Final Report

In-car Mobile Signal Attenuation Measurements

Final report

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1 Executive summary

This study was conducted by LS telcom UK and Siroda for Ofcom and involved using drive tests to measure the attenuation of mobile signals in different frequency bands caused by a representative range of different vehicle types. The key objective of the study was to better understand the effect of vehicle signal losses and improve in-vehicle road coverage predictions for mobile services.

The measurements involved the use of four high speed TSMW scanners attached to different antennas; one mounted on the roof of the vehicle, and three in different positions within the vehicle (dashboard, console and foot-well). All of the four scanner measurements were made at the same time to enable the level of attenuation caused by the vehicle in different locations within the vehicle to be compared.

Eight different vehicle types were used in the tests, and their attenuation was measured along the same 100km route through Berkshire which included a mix of urban, suburban and rural areas. This approach enabled mobile signal level data to be captured across all the mobile frequencies of interest; 800 MHz, 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz.

The key findings from this study were:

- Across all vehicles and frequencies, the weighted median in-vehicle penetration loss to the dashboard and console was 8.9 dB. The standard deviation of the variation in the penetration loss around this mean value was 5.6 dB.
- The attenuation in the dash position was the lowest for all tested vehicles and the attenuation in the footwell presented the highest.
- No clear dependency was found between frequency and the signal attenuation as demonstrated in Figure A. The maximum variation of attenuation across all vehicle types was less than 5.1 dB for console and dashboard positions as indicated in **Table. A**.

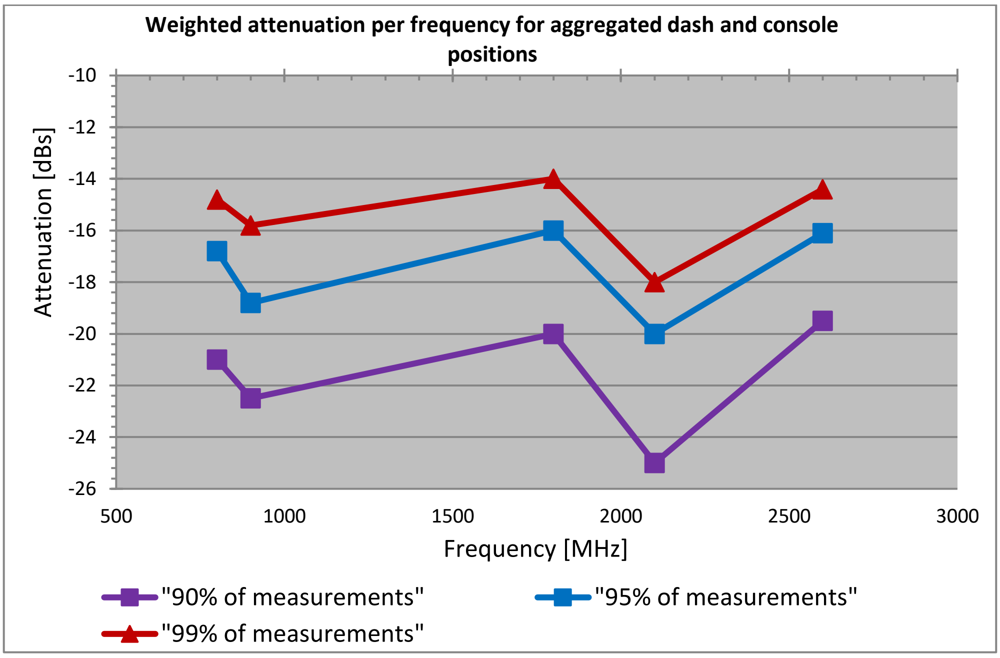


Figure A : Weighted attenuation per frequency for aggregated dash and control positions

Vehicle	Veh. A	Veh. B	Veh. C	Veh. D	Veh. E	Veh. F	Veh. G	Veh. H
Max Variance	3.8 dB	3.8 dB	3.5 dB	3 dB	3 dB	4.1 dB	5.1 dB	3.5 dB

Table. A: Max variance among measured frequencies for each vehicle

The weighted attenuation for various percentages of measurements seen across all vehicles and frequencies in the dash and console position is presented in **Table B** and their CDF graph below in Figure B.

% measurements	50%	90%	95%	99%
Attenuation	-8.9 dB	-16.3 dB	-18.5 dB	-23 dB

Table B: Weighted attenuation for various percentages of measurements

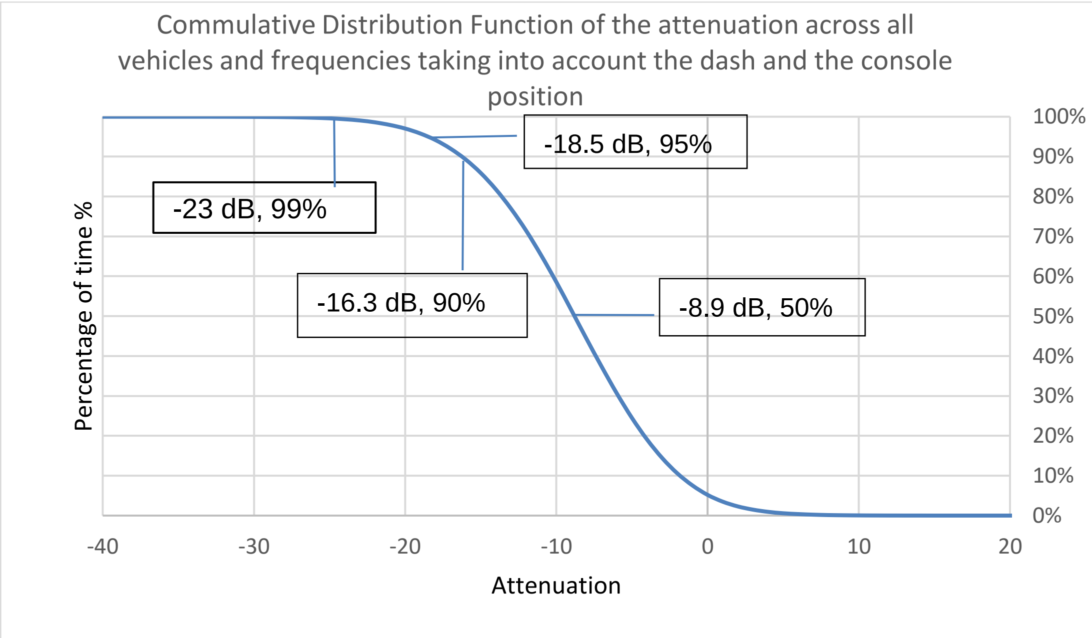


Figure. B: CDF of the signal attenuation across all vehicles and frequencies as measured in the dash and console positions

These values will help inform the effect of mobile signal losses into vehicles and improve in-vehicle road coverage predictions for mobile services.

2 Overview of the measurement campaign

2.1 In-vehicle mobile measurements will serve to enhance the customer experience

The use of mobile phones is ubiquitous and coverage of 4G cellular networks has expanded to almost 98% of UK premises outdoor[1]. The availability of the different services varies from location to location (urban and rural) however, there has been increasing levels of 4G coverage from all the operators in underserved areas. Ofcom regularly provides an update on the UK communications market via its Communications Market Report[1] which includes how both coverage and performance from across the mobile operators has changed from the previous year.

In addition, Ofcom has gathered increasingly more informative data on coverage and quality of experience for consumers including call quality of networks and performance of different types of handsets. Therefore, given the developments in the type of materials used to manufacture vehicles, Ofcom would like to better understand the signal attenuation inside vehicles for consumers using their mobile phones.

In the early years of the mobile industry, in-vehicle car phones were the most common type of handset available and these professionally installed equipment complete with fixed cradle, external antenna and dedicated handset design for the vehicle. As new mobile technology generations emerged, the in-vehicle installations evolved, with cradles mounted on the windscreen or centre console and some with or without external antennas. In parallel, the car body materials have changed, so too the interiors, windows and sunroofs each potentially causing a variation of the signal attenuation.

Furthermore, mobile coverage along the roads is critical for both public services (i.e. emergency services) and connectivity for consumers. In this study, we have examined the impact of mobile phone use in different types of vehicle and particularly the position of the handsets and the impact this has to user performance for a range of frequency bands.

The position of the handset in the vehicle is important because depending on where the handset is located could greatly reduce the quality of experience and lose service completely. Therefore, Ofcom would like to gain a better understanding of mobile phone usage on the road network and also develop a figure for in-vehicle signal attenuation that could be used for planning and prediction exercises of mobile networks for road coverage.

This study also demonstrates how not only the car body material impacts the signal attenuation but also the position of the handset in the vehicle. This may help Ofcom provide further consumer information to both the car industry and consumers themselves in the most suitable position for a mobile phone inside vehicles to ensure optimum quality of experience.

[1] Communications Market Report, Ofcom 2016

3 Measurement methodology description

In this section we describe our approach to the in-vehicle signal attenuation measurement that we have undertaken for Ofcom.

3.1 Equipment set up and approach to gathering data

Test Methodology

The signal strength measurements were undertaken using a Rohde and Schwarz Romes drive test system with TSMW receiver with BCH decode facility. The Romes modular software platform was considered the most appropriate tool conducting the network measurements given its suitability for conducting in-vehicle measurements. The platform provides coverage and performance measurements but for this project it was used in combination with a wireless communications scanner.

Figure 1: Romes System with TSMW

Figure 2: TSMW Rear with twin RF inputs

The R&S TSMW drive test scanner is a high-power platform for measurement of mobile radio networks. The TSMW contains two highly sensitive 20 MHz front ends for any input frequencies from 350 MHz to 4400 MHz, and a software-defined architecture offering performance and flexibility.

Calibration certificates are available as required. The twin inputs were configured independently using the Romes software, enabling simultaneous measurement of the internal and external signal levels.

We configured the test system as shown in the diagram below. The two RF inputs of the receiver were attached to four wideband antennas with ground planes, mounted externally at a central point on the vehicle roof, and internally in the centre console, footwell or dash. This was to ensure the internal and external signal levels could be measured simultaneously.

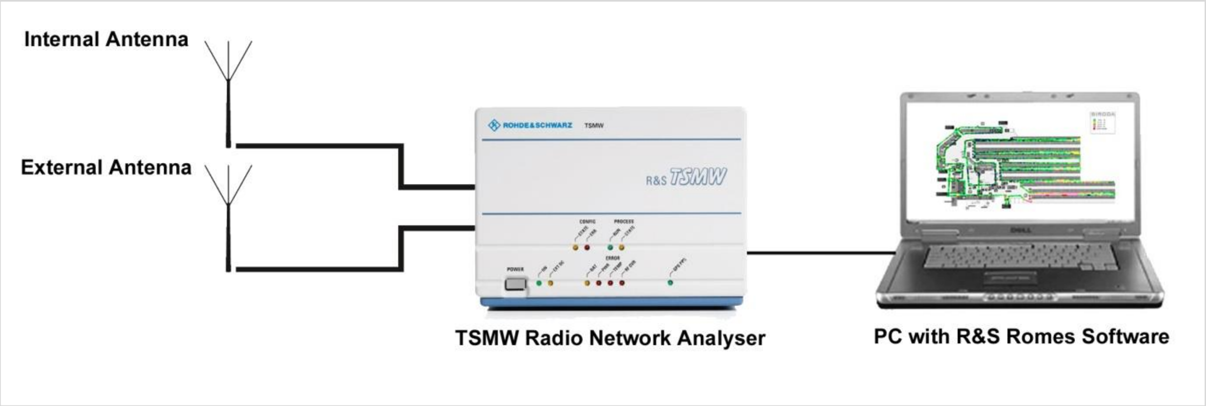


Figure 3: System Configuration

Figure 4: Broadband Test Antenna and Ground Plane

The image above shows how the measurement antenna was deployed in practice on the roof of the vehicle. This is a photo of the antenna used for measurements of the small car.

Figure 5: Dash mounted antenna position

Figure 6: Antenna position in the footwell

Figure 7: Antenna position in the central console of the vehicle

3.2 The implications for the choice of test route

The final test route was chosen based on existing drive measurements of the area which was known to have sufficient coverage across each of the mobile bands to be measured LTE 800, UMTS 900, UMTS 2100, LTE 1800 and LTE 2600 bands. Furthermore, the route ran through urban, suburban and rural environments, with a variety of road types to ensure the maximum variation of orientations could be captured.

The final area chosen was a route taking in both Reading and Newbury which ensured there would be sufficient 2600 MHz coverage to be measured as informed by the map shown in Figure 8. The route also included enough rural parts and orientations so that enough samples could be gathered to provide a statistically sound set of results.

