Background Radio noise

Update on Ofcom's long-term radio noise monitoring campaign

Report

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Summary

All electronic devices generate what is called “radio noise” in the form of unwanted random emissions that can create low level of interference to radiocommunications systems. It can be considered as a form of pollution of the radio spectrum that degrades the performance of radio receivers. The increasing use of electronic devices in everyday life means that radio noise will likely also be increasing.

It is important to quantify radio noise and understand its impact on spectrum users. This report provides an update on Ofcom’s ongoing radio noise measurement campaign. Our campaign focuses on radio noise in indoor environments, and the comprehensive approach we have undertaken makes this study the first of its kind in the UK and beyond.

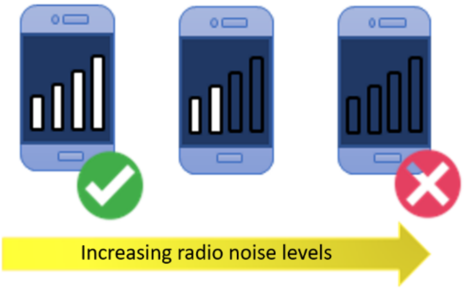
One of Ofcom’s principal responsibilities is to secure the efficient use of spectrum in the best interests of all UK consumers and enabling wireless services in the wider economy as set out in our Plan of Work[1]. This requires an in-depth understanding of spectrum use in the UK and how certain factors such as radio noise including unwanted emissions can have an impact on its quality.

What are radio noise and unwanted emissions, and their impact on spectrum users

Radio noise derives from both natural (e.g. lightning discharges, solar storms, etc.) and human-made sources[2] (e.g. ICT equipment). Unwanted emissions originate from devices that transmit information for a given service (e.g. mobile phones), but they are not the emissions we want to receive for another service.

Both radio noise and unwanted emissions can be regarded as ‘spectrum pollution’. Natural and human-made radio noise sources are not evenly distributed across the spectrum. At frequencies up to about 50 MHz, natural electric activity in the atmosphere and the noise emitted by celestial bodies such as the sun, planets and constellations are the dominant sources of radio noise while human-made sources become more prominent in spectrum above about 30 MHz.

Figure 1: Impact of radio noise



Spectrum pollution caused by radio noise, unwanted emissions, or both, is highly undesirable. It can lead to increased interference resulting in poor spectrum quality, reduced service coverage, poor quality of service and shorter battery life of devices. Most importantly, the level of spectrum pollution can directly affect the minimum signal strength needed to support the desired quality of service. More spectrum, transmit power, or both, are needed to deliver a given amount of information and the systems do not always achieve the data rates they were designed for.

Why is it important to undertake radio noise measurements

The existing information on radio noise from human-made sources is limited and out of date. Although it was studied extensively in the second half of last century, the research was limited to noise in

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[1] Ofcom's plan of work 2024/25, published December 2023

[2] Electromagnetic energy generated as a by-product of electric or electronic processes, but not intended to produce an information carrying radio signal.

outdoor environments, leaving a gap in knowledge for indoor environments where almost no information exists. Another gap is the very limited empirical evidence for spectrum above 400 MHz.

The other crucial aspect to consider is how spectrum usage and the nature of human-made radio noise have significantly changed over the last ~30 years. Advances in electronics and the near-global availability of the internet have led to the emergence of new technologies and services that share the limited spectrum. We are now much more reliant on wireless connectivity and the number of portable and handheld wireless devices has increased dramatically. Electrical, electronic, and wireless equipment have become more widespread, and they can operate at higher clock speeds and frequencies. Consequently, they are likely to contribute to radio noise across a broad range of spectrum. Therefore, it is essential to gather new empirical evidence to determine if previous assumptions about the extent of radio noise remain valid and to extend our knowledge for indoor environments and higher frequencies.

Ofcom’s radio noise measurement campaign and status

Ofcom is a long-standing contributor to the international spectrum regulatory technical work on radio noise undertaken within the radio sector of International Telecommunication Union (ITU-R) Study Group 3 (SG 3).

Figure 2: Radio noise monitoring system

In 2021, we launched a project to update research on background radio noise in the UK and to extend our previous work[3] undertaken in the early 2000s on outdoor radio noise. Recognising the lack of empirical data for frequencies above 400 MHz and in indoor environments, the project focused on developing compact, radio noise monitoring systems in-house as shown in Figure 2. These systems are designed to collect long-term data and can easily be relocated to different locations.

Measuring radio noise is a complex and technically challenging task. Sophisticated equipment is required to detect very weak emissions and advanced signal processing algorithms to distinguish background radio noise from intended signals and unwanted emissions. Another challenge arises from the necessity to consider for various noise sources, both indoor and outdoor, which can differ greatly in attributes and intensity.

This project is part of our Spectrum Roadmap[4] commitment of making more use of real-world data and measurements for better spectrum management, to authorise spectrum more easily and efficiently, and to identify causes of spectrum pollution. The results of this research will help us to update and develop new radio noise models to further enhance our technical spectrum authorisation processes and establish realistic safety margins for spectrum sharing studies, reflecting an updated view of the extent of background radio noise across different spectrum ranges.

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[3] In early 2000s, Ofcom commissioned MASS consultants for measurements of background radio noise in outdoor environments. Published paper can be found here

[4] Spectrum Roadmap, published 31 March 2022.

Our approach to radio noise measurements

We have developed six compact and sensitive radio noise monitoring systems. We have been undertaking measurements between 400 MHz to 1500 MHz across multiple locations in the UK and plan to cover more indoor and outdoor environments in future.

Our approach to outdoor measurements involves installing the monitoring system antenna at a fixed location outdoors and making repeated measurements for each frequency of interest. This enables us to capture the long-term temporal variability of radio noise in different outdoor environments. The outdoor noise levels are not expected to vary significantly over relatively short distances but do tend to change depending on the density of human-made noise sources in the environment (for example, noise sources in city centres and transport hubs versus only a few in quiet rural areas).

In indoor settings, understanding the spatial as well as the temporal variability within and across different indoor environments becomes equally important. We conduct at least one week of measurements for each frequency of interest at multiple locations covering different areas within each building. This helps us to understand how the extent of radio noise differs by building type (e.g. residential vs offices), building layout (e.g. open office vs residential spaces), building materials (e.g. modern office buildings vs residential housing stock) and, above all, the wide variety and density of noise sources in the vicinity of the monitoring location.

The indoor locations where we have conducted measurements so far include two of our offices in London and Edinburgh, our electronics lab in Baldock, and one residential setting. We have two outdoor monitoring systems, one in a rural location near our electronics lab in Baldock and the other in Wraysbury, a suburban town in the proximity (around 5 km) of London Heathrow airport.

Figure 3: Background radio noise monitoring location as of October 2024

Ofcom London Office **Ofcom Edinburgh Office** **Ofcom Baldock Office**

Residential Setting **Outdoor Rural (Baldock)** **Outdoor Suburban (Wraysbury)**

In addition, we have used measurements undertaken in controlled environment in our lab[5] to verify our approach, data processing methodology and quality assure our real-world results.

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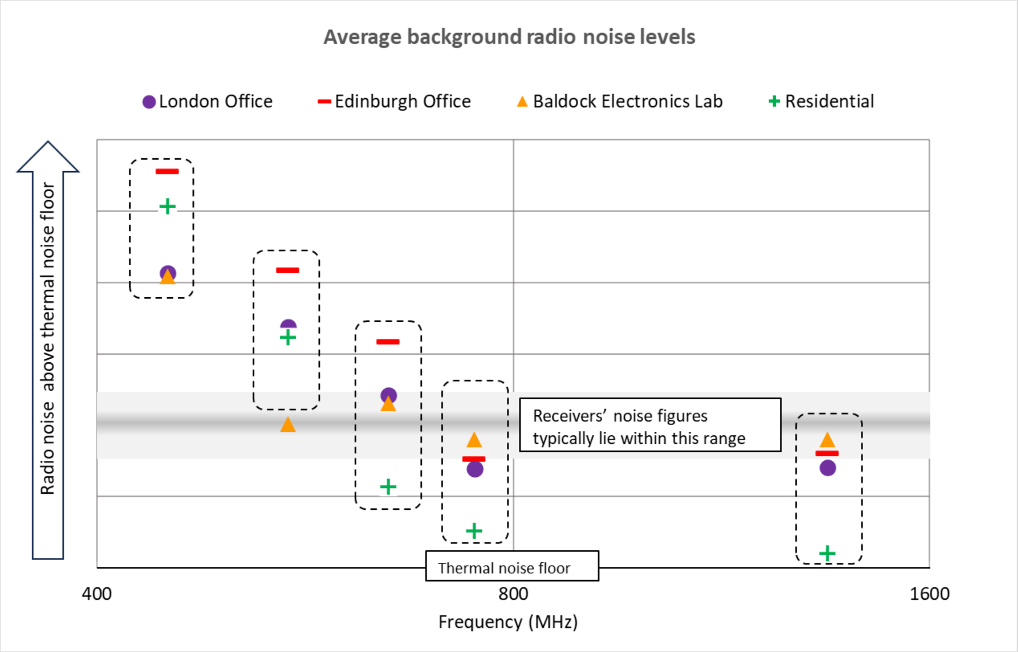
[5] Creating mock up environments (such as office) inside an anechoic chamber which ensures the radio noise results are not skewed by the local intended transmissions of radio services such as high-powered TV transmitters, mobile base stations, etc.

What we have found - in brief

The results presented in this update are based on our measurements up to September 2024. The average levels of radio noise from human made sources are presented in Figure 4. The horizontal axis provides the view of frequency bands covered while the vertical axis highlights the average noise levels at different indoor premises above the baseline thermal noise floor[6]. The grey horizontal line depicts the typical wireless equipment performance (receiver noise figure[7]) and noise levels above this are likely to impact the indoor performance of the services operating in these spectrum ranges. The blurred band reflects the fact that some equipment has better performance than others.

Figure 4: Summary of average indoor radio noise levels from human made noise sources



Indoor results:

- Our indoor results as presented in Figure 4 confirm the strong correlation between the level of radio noise and density of local devices (both in quantity and equipment quality) in each indoor environment. The level of radio noise rises with more active electronic devices and drops as the devices are switched off or become inactive.
- Our findings highlight the presence of background radio noise in all measured frequencies. The observed levels are significantly higher than what was believed to be the case from the existing limited historical information, or the levels observed outdoors.
- In general, radio noise decreases as frequency increases and beyond 1 GHz, the average levels are below the typical minimum performance of wireless equipment. However, we also note that radio noise in all locations covered so far exhibits spatial and temporal variabilities and with more active electronic devices in a location, the levels can be higher than average levels.
- Radio noise levels observed in offices and the electronics lab are in general higher than in residential premises. This can be explained by the significantly higher number of devices and computing equipment used within office spaces.

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[6] Thermal noise floor is the lowest level of noise that can be achieved in an electronic system.

[7] Noise figure is the amount of noise power added by the electronic circuitry in the receiver to the thermal noise power (noise floor). This noise is present in the receive channel and cannot be removed.

- During office hours, when more devices are active, the average levels are observed to be twice as high as in non-office hours.
- In residential settings, as expected, the radio noise levels are again significantly higher in spaces with more active electronic devices such as living rooms and home office areas and lower in spaces used less frequently.

Outdoor Results:

- We found negligible background radio noise in frequencies above 400 MHz in both the measured outdoor environments (rural and suburban).
- The low levels of radio noise are expected as there are very few noise sources in the two locations. In our rural settings, there are overhead power lines and a dual carriageway within 500 m. In our suburban settings, although the site is very close to a busy airport, there are only a few potential noise sources in proximity to our monitoring station.
- The results confirm the findings of previous 2003 Ofcom's funded measurement campaign which observed similar insignificant levels in rural and suburban settings.

Next steps

We have developed advanced facilities for conducting radio noise measurements supported by a robust methodology to quantify its extent and impact. Our forward-looking plans include:

- Monitoring more indoor residential premises, businesses, and commercial centres to have a robust and stable view of the extent of radio noise. We may also cover busy outdoor environments, such as city centres and transport hubs to compare the results with those from quieter rural and suburban areas already covered in the campaign.
- Revisiting some of the indoor locations after a gap of six months to a year or more to understand the evolution of radio noise over longer time period.
- We will continue to make regular technical contributions by submitting our findings and data to the ITU-R SG 3 as part of our international technical spectrum management framework. The results of this research project will help to update "Recommendation ITU-R P.372 - Radio noise[8] with the inclusion of models to predict the extent of radio noise in indoor environments. We envisage this work to be completed by 2026.

The rest of the report is structured as follows:

- **Section 1: Introduction:** We start with a brief introduction to radio noise, its constituents, and characteristics. We also provide a gap analysis of existing state of art and the motivation for our measurement campaign.
- **Section 2: Ofcom's radio noise measurement campaign** explains the monitoring systems we are using and our approaches for measuring different radio noise components. We also provide more information about our measurement environments.
- **Section 3: Analysis and results:** We share our results and findings for all four indoor premises, i.e. Ofcom's London and Edinburgh offices, Electronics Lab at Baldock and one residential setting. We also briefly cover the results of the two outdoor monitoring sites.
- **Section 4: Conclusions and next steps** provide our remarks on key findings and lists the next steps we will be undertaking to conclude our work.

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[8] Recommendation ITU-R P.372 Radio Noise, https://www.itu.int/rec/R-REC-P.372-14-201908-I/en.

Introduction

1.1 Radio noise and unwanted emissions are the primary contributors to spectrum pollution and their significant presence can reduce the quality of received signals. Given its importance and implications on efficient use of spectrum, we have consistently aimed to understand and quantify the extent and impact of spectrum pollution in the UK.

