The Effect of Building Materials on Indoor Mobile Performance

Reference: ComReg 18/73

Date: 02/08/2018

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Chapter 1

1 Introduction

1.1 The Commission for Communications Regulation (ComReg), in its Radio Spectrum Management Strategy Statement for 2017 to 2018[1], outlined a number of issues it believed may be currently affecting mobile user experience. These issues include:

- the increased use of phones with poorer antenna performance;
- changing consumer habits (such as an increased use of data and a greater reliance on smartphones), leading to increased coverage and reliability expectations;
- the use of better building insulation materials (e.g. window insulation/tinting, foil-backed insulation) leading to a reduction in already poor indoor signal penetration; and
- the ability of Mobile Network Operators (MNOs) to find suitable cell sites or obtain planning permission.

1.2 ComReg noted that it would endeavour to develop a greater understanding of issues affecting mobile coverage, seek solutions to deliver improved outcomes and through this support the Government's proposed Task Force on Rural Mobile Coverage and Broadband (the "Taskforce").

1.3 In late 2016, in accordance with its strategic plan and in alignment with interventions identified by the Taskforce, ComReg commenced two parallel projects in order to gain a greater understanding of two factors in particular that affect mobile user experience:

i. **Mobile Handset Performance**: To measure the antenna performance of mobile handsets available on the Irish market in order to quantify the performance of each handset when making or receiving a mobile call and to stream data.

ii. **Effect of Building Materials on Indoor Mobile Performance**: To determine the extent to which some representative modern building materials impact on in-building coverage by measuring overall attenuation through each building material tested.

1.4 In relation to mobile handset performance, ComReg recently published a Technical Report (ComReg Document 18/05[2]) into mobile handset voice performance.

[1] https://www.comreg.ie/publication/radio-spectrum-management-strategy-statement-2016-2018-design/
[2] https://www.comreg.ie/publication/mobile-handset-performance-voice/

1.5 This technical report presents the measurement results of the tests carried out by ComReg in relation to the effect of building materials on indoor mobile performance.

Chapter 2

2 Background

2.1 Mobile technology has become ubiquitous in daily life. ComReg's most recent mobile data forecast conducted by Frontier Economics[3] shows that total annual mobile data traffic in Ireland is forecast to increase from 268 million GB/year in 2017 to 1,059 million GB/year in 2022, as indicated by the red line in Figure 1. According to Cisco, 80% of mobile data usage occurs indoors[4].

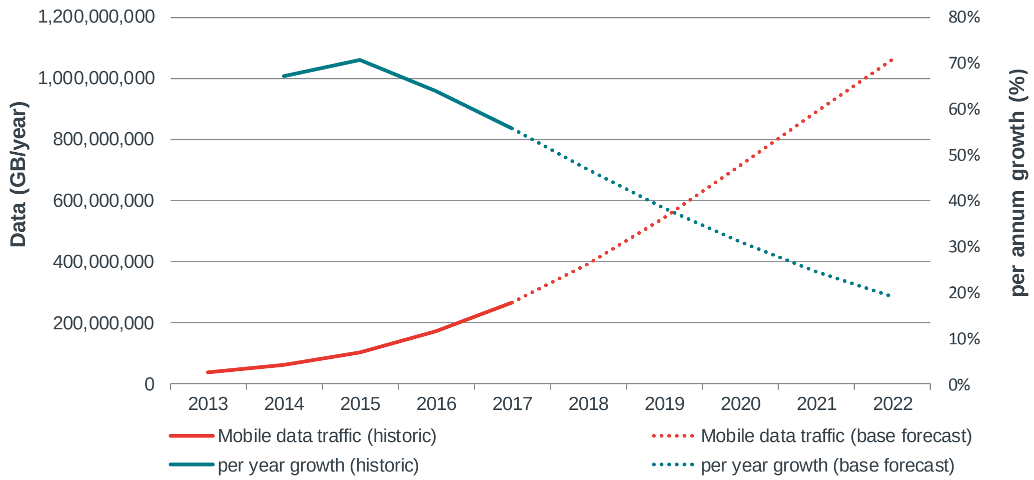


Figure 1: Base forecast of total mobile data traffic (Source: Frontier)

2.2 In parallel with this growth in mobile traffic, there has been a drive towards more energy-efficient building materials. The 2012 Energy Efficiency Directive ("EED")[5] requires EU Member States to set up energy efficiency schemes. Ireland's scheme - known as "*Better Energy Homes*" - has so far resulted in improved energy efficiency in 217,485 homes since its establishment in March 2009[6].

2.3 The Irish Government published revised Building Regulations for all newly-constructed buildings in 2011 and again in 2017 which make it a legal requirement for the latest EU energy efficiency targets to be met in all new builds. In order to achieve these energy efficiency targets, changes to building construction methods and materials have been required. These changes aim to maximise heat capture and minimise heat loss through the walls, roof and

[3] ComReg Document – 18/35 – Mobile Data Traffic Forecast in Ireland - https://www.comreg.ie/publication/mobile-data-traffic-forecast-in-ireland-information-notice/
[4] http://www.cisco.com/c/dam/en/us/solutions/collateral/service-provider/small-cell-solutions/platform-for-service-innovation.pdf
[5] http://www.seai.ie/EEOS/Energy-Efficiency-Directive-2012-27-EU.pdf
[6] https://www.seai.ie/resources/seai-statistics/better-energy-home-statistics/

windows of modern buildings, chiefly through the use of new window, brick and insulation materials.

2.4 Some modern building materials – especially those containing metals such as foil-backed thermal insulation or windows with aluminium or metallic frames - can have a significant impact on radio signals as they penetrate a building. The foil or metal layers help reduce heat loss from inside, but also act to 'reflect' incoming radio signals from outside, effectively shielding the inside of the building from mobile signals outside.

