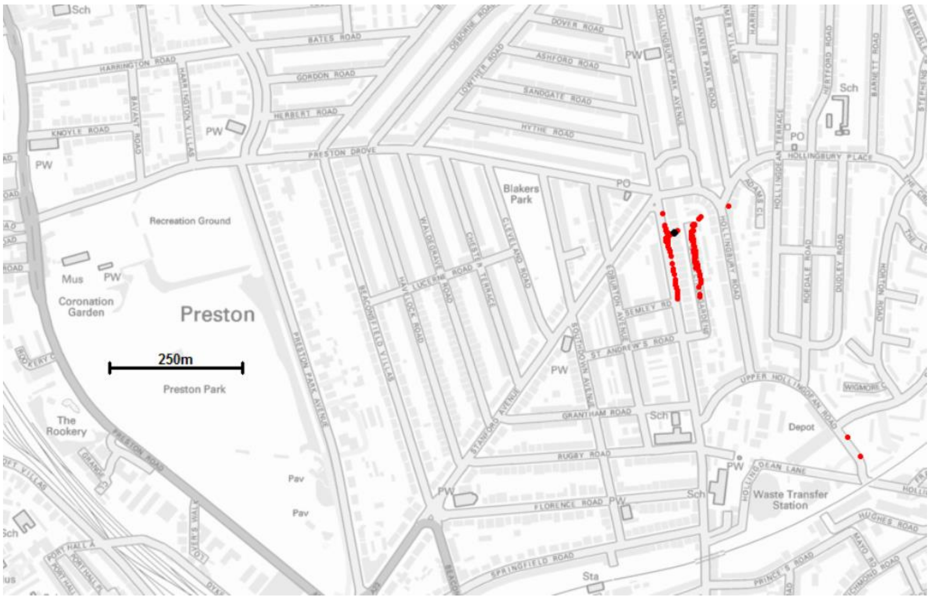
The portion of the measurement route for which the signal was above the noise level is shown below.



B.5 House E

This larger Victorian property is located on a ridge with a clear line-of-sight to the Whitehawk Hill relay. A small Yagi is aligned on that transmitter.

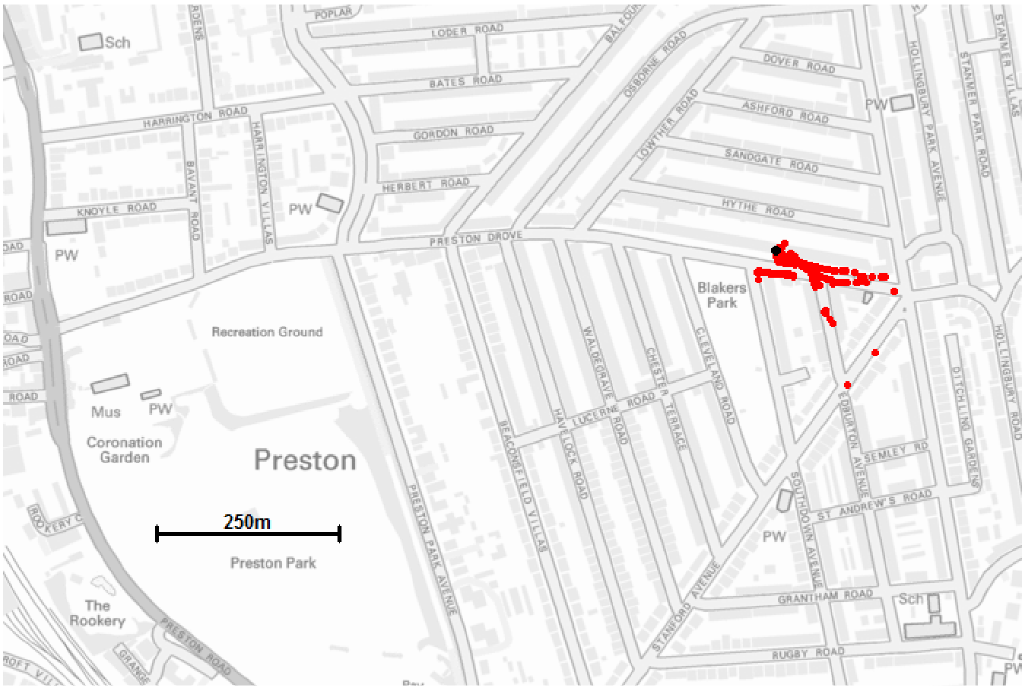
The portion of the measurement route for which the signal was above the noise level is shown below.



B.6 House F

Another large Victorian property, this house occupies an elevated position with clear views to the seafront some 2.5km distant and a line-of-sight to the Whitehawk Hill transmitter from the rooftop.

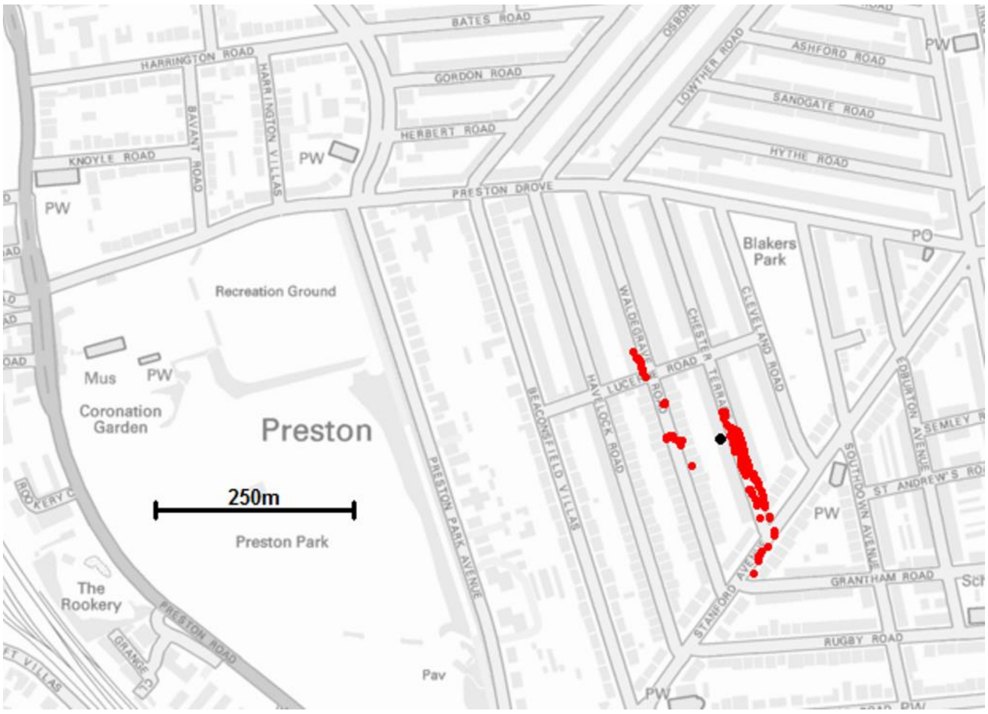
The portion of the measurement route for which the signal was above the noise level is shown below.



B.7 House G

This property has a good quality Group A Yagi oriented on Rowridge.

The portion of the measurement route for which the signal was above the noise level is shown below.



B.8 House H

Situated at the lower end of this inclined street, the property has a small yagi aligned with the Whitehawk Hill transmitter.

The aerial installation at this property seemed to be faulty (possibly caused by the unsupported downlead). Only a very small portion of the measurement route was above the noise level as is shown below.