1.2 Recognising the lack of empirical evidence for frequencies above 400 MHz, especially in indoor environments, we launched a project in 2021 to revitalise research on the extent of radio noise in the UK. The project's aim is to establish a long-term, in-house radio noise monitoring and analysis capability to help us:

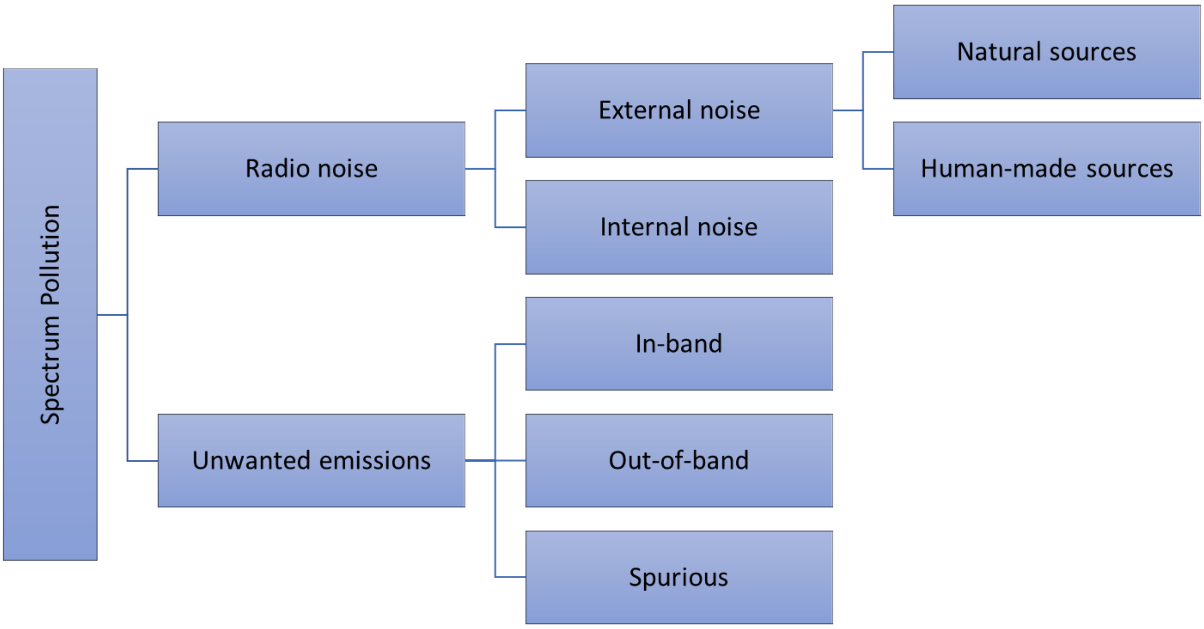
a) **Establish realistic reliability margins** for spectrum sharing studies, reflecting an updated view of the extent of background radio noise across different spectrum ranges and the extent to which it is already affecting services.

b) **Enhance spectrum quality** by refining agreements on unwanted emission and authorising spectrum use more efficiently.

c) **Refine parameters** used in predicting and reporting mobile, broadcast and other services' coverage.

1.3 We note the terms "spectrum pollution", "ambient electromagnetic noise" and "electromagnetic interference" are often used interchangeably in the technical literature. In Figure 5, we provide a generic classification of the terminology used in this report. Unless otherwise stated, the focus of our monitoring project is on "radio noise" from human-made sources along with unwanted emissions (excluding in-band transmissions) that exhibit similar characteristics to noise from human-made sources. We refer to all of this as "radio noise" in this document.

Figure 5: **Spectrum pollution and its generic classification**



Radio noise

1.4 Every wireless equipment experiences radio noise, which can either be internal or external to the device. Internal radio noise is partly due to thermal vibrations of the component molecules and also from imperfections. Thermal noise can be controlled by operating a device at a low temperature (e.g. liquid helium for astronomy), which is generally impractical for most terrestrial equipment. The operation of any device also adds noise, though high-quality components and good design can keep it to a minimum level (Noise Figure[9]).

1.5 External radio noise derives from natural sources (such as aurora borealis, solar storms, lightning discharges, etc.) and human-made sources (e.g. electrical and electronics equipment, machinery, power transmission lines, ICT equipment, etc).

1.6 Radio noise from human-made sources is believed to be increasing. Up to the late 1970s, the most important sources of noise were automotive, power transport, power generating facilities, lighting systems, consumer appliances and industrial equipment; predominantly impacting the frequency bands below 400 MHz. While technological improvements have since led to lower noise emissions from these sources, the proliferation of new radio and other equipment are now believed to be contributing to radio noise.

1.7 Recent evidence suggests that use of spectrum and electronic and wireless devices increased exponentially over the years. Outdoors, there is a surge of transmitters, solar panels, wind generators and electric vehicle charging points. LED lighting (but not all) is a known source of noise in indoor environments, in addition to the ever-increasing use and number of computers, monitors, set-top boxes, broadband routers, televisions, switching power supplies, chargers, and similar always-on electronic equipment. The clock speeds of processing units in computers, tablets and mobiles have improved from Hz to GHz range; all sources of unwanted noise and in frequency bands previously considered to have little or no radio noise from human-made sources.

1.8 The use of Internet of Things (IoT) services and billions of connected devices will further change the spectrum use and quality landscape, with wireless chips and sensors becoming common in almost everything from door locks to light switches, smart metering of energy use, kitchen appliances and vehicles. Each of these sensors will be a potential source of radio noise.

Unwanted emissions

1.9 Unwanted emissions derive from devices that transmit information (e.g. mobile base stations, TV transmitters, mobile phones, etc.) but they are not the emissions we want to receive for the intended services. For example, a device operating in a neighbouring frequency to a transmitter may experience the transmitter's in-band and out-of-band unwanted emissions as illustrated in Figure 6.

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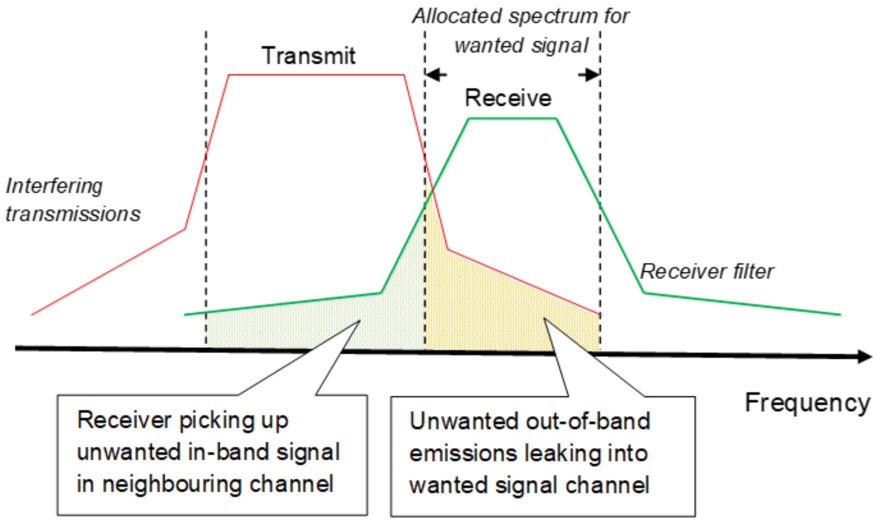
[9] Noise figure is the amount of noise power added by the electronic circuitry in the receiver to the thermal noise power (noise floor). This noise is present in the receive channel and cannot be removed.

1.10 There are other types of unwanted emissions. For example, unwanted emissions occur because frequencies can combine to create a ‘product’[10] at another frequency, which may happen to fall into spectrum allocated for the wanted signal.

Figure 6: Illustration of in-band and out-of-band unwanted emissions



Radio noise characterisation

1.11 Radio noise from human-made sources can be formally defined as[11] “*the aggregated unintended radiations from individual or multiple electrical and electronic equipment and machinery; that do not originate from the intended use of the radio communication transmitters in a given frequency band*”. Spurious and weak out-of-band emissions from radio systems can be part of the aggregated noise level received as these emissions exhibit similar characteristics as unintended radiation.

1.12 In the absence of a dominant single noise source, radio noise and unwanted emissions often exhibit a normal distribution and can be regarded as white Gaussian noise. However, some noise sources emit impulses or single carriers, and this leads to the following broad categorisation of noise generated by human-made sources.

a) **White Gaussian Noise (WGN):** Wideband noise with a flat power spectral density over a large frequency range with the characteristics approaching additive white Gaussian noise.

b) **Impulsive Noise (IN):** Short duration noise which appears as peaks in the time domain but can span large bandwidths in frequency.

c) **Single Carrier Noise (SCN):** Noise with frequency-dependent characteristics and can appear as a single or multiple-carrier, peak or multiple peaks in the frequency spectrum.

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[10] Intermodulation products occur due to the non-linearity of receivers. Signals of different frequencies combine to produce artefacts or peaks in other frequencies than the frequencies of the intended signals.

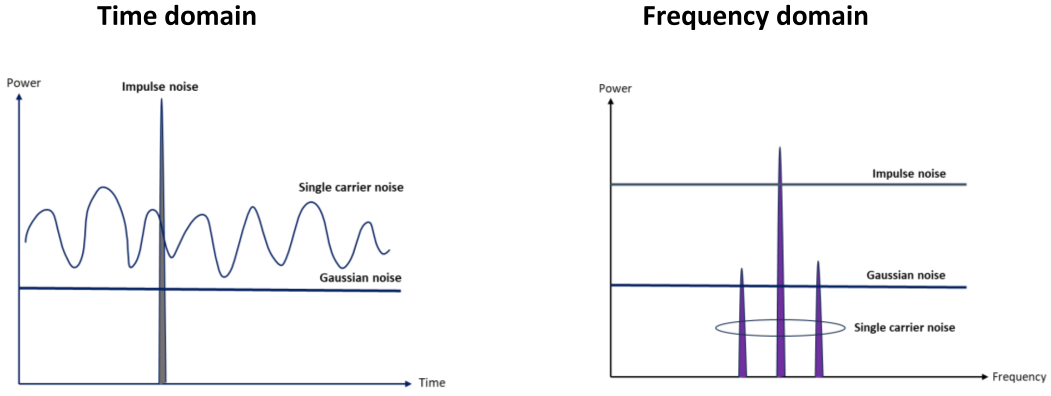
[11] Recommendation ITU-R P.372 Radio Noise, https://www.itu.int/rec/R-REC-P.372-17-202408-I/en.

1.13 Each component of radio noise exhibits different characteristics in both the time and frequency domain as illustrated in Figure 7. The level of WGN component scales with bandwidth and can be quantified using relatively simple approaches such as the root mean square (rms) level of received ambient noise power[12] in small bandwidths of 1- 2 MHz. However, WGN levels can vary over time, requiring long-term measurements to capture daily, weekly or seasonal activity of human made noise sources.

1.14 The levels and characteristics of IN and SCN components are best captured by raw sampling methods[13]. Large bandwidths, typically comparable to those of radio services, are required as IN, in particular can span very large bandwidths in the frequency domain.

1.15 The IN component is further classified into Class A and B based on the bandwidths used by typical receivers. Class A noise or interference is defined as spectrally comparable to or narrower than the receiver bandwidth considered (e.g. intra/inter system out-of-band emissions). In contrast, Class B noise is broadband compared to the receiver bandwidth and typically consists of short duration impulses that are wideband in frequency.

Figure 7: An illustration of radio noise components in time and frequency domain



1.16 In an environment, radio noise can be a combination of WGN and IN/SCN components with the dominant type depending on the intensity and distance of the sources. In indoors, it is likely that multiple noise sources are present in smaller confined spaces as compared to outdoors, resulting in a mix of WGN, IN and SCN and all three superimposed.

1.17 The characteristics of radio noise was extensively studied in the second half of last century most notably by Middleton[14,15], which is considered a comprehensive theory on this subject, providing a mathematical framework that describes the physical processes behind noise

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[12] The root mean square (rms) level of radio noise is a measure of the average noise power measured by the receiver over the resolution bandwidth of the receiver. Modern receivers can usually compute and display/export the rms levels.

[13] A signal consists of an amplitude and a phase which varies with time and can be represented by the in-phase (I) and quadrature (Q) representation. Typically, in digital receivers, the received input is separated in the I and Q components and sampled to create a digital representation of the signal. This is known as IQ sampling. From the IQ data, further processing may be performed to determine, e.g. the rms level.

[14] D. Middleton, "Man-Made Noise in Urban Environments and Transportation Systems: Models and Measurements," in *IEEE Transactions on Communications*, vol. 21, no. 11, pp. 1232-1241, Nov 1973.

[15] D. Middleton, "Statistical-physical models of man-made and natural radio-noise, Part I, II and III" Office of Telecommunications and NTIA Reports, 1975 -1978.

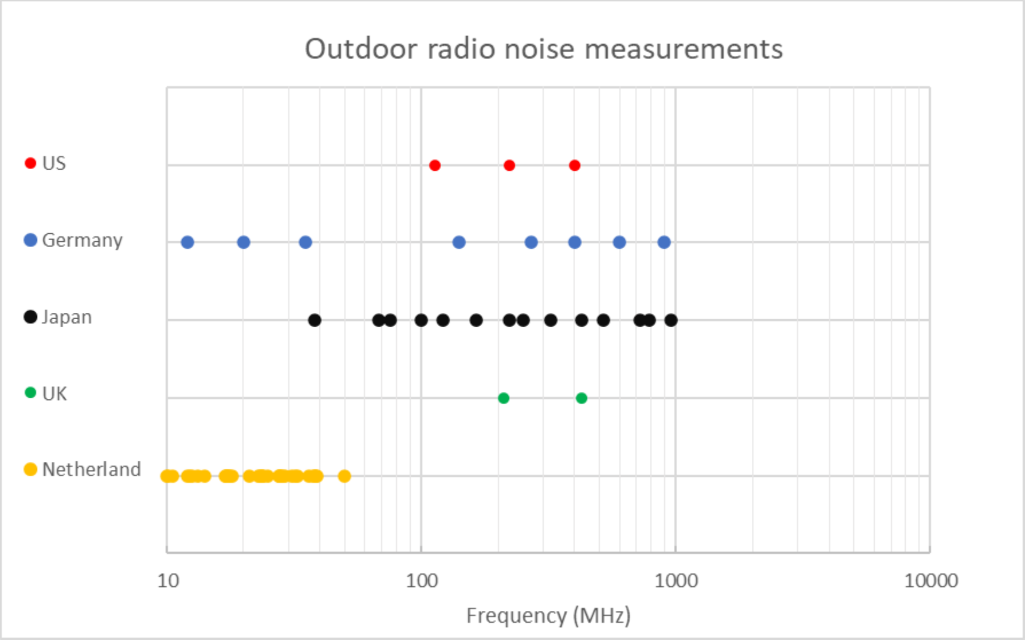
generation. It also outlines parameters for describing noise environment, such as density of noise sources and aggregation of total noise at a specific location in an environment.

Current state of the art on radio noise

1.18 Recommendation ITU-R P.372[16] of ITU-R SG 3 provides information on the background levels of radio noise from all sources in the frequency range from 0.1 Hz to 100 GHz. It takes account of noise emitted by lightning, atmospheric gases, clouds, rain, the Earth's surface, the galaxy, and human-made sources. The Recommendation provides noise figures or noise temperatures to estimate the impact of different sources of noise on system performance.

1.19 Part 6 of ITU-R P.372 covers radio noise from human-made sources and provides an outdoor noise model based on measurements undertaken in the second half of the last century. The predominant outdoor sources back then were noise from automotive engine ignition, power generators, etc. that do not exist anymore, or the technology has evolved in similar systems used today. Figure 8 provides a summary of limited underlaying empirical data and the monitored spectrum from across the world[17] that has been used for the development of outdoor noise model of ITU-R P.372.