2.5 The combined effect of the use of more heat-efficient building materials and a great increase in overall mobile voice and data traffic has contributed to a deterioration in the perceived quality of indoor mobile performance in many homes. Underscoring this, ComReg's 2017 Mobile Consumer Experience survey[7] found that "*Deterioration in the reception quality of the call while at home (indoors) was the most frequently cited service issue experienced by respondents who had a service issue in the last month (51% of respondents who had a service issue in the last month)".*

2.6 With this in mind, ComReg has set out to quantify the effects of some representative modern building materials on indoor radio signal performance. To do this, ComReg obtained a range of brick, roof tile, window and insulating materials used in contemporary Irish building construction. A dedicated laboratory test environment has been constructed which allows radio signal attenuation through a sample of each of these materials to be measured over the frequency range in which mobile signals operate in Ireland. The resulting attenuation measurements allow an assessment of the range of attenuations caused by different building materials to be made. In carrying out the measurements, ComReg collaborated with Aalborg University[8] and the measurement methodology was also reviewed by Queen's University Belfast[9].

2.7 The remainder of this report is structured as follows:

- Chapter 3 describes the test methodology;
- Chapter 4 reports measurement results;
- Chapter 5 sets out conclusions on each set of materials; and
- Chapter 6 provides commentary and next steps.

[7] https://www.comreg.ie/?dlm_download=mobile-consumer-experience-survey
[8] https://www.en.aau.dk/
[9] http://www.ecit.qub.ac.uk/CWI

Chapter 3

3 Test Methodology

3.1 Test Materials

3.1 Table 1 lists all the building materials tested to date. Materials are divided into four categories – windows, insulating materials, block materials and roofing materials.

Table 1 : List of selected building materials used for testing

No	Category	Material Name
1	**Window**	PVC standard – Double-glazed
		PVC standard – Triple-glazed
		PVC passive – Future proof – Double-glazed
		PVC passive – Future proof – Triple-glazed
		AluClad – Double-glazed
		AluClad – Triple-glazed
		Alu passive – Ecotherm – Double-glazed
		Alu passive – Ecotherm – Triple-glazed
		Hardwood – Double-glazed
		Hardwood – Triple-glazed
2	**Insulation**	Polyiso Rigid Foam Insulation – 50mm
		Polyiso Rigid Foam Insulation – 80mm
		Polyiso Rigid Foam Insulation – 150mm
		Isover – Heatshield – Fibre Glass – 140 mm
		Earthwool – 100 mm
		Rockwool – 100 mm
		Plasterboard
		Plasterboard – Foil-backed
3	**Block**	Solid Concrete Block
		Cavity Concrete Block
		Red Textured Brick
4	**Roof**	Thrutone+ Relief Slate – Black Concrete Flat Roof Tile – Red

3.2 Test Frequency Range

3.2 The radio propagation characteristics of each building material were measured over a *Test Frequency Range* defined as 400 MHz to 2.2 GHz. This covers the full range of frequencies currently used in 2G/3G/4G cellular signals in Ireland.

3.3 Test Procedure

3.3 To measure attenuation through each building material a radio-isolated anechoic chamber[10] of 8 metres in length was constructed for ComReg by MVG[11] to test a specimen of each building material in the far-field electromagnetic region[12]. A plan view of the chamber is shown in Figure 2.

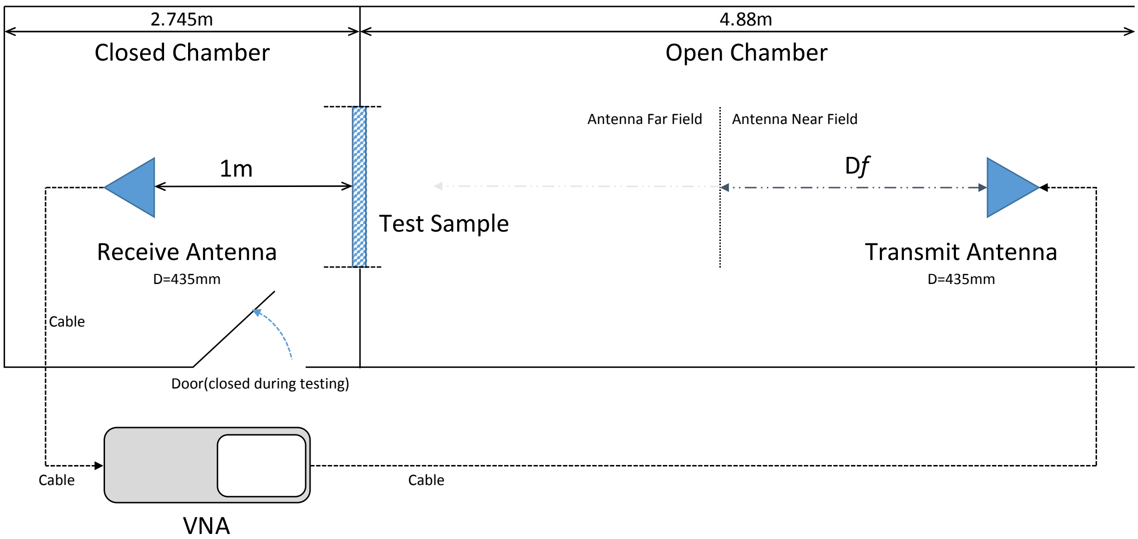


Figure 2: Plan view of 8m semi-anechoic chamber used in testing

3.4 The chamber was divided into a short 'receive' section and a longer 'transmit' section. The floor, inner walls and roof of the chamber were lined with radar absorbing material (RAM) in order to reduce unwanted reflections.

3.5 Two identical RF horn antennas with a calibrated frequency range of 400 MHz to 6 GHz were used. Each antenna was placed horizontally on an identical non-conductive antenna stand made from fibreglass and plastic. These are shown in Figure 3.

[10] An **anechoic chamber** (an-echoic meaning "non-reflective, non-echoing, echo-free") is a room designed to completely absorb reflections of either sound or electromagnetic waves.
[11] Microwave Vision Group (MVG) – http://www.mvg-world.com/
[12] The far field is the region in which the field acts as "normal" electromagnetic radiation.