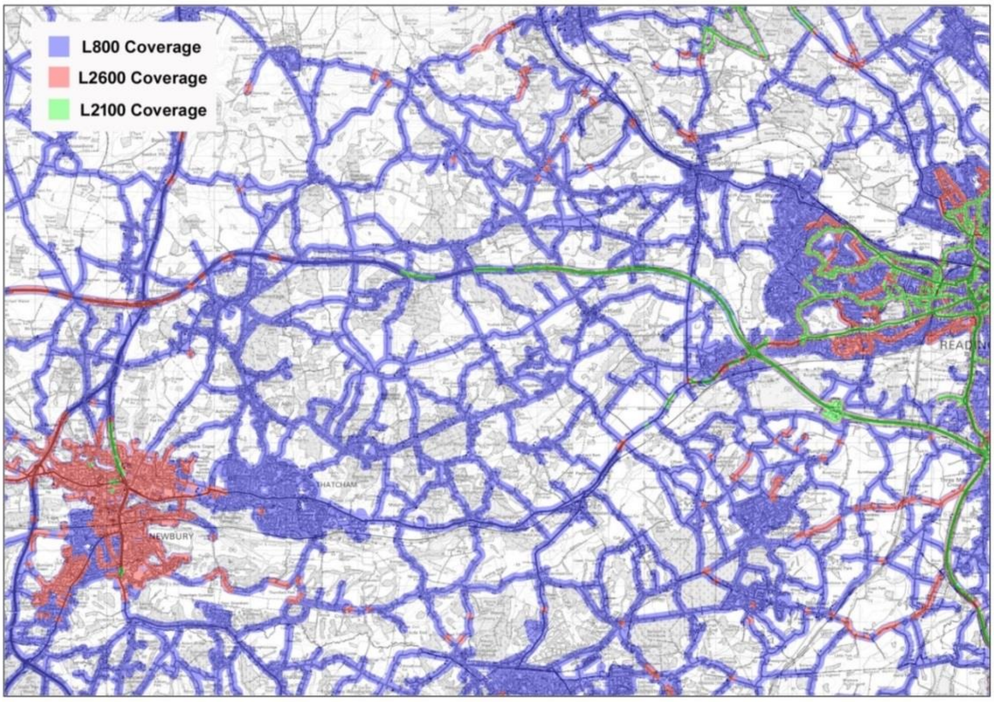


Figure 8: Map of existing mobile coverage in the Berkshire area

The positioning was provided by the integrated GPS receiver in the TSMW and one frequency in each band was measured. This resulted in a cycle time of approximately 400ms per measurement.

Data Processing

A MNC/Cell Id match was used to ensure the signal levels being compared in each band are from the same source otherwise the measurement would be invalid if one of the antennas was connected to different base station antenna. Results within 10dB of the minimum receiver sensitivity were discarded so too were measurements with extensive idle time when the vehicle was in traffic.

We have produced raw results for each test vehicle as georeferenced asci files which contain measurements for each band and antenna, and also processed to produce map overlays, distribution graphs and average/std deviation values for the vehicle tested.

3.3 Approach to undertaking in-vehicle signal attenuation measurements

The measurements were conducted by Siroda, who were responsible for supplying and setting up the equipment and ensuring sufficient data was gathered from the measurement campaigns of each of the vehicles. The set up required a consistent approach for conducting the tests and driving the same route to ensure the results were comparable.

We were able to source and test all the specific vehicle models required by Ofcom which included:

1. Vehicle A popular small car
2. Vehicle B popular small car
3. Vehicle C popular hybrid
4. Vehicle D popular executive style car
5. Vehicle E popular executive style car
6. Vehicle F popular van
7. Vehicle G popular SUV
8. Vehicle H fully electric

The in-vehicle measurements used two scanners so that the three internal and one external antenna positions could be measured at the same time. Bench testing was undertaken in each band to confirm there was no variation in performance between each receiver input.

The test set up was repeated for each vehicle using the antenna positions as suggested by Ofcom which included:

1. The car manufacturer installed handset cradle, if one is present, otherwise a windscreen mounted cradle;
2. The central console storage area (typical location a user may place the handset if they were to use Bluetooth handset);
3. Footwell area at the seat next to the driver's seat.

In practice, given the range of different interiors for each of the cars, the mounting positions chosen were dependent on a mix of convenience of attachment and alignment against the suggested positions.

The route was agreed with Ofcom to take into account urban, suburban and rural areas and to ensure a variety of received signal angles, which meant not too many long straight roads.

We shared the first set of raw measurement results with Ofcom after the first week of testing for one vehicle. This was to ensure the results gathered were as expected and the relevant main data captured (i.e. includes time, location and frequency details). It became apparent from Ofcom's feedback to the results that more samples were needed and the route extended.

It should be noted that the duration of the route is traffic dependent and when idle measurements are not used. Therefore, the balance of samples for each band varied depending on where the delays occur. For example, if in Reading, then proportionally, we gathered more 2600MHz readings and if out of town, then more 800MHz measurements were gathered.

Furthermore, the number of samples will also depend to an extent on the characteristics of the vehicle, as there needs to be a match between all 4 antenna measurements to get a result. In the following sections, it is explained how this these deviations were taken into account.

4 Key results from in-vehicle measurements

In this chapter, we present the key results from the in-vehicle measurements undertaken. This includes making comparisons between some of the results which show the signal level recorded for each of the positions and frequency bands and also the delta between the measurements at the rooftop and those inside the vehicle. We refer to this delta as the attenuation.

4.1 Presentation of results

The raw data was gathered from four antennas mounted to the vehicle. One antenna was placed on the rooftop and the other antennas in three designated positions inside the vehicle. The appropriate signal level measurement was taken for each frequency band and technology as shown below:

- RSCP in dBm for UMTS 900/2100 MHz
- RSRP in dBm for LTE 800/1800/2600 MHz

We present the results of the measurements from the three following positions inside the vehicle:

- Dash
- Console
- Footwell

We calculate the difference in signal level (RSSI attenuation and RSRP attenuation) by subtracting the signal level measured inside the vehicle from the signal level measured from the rooftop antenna. We then use this level to determine the range of signal levels for each position. We present the core high level results which show the mean, median and standard deviation of the measurements for each position in the vehicle and each band to make comparisons. For example, we can identify from the results how each of the vehicles compares in terms of attenuation for different frequency bands and the positions of the antennas in the vehicle.

4.1.1 Post processing analysis

Thousands of samples were gathered for each drive test across each of the frequency bands. This number of samples (ranging from 3,000 to 11,500 depending on the frequency) enabled us to plot the distribution of the signal level in each position for each vehicle and for each frequency.

However, given the processing of the large number of samples and the statistical variation that can be introduced we also calculated the median and standard deviation values. As it is shown in the dedicated results section of the document, the standard deviation calculated for each frequency was very similar (within 1-2 dBs).

A description of the post processing methodology to derive a generalised value of the signal attenuation is summarised below:

1. We calculated the delta between the antenna rooftop measurements and the antenna at each position in each vehicle for every frequency.
2. We calculated the impact of the frequency for each vehicle and position
3. We calculated the impact of each position across the vehicles
4. Based on the consistently poor results (highest attenuation in most cases) for the footwell this position was disregarded in the derivation of the final vehicle penetration loss.
5. We categorised each occurrence of the delta value for each position (console and dash) and each frequency for every car. For example, using a range of 10 dB to -42 dB in 1 dB steps we determined how many times each value was recorded. We then aggregated these values in a single table which provided a representative picture of the delta occurrences for each car.
6. We determined and applied a weighting of the attenuation based on the market share across all eight vehicles.
7. After applying the weighting factors, we added the weighted occurrences to produce the picture of all eight vehicles.
8. By producing the CDF of the results, we were able to calculate the attenuation of 50%, 90%, 95%, 99% of the measurements.

4.2 Signal attenuation results from each vehicle

The following sub-sections provide an overview of the results from the measurements of each vehicle. Each of the tables presents the mean attenuation for each frequency band and position in the vehicle. The objective of presenting these results was to identify particular trends in the attenuation levels between the vehicles, internal antenna positions and the frequency bands.

4.2.1 Vehicle A

This vehicle is one of the most popular small cars in the UK[2]. We tested the attenuation in a basic four door model and it can be seen from the pictures in the appendix the interior is not so cluttered. The interior is predominantly plastic material and the seats are cloth covered. In the table below we show a snapshot of all the results gathered for this vehicle i.e. all frequency bands, in all positions taking the mean, median and standard deviation.

Frequency	Position	Mean attenuation (dB)
L800	Dash	-6.5
	Console	-11.0
	Footwell	-17.2
U900	Dash	-7.8
	Console	-13.2
	Footwell	-20.3
L1800	Dash	-6.6
	Console	-10.6
	Footwell	-15.1
U2100	Dash	-7.5
	Console	-14.4
	Footwell	-19.9
L2600	Dash	-5.8
	Console	-11.1
	Footwell	-16.0

Table 1: Summary of mobile signal attenuation (mean) results for vehicle A

[2] This is according to new vehicle registrations for June 2017 from Society of Motor Manufacturers and Traders (SMMT)

We draw out the key observations from the results of vehicle A in the table below.

Vehicle	Position	Worst result		Best result	
		Mean attenuation (dB)	Frequency band	Mean attenuation (dB)	Frequency band
Vehicle A	Footwell	-20.3	900MHz	-15.1	1800 MHz
	Console	-14.4	2100 MHz	-10.6	1800 MHz
	Dash	-7.8	900 MHz	-5.8	2600 MHz

Table 2: Best and worst results for attenuation and associated frequency band

The attenuation level at the dash is lowest across all positions and is quite similar for all bands with max 2 dB difference between bands.

4.2.2 Vehicle B

Vehicle B is another highly popular small car in the UK. We tested the attenuation in a basic four door model and it can be seen from the pictures in the appendix the interior is not so cluttered. The interior is predominantly plastic material and the seats are cloth covered. In the table below we show a snapshot of all the results gathered for this vehicle i.e. all frequency bands, in all positions taking the mean, median and standard deviation.

Frequency	Position	Mean attenuation (dB)
L800	Dash	-6.9
	Console	-9.4
	Footwell	-16.3
U900	Dash	-6.8
	Console	-10.7
	Footwell	-15.8
L1800	Dash	-7.5
	Console	-9.3
	Footwell	-14.1
U2100	Dash	-6.7
	Console	-13.1
	Footwell	-16.6
L2600	Dash	-5.2
	Console	-10.3
	Footwell	-12.8

Table 3: Summary of mobile signal attenuation results for vehicle B

We draw out the key observations from the results of vehicle B in the table below.

Vehicle	Position	Worst result		Best result	
Vehicle B		Mean attenuation (dB)	Frequency band	Mean attenuation (dB)	Frequency band
	Footwell	-16.6	2100 MHz	-12.8	2600 MHz
	Console	-13.1	2100 MHz	-9.3	1800 MHz
	Dash	-7.5	1800 MHz	-5.2	2600 MHz

Table 4: Best and worst results for attenuation and associated frequency band

The attenuation level is lowest at the dash and is quite similar for all bands with max 2.3 dB difference between bands

4.2.3 Vehicle C

Vehicle C is one of the first hybrid vehicles developed. It is a popular medium size family car but it is also used for private passenger hire. We tested the attenuation in a basic four door model and it can be seen from the pictures in appendix the interior is not so cluttered. The interior is predominantly plastic material and the seats are cloth covered. In the table below we show a snapshot of all the results gathered for this vehicle i.e. all frequency bands, in all positions taking the mean, median and standard deviation.

Frequency	Position	Mean attenuation (dB)
L800	Dash	-6.2
	Console	-10.6
	Footwell	-17.3
U900	Dash	-7.4
	Console	-11.7
	Footwell	-17.3
L1800	Dash	-4.6
	Console	-8.6
	Footwell	-13.1
U2100	Dash	-5.9
	Console	-11.7
	Footwell	-17.2
L2600	Dash	-3.9
	Console	-9.3
	Footwell	-12.9

Table 5: Summary of mobile signal attenuation results for vehicle C

We draw out the key observations from the results of vehicle C in the table below

Vehicle	Position	Worst result		Best result	
Vehicle C		Mean attenuation (dB)	Frequency band	Mean attenuation (dB)	Frequency band
	Footwell	-17.3	800/900 MHz	-12.9	2600 MHz
	Console	-11.7	900/2100 MHz	-8.6	1800 MHz
	Dash	-6.2	800 MHz	-3.9	2600 MHz

Table 6: Best and worst results for attenuation and associated frequency band

The attenuation level at the dash is lowest and is quite similar for all bands with max 3.5 dB difference between bands.

4.2.4 Vehicle D

Vehicle D is one of the most popular executive cars in the UK. We tested the attenuation in a four door model and it can be seen from the pictures in appendix the interior is not so cluttered. The interior is largely plastic material and the seats are leather. In the table below we show a snapshot of all the results gathered for this vehicle i.e. all frequency bands, in all positions taking the mean, median and standard deviation.

Frequency	Position	Mean attenuation (dB)
L800	Dash	-5.2
	Console	-11.6
	Footwell	-18.3
U900	Dash	-6.0
	Console	-10.5
	Footwell	-19.1
L1800	Dash	-7.2
	Console	-9.7
	Footwell	-15.6
U2100	Dash	-7.6
	Console	-12.0
	Footwell	-18.8
L2600	Dash	-4.6
	Console	-10.2
	Footwell	-14.2

Table 7: Summary of mobile signal attenuation results for vehicle D

We draw out the key observations from the results of vehicle D in the table below

Vehicle	Position	Worst result		Best result	
Vehicle D		Mean attenuation (dB)	Frequency band	Mean attenuation (dB)	Frequency band
	Footwell	-19.1	2100 MHz	-14.2	2600 MHz
	Console	-12.0	2100 MHz	-9.7	1800 MHz
	Dash	-7.6	2100 MHz	-4.6	2600 MHz

Table 8: Best and worst results for attenuation and associated frequency band

The attenuation level at the dash is lowest and is quite similar for all bands with max 3 dB difference between bands.

4.2.5 Vehicle E

Vehicle E is another one of the most popular executive cars in the UK. We tested the attenuation in a four door model and it can be seen from the pictures in appendix the interior is not so cluttered. The interior is largely plastic material and the seats are leather. In the table below we show a snapshot of all the results gathered for this vehicle i.e. all frequency bands, in all positions taking the mean, median and standard deviation.