Figure 8: Radio noise measurement campaigns underpinning ITU-R P.372 outdoor noise model



1.20 For indoor environments, ITU-R P.372 acknowledges the insufficient availability of measurement data to describe the expected levels of indoor radio noise and only a few indicative values are provided for two frequencies (210 MHz and 425 MHz) based on the measurements in Europe between 2005 and 2007.

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[16] Recommendation ITU-R P.372 Radio Noise, https://www.itu.int/rec/R-REC-P.372-17-202408-I/en.

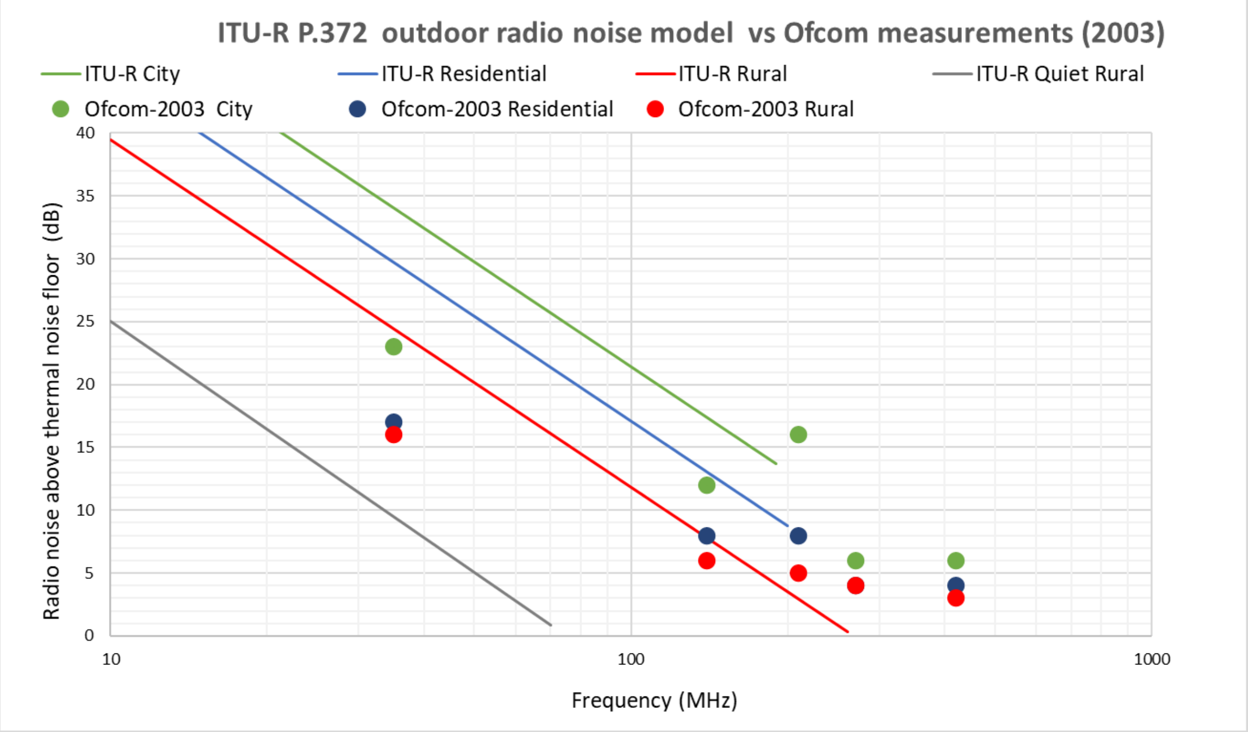
[17] Witvliet, B.A., "Gap Analysis of Ambient Electromagnetic Noise Measurements Stored in the ITU Data Banks", Sensors 2024, 24, 6832. Published paper can be found here

1.21 Ofcom has been a long-standing contributor to the international spectrum regulatory technical work on radio noise undertaken within ITU-R SG 3. In 2001, Ofcom (then the Radiocommunications Agency) commissioned MASS consultants to measure background radio noise levels in the UK[18]. Measurements were conducted at eight outdoor locations, with an average of one full day of measurements at each site, ranging from quiet rural environments to busy city centres. The study also considered the IN components of radio noise in bandwidths up to 10 MHz but noted that WGN generally dominated in the outdoor environments.

1.22 The methodology adopted was similar to work carried out by NTIA in 1998[19] but extended to frequencies between 100 MHz and 3 GHz. The measurement data and results of the study were submitted to ITU-R SG 3 in 2006 highlighting significantly higher levels of outdoor radio noise measured in the UK for frequency bands up to 400 MHz as compared to the predictions of ITU-R P.372 model.

1.23 Figure 9 compares the ITU-R P.372 prediction model (coloured lines) and Ofcom's 2003 measurements (dots), showing increased outdoor radio noise levels above 200 MHz than the prediction method even back in 2003. Extrapolating ITU-R P.372 model would suggest that radio noise from human-made sources has no impact beyond 400 MHz and the levels should be below the thermal noise floor. However, the 2003 measurements in the UK may better represent the current noise environment, as they include sources not available or not commonly used in the 1960s.

Figure 9: Comparison of ITU-R P.372 prediction method with Ofcom`s 2003 measurements



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[18] A. Wagstaff and N. Mericks, "Man-made noise measurement programme", in *IEE Proc. on communications*, vol. 152, no. 3, June 2005. Published paper can be found here

[19] NTIA Report 98-355, "Man-made noise in the 136 to 138 MHz VHF Meteorological Satellite Band", Sep. 1998

1.24 The other two relevant ITU-R recommendations on radio noise are ITU-R SM.1753[20] and ITU-R SM.2093[21] which cover measurement methods and the representation of radio noise for outdoor and indoor environments, respectively. These Recommendations were developed to provide consistent and frequency-independent measurement methods and data analysis processes, ensuring comparable and reproducible results across different measurement systems and campaigns.

1.25 The guidance provided in ITU-R SM.1753 and ITU-R SM.2093 forms a solid foundation for understanding the technical challenges associated with radio noise measurements and processing. However, further work is needed to update these recommendations to offer consistent guidance on key approaches and processes required to capture the temporal and spatial variability of radio noise.

1.26 In summary, the current empirical data on radio noise from human-made sources is outdated, especially for frequency bands above 400 MHz. Given the rapid evolution of the radio landscape, where electrical, electronic, and wireless devices have become more prevalent and operate at higher clock speeds and frequencies, it is likely that these devices contribute to unwanted emissions across a broad range of frequencies well above 400 MHz.

1.27 Ofcom’s long-term monitoring campaign, initiated in 2021, aims to collect updated empirical evidence to help revise and develop new radio noise models. This will enhance our technical spectrum authorisation processes and establish realistic margins for spectrum sharing studies, reflecting a current understanding of background radio noise.

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[20] Recommendation ITU-R SM.1753, Methods for measurements of radio noise

[21] Recommendation ITU-R SM.2093, Methods for measurements of indoor radio environment

Ofcom’s radio noise measurement campaign

2.1 This section provides details on Ofcom’s background radio noise measurement campaign. As part of our efforts to establish the recent trends of radio noise levels in different indoor and outdoor environments in the UK, we have trialled, tested, and developed appropriate measurement approaches, systems, and methodologies for data analysis.

White Gaussian Noise measurement system

2.2 For the White Gaussian Noise (WGN) component, we have developed six compact monitoring system capable of automated data collection over long duration, allowing us to observe both spatial and temporal variations. We undertake measurements in small bandwidths in the range of 1-2 MHz in unoccupied or predominantly free spectrum. Our journey towards developing compact WGN monitoring systems and the technical specifications is covered in Annex A1.

2.3 Another important aspect of our WGN monitoring framework is the data analysis methodology. This involves measurements processing, applying various corrections and removal of data that may not correspond to WGN. Complete technical details on our approach are covered in Annex A2.

Impulse and single carrier noise measurement system

2.4 IN spans over large bandwidths, and to quantify its impact on current radio services it is essential to take measurements in bandwidth comparable to or larger than those used by the radio services.

2.5 The guidance in current ITU-R recommendations is outdated, suggesting measurement bandwidths of 1-2 MHz for IN characterisation. This approach may be appropriate for services operating in bands such as HF (3-30 MHz) that employ bandwidth in fractions of MHz. However, current and emerging services such as 5G and upcoming 6G networks, use and will deploy bandwidths of 100 MHz or more in the spectrum below 6 GHz, and even wider bandwidth for mmWave bands.

2.6 Another main challenges with the radio noise measurements in real world environments is to ensure that results are not impacted by the emissions from radio services or non-radio noise sources. Data processing methods can be developed to separate intended emissions from the radio noise however, such approaches do not always guarantee the complete elimination or separation of radio noise from intended transmissions, given the numerous and time variant transmissions modes of radio services.

2.7 Finding free or unoccupied spectrum in the order of tens of MHz is nearly impossible in urbanised environments and it is highly likely that radio noise measurements will capture intended transmissions. This makes the use of controlled environments (e.g. screened rooms, Faraday cages, anechoic chambers, etc.) very attractive for undertaking radio noise measurements and quality assure results from real-world environments.

2.8 We are conducting IN/SCN measurements in an anechoic chamber at our Baldock electronics lab with a signal and spectrum analyser[22] and using the same wideband passive antenna as employed by our WGN monitoring systems.

2.9 We have also assessed various noise sources (LED lights, ICT equipment) to understand the impact of bandwidth on IN characterisation. Our findings indicate that larger bandwidths, well above 1-2 MHz, are essential. Measurements taken over smaller bandwidths risk missing sufficient IN components for proper characterisation. We are considering a bandwidth of 80 MHz for our IN/SCN measurements. Additionally, we can generate results for smaller bandwidths (such as 1 MHz or 10 MHz) to compare against the 80 MHz results.

Measurement approach and locations

2.10 Our approach to undertake outdoor WGN measurements involves installing the monitoring system antenna at a fixed location outdoors. Continuous measurements are made for each frequency of interest enabling us to capture the long-term temporal variability of radio noise in different outdoor environments.

2.11 For WGN, we undertake measurements over small bandwidths between 1-2 MHz split across several channels with each channel having a resolution bandwidth of less than 200 kHz. This approach helps in the post processing of data to identify and eliminate non-WGN components, including occupancies by radio services which varies in time and frequency, especially if the measurements are made in partially occupied frequency bands.

2.12 The outdoor noise levels are not expected to vary significantly over relatively short distances or durations but do tend to change depending on the density of human-made noise sources in the environment, such as more noise sources in city centres, transport hubs versus only a few in quiet rural areas.

2.13 In indoor settings, understanding the spatial as well as the temporal variability of radio noise within and across different indoor environments becomes equally important. We conduct at least one week of measurements for each frequency of interest at multiple locations covering different areas within each building.

2.14 This method allows us to determine how radio noise differs by building type (e.g. residential vs offices), building layout (e.g. open office vs residential spaces), and building materials (e.g. modern office buildings vs residential housing stock). Additionally, it helps us to assess the impact of the variety and density of noise sources near the monitoring location.

2.15 For IN/SCN components, as explained, measurements in controlled environment may be the most practical approach. However, we acknowledge that this method may not fully capture the complexity of real-world environments, where a variety of noise sources are present.

2.16 Another advantage of controlled environment measurements is that they enable us to quality assure and benchmark our real-world results ensuring the robustness of our approach and the reliability of our data processing methodology.

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[22] FSW signal and spectrum analyzer

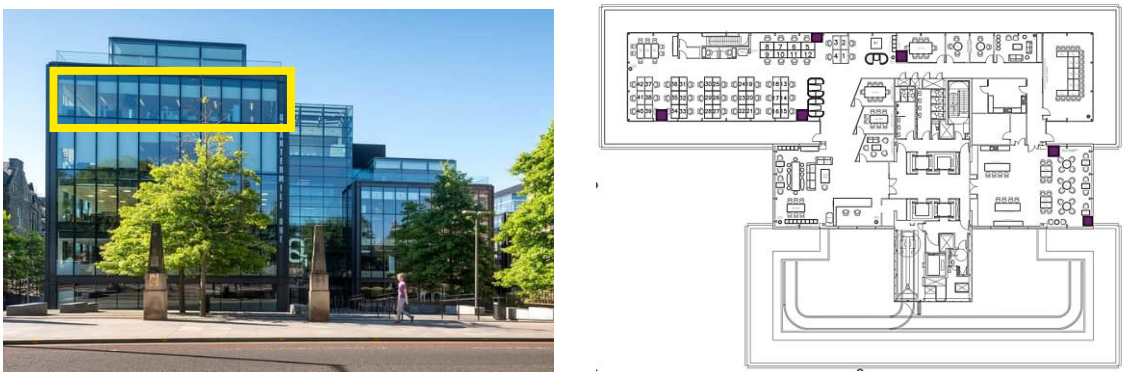
Indoor environments

2.17 The premises where we have conducted measurements so far include our two offices in London and Edinburgh, our electronics lab in Baldock and one residential setting. In Figure 10 and Figure 11, pictures and floor plans of the premises are provided.

Figure 10: Indoor offices and lab premises. The locations where WGN monitoring system was placed within each premises are highlighted with purple markers on the floor plan

London Office

Edinburgh Office



Baldock Electronics Lab

Indoor 1- Office environment - London

2.18 We have been conducting measurements on the 3rd floor of our London office since November 2022. This office is representative of a typical open-plan office buildings in many cities of the UK. It is a multistorey, modern concrete building with large thermally efficient windows with an average attenuation of at least 20 dB for frequencies up to 6 GHz. This reduces the risk of outdoor signals in adjacent bands interfering with our indoor measurements. So far, we have collected data across numerous distinct locations (workstations, meeting rooms, open meeting spaces, etc.) and are also revisiting previously measured locations with a gap of six months or so to identify any noticeable changes to the level of radio noise.

2.19 The measurement locations we have selected are partly based on the practicality of leaving the monitoring equipment at that location for the duration of the measurements which is about at least one week. We have captured multiple scenarios with varying distances between the monitoring system and observable electronic equipment, workspaces, boundaries of the building and areas of busy office activity.

Indoor 2- Office environment- Edinburgh

2.20 One of the WGN monitoring systems has been recently located in Ofcom’s office in Edinburgh (since May 2024). This office has similar construction and material properties to our London office however the open plan layout differs in terms of workstation spaces, meeting areas, etc.

2.21 The comparison of results from London and Edinburgh office allows us to understand the variability of measured radio noise in very similar settings such as building type, construction material, similar noise sources (ICT equipment) and activity periods.