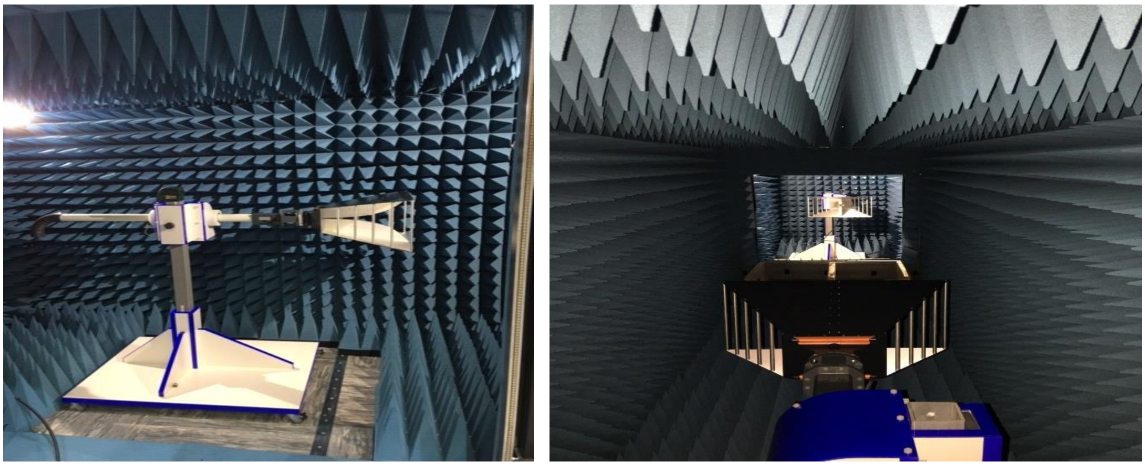


Figure 3: RF transmission horn antennas – receive (left) and transmit (right)

3.6 The antennas were placed at distances from the test sample to simulate the propagation of real-world mobile signal carriers from a distant base station through the building material before being received by an indoor mobile terminal.

3.7 For each of the building materials listed in Table 1, a test specimen was mounted in a 1-by-1m upright wooden frame placed on a wheeled base. Figure 4 shows an example of a plasterboard material installed in its wooden frame standing on a wheeled base. A sample of each building material under test was placed between the two sections of the chamber in the path from the transmit antenna to the receive antenna.

Figure 4: 1-by-1m wooden Test Frame with plasterboard insulating material mounted on a wheeled base

3.8 Both the transmit and receive antennas were connected to a Vector Network Analyser (VNA) placed outside the chamber as shown in Figure 2. The VNA generates the test signal for the transmit antenna as well as measuring the signal from the receive antenna. In doing so, it is able to measure the Scattering parameters[13] (or "S-parameters") for each test material, which provides information about the increase in loss when compared to the propagation loss due to the presence of the material sample over the Test Frequency Range.

3.9 Prior to testing each sample, each Test Frame was covered with Radar Absorbing Material as shown in Figure 5 again to limit scattered signals from it.

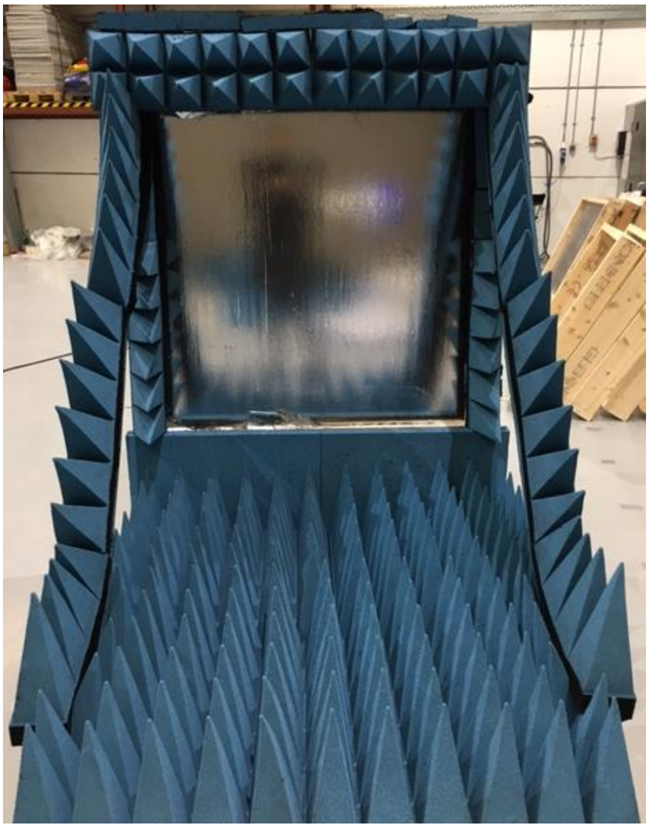


Figure 5: Test Frame covered with RAM prior to insertion into chamber

3.10 Test Frames were inserted into the chamber one at a time for testing, as shown in the example of Figure 6.

[13] Scattering parameters are a set of co-efficients which describe the output response of a linear electrical network to various input stimuli.