Frequency	Position	Mean attenuation (dB)
L800	Dash	-6.0
	Console	-10.5
	Footwell	-18.7
U900	Dash	-6.1
	Console	-11.7
	Footwell	-20.6
L1800	Dash	-5.9
	Console	-9.5
	Footwell	-17.8
U2100	Dash	-5.7
	Console	-12.4
	Footwell	-20.6
L2600	Dash	-4.8
	Console	-9.4
	Footwell	-15.2

Table 9: Summary of mobile signal attenuation results for vehicle E

We draw out the key observations from the results of vehicle E in the table below.

Vehicle	Position	Worst result		Best result	
Vehicle E		Mean attenuation (dB)	Frequency band	Mean attenuation (dB)	Frequency band
	Footwell	-20.6	2100 MHz	-15.2	2600 MHz
	Console	-12.4	2100 MHz	-9.4	2600 MHz
	Dash	-6.0	800 MHz	-4.8	2600 MHz

Table 10: Best and worst results for attenuation and associated frequency band

The attenuation level at the dash is lowest and is very similar for all bands within around max 1.3 dB.

4.2.6 Vehicle F

Vehicle F is a van and one of the most popular commercial vehicles in the UK. We tested the attenuation in a standard model and it can be seen from the pictures in appendix the interior. The interior shows three seats in the main cabin and largely plastic material and the seats are cloth covered. In the table below we show a snapshot of all the results gathered for this vehicle i.e. all frequency bands, in all positions taking the mean, median and standard deviation.

Frequency	Position	Mean attenuation (dB)
L800	Dash	-8.3
	Console	-15.1
	Footwell	-16.8
U900	Dash	-10.1
	Console	-14.7
	Footwell	-20.7
L1800	Dash	-8.8
	Console	-13.3
	Footwell	-16.2
U2100	Dash	-8.9
	Console	-17.1
	Footwell	-19.6
L2600	Dash	-5.9
	Console	-12.7
	Footwell	-13.4

Table 11: Summary of mobile signal attenuation results for vehicle F

We draw out the key observations from the results of vehicle F in the table below.

Vehicle	Position	Worst result		Best result	
Vehicle F		Mean attenuation (dB)	Frequency band	Mean attenuation (dB)	Frequency band
	Footwell	-20.7	900 MHz	-13.4	2600 MHz
	Console	-17.1	2100 MHz	-12.7	2600 MHz
	Dash	-10.1	900 MHz	-5.9	2600 MHz

Table 12: Best and worst results for attenuation and associated frequency band

The attenuation level at the dash is lowest and is very similar for all bands within around max 4.2 dB

4.2.7 Vehicle G

Vehicle G is a popular SUV in the UK. We tested the attenuation in a standard five door model and it can be seen from the pictures in appendix the interior is spacious cabin with not too much clutter. The interior is largely plastic material and the seats are cloth covered. In the table below we show a snapshot of all the results gathered for this vehicle i.e. all frequency bands, in all positions taking the mean, median and standard deviation. Note this vehicle had a large panoramic roof.

Frequency	Position	Mean attenuation (dB)
L800	Dash	-2.6
	Console	-9.3
	Footwell	-14.1
U900	Dash	-4.4
	Console	-10.7
	Footwell	-16.8
L1800	Dash	-3.1
	Console	-8.0
	Footwell	-13.0
U2100	Dash	-5.7
	Console	-13.1
	Footwell	-16.5
L2600	Dash	-3.5
	Console	-9.0
	Footwell	-12.1

Table 13: Summary of mobile signal attenuation results for vehicle G

We draw out the key observations from the results of vehicle G in the table below.

Vehicle	Position	Worst result		Best result	
Vehicle G		Mean attenuation (dB)	Frequency band	Mean attenuation (dB)	Frequency band
	Footwell	-16.8	2100 MHz	-12.1	2600 MHz
	Console	-13.1	2100 MHz	-8.0	1800 MHz
	Dash	-5.7	2100 MHz	-2.6	800 MHz

Table 14: Best and worst results for attenuation and associated frequency band

Overall the SUV had the lowest attenuation compared the other vehicles and the attenuation level at the dash is lowest and is very similar for all bands within around max 1.8 dB.

4.2.8 Vehicle H

Vehicle H is a fully electric vehicle with a carbon fibre body thus potentially improving the level of signal penetration into the vehicle. We tested the attenuation in a four door model and it can be seen from the pictures in appendix the interior. The interior is largely plastic material and the seats are cloth covered. In the table below we show a snapshot of all the results gathered for this vehicle i.e. all frequency bands, in all positions taking the mean, median and standard deviation.

Frequency	Position	Mean attenuation (dB)
L800	Dash	-7.6
	Console	-11.6
	Footwell	-15.8
U900	Dash	-6.6
	Console	-10.1
	Footwell	-16.1
L1800	Dash	-7.8
	Console	-8.1
	Footwell	-14.1
U2100	Dash	-8.7
	Console	-10.5
	Footwell	-17.0
L2600	Dash	-8.4
	Console	-8.1
	Footwell	-12.0

Table 15: Summary of mobile signal attenuation results for vehicle H

We draw out the key observations from the results of vehicle H in the table below.

<table>
<tr><th>Vehicle</th><th rowspan="2">Position</th><th colspan="2">Worst result</th><th colspan="2">Best result</th></tr>
<tr><td rowspan="4">Vehicle H</td><th>Mean attenuation (dB)</th><th>Frequency band</th><th>Mean attenuation (dB)</th><th>Frequency band</th></tr>
<tr><td>Footwell</td><td>-17.0</td><td>2100 MHz</td><td>-12.0</td><td>2600 MHz</td></tr>
<tr><td>Console</td><td>-11.6</td><td>800 MHz</td><td>-8.1</td><td>1800 / 2600 MHz</td></tr>
<tr><td>Dash</td><td>-8.7</td><td>2100 MHz</td><td>-6.6</td><td>900 MHz</td></tr>
</table>

Table 16: Best and worst results for attenuation and associated frequency band

The attenuation level at the dash is lowest and is very similar for all bands within around max 2.1 dB.

5 Detailed findings

The objective of this study was to understand the effects of mobile signal attenuation across a range of different vehicle models. The impact of the signal attenuation that occurs can greatly impact the service quality experienced by consumers. For example, in an area with already poor coverage the impact of an additional 5-6 dB signal loss when trying to use a mobile phone can result in a complete loss of service. This means that the poor mobile experience is enhanced due to the attenuation level within the vehicle.

In this summary, we have considered the results from each of the vehicles tested and determined any particular pattern or trend emerging. In particular, we examined differences between the positions of the antenna in each of the vehicles and trends against the frequency bands, to identify if one band performs better than another or if one position is more optimum than another in terms of limiting attenuation.

Furthermore, we determined how the impact of the vehicle interior might affect the mobile signals.

- For every car and every frequency band the pattern largely holds such that the attenuation:
  - for the footwell is highest (ranging from -12 dB to -20 dB),
  - followed by the console (ranging from -8 dB to -17 dB)
  - then the dash (ranging from -2 dB to -10 dB) has the lowest attenuation
- Overall vehicle G had the lowest attenuation compared the other vehicles. The vehicle with the highest overall attenuation across positions and frequency bands was the vehicle F which is the van with fewer windows compared to the cars.

Roof and dash position:

- The lowest overall attenuation is -2.6 dB for vehicle G over 800 MHz which is the only vehicle that has a glass roof. Followed by vehicle C with -3.9 dB over 2600 MHz
- The highest overall attenuation is -8.7 dB for vehicle H over 2100 MHz and -10.1 dB for the van vehicle F over 900 MHz

Roof and console position:

- The lowest attenuation is -8 dB for vehicle G over 1800 MHz, followed by vehicle H with -8.1 dB over 1800 MHz and 2600 MHz
- The highest attenuation is -14.4 dB for the car vehicle A over 2100 MHz and -17.1 dB for the van vehicle F over 2100 MHz

Roof and footwell position:

- The lowest attenuation is -12 dB for van vehicle H over 2600 MHz and -12 dB for the car vehicle H over 2600 MHz
- The highest attenuation is -20.6 for the car vehicle E and -20.7 dB for the van vehicle F over 900 MHz

For all in-car positions we found the following trend:

Average:

The average value of the received signal level for the dash, console and footwell values is similar to the values shown by the console position: between -69.7 dBm for vehicle C (900 MHz) and -103.9 dBm for vehicle A (2600 MHz)

Standard deviation:

The standard deviation of the attenuation values of dash, console and footwell values is between 10.3 dB for footwell and vehicle B (800 MHz) and 16.4 dB for console and vehicle H (2100 MHz).

The plots in the figure below show for each vehicle and antenna position the RSCP and RSRP per frequency band relative to the rooftop antenna. We are able to compare for each vehicle the signal level received inside and any trends that emerge.

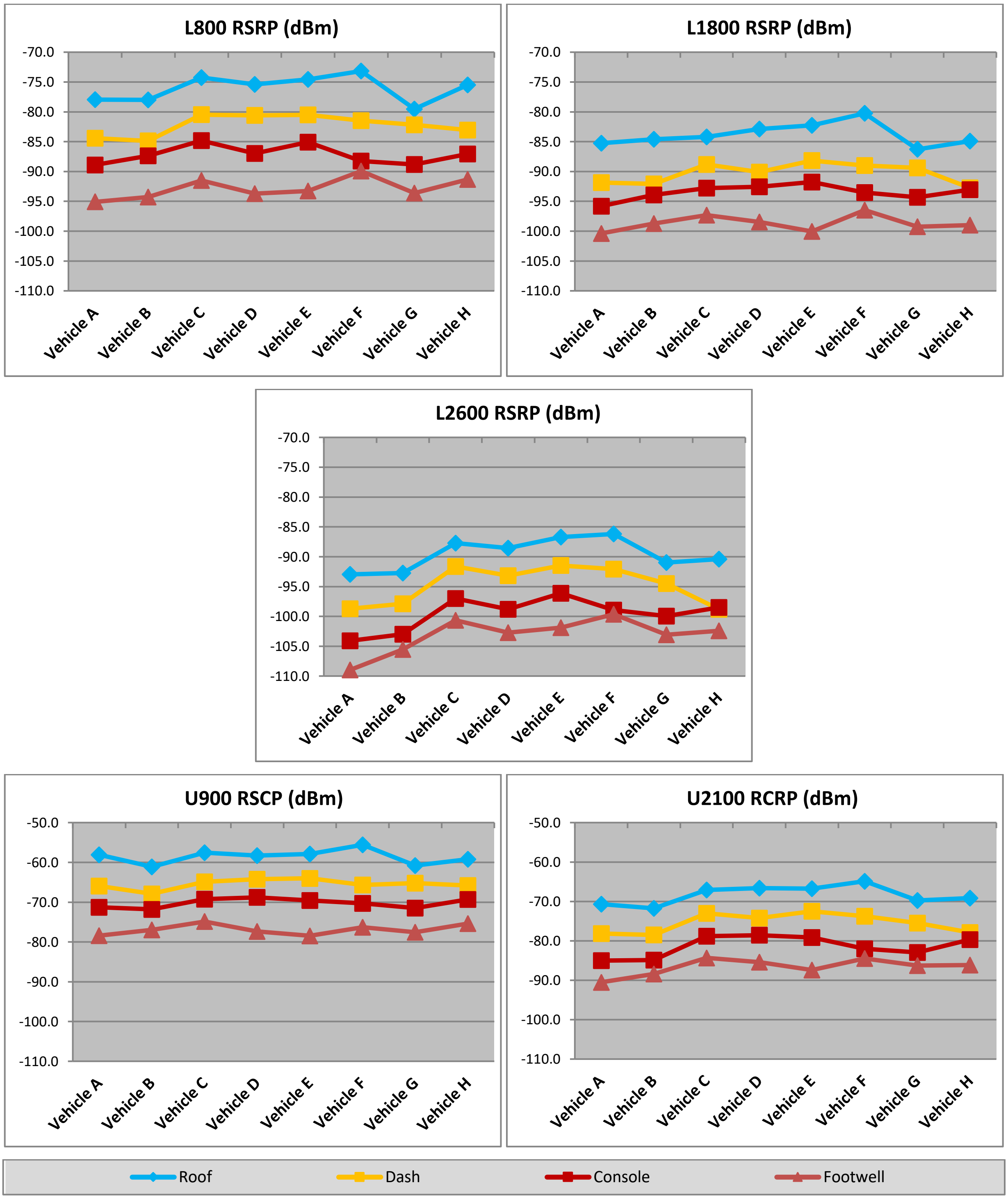


Figure 9: Mean values for RSRP and RSCP for each vehicle and position per frequency band

The best received signal level is on the rooftop antenna by vehicle F, this is due to the height of the van relative to the cars.

The lowest received signal level is on the rooftop antenna by vehicles A and B, which are both in the small car category having the shortest height relative to the other models.