Indoor 3-Electronics Lab environment- Baldock

2.22 We have conducted measurements in three areas of our lab at Baldock.

a) **RF Electronics Lab:** A specialised workspace for test and measurement systems operating in the range of 3 kHz to 100 GHz. The layout of the lab includes workstations and multiple benches with a semi-anechoic chamber adjoined to it. The workstations have multiple ICT devices similar to our London and Edinburgh offices. The benches typically have RF equipment such as spectrum analysers, signal generators, amplifiers, antennas and power meters. On a typical workday, there are three to four systems in operation, each consisting of multiple RF and/or ICT equipment.

b) **Spectrum Monitoring Centre:** This area houses RF surveillance, monitoring and analysis equipment and is always in operation. The equipment rack contains tens of receivers, spectrum analysers, signal processors, servers and network switches.

c) **Meeting room:** Typical of any other meeting room in offices with audio/video conferencing systems

Indoor 4- Residential Setting

2.23 In residential settings, our approach is to collect data in rooms representative of a typical residential environment in the UK. We intend to take measurements in a number of premises to help us better understand and model the levels of radio noise observed in such environments. So far, we have conducted measurement in the following areas of a two-storey detached property as shown in Figure 11.

a) **Living Room** contains multiple RF emitting devices such as an audio/video surround system. Mobile phones, and laptops are often in simultaneous use during activity periods.

b) **Utility Room** has several operational electrical appliances that are in continuous or routine operation including a large fridge-freezer, freezer, washing machine and microwave oven.

c) **Kitchen/Dining Room** is an open-plan layout and contains electrical appliances such as a microwave, kettle, and convection oven, TV and set top boxes, etc.

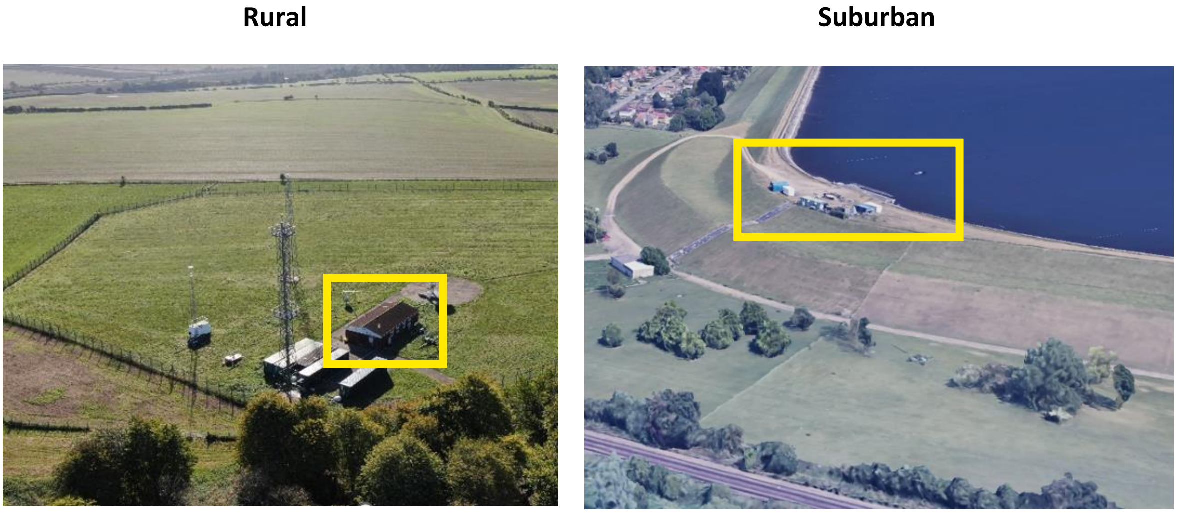
d) **Entertainment/Music Room** contains various musical instruments, audio systems, other portable electronic and ICT devices.

Figure 11: WGN monitoring in a residential setting

Outdoor environments

2.24 We have two outdoor monitoring systems, one in a rural location near our electronics lab in Baldock and the other in Wraysbury, a suburban town in proximity (around 5 km) of London Heathrow airport. The yellow bounding boxes in Figure 12 show the location of outdoor monitoring units.

Figure 12: Outdoor rural and suburban monitoring environments



Rural

Suburban

Controlled measurements in anechoic chamber

2.25 We are also conducting controlled radio noise measurements in an anechoic chamber at our Baldock electronics lab that allow us to:

a) Quantify the extent of background radio noise under controlled conditions, ensuring that measurements are not affected by general intended use of spectrum such as signals from high-powered TV transmitters, mobile base stations, and other radio services.

b) Verify our WGN measurement approach, data processing methodology and its ability to remove non-WGN components, and quality assure our results from real-world premises.

c) Undertake measurements using raw sampling approach[23] for bandwidth up to 80 MHz to characterise all components of radio noise (WGN, IN/SCN).

d) Verify comparable results with raw sampling and rms measurement approaches.

2.26 Our setup inside the chamber mimics a small office environment with the list of equipment given in Table 1. The equipment used is of similar specifications as those used in other Ofcom offices, including London and Edinburgh.

Table 1: List of equipment in small office space created inside anechoic chamber

List of equipment	• Two laptops, one desktop, three PC monitors, keyboards/mouse • Network peripherals including fibre-to-ethernet converter, an ethernet switch and ethernet cables • Mains cable, extension leads, LED lights

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[23] A signal consists of an amplitude and a phase which varies with time and can be represented by the in-phase (I) and quadrature (Q) representation. Typically, in digital receivers, the received input is separated in the I and Q components and sampled to create a digital representation of the signal. This is known as IQ sampling or raw sampling. From the IQ data, further processing may be performed to determine, e.g. the rms level.

2.27 We capture simultaneous rms and raw sampling measurements with our WGN monitoring system and a spectrum analyser, respectively. Both systems are placed outside the chamber, each connected to a wideband omni antenna inside the chamber through an interface panel with bulkhead RF connectors.

2.28 Measurements are undertaken with varying distances of 1-3 m between the antennas and the office setup. Figure 13 shows the mock setup with the equipment and WGN monitoring system antenna (left) and the spectrum analyser antenna (right).

Figure 13: Mock office setup inside Ofcom's anechoic chamber at Baldock

Analysis and results

3.1 In this section, we provide the interim results of our radio noise measurement campaign, based on the data collected as of September 2024. We start with the findings of the controlled measurements inside the anechoic chamber at our Baldock electronics Lab followed by the key results of radio noise in real-world indoor and outdoor environments. Annex A3 provides further detailed results of our monitoring campaign.

3.2 The metric for quantifying radio noise is the “Fa” value which determines the levels of external radio noise above the thermal noise floor. In Table 2, we provide the explanation of the terms used throughout this section for the presentation of results.

Table 2: Terminology used in the presentation of radio noise results

Term	Comment
Fa	External radio noise level in dB above thermal noise floor (kTB, where k is the Boltzmann's constant (1.374 × 10^{-23} joules/K), T represents absolute temperature in Kelvin, and B is bandwidth in Hz
Median and Standard Deviation (SD) of Fa	Median and SD of all Fa values for the same location
Average Fa	Average of median Fa across multiple locations
CDF of Fa	Cumulative distribution function (CDF) of all Fa values

3.3 To determine the “Fa” value, the noise levels measured by the monitoring equipment need to be adjusted to correct for the internal noise of the equipment and the system gains and losses. The high-level steps of our data analysis methodology for the WGN component are summarised in Table 3 and the complete technical details are provided in Annex 2. We apply similar corrections to the raw sampling measurements conducted with spectrum analyser.

Table 3: Data processing steps to quantify radio noise levels

Steps	Comment
1	Correction applied to raw rms measurements to compensate for system gain
2	Correction applied to Step 1 output to compensate for equipment noise figure
3	Establish “Fa”, in “free” spectrum from Step 2 data
4	Establish “Fa”, in “partially occupied” spectrum from Step 3 data

Radio noise results in controlled setting

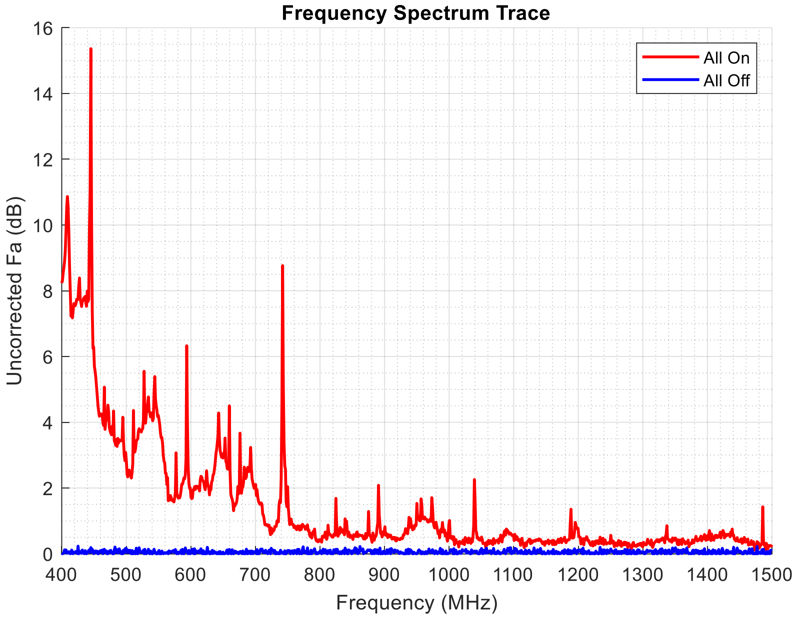
3.4 Measurements in controlled settings allow us to recreate mock environments, such as a small office or residential living space inside an anechoic chamber (as shown in Figure 13). This setup enables us to refine our methodologies for measuring all the components of radio noise, i.e. WGN and IN/SCN.

3.5 We follow a structured approach to our measurements by first establishing the baseline noise level where all devices, including lights and power supplies, in the chamber are switched off, followed by a gradual switch on of the devices. We capture both the rms and IQ/raw sampling data[24] with the WGN monitoring system and spectrum analyser, respectively.

3.6 In Figure 14, we show the spectrum trace[25] captured between 400 MHz and 1500 MHz under two conditions, namely, all devices switched on ("All On") and all devices switched off ("All Off"). The spectrum trace has not been corrected for the monitoring systems gains and losses. For the frequencies below 1 GHz, we note that the active devices result in a noticeable increase in the Fa relative to the scenario when all devices are off.

3.7 A higher average level corresponding to the WGN component is also observed and the presence of multiple peaks in the trace indicate the presence of SCN. We note that the levels and frequency range over which devices contribute to radio noise may vary between equipment quality and type and we are further investigating this aspect in our ongoing work.

Figure 14: Spectrum trace of the average noise levels relative to all devices inactive



Extent of WGN in controlled settings

3.8 To understand the contribution of each of the devices in our mock setup on the noise levels, we take measurements while performing a gradual switch on and off of the equipment (listed in Table 1). We start by switching on the chamber lights, followed by the laptops and the desktop, and finally the monitors and launching a video streaming application. To test for consistency, all equipment is then switched off in the reverse order, and the gradual switch on of the equipment is repeated.

3.9 The median Fa levels at the different stages of the controlled experiment using the compact WGN monitoring system are shown in Figure 15. We note that the radio noise levels from different devices differ across the frequency bands, with higher noise in the lower

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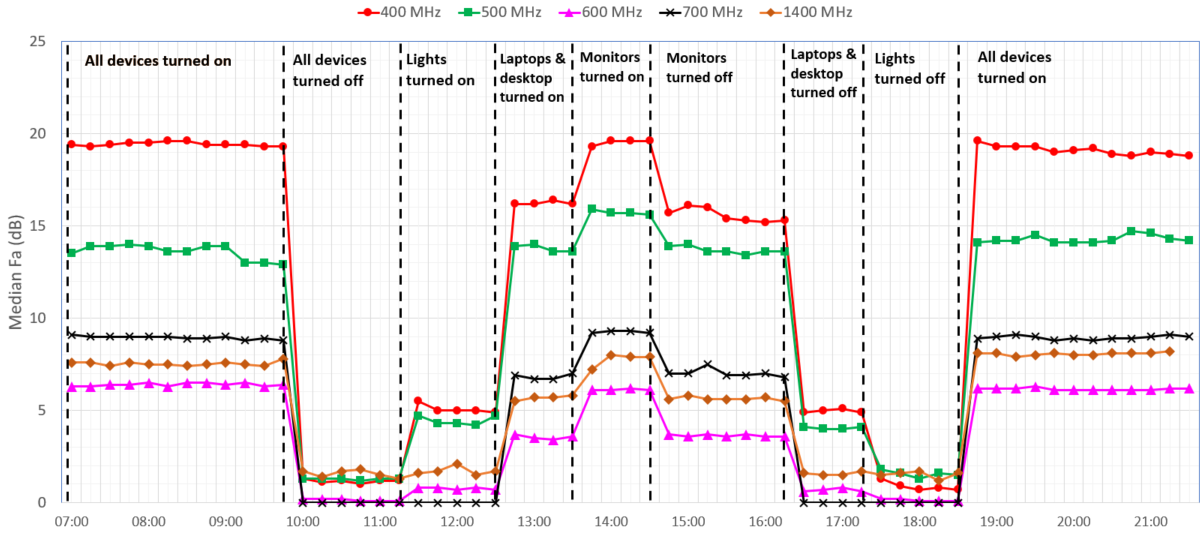
[24] Raw sampling measurements of 10 seconds are conducted with an acquisition bandwidth of 80 MHz, sampling rate of 100 MS/s with a 16-bit resolution.

[25] We used the 'Average' detector mode to capture the trace in Figure 14.

frequencies. We also observe that the various devices have different impact on the median Fa. For example, the plot shows that the laptops and desktops result in a higher increase in Fa compared to the monitors and lighting system. Nonetheless, the levels from the latter are not negligible.