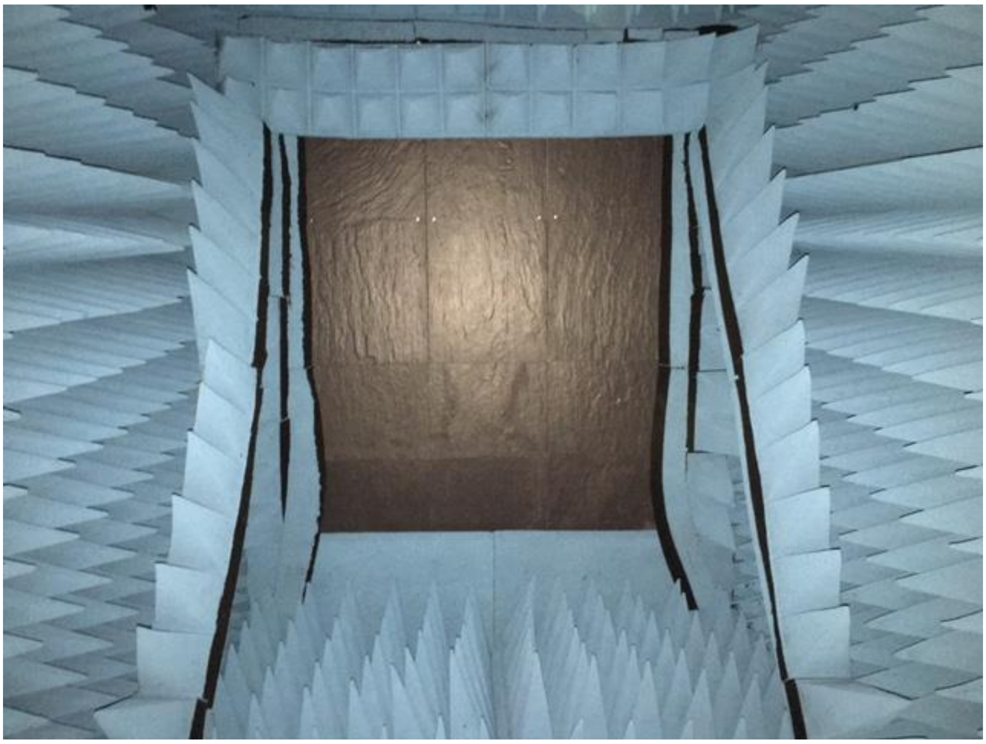


Figure 6: Test Frame containing slate roofing material in position for testing

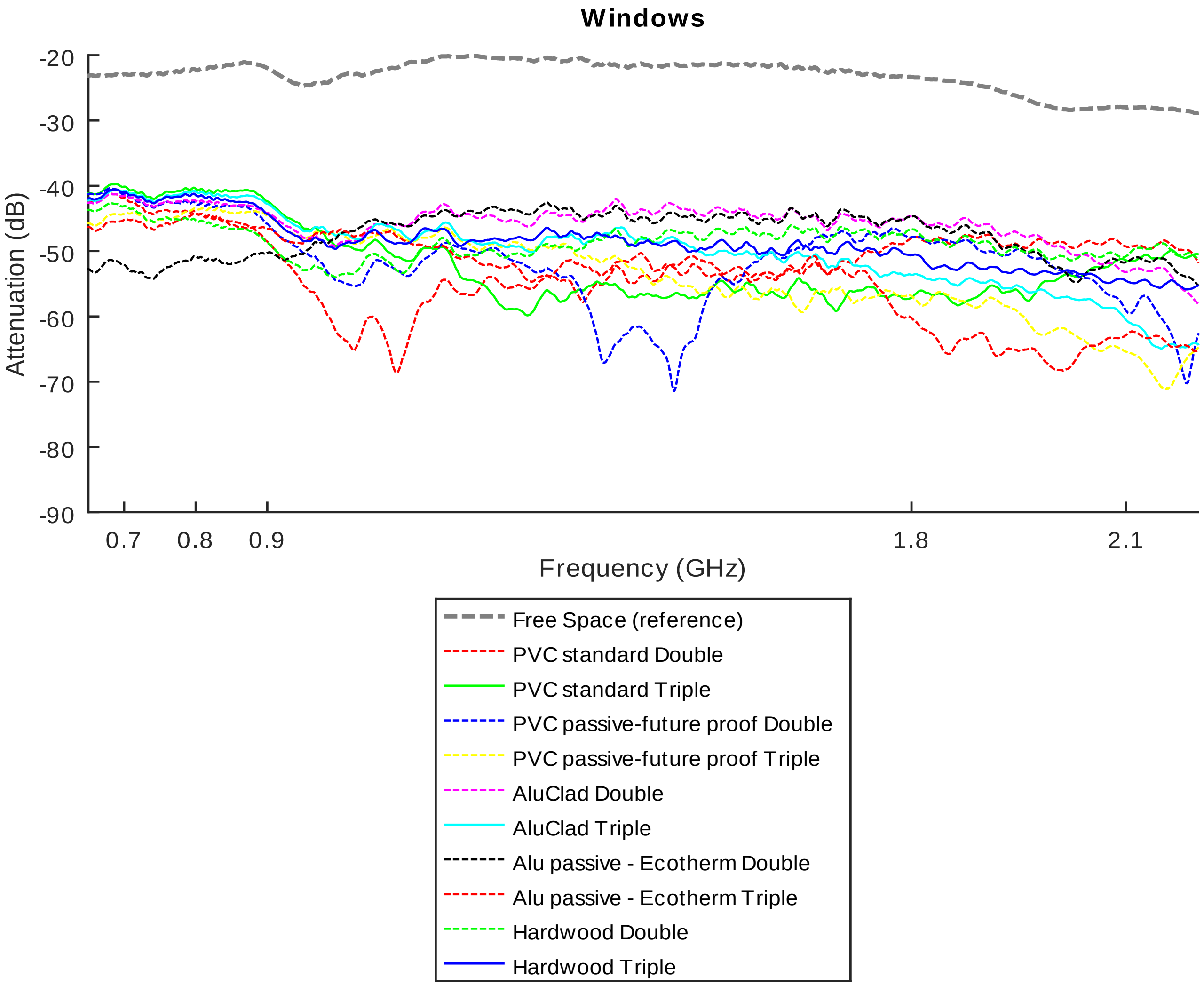
3.11 A control measurement was taken with an empty Test Frame in order to characterise the chamber and test setup, as shown on the right-hand side of Figure 3. This measurement is then used as a reference against which each building material's inserted loss can be compared. Annex: 1 lists the equipment used and provides a few examples of materials under measurement.