We also observe the varying nature of signal power at the rooftop antenna for the different cars. There are a number of factors that cause these differences including:

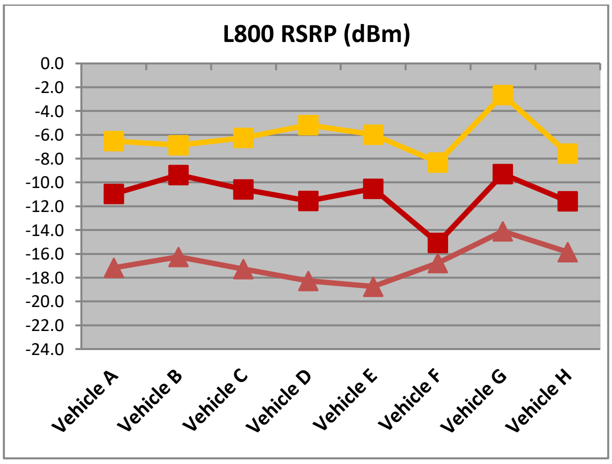
- Height of the vehicles – the height of each vehicle is slightly different which can cause an impact to the received signal level. E.g. a 1 dB difference for a 30cm variation in height.
- Size of the vehicle rooftop – The rooftop sizes differ across the vehicles, a slightly larger rooftop increases the probability of more reflections affecting the received signal level.
- Material of the car body – The vehicle body material can differ and in the case of vehicle G almost the entire roof is made of glass. The characteristics of the body can also affect the signal.
- The measurement process will also introduce a variation dependent on the losses of the vehicle. Only measurements where the same cell can be simultaneously seen on all four antenna ports will produce a valid result. Hence, where attenuation or directional effects of the vehicle are more pronounced, a higher average signal level will be required to ensure this occurs, and hence lower level signals are less likely to be recorded
- Dependent on how the average has been calculated, there will be some variation due to road speed relative to coverage level – i.e. holdups in urban areas will likely result in higher average signal levels overall

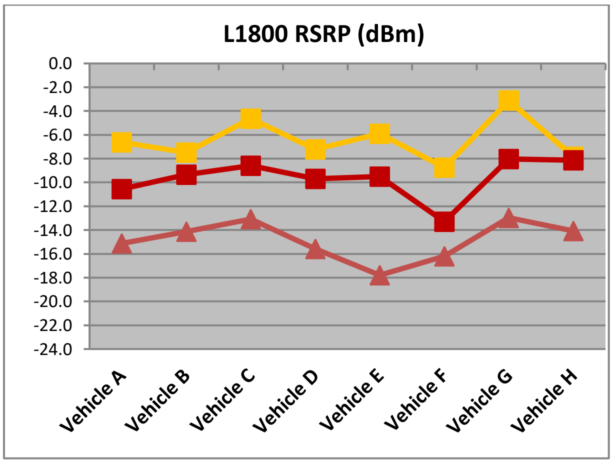
We observe a max 7 dB difference in mean received signal level across all vehicles and frequency bands which is driven by the factors listed above. However, this does not impact the measured results and subsequent post processing.

The least amount of attenuation measured between the roof and dash of the vehicle G maybe due to the amount of windows including a panoramic sunroof, also made of glass.

There are narrow gaps in attenuation for vehicle F at the positions between the console and footwell, except for 900 MHz.

It can be seen for example that although the lowest received signal levels are for 1800 MHz and 2600 MHz the gaps between the positions in those bands are slightly narrower compared to the UMTS bands.





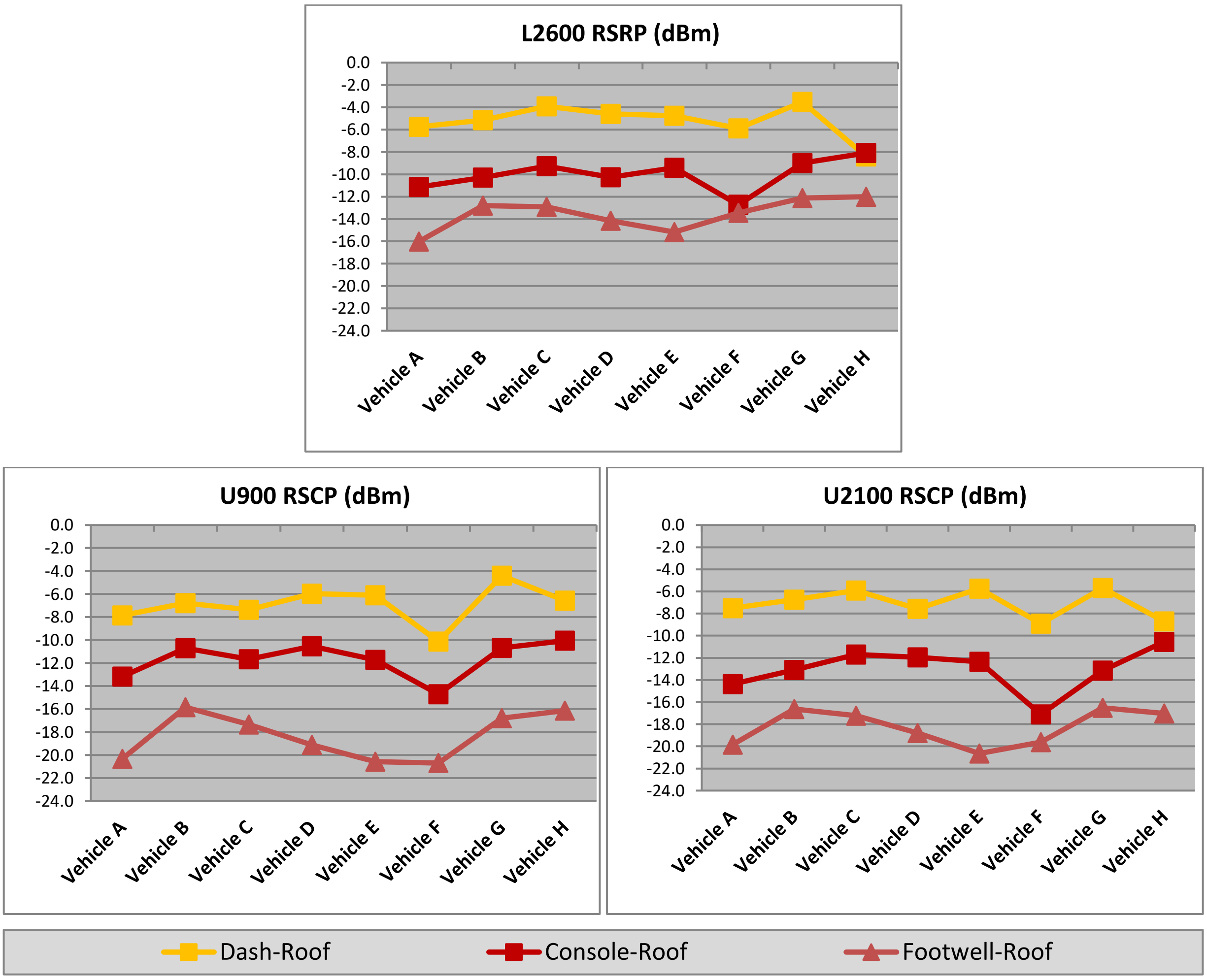


Figure 10: Attenuation of RSRP and RSCP mean values for each vehicle and position per frequency band

The plots in Figure 10 show the attenuation of the RSRP and RSCP mean values for each vehicle and position across the frequency bands. It shows for example which vehicles have the widest range of attenuation over the three positions. Vehicles E and D appear to have a commonly high attenuation in the footwell relative to the other positions across all frequency bands. Furthermore, the attenuation levels for the LTE bands appear to be slightly better than the UMTS bands.

5.1 Approach to derive attenuation value

We use the post processed results to determine the value for attenuation that can be used to make coverage predictions for mobile use inside vehicles. We examine the impact of attenuation across each of the main parameters namely frequency band, position inside the vehicle and across vehicles.

We first look at the variance of the attenuation values across each parameter that determines the magnitude of the range we consider for the attenuation value. Secondly, we determine the median and standard deviation value across each of the parameters to derive a single number that represents all vehicles, all positions and all frequencies. In order to derive as realistic value as possible we calculate a weighted value of the attenuation based on the UK market penetration across each of the vehicle types.

5.2 Implications for the findings

In this section, we examine how each of the parameters vary comparing the impact of frequency across vehicle types and impact of the positions across vehicle types. We then combine the two sets of data to derive a single value of attenuation.

5.2.1 Impact of frequency

We found that there is some variation of the attenuation between the different frequency bands per vehicle and across all vehicles. In the table below we show the mean attenuation for the different types of vehicle to examine the impact of the attenuation against frequency.

Vehicle	Position	U900	U2100	L800	L1800	L2600	Max Variance
A	Dash	-7.8	-7.5	-6.5	-6.6	-5.8	3.8
	Console	-13.2	-14.4	-11.0	-10.6	-11.1	
B	Dash	-6.8	-6.7	-6.9	-7.5	-5.2	3.8
	Console	-10.7	-13.1	-9.4	-9.3	-10.3	
C	Dash	-7.4	-5.9	-6.2	-4.6	-3.9	3.5
	Console	-11.7	-11.7	-10.6	-8.6	-9.3	
D	Dash	-6.0	-7.6	-5.2	-7.2	-4.6	3.0
	Console	-10.5	-12.0	-11.6	-9.7	-10.2	
E	Dash	-6.1	-5.7	-6.0	-5.9	-4.8	3.0
	Console	-11.7	-12.4	-10.5	-9.5	-9.4	
F	Dash	-10.1	-8.9	-8.3	-8.8	-5.9	4.1
	Console	-14.7	-17.1	-15.1	-13.3	-12.7	
G	Dash	-4.4	-5.7	-2.6	-3.1	-3.5	5.1
	Console	-10.7	-13.1	-9.3	-8.0	-9.0	
H	Dash	-6.6	-8.7	-7.6	-7.8	-8.4	3.5
	Console	-10.1	-10.5	-11.6	-8.1	-8.1	

Table 17: Variance impact on frequency per vehicle for dash and console

It can be seen that the Vehicle G has largest variance (5.1 dB) across all frequency bands followed by Vehicle F(4.1 dB), and finally the Vehicle D and the Vehicle E (3.0 dB). However, there is no obvious pattern across frequency bands or vehicle type except that collectively the LTE bands largely tend to have lower attenuation than the UMTS bands. The variance also reduces when comparing between technologies so for LTE bands only the max variance is 2.6 dB across all vehicle and for UMTS frequencies only the max variance is 2.4 dB.

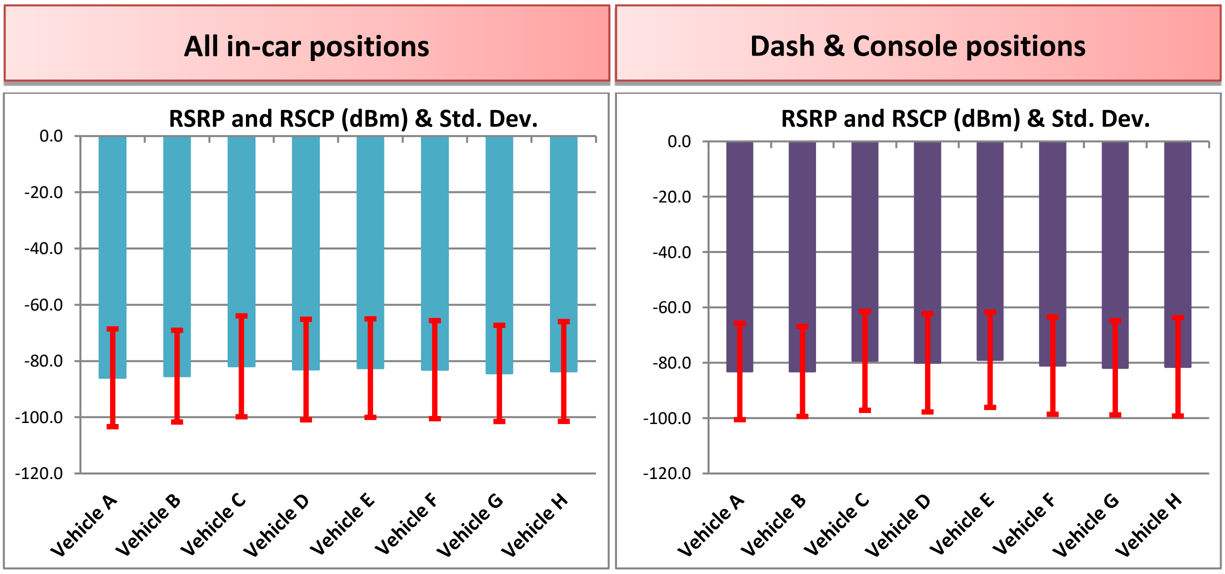
Overall, we conclude that the attenuation does not directly correlate with the frequency. It was expected that higher frequency bands had increased probability of signal attenuation, however the results indicate that the size of the apertures (windows, rooftop etc) is the most dominant factor when it comes to propagation losses.

5.2.2 Impact of different position across vehicles

We found there is quite significant variation of the attenuation between all different positions that were dependent on the type of vehicle. The most significant attenuation was observed in the footwell for all vehicles and our results of all in-car positions (for LTE bands) shows that by removing the consideration of the footwell the attenuation becomes a lot closer to the console value.

The best position was at the dash with lowest attenuation which was due to the windscreen being the only obstacle affecting the attenuation of the signal from outside the vehicle and also given that glass has lower attenuation compared to the body of the vehicle. Thus, it was expected that the value at the dash had the lowest signal attenuation.

The charts in figure below show the signal level received at a range of different combinations of positions (including all positions) for each vehicle for all frequency bands. It can be seen that taking the dash and console positions shows an improved level of attenuation for each vehicle compared to all positions which also takes into account the footwell. The height of the columns in the charts show the average combined RSRP and RSCP, while the vertical line represents the standard deviation.