Figure 15: Timeseries plot of the median Fa at different phases of controlled measurements

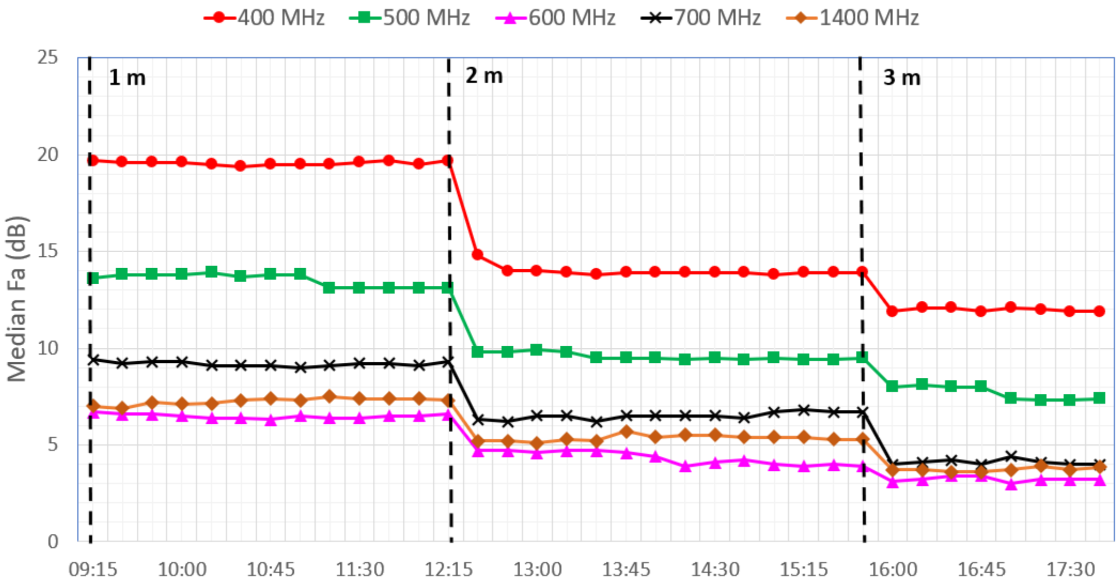


Impact of proximity of noise sources on WGN levels

3.10 In order to understand how Fa values vary with distance from noise sources, we repeat the measurements with the monitoring system antenna at three distances from the mock office setup. The measured Fa values are shown in Figure 16 when all equipment is switched on. As expected, the Fa levels decrease with increasing separation distances, similar to RF signals which attenuate with propagation distance.

3.11 We plan to further explore the impact of separation distances on a variety of noise sources and these findings will be one of the key inputs for our work on the development of noise model based on physical parameter for indoor environments.

Figure 16: Timeseries plot of median Fa values at varying antenna distances from noise sources



Comparison of RMS and Raw sampling measurement approaches

3.12 As part of our investigation, we also compared the Fa levels measured using the raw/IQ sampling approach with the spectrum analyser and the rms measurements from the compact monitoring system. The purpose of this comparison was to validate our approach and demonstrate that the noise levels are agnostic to the monitoring equipment or measurement method used, provided the dynamic range and sensitivities of the monitoring equipment are similar. We also expected to find similar results from both methods in case the WGN component of radio noise is dominant in our setup.

3.13 Due to the larger measurement file sizes, we only took 10 s of raw sampling measurements, compared to over an hour with the rms method. The median and SD of the Fa values are presented in Table 4 and highlight almost identical median levels using either approach. The SDs differ by up to 3 dB and this can be due to several factors, including the differences in measurement duration and other radio noise components than WGN being captured in the raw sampling data. We expect that taking longer raw measurements could help reduce the differences in the SD and we will investigate further as part of our ongoing work.

3.14 It is worth noting that the radio noise levels at 400 MHz and 500 MHz are well above 10 dB, with a median close to 20 dB at 400 MHz. The levels generally tend to decrease with increasing frequency, although higher values are recorded at 700 MHz compared to 600 MHz. This can be attributed to the characteristics of the computing devices in our setup, e.g. their clock speeds.

Table 4: Comparison of rms and raw sampling Fa values in controlled environment

	Median Fa (dB)				
	400 MHz	**500 MHz**	**600 MHz**	**700 MHz**	**1400 MHz**
rms	19	14	6	10	7
Raw/IQ	18	12	6	9	7
Difference	1	2	0	1	0
	SD (dB)				
	400 MHz	**500 MHz**	**600 MHz**	**700 MHz**	**1400 MHz**
rms	2.1	1.7	1.3	1.9	2
Raw/IQ	5	4.6	3.5	4.2	3.7
Difference	2.9	1.9	2.2	2.3	1.7

Analysis of all components (WGN, IN/SCN) of radio noise

3.15 We undertook multiple measurements of 10 s duration each over bandwidths of 80 MHz, and centre frequencies ranging from 400 MHz to 1500 MHz. This choice of 80 MHz bandwidth and measurement duration provided us with a reasonable trade-off between capturing the different radio noise components including IN and SCN, the volume of data captured and associated computational/processing complexity.

3.16 Furthermore, from the raw sampling data captured over wider bandwidths, it is possible to postprocess and extract results as if the measurements were undertaken using a smaller bandwidth. This is useful when comparing the statistics of IN/SCN with different measurement bandwidths and help in supporting our view that larger bandwidths are required for IN/SCN characterisation.

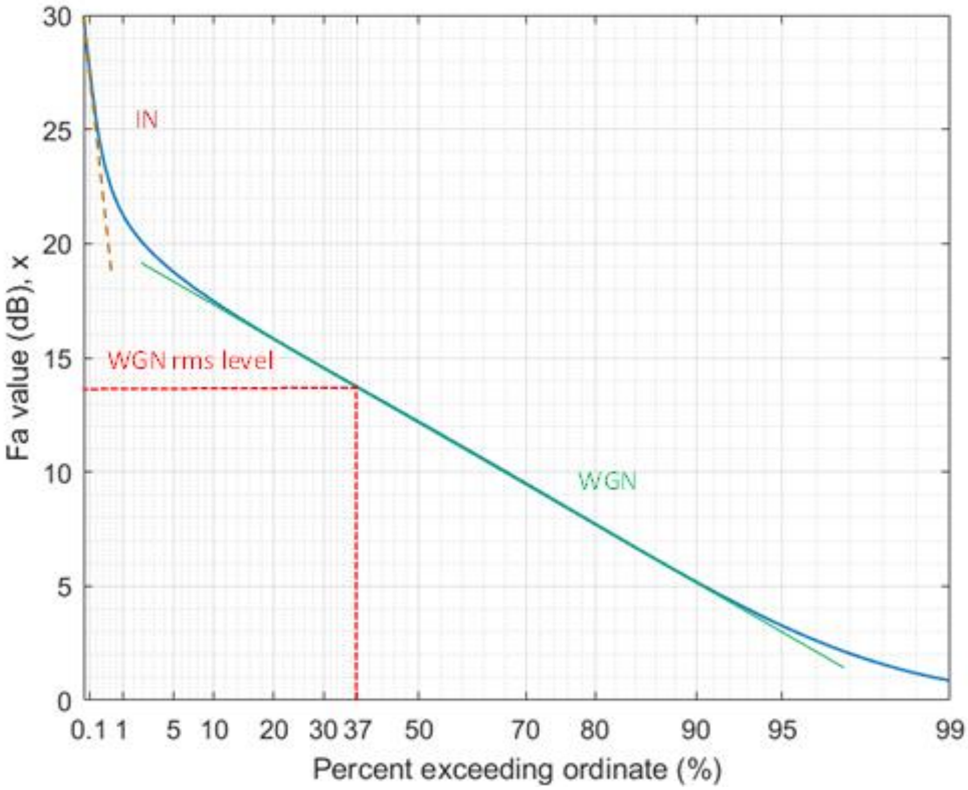
3.17 There are several methods to analyse radio noise measurement data to illustrate the extent of the IN/SCN and WGN. One of the widely applied approaches is to use the Amplitude Probability Distribution (APD) plot, which is a graphical representation of the amount of received power in the environment. The APD is in fact an alternative representation of a complementary cumulative distribution function (CCDF) plot with a Rayleigh scaling applied to the ordinate axis.

3.18 The distinct components of radio noise can be identified from the APD graph as each component exhibits and is modelled assuming distinct characteristics. It is however important to acknowledge that these statistical models and the actual measured radio noise levels may exhibit different features.

3.19 An illustration of the APD plot from the raw sampling data at 500 MHz with all the devices switched on is shown in Figure 17. The Fa values can be estimated by assuming that the radio noise comprises of two dominant and distinct components, namely, WGN and IN. The WGN level can be read from the 37% value on the APD curve[26], which in this case is 14 dB and aligns with the rms value measured as reported in Table 4. The other important finding from this analysis is that most of the overall noise power is contained in the WGN component. We have observed similar trends in the other frequencies' data.

3.20 We have made progress towards developing our approach for characterising and understanding the levels of IN and SCN. Additionally, we are re-assessing the long-established assumptions regarding the statistical distributions of the various radio noise components in light of our measurement data and its statistics.

Figure 17: APD of raw sampling measurements at 500 MHz for a mock office environment



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[26] Recommendation ITU-R SM.2093, Methods for measurements of indoor radio environment

Radio noise results from real-world settings

3.21 This section shares our findings for all four indoor premises, i.e. Ofcom's London and Edinburgh offices, electronics Lab at Baldock and one residential setting. We also briefly cover the results of the two outdoor (rural and suburban) monitoring sites.

3.22 At each of the indoor and outdoor premises where measurements are conducted with the compact WGN monitoring systems, we first carry out an initial spectrum sweep to identify a quiet or mostly unoccupied part of the spectrum, so that the results are not negatively impacted by signals on the same or adjacent frequencies.

3.23 The frequencies monitored at different premises are listed in Table 5 and vary slightly to ensure the quietest range of spectrum is selected for measurements. For clarity, the results are presented by rounding the frequencies to the nearest hundred as shown in the last column of Table 5.

Table 5: Frequencies monitored with WGN compact monitoring system

Locations	Indoor/Outdoor	Measured Frequencies (MHz)	Presented in results (MHz)
London Office	Indoor	464, 573, 658, 735/784, 1393	400, 500, 600, 700, 1400
Baldock Office	Indoor	404, 546, 650, 735, 1378	400, 500, 600, 700, 1400
Edinburgh Office	Indoor	427, 510, 610, 735, 1392	400, 500, 600, 700, 1400
Residential	Indoor	416, 562, 675, 735, 1392	400, 500, 600, 700, 1400
Rural (Baldock)	Outdoor	430, 548, 678, 754, 1392	400, 500, 600, 700, 1400
Suburban (Wraysbury)	Outdoor	464, 610, 730, 876, 1420	400, 600, 700, 1400
Controlled environment	Indoor	430, 548, 678, 735, 1392	400, 500, 600, 700, 1400

Summary of WGN results for all indoor premises

3.24 In Figure 18, the background radio noise results are presented for all premises and bands measured. The horizontal axis lists the four premises while the vertical axis provides the average and SD of the median Fa values of all locations measured within each premises and frequency.

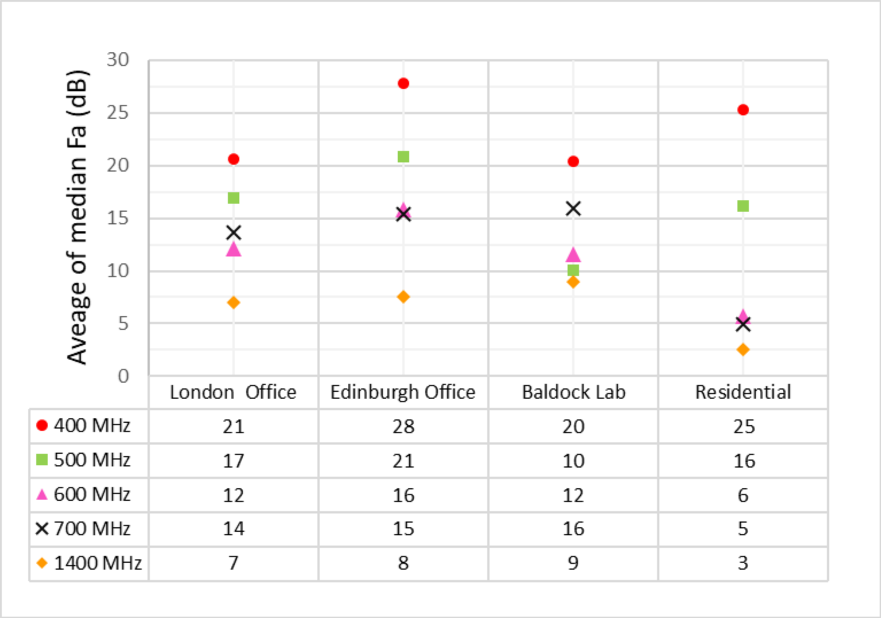
3.25 The results highlight the presence of background radio noise in all measured frequencies up to 1.4 GHz. In general, radio noise decreases as frequency increases, and beyond 1 GHz the average levels are below 10 dB. We also note that radio noise in all locations covered so far exhibits spatial and temporal variabilities and with more active electronic devices in a location, the levels are higher than the average levels.

3.26 Average noise levels observed in offices and the electronics lab are in general higher than in residential premises. This can be explained by the significantly higher number of devices and computer equipment used within office spaces.

3.27 We also note that the Fa values measured in both offices are within ± 3 dB of the levels measured in our mock small office setup inside the anechoic chamber (c.f., Table 4). The difference in the noise levels can be attributed to the difference in the number of nearby devices (only a few versus numerous) between the controlled office setup and real offices.