Chapter 4

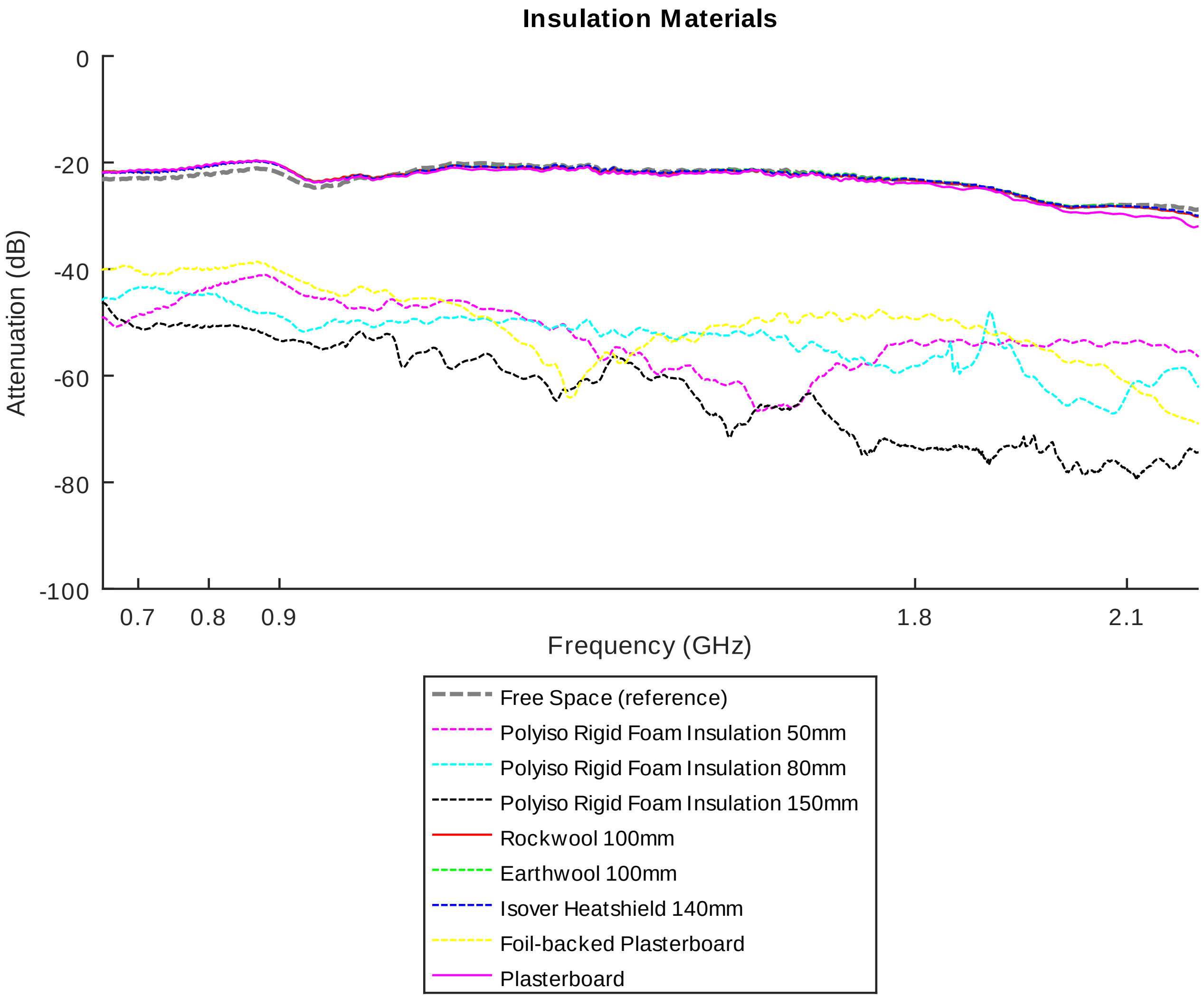
4 Results

4.1 This section presents the attenuation measurement results for each building material sample studied across the Test Frequency Range, along with a Free Space reference result for comparison in each case.