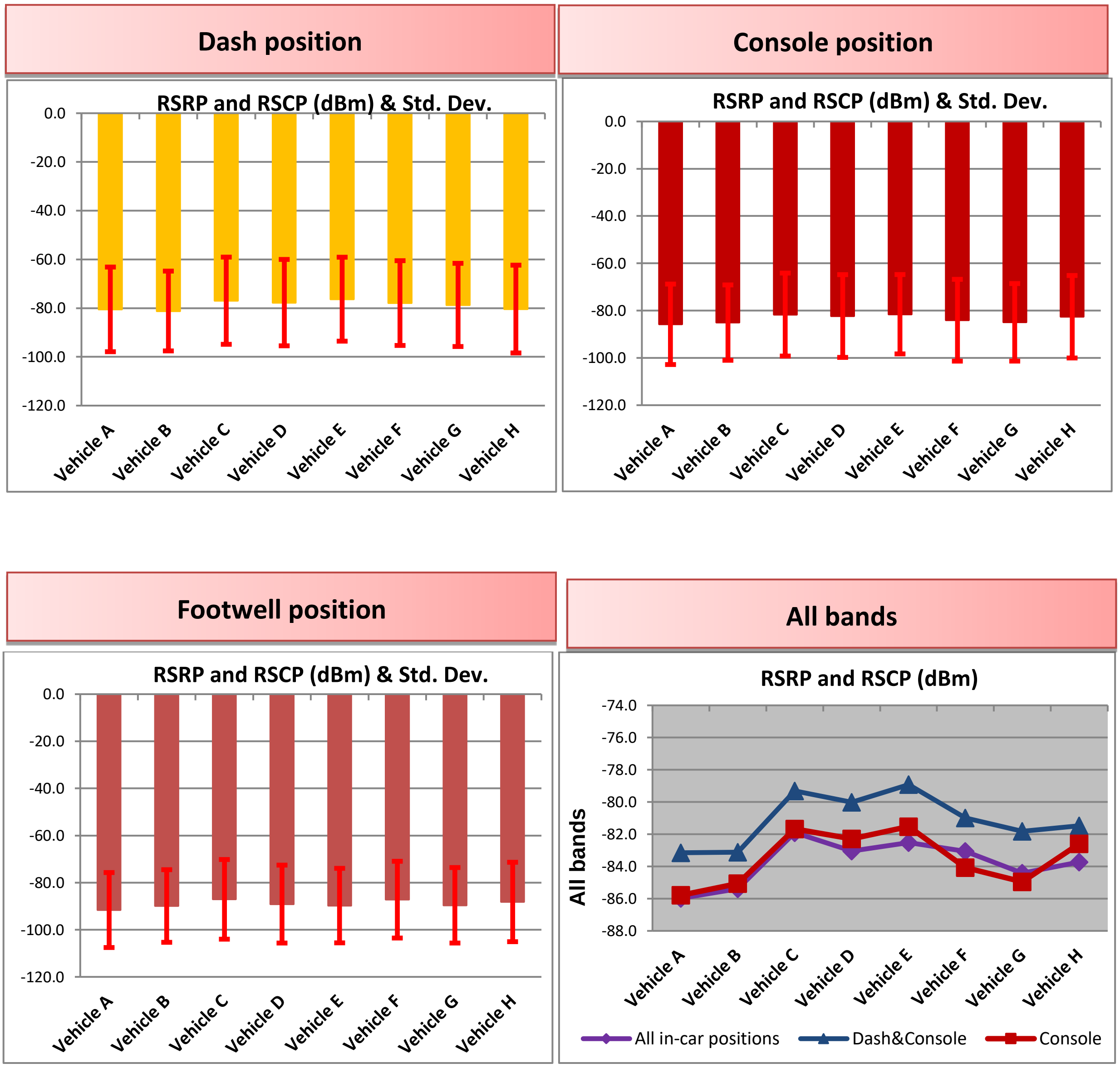


Figure 11: Signal level across vehicles for each position for all frequency bands

We conclude from this, that a mobile phone located in the footwell position demonstrates the riskiest from the three positions for providing an adequate quality of experience to the user and therefore, it will not be further considered in the next steps of the analysis. We therefore, use only the dash and console positions to derive a single value for the in-vehicle attenuation.

In the table below we compare the attenuation variation across all vehicle types for all positions versus just the mean for both dash and console positions. We observe that the difference ranges between -2.1 dB for vehicle F and -3.6 dB for vehicle E. The dash and console positions provide better attenuation for all cars compared to all positions and also these two locations are more likely to be where users will place their mobile phones inside vehicles.

Attenuation of RSRP and RSCP Mean (dB)			
Vehicle	Attenuation roof and all in-car position	Attenuation roof and Dash&Console	Attenuation all in-car position and Dash&Console
A	-12.5	-9.7	-2.8
B	-11.0	-8.8	-2.3
C	-10.9	-8.3	-2.6
D	-11.7	-8.6	-3.0
E	-12.0	-8.4	-3.6
F	-13.9	-11.8	-2.1
G	-9.8	-7.2	-2.6
H	-11.1	-8.8	-2.2

Table 18: Mean values of attenuation of RSRP and RSCP for all bands for different positions

Therefore, in order to down select the value from the range of attenuation values across vehicles we calculated the mean of all vehicles for all frequency bands for the dash and console position which is described in more detail in the next section.

5.3 Recommendation for in-vehicle signal attenuation level

In this section, we calculate the mean of all frequency bands, all vehicles for the dash and console positions and standard deviation to derive a single value for the signal attenuation. We are then able to calculate the weighted value based on the representative market penetration for each of the vehicles tested.

We used data from the Society of Motor Manufacturers and Traders (SMMT) to gather the new vehicle registrations for the year to date for each of the vehicles tested, so that we can estimate the weighting each vehicle contributes to the overall attenuation value.

Vehicle	YTD sales	Percentage of total	Category
A	59380	30,74%	Car
B	33560	17,37%	Car
C	2778	1.44%	Car
D	27386	14.18%	Car
E	21320	11.04%	Car
F	13415	6.94%	Van
G	33574	17.38%	Car
H	1754	0.91%	Car
Total vehicles	**193167**	**100.00%**	

Table 19: Market representation of vehicles tested

Figure 12 shows weighted attenuation (dB) for dash and console positions across the measured frequencies for 90%, 95% and 99% of the measurements. The plot shows the level of variation of attenuation across the frequency bands which do not exceed 5 dB.

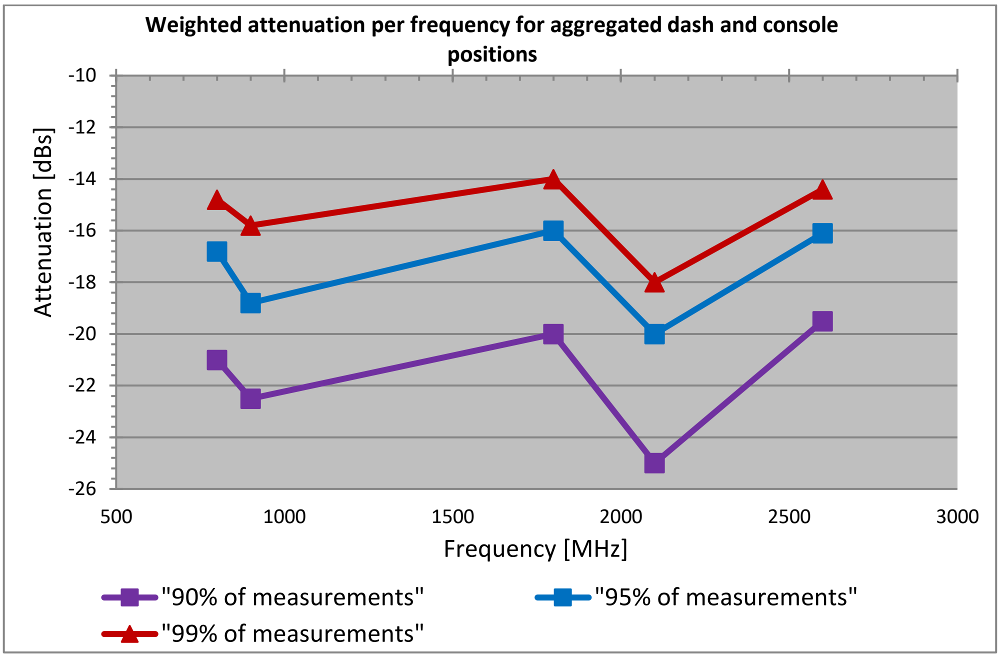


Figure 12: Weighted dash and console attenuation per frequency

Frequencies (MHz)	90% of measurements (dB)	95% of measurements (dB)	99% ofmeasurements (dB)
800	-14.8	-16.8	-21.0
900	-15.8	-18.8	-22.5
1800	-14.0	-16.0	-20.0
2100	-18.0	-20.0	-25.0
2600	-14.4	-16.1	-19.5

Table 20: Weighted dash and console attenuation per frequency for 90%, 95% and 99% of the measurements

Received signal value across all frequencies, all cars and dash and console and std deviation shows the RSPR and RSCP level for all frequencies, all vehicles and dash and console used to derive the single attenuation level.

RSRP and RSCP for all frequencies all vehicles and dash and console dBm (weighted)	RSRP and RSCP for all frequencies all vehicles and roof dBm (weighted)	Std dev. (dB) dash and console
-81.8	-72.8	17.3

Table 20: Received signal value across all frequencies, all cars and dash and console and std deviation

We derive the value of the weighted attenuation for the dash and console by subtracting the RSRP and RSCP signal level derived for dash and console with RSRP and RSCP signal level derived for the roof and yielding a median attenuation value of -8.9 dB.

However, given the statistical nature and variation of the results produced, we took the measurements gathered across all vehicles, positions and frequencies and produced the weighted occurrences of attenuation as a CDF curve. By analysing the CDF distribution, we produced levels of attenuation which provide us with confidence that each value will not be exceeded for 50%, 90%, 95% and 99% of total number of measurements. Those results are -8.9 dB, -16.3 dB -18.5 dB and -23 dB for each percentage respectively as shown in Figure 13.

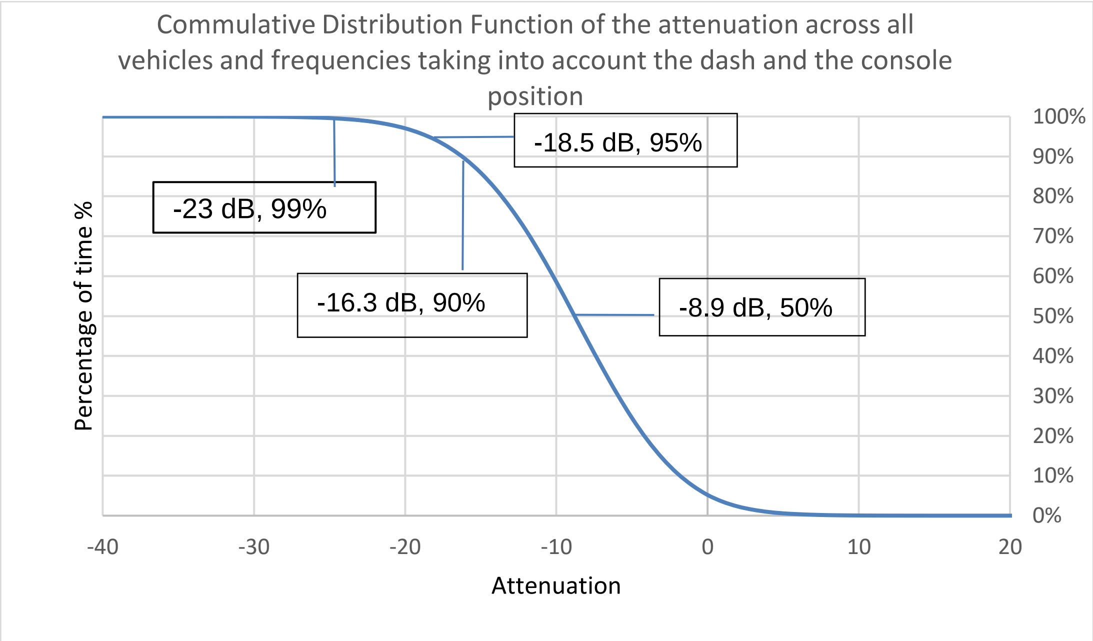


Figure 13: CDF of attenuation weighted based on the market representation of the examined cars

6 Appendix

6.1 Received signal level results per vehicle

The following tables show the mean, median and standard deviation for the RSRP and RSCP received at each of the measurement positions inside each vehicle.