Figure 18: Average and SD of median Fa across all measured locations in indoor environments

Average of the median Fa levels



	London Office	Edinburgh Office	Baldock Lab	Residential
● 400 MHz	21	28	20	25
■ 500 MHz	17	21	10	16
▲ 600 MHz	12	16	12	6
× 700 MHz	14	15	16	5
◆ 1400 MHz	7	8	9	3

Standard deviation of the median Fa levels

	London Office	Edinburgh Office	Baldock Lab	Residential
● 400 MHz	1.2	1.2	1.5	1.4
■ 500 MHz	1.5	1.9	2.1	1.4
▲ 600 MHz	1.6	1.7	1.8	1.5
× 700 MHz	2.3	2.0	1.7	1.6
◆ 1400 MHz	3.3	2.2	1.4	1.1

Spatial variability of radio noise in premises

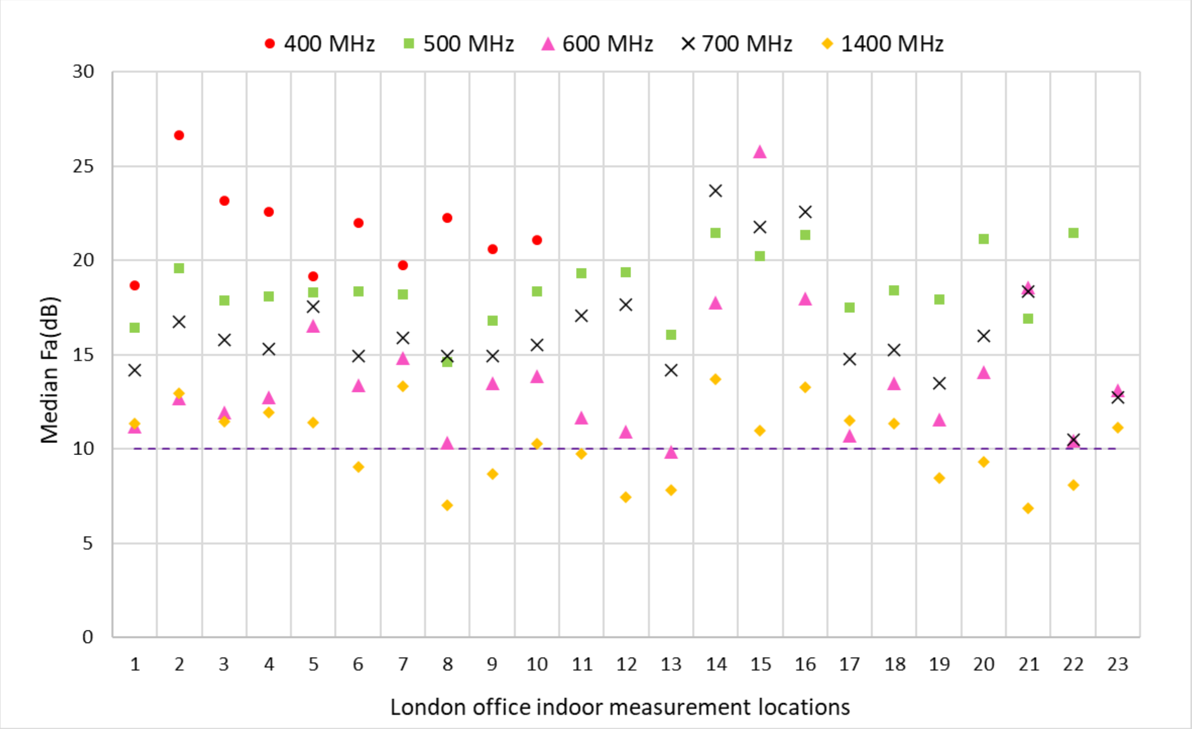
3.28 We take measurements in numerous locations within the open floor space of our London and Edinburgh offices (as shown in the floor plan of Figure 10). We have covered more than twenty unique locations on the 3rd floor of our London office and have also revisited some of the locations after a gap of about six months.

3.29 In Figure 19, the median Fa levels are presented for all locations of the London office to highlight the variability across locations. The results confirm noise levels are sensitive to the density of electrical and electronic devices in the vicinity of the measuring equipment and generally tend to decrease with frequency.

3.30 However, the Fa values for 700 MHz are observed to be higher than 600 MHz and even 500 MHz for some locations. This trend is consistent with our findings of the mock office setup inside the anechoic chamber as covered in paragraph 3.14.

3.31 The Fa values of 400 MHz are observed to be the highest in the range of 20 dB or more across all measured locations noting this frequency was not monitored in some locations at the start of the measurement campaign.

Figure 19: Spatial variability of radio noise levels across all locations measured in London Office



Temporal variability of radio noise in premises

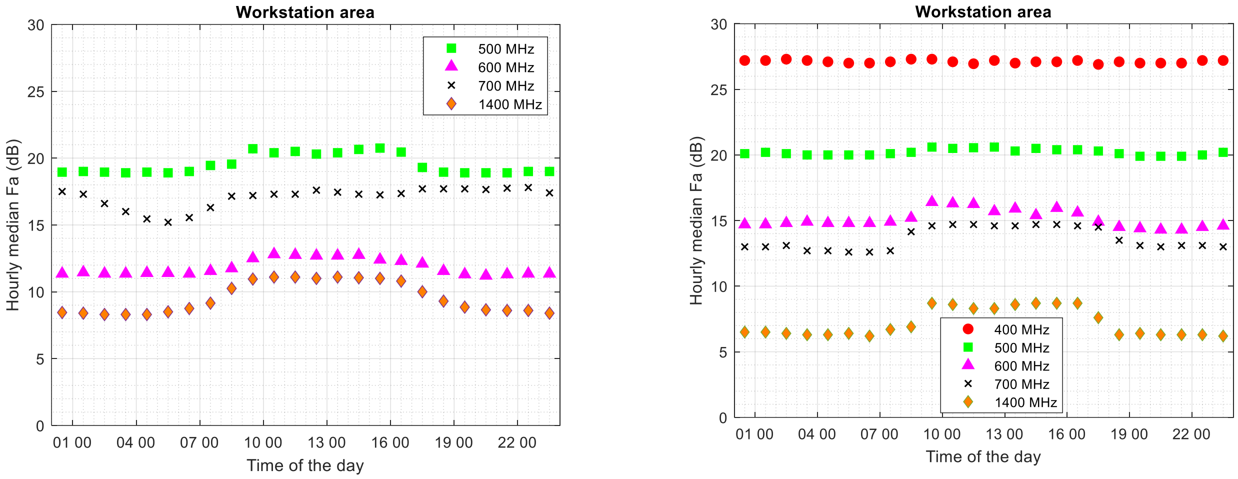
3.32 Our analysis of the radio noise measurement confirms that the radio noise levels vary with human/device activity with higher levels of noise observed when more devices are in various states of activity and use while the levels drop when fewer devices are active. In indoor environments such as offices and residential premises, we also note a minimum level of noise which can indicate the continuous operation of some equipment.

3.33 An example is shown in Figure 20 for one location from each of Ofcom's offices and one location from the residential setting. Higher levels of Fa are recorded during typical office hours (i.e. between 8 am and 5 pm) and similar trends observed in residential location.

However, this trend is not always clearly distinguishable for all monitored frequencies, highlighting the varying impact of noise sources and their activity across frequency.

3.34 In Annex A3, we provide the time variability results (hourly median Fa) for all locations.

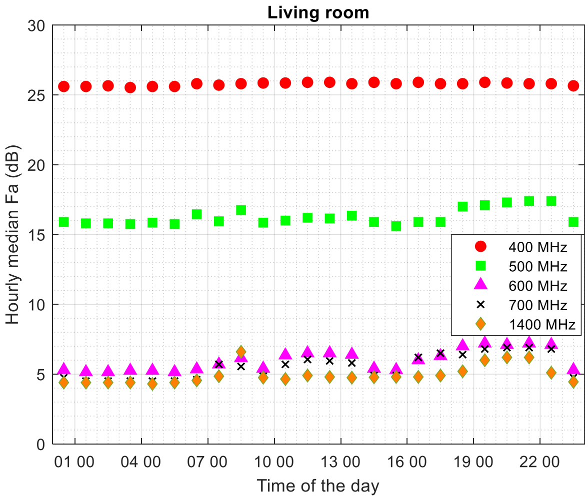
Figure 20: Hourly Fa values highlighting temporal variability of background radio noise



London office

Edinburgh office

Residential

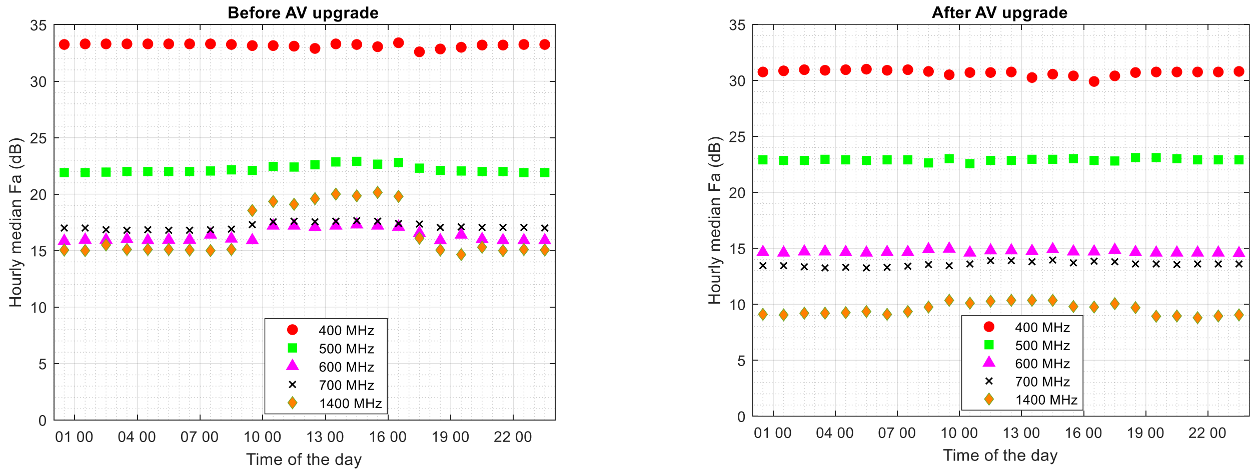


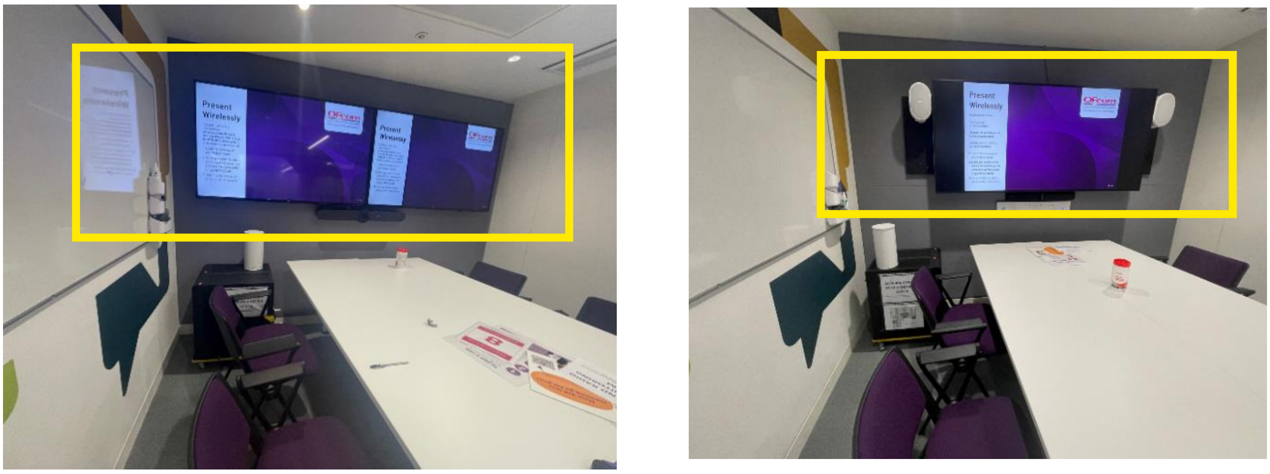
Variability in equipment quality and its impact on radio noise

3.35 During our measurement campaign, we observed sudden increase or decrease in Fa levels for some of the monitored locations. We were able to trace most of these anomalies arising from either a change in the device density around that location or the replacement or upgrade of the office equipment.

3.36 In Figure 21, we provide a comparison of the median Fa values measured in the meeting room of our London office over a period of few weeks. The Audio/Video (A/V) conferencing system including the large display screen of the meeting room underwent an upgrade during this period. A noticeable decrease in the median Fa values at 700 MHz and 1400 MHz can be observed after the upgrade highlighting how the equipment quality (in terms of their radio noise emission characteristics) can impact the overall radio noise levels in an environment.

Figure 21: Plot of the measured hourly Fa values in a meeting room before and after an A/V upgrade





Before AV upgrade

After AV upgrade

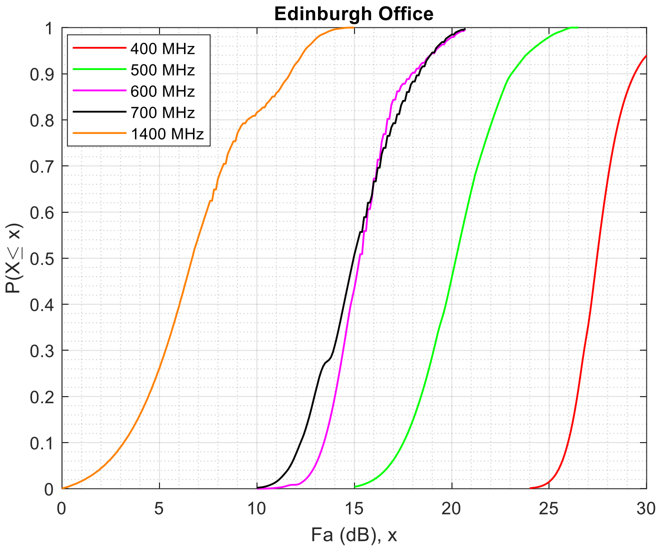
Comparison of two offices

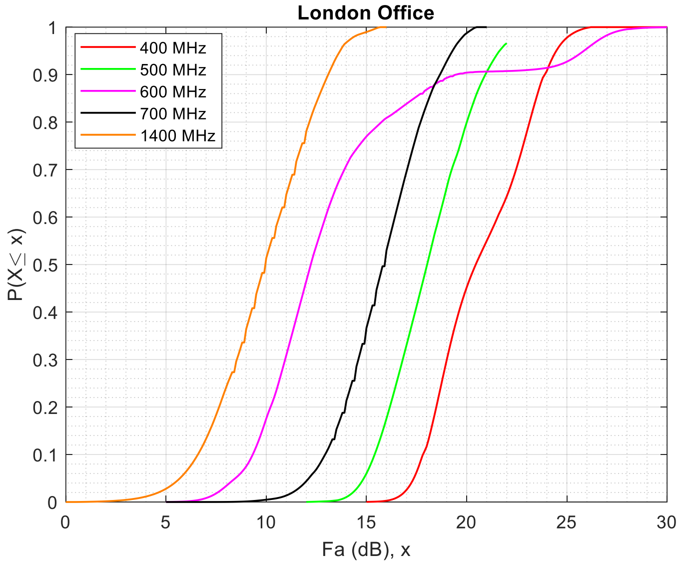
3.37 We undertook a comparison of results from the London and Edinburgh office to understand the variability of Fa values in two very similar settings such as building type, construction material, similar noise sources (ICT equipment) and activity periods.

3.38 In Figure 22, the CDF of the Fa values of both offices show that radio noise is present in all locations and frequencies monitored between 400 MHz and 1.4 GHz. A median Fa of at least 10 dB was observed for all frequencies below 1 GHz.

3.39 For some of the frequencies (1400 MHz for Edinburgh and 600 MHz for London office), the CDF curves of Figure 22 do not exhibit the typical “S” shape curve of a Gaussian distribution. This can be attributed to several factors such as the density of devices and the presence of one or a few strong radio noise sources closer to the monitoring system. Also, as we collect measurements across more locations in the Edinburgh office, we expect that the distribution of Fa will appear smoother.