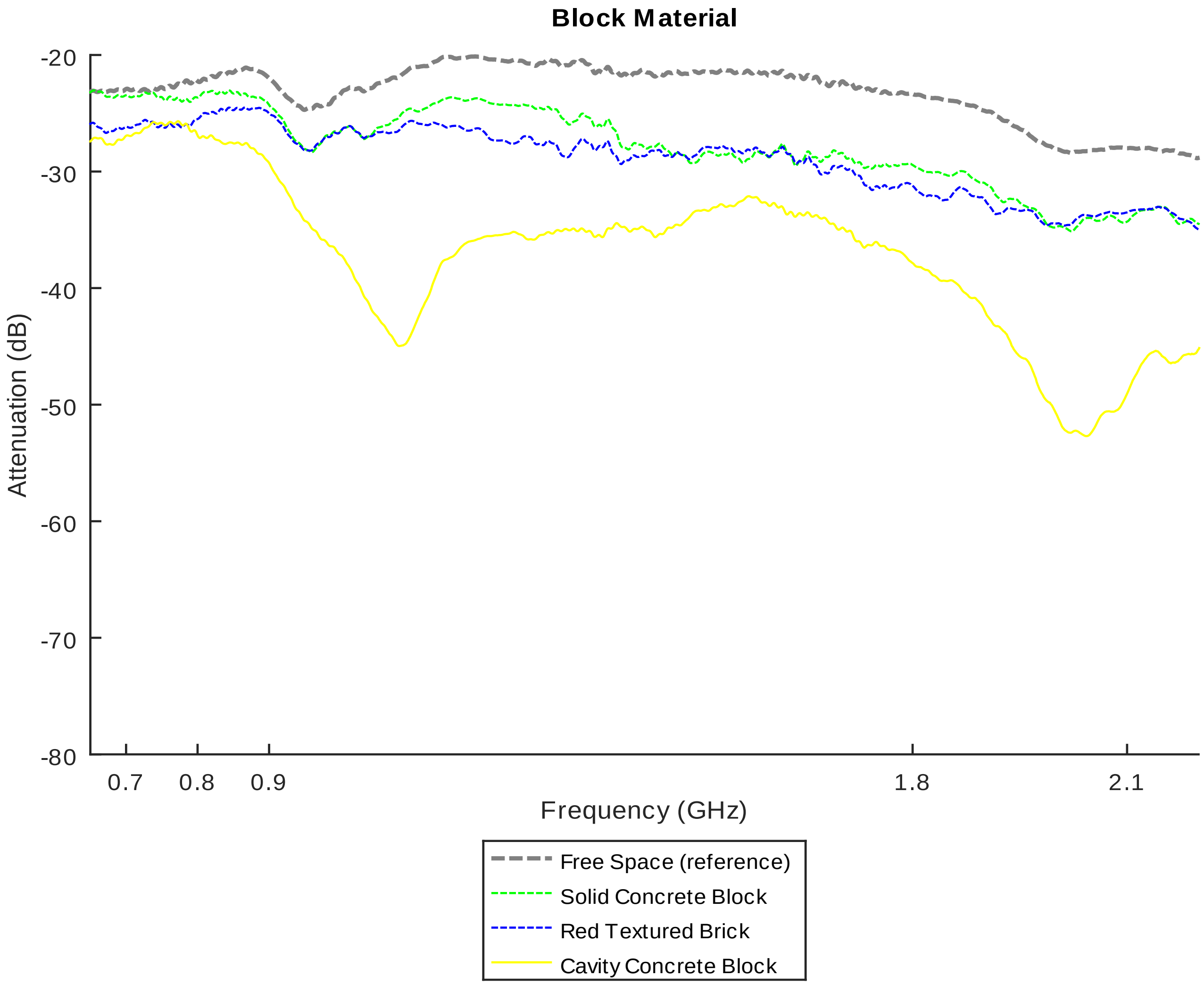
4.1 Windows


Windows
-20
-30
-40
-50
-60
-70
-80
-90
Attenuation (dB)
0.7
0.8
0.9
1.8
2.1
Frequency (GHz)
Free Space (reference)
PVC standard Double
PVC standard Triple
PVC passive-future proof Double
PVC passive-future proof Triple
AluClad Double
AluClad Triple
Alu passive - Ecotherm Double
Alu passive - Ecotherm Triple
Hardwood Double
Hardwood Triple

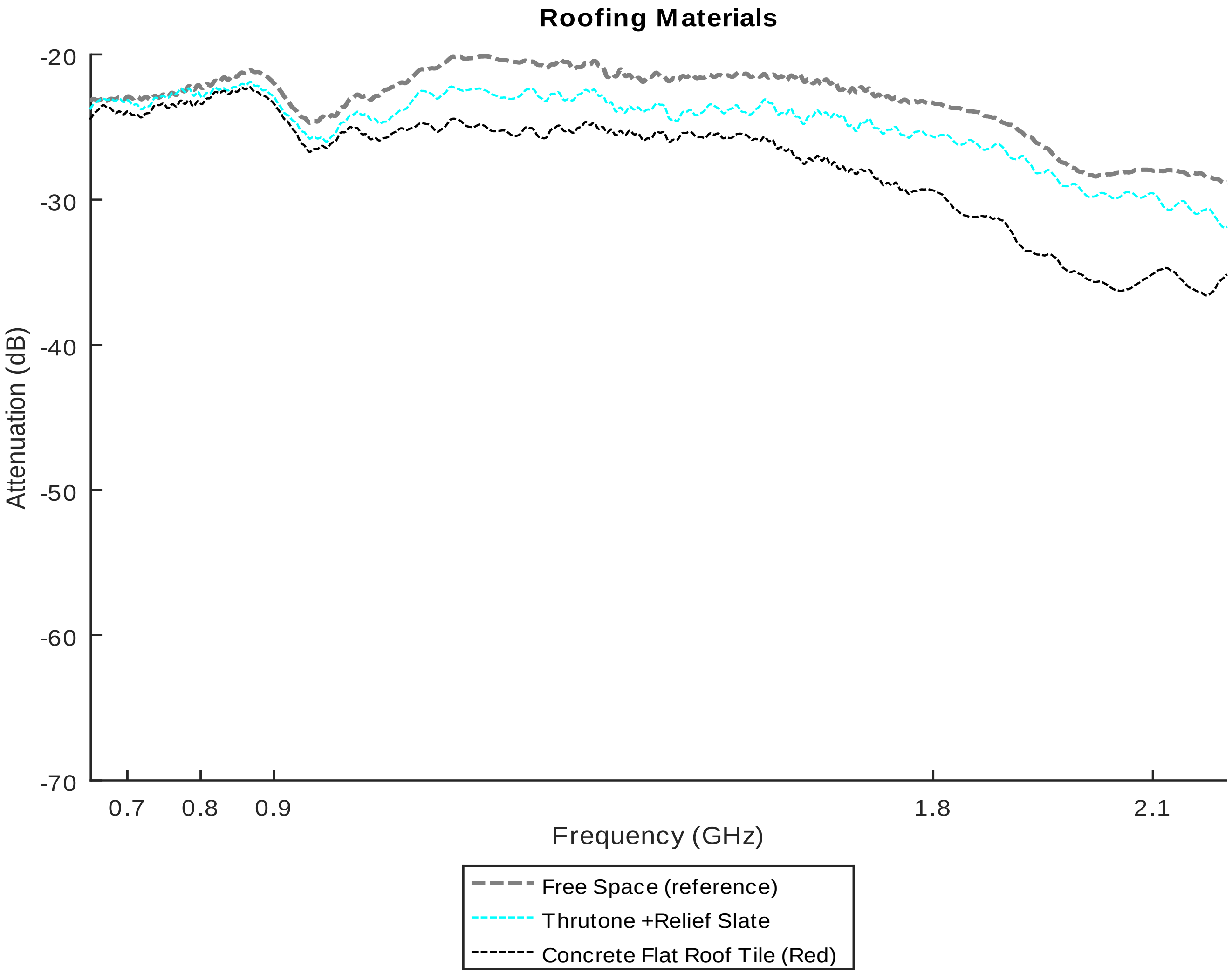
4.2 Insulation Materials



4.3 Block Materials



4.4 Roofing Materials



Chapter 5

5 Conclusions on each set of materials

Windows

- For all **window materials** tested (shown in Section 4.1) there was between 15 and 45 dB additional power loss compared to the reference loss. Losses tended to increase with frequency.

- Window frames made of **Aluminium or PVC** tended to attenuate more than window frames made from **hardwood**. **Triple-glazed** windows in some cases tended to attenuate more than windows with only two glass layers.

Insulating Materials

- Across all **insulation materials** tested (shown in Section 4.2), there was between 15 and 60 dB additional power loss compared to the reference loss. Again, losses tended to increase with frequency.

- **Insulation materials with metallic layers** tended to cause significantly more attenuation compared to materials without metallic content, such as plain plasterboard. Note for example that **foil-backed plasterboard** attenuated by up to an additional 45 dB compared to the reference loss at some frequencies, while plain plasterboard (which has no metallic layers) barely exhibited any attenuating effect on radio signals.