6.1.1 Vehicle A

Frequency	Position	Mean	Median	Std Dev
L800	Dash	-84.4	-85.5	12.2
	Console	-88.9	-90.2	12.4
	Footwell	-95.1	-96.6	11.6
U900	Dash	-65.9	-67.3	13.5
	Console	-71.3	-72.5	13.2
	Footwell	-78.4	-79.7	13.0
L1800	Dash	-91.9	-93.5	13.8
	Console	-95.8	-97.4	13.7
	Footwell	-100.4	-103.4	10.7
U2100	Dash	-78.1	-79.7	14.9
	Console	-85.0	-86.7	14.8
	Footwell	-90.5	-91.7	15.0
L2600	Dash	-98.7	-99.7	13.5
	Console	-104.1	-105.6	13.2
	Footwell	-109.0	-111.5	12.1

Table 21: Summary of signal level results for each position across frequency band for vehicle A

6.1.2 Vehicle B

Frequency	Position	Mean	Median	Std Dev
L800	Dash	-84.9	-85.3	11.1
	Console	-87.4	-881	11.2
	Footwell	-94.3	-95.6	10.3
U900	Dash	-67.9	-68.2	13.0
	Console	-71.8	-72.5	13.1
	Footwell	-76.9	-77.3	12.7
L1800	Dash	-92.1	-93.0	12.9
	Console	-93.9	-94.8	12.4
	Footwell	-98.7	-100.5	11.2
U2100	Dash	-78.5	-79.8	15.1
	Console	-84.8	-86.2	14.7
	Footwell	-88.4	-90.3	15.0
L2600	Dash	-97.9	-98.2	13.2
	Console	-103.0	-104.1	13.1
	Footwell	-105.5	-107.6	11.5

Table 223: Summary of signal level results for each position across frequency band for vehicle B

6.1.3 Vehicle C

Frequency	Position	Mean	Median	Std Dev
L800	Dash	-80.5	-81.6	13.1
	Console	-84.8	-85.5	13.2
	Footwell	-91.5	-93.0	12.5
U900	Dash	-64.9	-65.2	14.9
	Console	-69.2	-70.0	14.2
	Footwell	-74.9	-75.6	14.1
L1800	Dash	-88.8	-90.0	15.3
	Console	-92.8	-94.1	15.1
	Footwell	-97.3	-99.7	13.5
U2100	Dash	-73.0	-73.8	16.4
	Console	-78.8	-79.6	16.1
	Footwell	-84.3	-85.2	16.3
L2600	Dash	-91.6	-90.4	15.6
	Console	-97.0	-97.1	14.7
	Footwell	-100.6	-101.0	13.6

Table 23: Summary of signal level results for each position across frequency band for vehicle C

6.1.4 Vehicle D

Frequency	Position	Mean	Median	Std Dev
L800	Dash	-80.6	-81.1	12.6
	Console	-87.0	-87.6	12.3
	Footwell	-93.7	-94.6	12.4
U900	Dash	-64.2	-65.4	13.4
	Console	-68.8	-70.2	13.5
	Footwell	-77.4	-78.7	13.5
L1800	Dash	-90.1	-91.4	14.7
	Console	-92.5	-94.1	14.8
	Footwell	-98.4	-100.6	14.0
U2100	Dash	-74.2	-75.0	16.2
	Console	-78.6	-79.7	16.2
	Footwell	-85.4	-86.7	15.9
L2600	Dash	-93.2	-91.7	15.4
	Console	-98.8	-98.7	14.1
	Footwell	-102.7	-103.6	12.7

Table 24: Summary of signal level results for each position across frequency band for vehicle D

6.1.5 Vehicle E

Frequency	Position	Mean	Median	Std Dev
L800	Dash	-80.5	-81.4	12.3
	Console	-85.1	-85.5	12.3
	Footwell	-93.3	-94.6	11.5
U900	Dash	-64.0	-64.9	13.4
	Console	-69.6	-70.4	13.6
	Footwell	-78.4	-79.6	13.3
L1800	Dash	-88.2	-89.3	14.7
	Console	-91.8	-93.4	14.3
	Footwell	-100.1	-102.2	13.1
U2100	Dash	-72.5	-73.0	16.0
	Console	-79.1	-79.7	16.1
	Footwell	-87.4	-88.4	15.6
L2600	Dash	-91.5	-92.3	13.6
	Console	-96.1	-97.8	13.5
	Footwell	-101.9	-104.4	10.5

Table 25: Summary of signal level results for each position across frequency band for vehicle E

6.1.6 Vehicle F

Frequency	Position	Mean	Median	Std Dev
L800	Dash	-81.5	-82.4	12.7
	Console	-88.2	-89.7	12.1
	Footwell	-89.9	-91.6	12.2
U900	Dash	-65.7	-67.0	13.4
	Console	-70.3	-71.5	13.2
	Footwell	-76.3	-77.8	13.3
L1800	Dash	-89.0	-89.4	15.2
	Console	-93.5	-94.6	14.9
	Footwell	-96.5	-98.2	14.4
U2100	Dash	-73.8	-74.6	16.2
	Console	-82.0	-83.3	16.3
	Footwell	-84.5	-85.9	16.3
L2600	Dash	-92.1	-93.0	15.0
	Console	-98.9	-100.3	14.2
	Footwell	-99.6	-102.1	12.3

Table 26: Summary of signal level results for each position across frequency band for vehicle F

6.1.7 Vehicle G

Frequency	Position	Mean	Median	Std Dev
L800	Dash	-82,2	-82,7	12,1
	Console	-88,8	-89,4	11,3
	Footwell	-93,6	-94,6	11,6
U900	Dash	-65,2	-65,6	13,0
	Console	-71,5	-72,6	12,8
	Footwell	-77,6	-78,0	12,8
L1800	Dash	-89,4	-90,4	14,0
	Console	-94,3	-95,8	13,4
	Footwell	-99,2	-101,2	13,4
U2100	Dash	-75,5	-77,3	15,3
	Console	-82,9	-84,9	15,1
	Footwell	-86,3	-88,2	15,2
L2600	Dash	-94,5	-93,2	15,3
	Console	-100,0	-98,9	14,1
	Footwell	-103,1	-103,0	12,7

Table 27: Summary of signal level results for each position across frequency band for vehicle G

6.1.8 Vehicle H

Frequency	Position	Mean	Median	Std Dev
L800	Dash	-83,0	-83,9	12,4
	Console	-87,1	-87,9	12,4
	Footwell	-91,3	-92,6	12,1
U900	Dash	-65,8	-67,0	13,3
	Console	-69,3	-70,2	13,2
	Footwell	-75,4	-76,3	13,3
L1800	Dash	-92,7	-94,5	14,6
	Console	-93,0	-94,9	14,9
	Footwell	-99,0	-100,9	14,2
U2100	Dash	-77,8	-79,5	16,2
	Console	-79,7	-81,2	16,4
	Footwell	-86,2	-87,7	16,1
L2600	Dash	-98,8	-98,3	15,5
	Console	-98,5	-98,5	15,4
	Footwell	-102,4	-103,8	13,7

Table 28: Summary of signal level results for each position across frequency band for vehicle H

6.2 Range of RSRP and RSCP for console position across frequency and vehicle

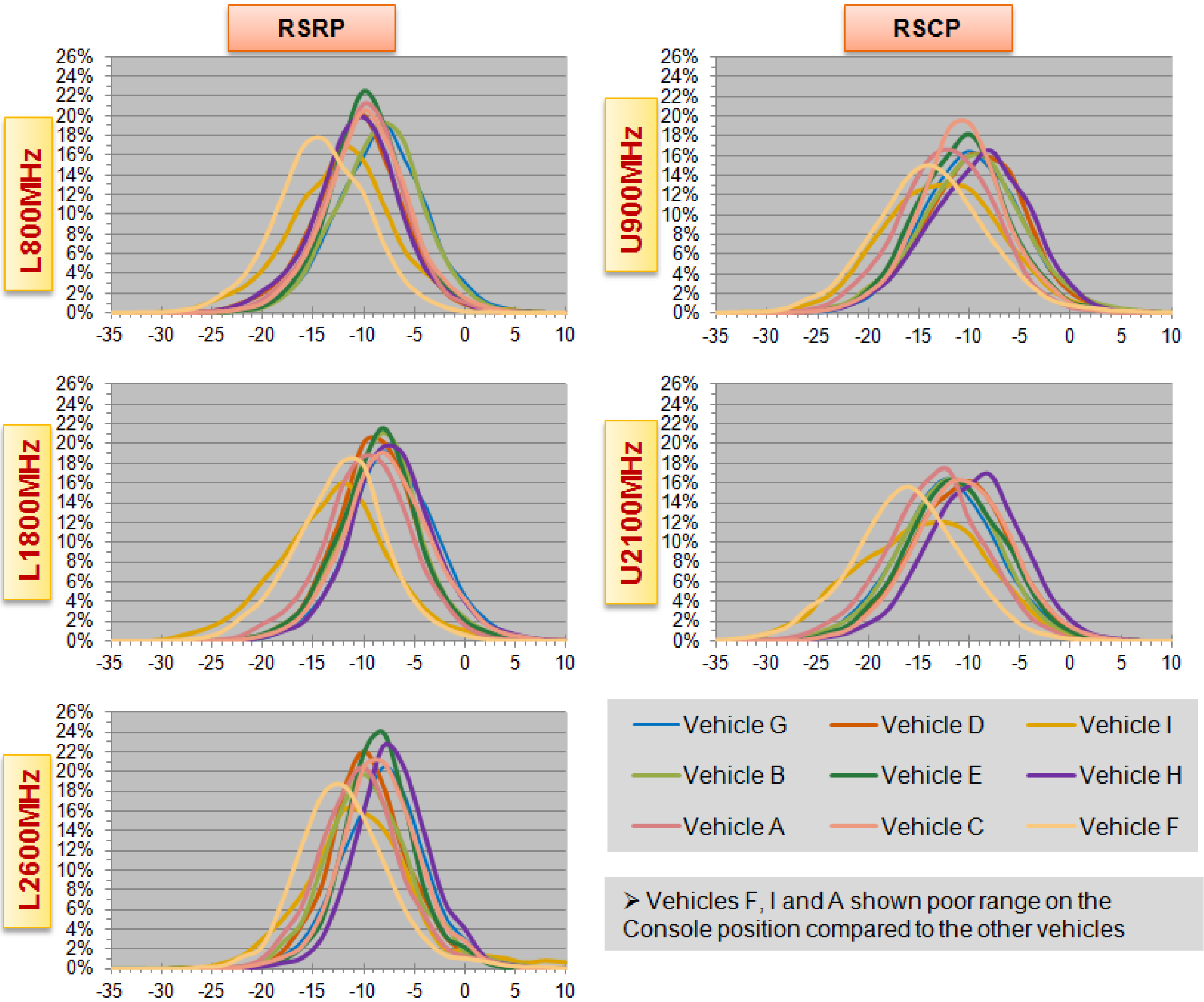


Figure 14: Range of RSRP and RSCP for console position across frequency and vehicle

The following plots show the weighted CDF for dash and console for each vehicle. A plot is produced for each frequency band to demonstrate the level of attenuation variance across frequency bands.