Figure 22: CDF of median Fa in the Edinburgh and London offices averaged across all locations





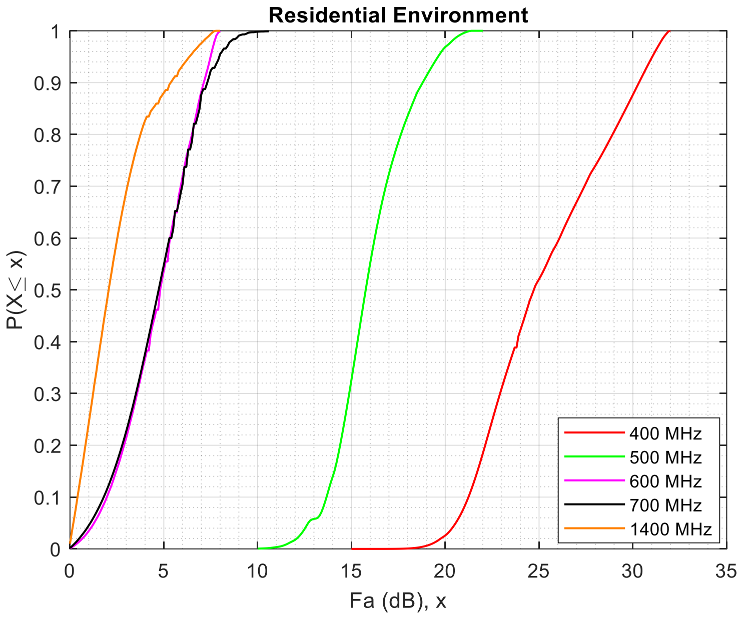
Residential result

3.40 So far, we have conducted radio noise measurements in only one residential premise covering four locations (living room, kitchen/dining space, utility and entertainment room). Our plan is to cover more typical premises and indoor residential spaces in the UK.

3.41 The CDF of Fa values across all four measured spaces is shown in Figure 23. The median Fa values for 400 MHz and 500 MHz are well above 10 dB while the levels drop below 5 dB for the other monitored frequencies. We also note that compared to our results from the two offices, the noise levels in the 400 MHz band are higher in the residential setting. This may be due to the different equipment type and its density in a typical residential environment compared to offices.

3.42 The results from individual locations such as living room and kitchen (not presented here), are higher since there are typically more active electronic devices and non-stop operation of some of the kitchen appliances as compared to the spaces occupied less frequently.

Figure 23: CDF of Fa values across all measured locations in a residential environment



Outdoor WGN results

3.43 **Rural:** Our measurements show a median Fa value of around 7 dB at 400 MHz and this has remained consistent since we started monitoring at this location. We also observe a median value of around 5 dB at 500 MHz. For the higher frequencies, we are not capturing any radio noise from human-made sources.

3.44 **Suburban**: For our suburban location, we are not observing any noticeable radio noise from any of the bands monitored.

3.45 The low levels of radio noise in the two outdoor locations are expected as there are very few noise sources in the vicinity. In our rural settings, there are overhead power lines and a dual carriageway within 500 m. Similarly, in our suburban settings, although the site is very close to a busy airport, there are only a few potential noise sources in proximity to our monitoring station. The results align with the finding of previous 2003 Ofcom's funded measurement campaign which observed similar insignificant levels in rural and suburban environments.

Conclusions and next steps

4.1 This report provides an update on Ofcom's ongoing measurement campaign on the long-term monitoring of background radio noise and quantifying its extent in the UK. The project aims to address the gap in the existing information on radio noise from human-made sources where limited empirical evidence exists for frequencies above 400 MHz and especially for indoor environments where a variety of noise sources (electronic and electrical devices) are in everyday use.

4.2 We have been conducting measurements with our compact radio noise monitoring systems developed in-house in two of our offices in London and Edinburgh, our electronics lab in Baldock, and one residential setting. We also have two systems monitoring typical outdoor rural and suburban environments.

4.3 Furthermore, we are conducting controlled measurements by creating mock real-world environments inside an anechoic chamber at our Baldock electronics lab. This setup allows us to refine our measurement approach for real-world environments and develop appropriate data analysis methodologies for quantifying all statistical components (white Gaussian, Impulse and Single Carrier) of radio noise and their impact on spectrum users.

Key findings

4.4 Our findings highlight that radio noise levels depend on frequency and proximity to noise sources. Generally, noise levels decrease with higher frequency and greater distance from the noise sources. Noise levels increase with more active electronic devices and drop when devices are switched off or become inactive.

4.5 Indoor noise levels show both temporal and spatial variability mainly due to density and proximity of the noise sources. Variability is also linked to the equipment type, where some devices may generate more radio noise than others.

4.6 In our current set of measurements, we have covered the frequency range between 400 MHz to 1.4 GHz. We observed radio noise in all indoor premises and measured frequencies. Radio noise levels in offices and the electronics lab are higher than in the residential setting, which can be attributed to the higher density of devices/ICT equipment. During office hours, the average noise levels are observed to be twice as high as in non-office hours. Similarly, higher radio noise levels are observed in residential spaces with more active electronic devices such as living rooms and lower levels in other less occupied spaces.

Impact Below and Above 1 GHz

4.7 Below 1 GHz, the average noise levels are consistently at least 10 dB above the thermal noise floor during periods of activity, especially in the office and lab environments. This indicates that services below 1 GHz are encountering additional noise indoors above their minimum sensitivity (*typically in the range of 6-10 dB above the thermal noise floor*) which may negatively impact their performance.

4.8 Above around 1 GHz, the average noise levels are often below the threshold to negatively impact the performance of the services or spectrum users. However, under extreme conditions (numerous active devices at very short distances, e.g. < 1 m), the noise levels can exceed the average and may impact services.

Outdoor Noise Levels

4.9 We found negligible radio noise levels in the two outdoor rural and suburban settings we are currently monitoring. These locations are fairly quiet with few potential noise sources. Our future plans include monitoring more urbanised outdoor environments such as city centres and compare the results with those from quieter areas.

Future Indoor Measurements

4.10 We plan to continue our measurement campaign focusing on more indoor residential settings and other premises such as transport hubs and commercial centres. We also intend to revisit some indoor locations after a gap of a year or more to understand the evolution of radio noise over longer time periods. For instance, changes in the environment due to new equipment/devices, changes in wireless services or working habits could impact noise levels.

Empirical Database

4.11 We have established a significant empirical database on the main component (i.e. white Gaussian noise) of radio noise in indoor environments. Additionally, we maintain a catalogue for each location, detailing device types, density, activity periods and their proximity to our monitoring systems. Planned measurements in real and controlled environments will help us to further enhance our database and to better quantify all the components of radio noise.

International Contributions

4.12 One of our primary future focus areas is to continue providing technical leadership and contributions on radio noise from human-made sources to the International Telecommunication Union-Study Group 3 (ITU-R SG 3) as part of our international technical spectrum management framework. We will continue submitting our findings, measurement data and share our data analysis methodologies and their implementation.

Proposed Radio Noise Modelling Approach

4.13 We plan to propose a new modelling approach for inclusion in Recommendation ITU-R P.372 on Radio noise. The current approach is purely empirical and based on limited and outdated information. Indoor and outdoor environment classification is somewhat subjective with categories like rural, suburban, city centre or indoor building types (domestic, office, hospital, etc.).

4.14 We believe an alternative and potentially more suitable approach is to predict radio noise levels based on physical models and parameters that can be calibrated with empirical evidence. Our findings highlight that radio noise levels are primarily dependent on device density and proximity, especially in indoor environments.

4.15 We are considering a physical model based on parameters such as distances to observable noise sources and their density, frequency, building types, equipment category and the radio noise propagation paths. We will use our empirical radio noise database to validate and calibrate this model. This approach can be extended by incorporating empirical evidence from other countries and ITU-R SG 3 members to further refine the model.

Acknowledgment

Ofcom’s long-term radio noise monitoring campaign would not have been possible without the extensive efforts of our dedicated spectrum engineers.

Their work in developing, deploying and maintaining monitoring systems has been invaluable. Throughout the testing and trialling of various equipment combinations, and the characterisation of individual components, our engineers have shown great care and precision. Their commitment has ensured that the monitoring systems operate as intended, delivering consistent performance over extended periods.

We would also like to convey our thanks to our national and international ITU-R SG 3 experts in this area for the insightful discussions, in particular:

- Ben A. Witvliet and Erik van Maanen of the Dutch Authority for Digital Infrastructure, The Netherlands.
- Erik Hill of the US delegation for progressing the work on Radio noise in ITU-R SG 3 correspondence group.
- Dave Darlington, British Broadcasting Corporation, The United Kingdom.

A1 WGN monitoring system

The journey towards the compact monitoring systems

A1.1 Measuring radio noise is a complex and technically challenging task. Sophisticated equipment is required to detect very weak signals to accurately determine noise levels. Additionally, advanced signal processing algorithms are essential to distinguish radio noise from intended signals and unwanted emissions.

A1.2 Radio noise levels may vary significantly, ranging from a few to tens of decibels (dB) above the thermal noise floor. This variability can be attributed to the monitored frequency range as well as the density of noise sources in an environment.

A1.3 Our aim was to develop a sensitive WGN measurement system with a large dynamic range to measure both significant and weak radio noise levels. Additionally, our design considerations included the operation of monitoring system for extended periods (e.g. several months) without needing regular physical maintenance or reconfigurations.

A1.4 Following initial experimentations with various equipment configurations, we developed a proof-of-concept (POC) system. The system consisted of a wideband omni-directional antenna, a relatively high-gain Low Noise Amplifier (LNA)[27], a tuneable bandpass filter[28] and a sensitive receiver unit.

A1.5 We found it more practical to use a wideband antenna instead of tuned antennas for each frequency of interest), as our setup needed to cover a broad range of frequencies from 400 MHz to potentially up to 6-8 GHz. Additionally, the local use of spectrum by radio services varies across the country which makes it impossible to monitor the exact same frequencies at all locations. The wideband approach also helps with minimising the number of antennas required.

A1.6 We extensively tested our POC system, initially running three units in parallel indoors at our Baldock electronics lab, while one POC system was trialled for outdoor use. Each unit was tuned to take measurements for one frequency at a time.

A1.7 After establishing that the POC was providing credible measurements, we further improved our setup by introducing RF switches and a filter bank[29]. This enabled us to undertake measurements over multiple frequencies by using a single wideband antenna, compared to our POC setup where each monitored frequency required its dedicated antenna.

A1.8 With this new setup, we encountered occasional overloading of the LNA. This was mainly caused by the high-powered transmissions from nearby radio services. The overloading of LNA was mitigated by moving it after the bandpass filter bank.

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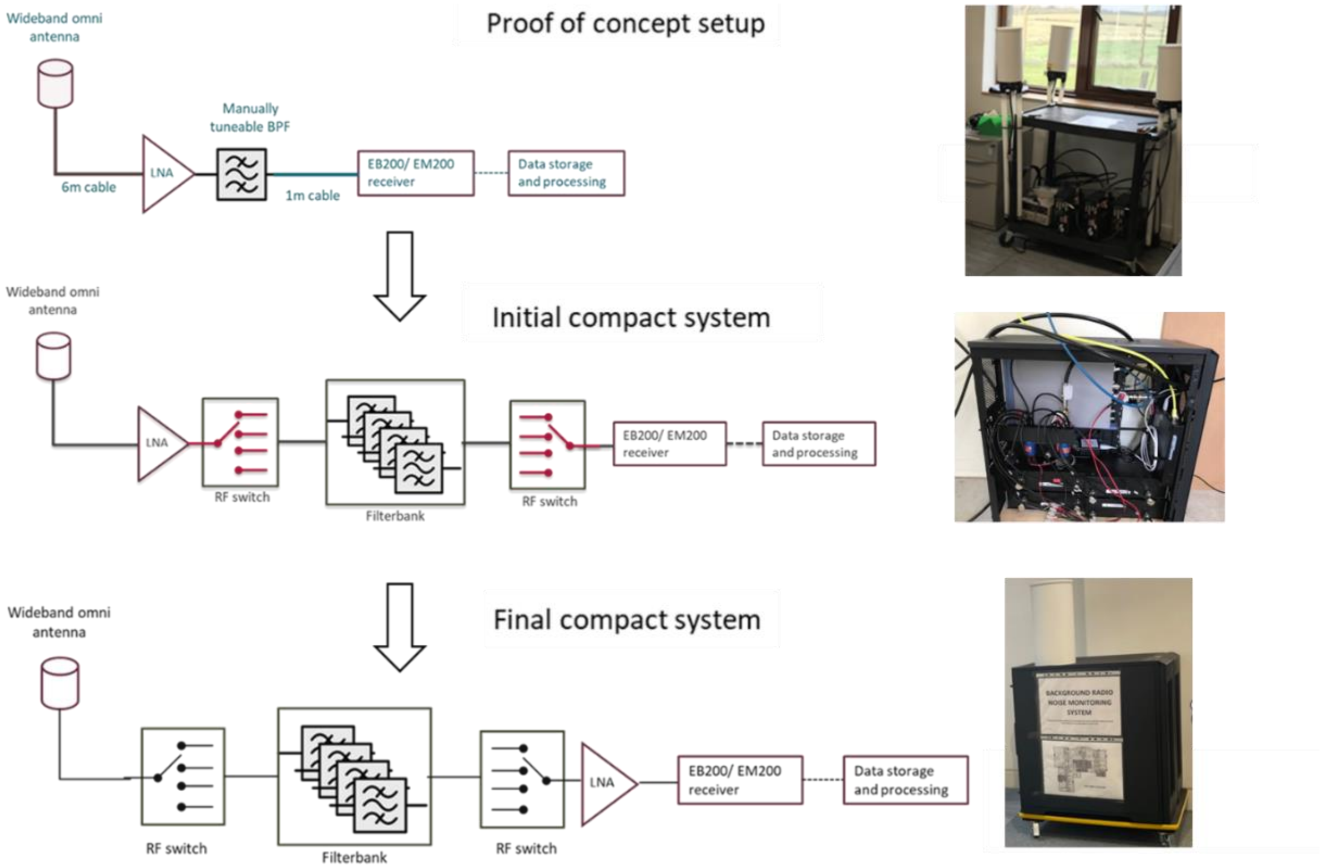
[27] A low noise amplifier (LNA) is typically used in the early stages of the RF chain to improve the sensitivity of the receiving system, allowing the detection of weak or low powered signals.

[28] A Bandpass filter (BPF) limits the signals that a receiving equipment would pick by attenuating signals that lie outside the frequencies of interest; thus the impact of signals adjacent to the measurement band is reduced.

[29] With the combination of the RF switch and filter bank, a single bandpass filter centred at the frequency of interest is activated for a specific time duration, thereby limiting the effect of signals in other frequencies not being measured.