- As well as plain plasterboard, several other more effective heat-insulating materials (including Isover Heatshield fibreglass insulation, Earthwool and Rockwool) also exhibited negligible attenuation compared to the reference loss. These materials **provide heat insulation without significantly affecting indoor signal reception**.

- Of all the insulation materials surveyed, **Polyiso Rigid Foam** products tended to exhibit the worst radio attenuation characteristics. These are rigid boards made of a sandwich of thermoset plastic called polyisocyanurate (also known as “PIR” or “Iso”) covered with metallic foils on both the inside and outside faces. Radio attenuation increased with the thickness of the foam insulation tested, with the thickest 150mm foam causing as much as 55 dB additional attenuation at higher frequencies compared to the reference result.

Block Materials

- The **Block** materials tested (shown in Section 4.3) predominantly exhibited 5 dB of attenuation compared to the reference result, with the exception of

cavity blocks, which caused an additional 25 dB of attenuation compared to free space.

Roof Materials

- Concrete roof tiles attenuated the most of the **roofing materials** tested (shown in Section 4.4), with roughly 5 dB of attenuation at higher frequencies compared to the reference result. Overall, **roofing materials had only a small effect on radio propagation**.

5.1 In summary, the building materials which caused the most radio attenuation were those used in heat insulation (especially those with one or more foil layers) and windows (especially triple-glazed windows with aluminium or PVC frames). Roofing materials tested did not contribute significantly to radio attenuation, while of the brick materials tested only Cavity Blocks caused significant attenuation.

Chapter 6

6 Commentary

6.1 The electrical properties of the building materials tested by ComReg affect radio wave propagation.

6.2 While mobile wireless devices and usage have changed rapidly in the past few years so too have consumer expectations. Consumers increasingly expect wireless devices of all kinds to provide seamless connectivity, both outdoors and indoors. However, the voice-centric devices have now almost disappeared and the modern generation of multi-functional, multi-band smartphone devices that replaced them have typically less sensitive receivers. Consequently the consumer experience of mobile signal may not be as good as with the older voice-centric devices. This appears to have led to a broadly based public view of reducing mobile voice coverage and a growing societal frustration with the experience of services delivered by wireless means.

6.3 Research conducted by ComReg on mobile handset performance[14] for voice suggests variation in performance of up to 14 dB between handsets which means that some handsets have poorer reception than others. Our reliance on the modern generation of multi-functional, multi-band smartphone devices has inevitably advanced the regularity of their use in multiple environments, including while indoors. While modern building conventions have focused on enhancing thermal efficiency, and will undoubtedly develop further, an unintended consequence has been how the utilisation of such building materials has served to have a negative impact on indoor wireless signal delivery.

6.4 This report finds that the use of some modern building materials, in particular, those containing metals such as foil-backed thermal insulation or windows with aluminium or metallic frames can have a significant detrimental effect on the propagation of radio waves as they penetrate a building. The losses suffered by radio waves penetrating these materials is in the order of 20 up to 60 dB – that is a reduction in signal strength of 100 up to 1,000,000 times and future ComReg research may, amongst other things, consider how these materials might act in aggregate. ComReg further notes that while many consumers currently receive some level of mobile signal while indoors, this position seems likely to be further exacerbated as building and insulating materials used become even more energy efficient.

6.5 A further problem associated with providing in-building coverage is not so much the increase in the average path loss, but the great increase in the variability of path loss that must be allowed for – mobile operators and regulators are not able

[14] See Document 18/05 at www.comreg.ie. A further report on the *data* performance of the same handsets will issue shortly.

to specify one loss parameter that could guarantee indoor coverage. Therefore, depending on the chosen materials, type and age of the building and the frequency of the radio wave, the resulting total attenuation could easily be sufficient to make it impossible for mobile handsets to operate effectively. These constraints also make accurate indoor coverage predictions problematic as there could be significant room to room variation within the same building itself.

6.6 Foreshadowing the findings of this report, ComReg[15] identified a number of potential means of addressing the mobile retail consumer experience, two of which focus on the indoor reception issue:

- the use of mobile repeaters to address indoor reception issues, noting that such repeaters would have to be CE-certified and be authorised (via a licence or a licence-emption) to use the cellular radio frequencies; and

- the ability to use fixed broadband connections (e.g. native Wi-Fi calling) for the provision of mobile services (both voice and data) to address indoor reception issues.

6.7 Following a recent public consultation, ComReg is putting in place licence exemption arrangements for the general usage of mobile phone repeaters[16]. These repeaters have no restrictions on the number of operators or technologies it may service, be it single/multi-operator or single/multi-band.

6.8 ComReg has previously acknowledged that, eventually and in most instances, native Wi-Fi calling is likely to be the most effective mechanism to improve indoor reception issues. Consumers who have both an internet connection and a Wi-Fi calling enabled phone would be able to avail of Wi-Fi calling. eir is the only Irish mobile network operator (MNO) to have rolled out native Wi-Fi calling on its network and is currently adding additional supported devices to extend the reach of the service[17]. ComReg is actively encouraging all mobile service providers to follow suit and notes that Vodafone plans to launch "*VoWifi*" (Voice over Wi-Fi) during 2018, which it seems will provide a similar service for Vodafone customers[18].

Further work.

6.9 ComReg will continue to examine the overall effect of different materials on all elements of the construction of buildings and will consider how to best establish the aggregate effect of building materials on signal propagation including

[15] See section 4.2.1 of Document 16/50 at www.comreg.ie
[16] See Document 18/58 at www.comreg.ie
[17] See https://www.eir.ie/wificalling/
[18] See https://www.siliconrepublic.com/comms/vodafone-voice-lte-wifi

collaboration with other research bodies[19] who are conducting similar measurements in this regard.