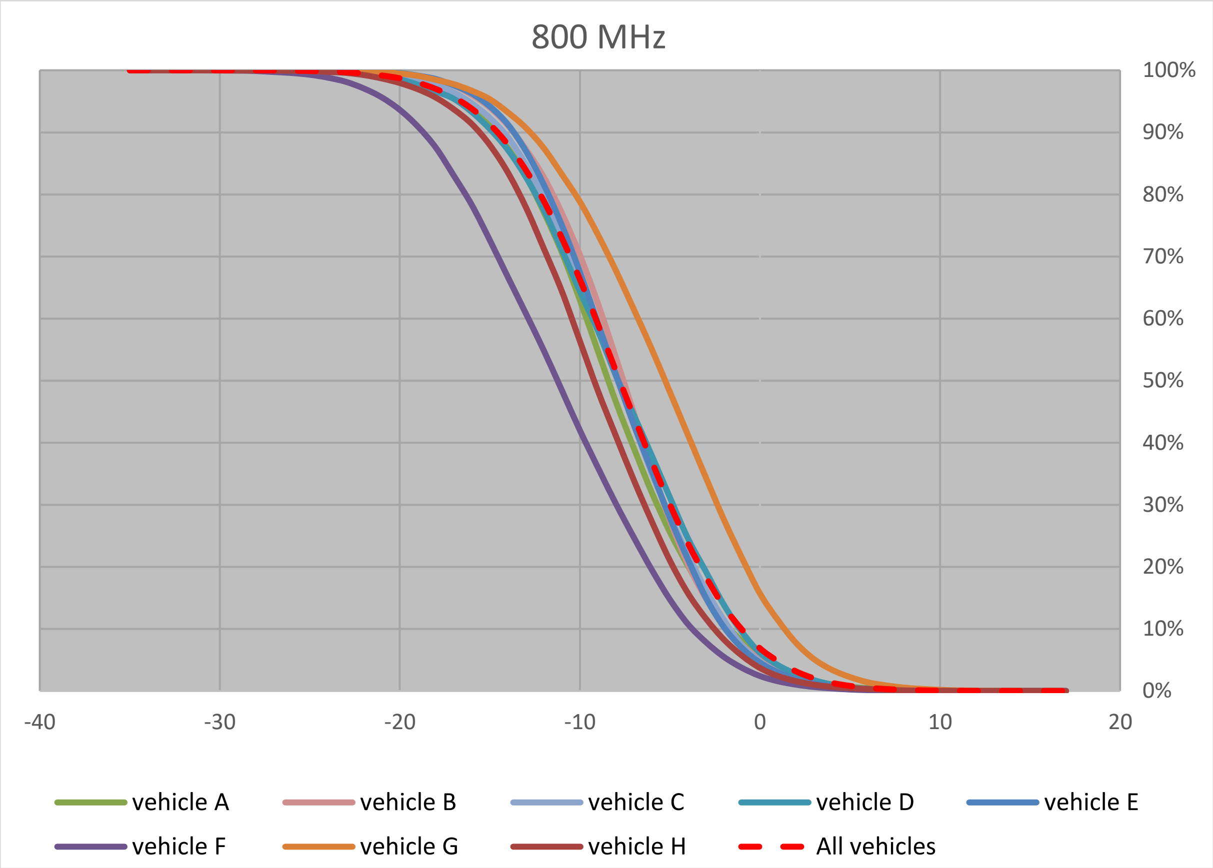


Figure 15: Weighted CDF for dash and console at 800 MHz across all vehicles

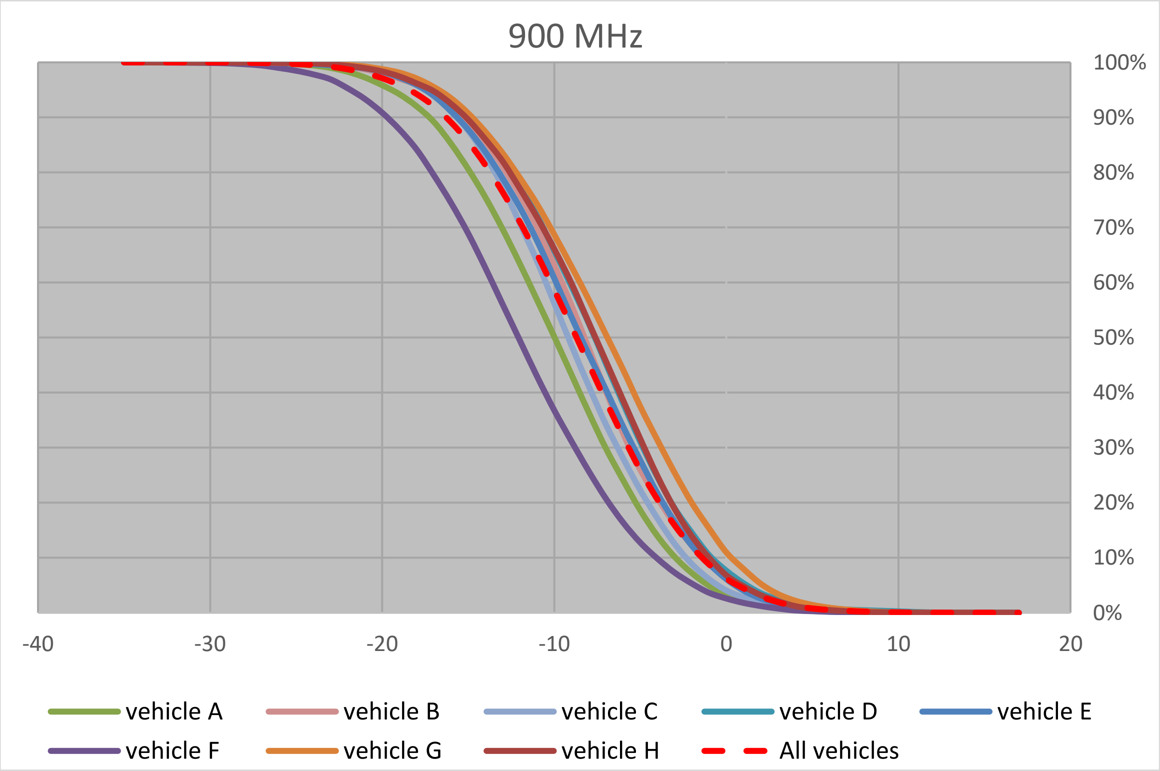


Figure 16: Weighted CDF for dash and console at 900 MHz across all vehicles

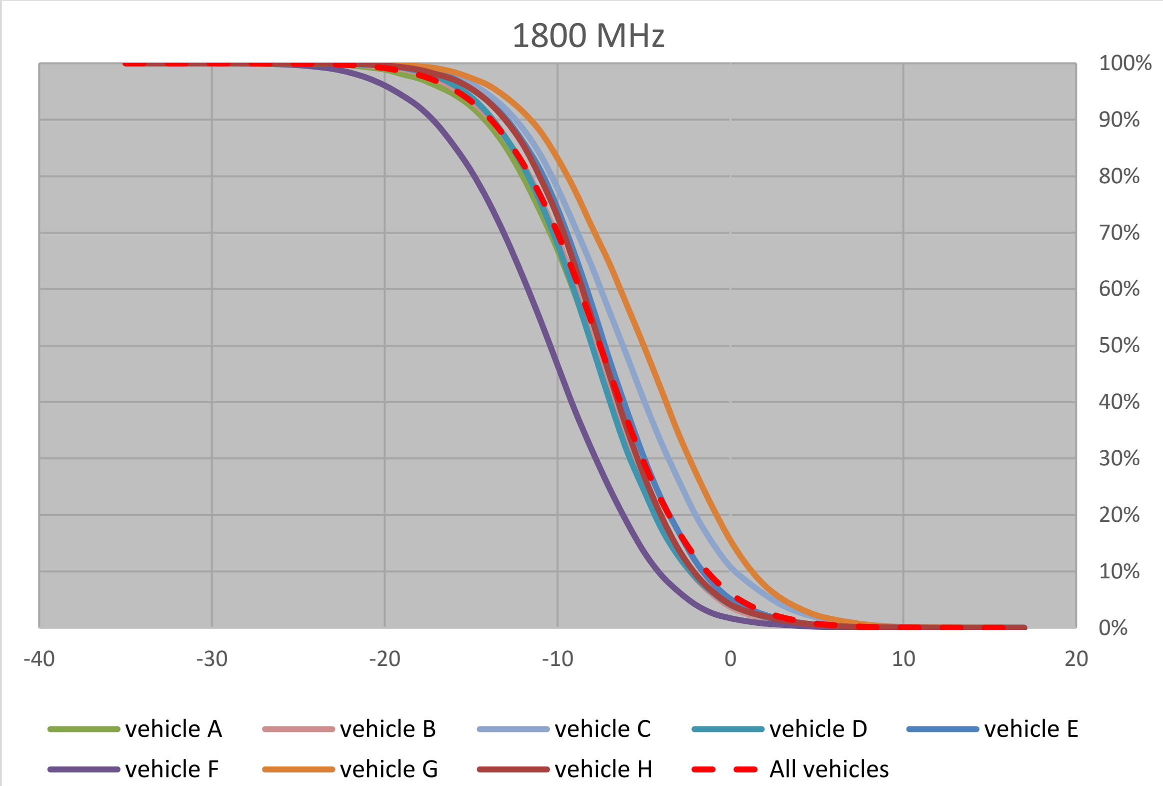


Figure 17: Weighted CDF for dash and console at 1800 MHz across all vehicles

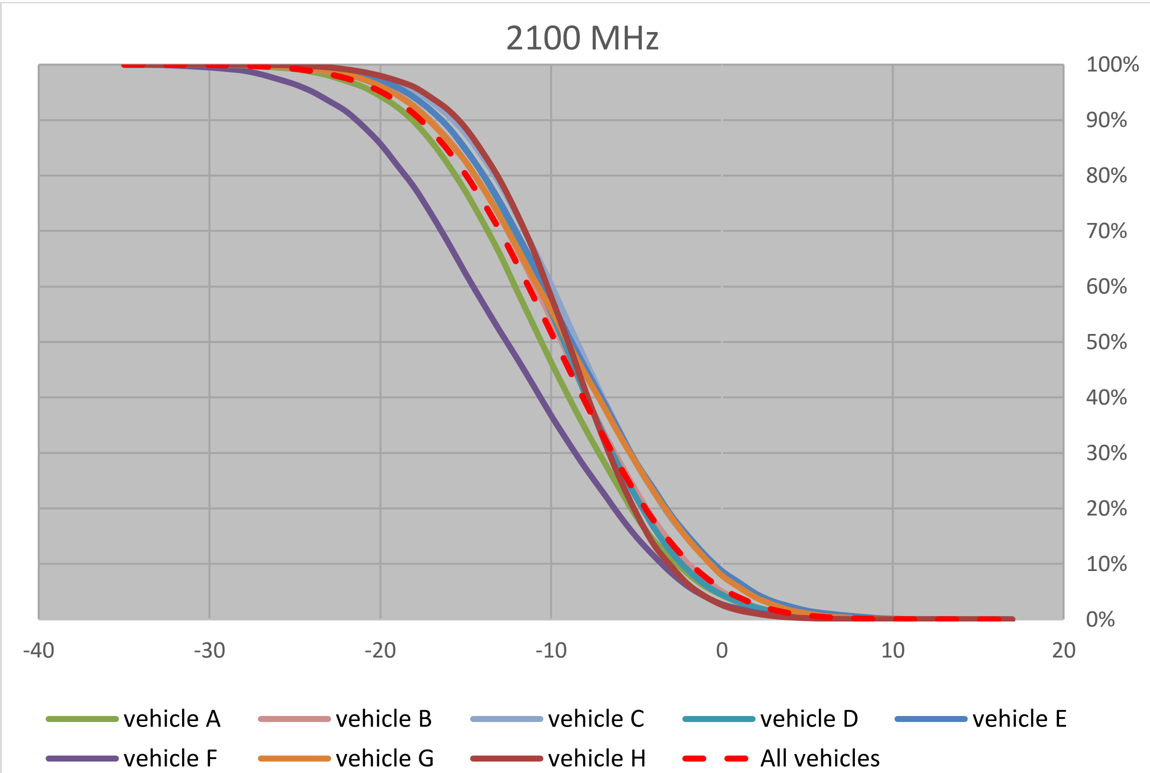


Figure 18: Weighted CDF for dash and console at 2100 MHz across all vehicles

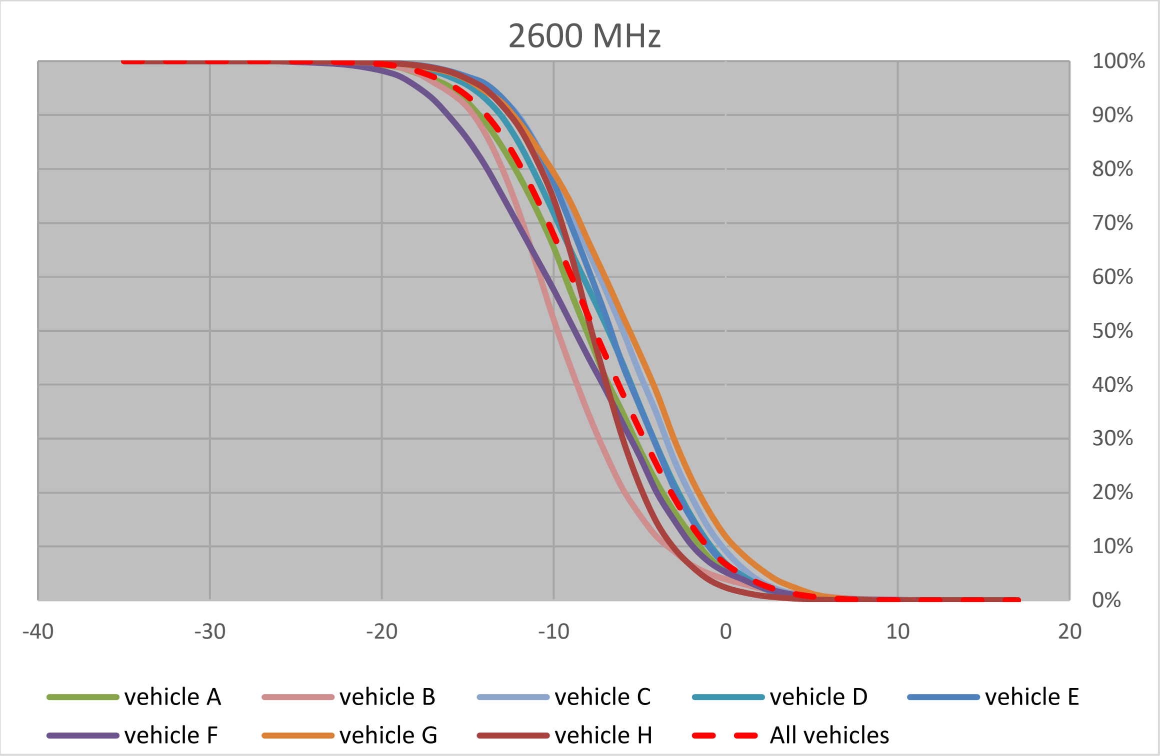


Figure 19: Weighted CDF for dash and console at 2600 MHz across all vehicles

6.3 Coverage map of drive test route for LTE800 per position

6.3.1 RSRP coverage roof position

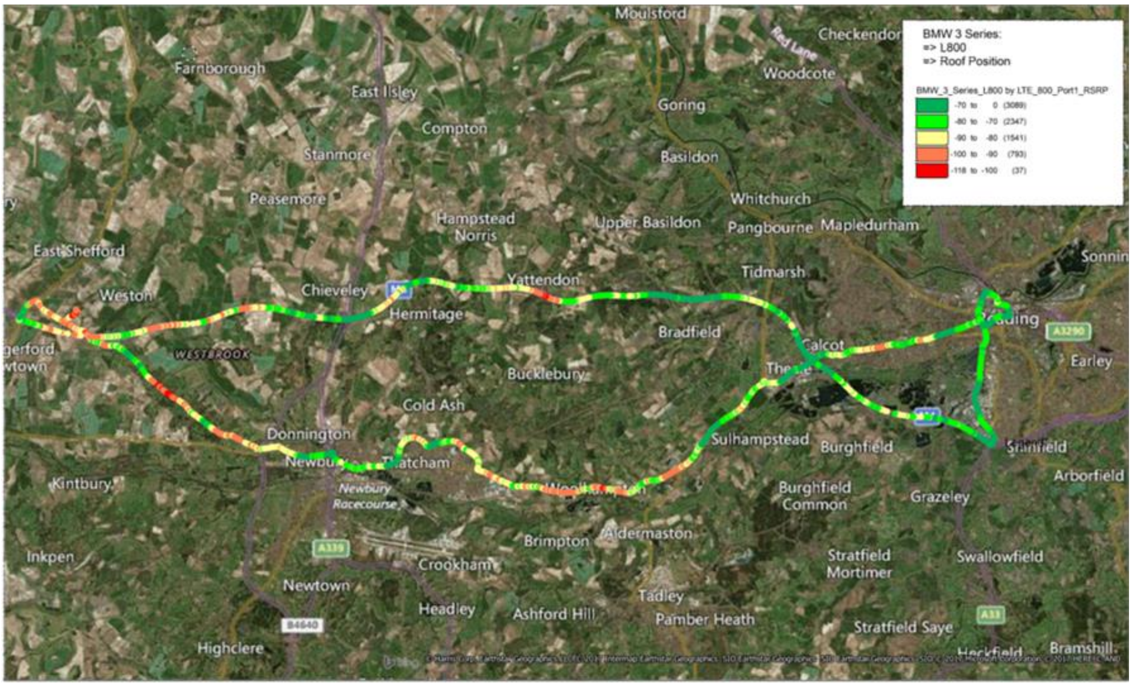


Figure 20: Coverage map of RSRP for LTE 800 MHz – roof position

6.3.2 RSRP coverage dash position

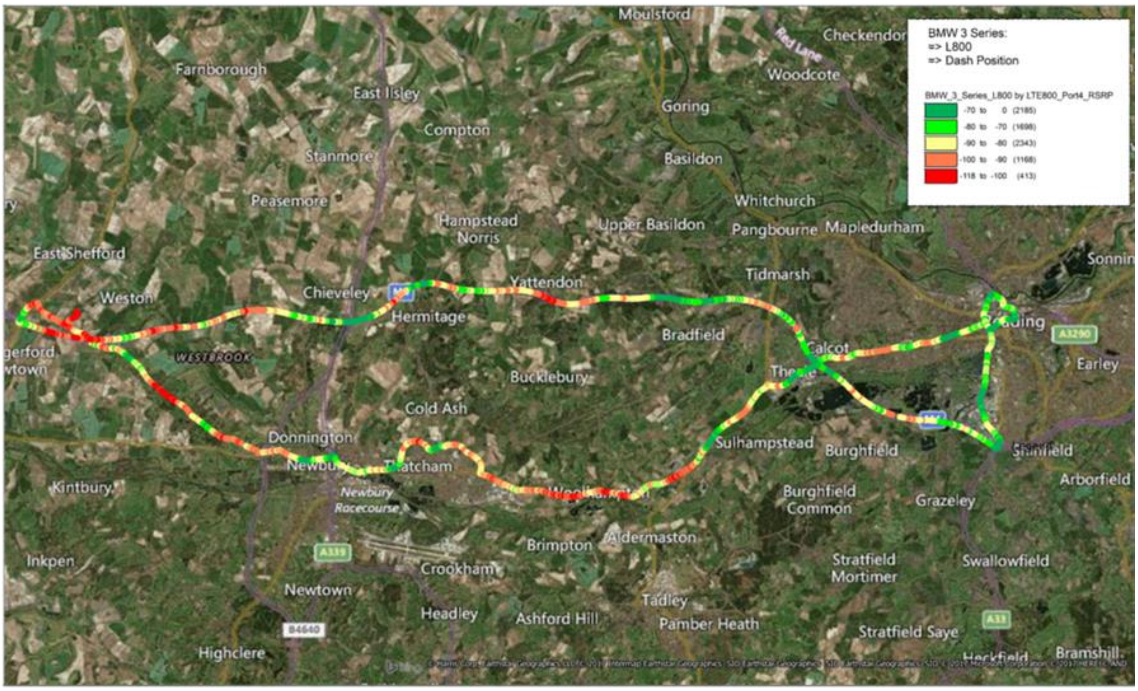


Figure 21: Coverage map of RSRP for LTE 800 MHz – Dash position

6.3.3 RSRP coverage console position

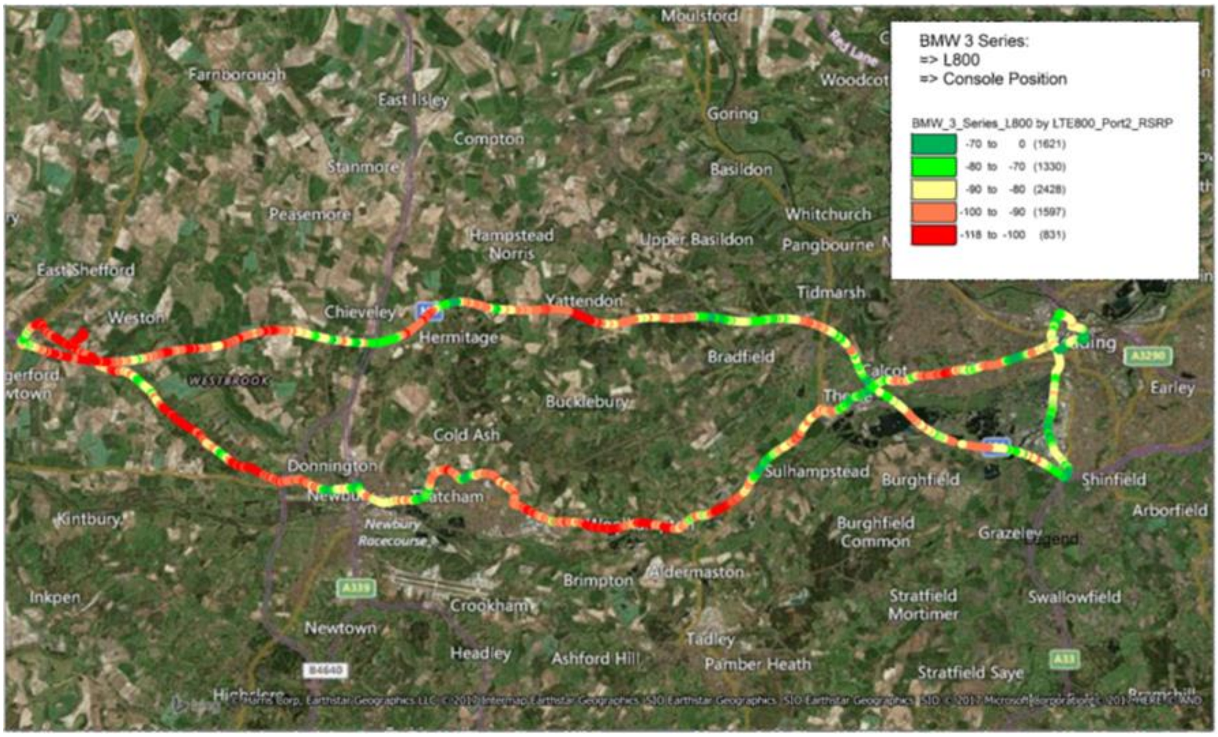


Figure 22: Coverage map of RSRP for LTE 800 MHz – console position

6.3.4 RSRP coverage footwell position

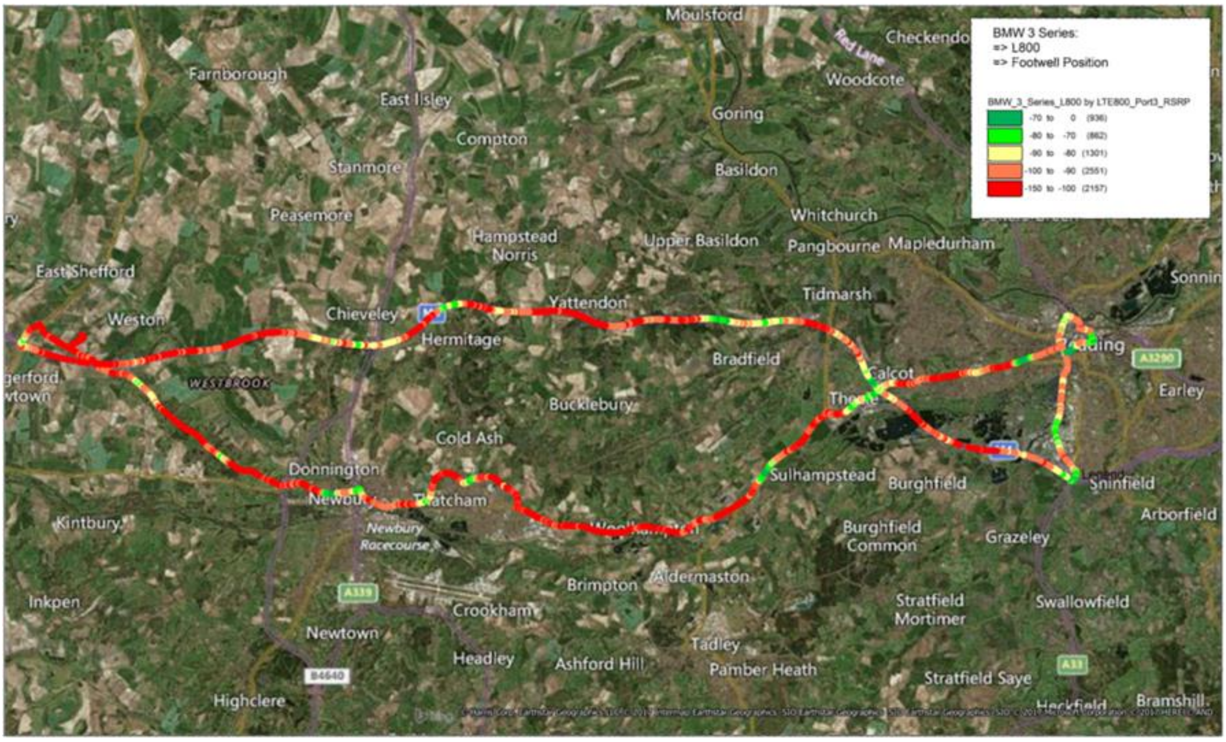


Figure 23: Coverage map of RSRP for LTE 800 MHz – footwell position

6.4 Impact on attenuation from an additional passenger

We tested the impact of signal attenuation inside a vehicle with another passenger. This was done to determine whether a passenger causes greater attenuation than if there was just a driver on their own. The results in the following table show the received signal level across frequency and position for all frequencies.

6.4.1 Vehicle with passenger

Frequency	Position	Mean	Median	Std Dev
L800	Dash	-81.7	-82.6	12.2
	Console	-85.7	-86.5	12,1
	Footwell	-96.6	-97.8	11.8
U900	Dash	-65.3	-66.0	13.1
	Console	-68.8	-70.1	12.9
	Footwell	-78.5	-79.7	12.9
L1800	Dash	-92.5	-94.4	14.8
	Console	-94.8	-96.7	14.3
	Footwell	-103.1	-105.6	13.5