6.10 In addition, ComReg will consider how it might best communicate these findings and solutions to consumers at large.

[19] Aalborg University - https://www.en.aau.dk/ and Ofcom - https://www.ofcom.org.uk/__data/assets/pdf_file/0016/84022/building_materials_and_propagation.pdf

Annex: 1 Measurement Equipment & Test Setup

Equipment Used

Equipment /Software used	Manufacturer	Model No/Version
Anechoic Chamber	Rainford EMC systems	-
Vector Network Analyser	Rohde & Schwarz	ZNB20 100 kHz – 20 GHz model
Dual Ridge Horn Antenna - Transmit	MVG	SH400
Dual Ridge Horn Antenna - Transmit	MVG	SH400
Broadband Radar Absorbing Material	MVG	Pyramidal Absorber – 80 MHz – 40 GHz
Cables	Butler Technologies	PE3650 50Ω RG214 Coax

Table 2: Measurement Equipment

Example of Materials Under Measurement – Test setup

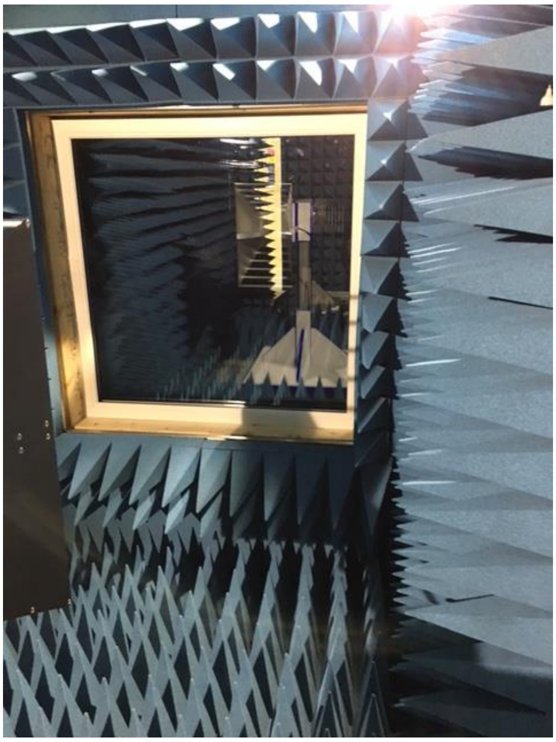


Figure 7: Test Frame containing a Window in position for testing

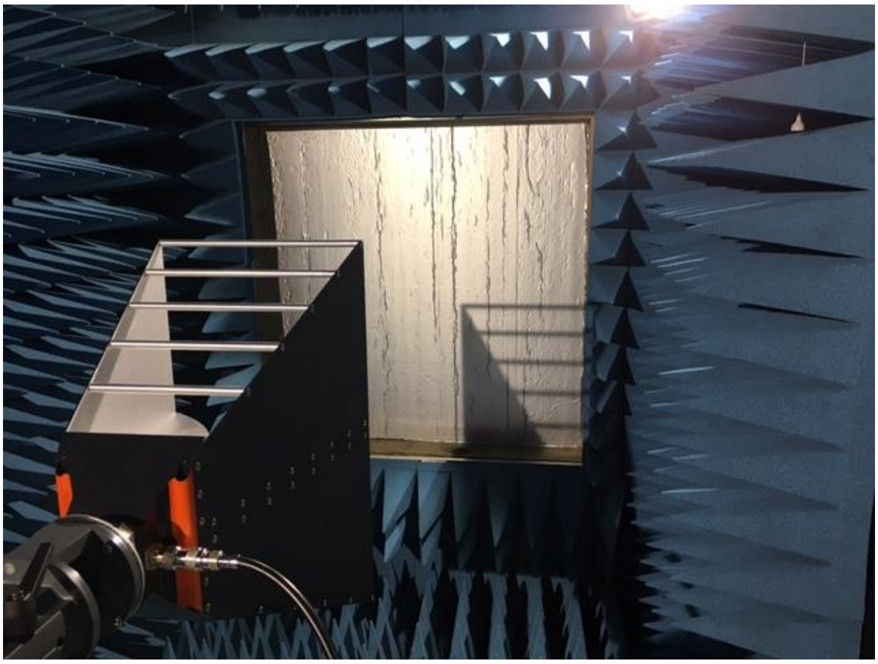


Figure 8: Test Frame containing Insulation material in position for testing

Figure 9: Test Frame containing Roofing material in position for testing

List of Abbreviations

<table>
<tr><th>Abbreviation</th><th>Explanation</th></tr>
<tr><td>dB</td><td>Decibels
Decibels is a ratio which describes change in signal strength
<table>
<tr><th>Decibels</th><th>Change in signal factor</th></tr>
<tr><td>0 dB</td><td>= x 1</td></tr>
<tr><td>3 dB</td><td>= x 2</td></tr>
<tr><td>6 dB</td><td>= x 4</td></tr>
<tr><td>10 dB</td><td>= x 10</td></tr>
<tr><td>20 dB</td><td>= x 100</td></tr>
</table>
</td></tr>
<tr><td>dBm</td><td>Abbreviation for Decibels relative to one milliwatt</td></tr>
<tr><td>2G</td><td>Second-Generation Cellular Technology</td></tr>
<tr><td>3G</td><td>Third-Generation Cellular Technology</td></tr>
<tr><td>4G</td><td>Fourth Generation Cellular Technology</td></tr>
<tr><td>CE</td><td>Conformité Européenne</td></tr>
<tr><td>EED</td><td>The Energy Efficiency Directive, introduced in 2012, establishes a set of binding measures to help EU members reach 20% energy efficiency by 2020.</td></tr>
<tr><td>EU</td><td>European Union</td></tr>
<tr><td>MNO</td><td>Mobile Network Operator</td></tr>
<tr><td>MVG</td><td>Microwave Vision Group</td></tr>
<tr><td>PIR</td><td>Polyisocyanurate</td></tr>
<tr><td>PVC</td><td>Polyvinyl chloride</td></tr>
<tr><td>RAM</td><td>Radar Absorbing Material</td></tr>
<tr><td>RF</td><td>Radio Frequency</td></tr>
<tr><td>SEAI</td><td>Sustainable Energy Authority of Ireland</td></tr>
<tr><td>EEOS</td><td>Energy Efficiency Obligation Scheme</td></tr>
<tr><td>VoWiFi</td><td>Voice over Wi-Fi</td></tr>
<tr><td>VNA</td><td>Vector Network Analyser</td></tr>
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