U2100	Dash	-75.6	-77.3	15.4
	Console	-80.2	-82.3	15.3
	Footwell	-89.4	-91.4	15.1
L2600	Dash	-96.2	-96.4	15.0
	Console	-100.7	-101.5	14.6
	Footwell	-105.6	-108.4	11.2

Table 30: Received signal measurements across frequency and positions with passenger

6.4.2 Vehicle without passenger

Frequency	Position	Mean	Median	Std Dev
L800	Dash	-80.9	-81.3	11.8
	Console	-84.7	-85.3	11.7
	Footwell	-92.5	-93.6	10.9
U900	Dash	-65.1	-66.0	12.4
	Console	-68.3	-69.5	12.2
	Footwell	-73.1	-73.8	12.6
L1800	Dash	-89.5	-91.8	13.2
	Console	-93.1	-95.3	12.9
	Footwell	-95.6	-98.1	12.6
U2100	Dash	-76.2	-77.9	15.2
	Console	-80.3	-82.3	15.2
	Footwell	-86.0	-88.0	15.5
L2600	Dash	-93.5	-93.7	14.2
	Console	-98.0	-98.0	13.9
	Footwell	-100.0	-102.0	12.5

Table 29: Received signal measurements across frequency and positions without passenger

In Table 30 it shows the small difference (max 2.7 dB) in received signal level between received at dash and console with and without a passenger. Thus, indicating the relatively small impact on levels of attenuation of a passenger inside the vehicle.

<table>
<tr><th>Vehicle</th><th>Position</th><th>U900</th><th>U2100</th><th>L800</th><th>L1800</th><th>L2600</th><th>Max Variance</th></tr>
<tr><td>With passenger</td><td>Dash& console</td><td>-67.0</td><td>-77.9</td><td>-83.7</td><td>-93.6</td><td>-98.5</td><td rowspan="2">2.7 dB at L2600</td></tr>
<tr><td>Without passenger</td><td>Dash& console</td><td>-66.7</td><td>-78.2</td><td>-82.8</td><td>-91.3</td><td>-95.8</td></tr>
</table>

Table 30: Comparison of received signal measurements with and without a passenger

Vehicle	Position	U900	U2100	L800	L1800	L2600	Max Variance
With passenger	Dash	7.1	6.6	6.3	7.2	4.8	0.9 dB at L1800
Without passenger		7.0	6.8	5.9	6.1	4.6	
With passenger	Console	10.6	11.2	10.3	9.4	9.3	0.6 dB at L800
Without passenger		10.3	10.9	9.7	9.6	9.2	

Table 31: Comparison of attenuation levels with and without a passenger