A1.9 This change had some impact on the sensitivity of our monitoring system, however we achieved an overall system noise figure of less than 6 dB for all frequencies. An illustration of our journey towards the compact WGN monitoring systems is shown in Figure 24.

Figure 24: Evolution of WGN monitoring system towards a compact unit



Equipment calibration procedure

A1.10 We characterise each of the components of our monitoring system to determine gains, losses and the overall noise figure of the system. For the antenna used with our monitoring system, we have relied on the specifications provided by the antenna vendor and additionally undertook in-house characterisation for quality assurance.

A1.11 One important aspect of radio noise measurements is to ensure that the monitoring equipment itself does not contribute to the measured noise levels. To understand whether our monitoring equipment is generating any noticeable noise which could be picked up by the antenna at the measurement frequencies, we carried out calibration measurements in an anechoic chamber.

A1.12 We compared the test measurements with the antenna connected to the system and with a terminated load. In both cases, the only active equipment in the chamber was our monitoring system. We noted that the measured values with the antenna and terminated load were very similar. We further processed the measurements with our WGN processing algorithm and noted Fa values of 0 dB for all frequencies, as expected.

Technical Specifications

A1.13 The equipment specification of the compact white Gaussian noise monitoring systems is provided in Table 6.

Table 6: WGN noise measurement system specifications

Function	Value
Receiver unit	Rohde & Schwarz EB200
LNA	Mini-circuit ZX60-83LN12 Gain of >18 dB, NF <2.5 dB
Antenna	300 MHz to 10 GHz: Cobham OA2-0.3-10.0V/1505 (wideband omni-directional)
Bandpass filter	K&L manually tuneable bandpass filter 1% nominal bandwidth for frequencies above 500 MHz and 5% nominal bandwidth for frequencies less than 500 MHz For 700 MHz, a custom filter is used from Wainwright Instruments that has sharp roll-off response with 70 dB rejection at 7 MHz from centre frequency. This gave the filter better selectivity ensuring it effectively isolates the desired frequency band while rejecting unwanted signals from adjacent band.
Cables	Ecoflex10 cables, 6 m from antenna to RF Switch
Power supply units	Regulated linear PSU (not switched mode)

A2 WGN Methodology

A2.1 The methodology we use and explained in this annex is suitable for measurement approaches employing root mean squared (rms) power levels on a given frequency to quantify the WGN component.

A2.2 The recommended practice is to undertake measurements for extended periods of at least few hours in "free" or "predominantly free" bands across several channels in a given frequency band, if possible; with each channel having a resolution bandwidth of less than 200 kHz. This approach helps in the post processing of data to identify and eliminate non-WGN components (*e.g. single carrier noise*) of radio noise, including occupancies by radio services which varies in time and frequency, especially if the measurements are made in partially occupied frequency bands. For measurements undertaken over multiple smaller channels, it is not mandatory to follow this approach.

A2.3 The requirements for the implementation of WGN methodology include:

a) *Radio Noise Measurements*: rms measurements by using rms/average detector method or post processed rms levels from raw sampling.

b) *Terminated measurements:* rms measurements by using rms/average detector method or post processed rms levels from raw sampling and replacing the receiving antenna of the monitoring system with a 50-ohms load.

c) *Monitoring system Gain:* The overall gain/loss of the system excluding the antenna factor.

d) *Monitoring System Noise figure:* Overall Noise figure of the monitoring system.

e) *Antenna factor:* Average antenna factor of the monitoring system antenna over the frequency range of interest.

A2.4 Table 7 lists the step-by-step procedure to quantify the WGN levels from rms measurements.

Table 7: Data processing steps to quantify WGN levels

Step 1	Correction applied to raw rms measurements to compensate for system gain
Step 2	Correction applied to Step 1 output to compensate for equipment noise (as per recommendation ITU-R SM.1753-2[30] section 10.2)
Step 3	Establish external noise "Fa" in "free" spectrum from Step 2 data
Step 4	Establish external noise "Fa" in "partially occupied" spectrum (as per recommendation ITU-R SM.1753- 2 Attachment 2) from Step 3 data

***Notations*:** Bold uppercase and lowercase letters denote matrices and column vectors, respectively; values in linear units are represented using lowercase letters and the uppercase letters are used for the values in decibels (dB); the entry corresponding to the mth row and nth column of a matrix $\boldsymbol{A}$ is represented by $A_{m,n}$; the superscript $(\cdot)^T$ is used to represent vector/matrix transpose operation; the $m \times n$ matrix of all ones is represented by $\mathbf{1}_{m\times n}$.

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[30] Recommendation ITU-R SM.1753, Methods for measurements of radio noise

Step 1: Correction for system gain

A2.5 This correction is required to compensate for the overall system gains and losses. However, the antenna factor is not considered at this stage. The overall gain of the monitoring system is mainly influenced by the LNA gain (if used), and a correction factor must be applied to both the terminated and actual measurements.

A2.6 Assume that measurements are taken over n_c different frequency channels, over n_t different time instances or timestamps with the resolution bandwidth of b_r in Hz. The rms measurement matrix in dBm can be expressed as:

$$\boldsymbol{P}^{(m)} = \begin{bmatrix} P_{1,1}^{(m)} & \cdots & P_{1,n_c}^{(m)} \\ \vdots & \ddots & \vdots \\ P_{n_t,1}^{(m)} & \cdots & P_{n_t,n_c}^{(m)} \end{bmatrix} \tag{1}$$

where $P_{j,i}^{(m)}$ is the rms levels measured at time instant j on the ith frequency channel in dBm/Hz.

Note: dBm/Hz values are calculated from the antenna voltage levels in $dB\mu V$ using the equation:

$$P_{j,i}^{(m)}\Big|_{\frac{dBm}{Hz}} = P_{j,i}^{(m)}\Big|_{dB\mu V} - 107 - 10\log_{10} b_r \tag{2}$$

A2.7 Similarly, let $\boldsymbol{P}^{(t)}$ be the $n_t \times n_c$ matrix of terminated measurements in dBm/Hz. For practicality, terminated measurements may be carried out for shorter duration than the actual measurements and $\boldsymbol{P}^{(t)}$ will have far fewer rows than $\boldsymbol{P}^{(m)}$. The measured and terminated rms levels corrected for the system gain in dBm/Hz is given by:

$$\boldsymbol{P}^{(mc)} = \boldsymbol{P}^{(m)} - \boldsymbol{G} \tag{3}$$

$$\boldsymbol{P}^{(tc)} = \boldsymbol{P}^{(t)} - \boldsymbol{G} \tag{4}$$

where $\boldsymbol{P}^{(mc)}$ and $\boldsymbol{P}^{(tc)}$ represent the measured and terminated matrices corrected for system gain. $\boldsymbol{G}$ is the $n_t \times n_c$ matrix of system gains in dB and is given by:

$$\boldsymbol{G} = \begin{bmatrix} G_1 & \cdots & G_{n_c} \\ \vdots & \ddots & \vdots \\ G_1 & \cdots & G_{n_c} \end{bmatrix} \tag{5}$$

where G_i is the gain of the system at the ith frequency channel and can be established as:

$$G_i = \sum_{k=1}^{K} \tilde{G}_{k,i} \tag{6}$$

where $\tilde{G}_{k,i}$ is the gain of the kth component in the receiver chain on the ith frequency channel and K is the total number of components in the receiver chain.

Step 2: Correction for system noise

A2.8 System noise or the noise figure of the monitoring system dictates its sensitivity, i.e. its ability to quantify the WGN levels above the thermal noise. The noise factor n_{f_i} of the monitoring system on the ith frequency channel can be established by using the cascaded equation:

$$n_{f_i} = \tilde{n}_{1,i} + \sum_{k=2}^{K} \frac{\tilde{n}_{k,i} - 1}{\prod_{j=1}^{i-1} \tilde{g}_{j,i}} \tag{7}$$

where $\tilde{n}_{k,i}$ and $\tilde{g}_{k,i}$ are the noise factor and gain of the kth component of the receiver chain of the monitoring system in linear units on the ith channel, respectively.

A2.9 In cases, where measured rms levels, $P_{j,i}^{(mc)}$, are only a few dBs higher than the terminated rms levels $P_{j,i}^{(tc)}$, a further correction is applied as recommended in section 10.2 of Recommendation ITU-R SM.1753-2. First, the measured values $P_{j,i}^{(mc)}$ are compared with the column average values of $P_{j,i}^{(tc)}$ (the average of the entries over the multiple n_t time instances for each frequency channel n_c). The averaged entries $\bar{p}_i^{(tc)}$ are computed in linear unit as:

$$\bar{p}_i^{(tc)} = \frac{1}{n_t}\sum_{k=1}^{n_t} p_{k,i}^{(tc)}, \qquad \bar{P}_i^{(tc)} = 10\log_{10}\bar{p}_i^{(tc)}. \tag{8}$$

Then, the correction is applied if the difference between $P_{j,i}^{(mc)}$ and $\bar{P}_i^{(tc)}$ of the ith frequency channel is less than $X_i\, dB$. In essence, the correction requires the noise factor of the monitoring system to be linearly subtracted from measured rms levels as:

$$P_{j,i}^{(mcx)} = \begin{cases} P_{j,i}^{(mc)} & if\ P_{j,i}^{(mc)} - \bar{P}_i^{(tc)} \geq X_i, \\ 10\log_{10}\left(p_{j,i}^{(mc)} - \left(\frac{\left(n_{f_i}-1\right)}{n_{f_i}}\right)\bar{p}_i^{(tc)}\right) & otherwise. \end{cases} \tag{9}$$

The coefficient X_i can be calculated as:

$$X_i(dB) = 10\log_{10}\left(\frac{11\left(n_{f_i}-1\right)}{n_{f_i}}\right) \tag{10}$$

Step 3: Establishing external noise “Fa” in “free” spectrum

A2.10 The matrix of F_a values (external noise above thermal noise in dB) is calculated using equation 10 in Recommendation ITU-R SM.1753-2 as:

$$\boldsymbol{F}_a = \boldsymbol{P}^{(mcx)} + \boldsymbol{B}^{(1)} \tag{11}$$

where the element in row j and column i of the $n_t \times n_c$ matrix $\boldsymbol{B}^{(1)}$ is:

$$B_{j,i}^{(1)} = \alpha_i - 20\log_{10}(f_i) + 203.8, \quad \forall j \tag{12}$$

and α_i is the average antenna factor at frequency f_i, in MHz, and assuming an isotropic reference antenna.

Note: All rms samples are converted to F_a values and further statistics such as the median hourly, daily and standard deviations can be generated for each frequency channel or for the combined frequency range. However, the statistics will only be representative of WGN component of radio noise if the measurements were undertaken on a free or predominantly free frequency or a range of frequencies in a given environment. It is important to undertake additional checks to ensure there are no emissions of radio transmitters in the frequency bands considered for measurements. The adjacent channel selectivity of the monitoring system should also be considered to understand the impact of occupancies in bands adjacent to measurement frequencies.

Step 4: Establishing external noise "$\boldsymbol{F_a}$" in "partially used" spectrum

A2.11 Finding free spectrum for radio noise measurements in real world environments is a challenge and it may not be valid to assume the measurement frequency (or range) considered is completely "free" for the whole measurement period in both time and frequency domains. Hence, it is important to remove those samples in $\boldsymbol{F}_a$ matrix of step 3 that may not be representative of the WGN component of radio noise.

A2.12 It is recommended to remove at least d_s % of the largest magnitude samples from $\boldsymbol{F}_a$ matrix for measurements undertaken in partially occupied bands. An appropriate value of d_s can be in range of 10-20 % for most of the bands above 400 MHz. It should be noted that the largest magnitude samples removal will also eliminate the single carrier noise (SCN). Hence, the WGN data processing methodology is not suitable for the SCN components of radio noise.

A2.13 Attachment 2 of recommendation ITU-R SM.1753-2 provides a method for the percentage of $\boldsymbol{F_a}$ samples that should be kept (i.e. 100-d_s). This method makes a valid assumption that measurements undertaken in partially occupied bands will contain both WGN and non-WGN samples and the resulting sample distribution may not be Gaussian. By removing the non-WGN samples, the mean and median of the remaining samples in $\boldsymbol{F_a}$ should be the same noting the symmetric properties of the probability density function of the Gaussian distribution.

A2.14 One drawback of this simple approach is that in some scenarios (e.g. presence of a dominant single noise source) discarding the largest magnitude samples from $\boldsymbol{F_a}$ matrix may also remove some WGN samples. Hence, a further correction is applied to the retained samples in $\boldsymbol{F_a}$. To calculate this correction factor, the terminated samples $\boldsymbol{P}^{(tc)}$ are used as these generally exhibit a Gaussian distribution.

A2.15 The methodology implements the overall approach to WGN samples retention and correction by first establishing the difference between the mean and the median of each percentile of all samples in $\boldsymbol{F_a}$ and selecting the maximum percentile to retain when the difference between the mean and median is at most 0.15 dB. Alternatively, one may set the lower bound d_l on the percentage of data to discard. The percentage of largest magnitude samples discarded from $\boldsymbol{F_a}$ in the processing is:

$$d = \max(d_s, d_l) \tag{13}$$

A2.16 Then the correction factor is established given that $d\%$ of the largest magnitude samples are discarded. Calculate the mean μ_{t_1} of all the terminated samples in $\boldsymbol{P}^{(tc)}$, and the mean μ_{t_2} using the samples in $\boldsymbol{P}^{(tc)}$ excluding the highest $d\%$ entries. The correction to apply is the difference of both means i.e. $(\mu_{t_1} - \mu_{t_2})$.

A2.17 Let the matrix of measurement samples with the $d\%$ largest magnitude entries removed/blanked be $\boldsymbol{P}_d^{(mcx)}$. The corrected F_a values are then calculated as:

$$\boldsymbol{F}_{a,c} = \boldsymbol{P}_d^{(mcx)} + \boldsymbol{B}^{(2)} \tag{14}$$

where the element in row j and column i of the $n_t \times n_f$ matrix $\boldsymbol{B}^{(2)}$ is:

$$B_{j,i}^{(2)} = (\mu_{t_1} - \mu_{t_2}) + \alpha_i - 20\log_{10}(f_i) + 203.8, \qquad \forall j \tag{15}$$

A3 Additional indoor results

A3.1 In this annex, we provide further results from the indoor premises.

Office environments

A3.2 In Table 8, the monitored locations within the two offices are grouped based on their usage and the proximity of noise sources to the monitoring system for each category. Excluding the canteen area, we note that most of the other categories share similar noise sources with only one or two different noise sources in each category.

Table 8: Classification of indoor measurement locations in an open-plan office space

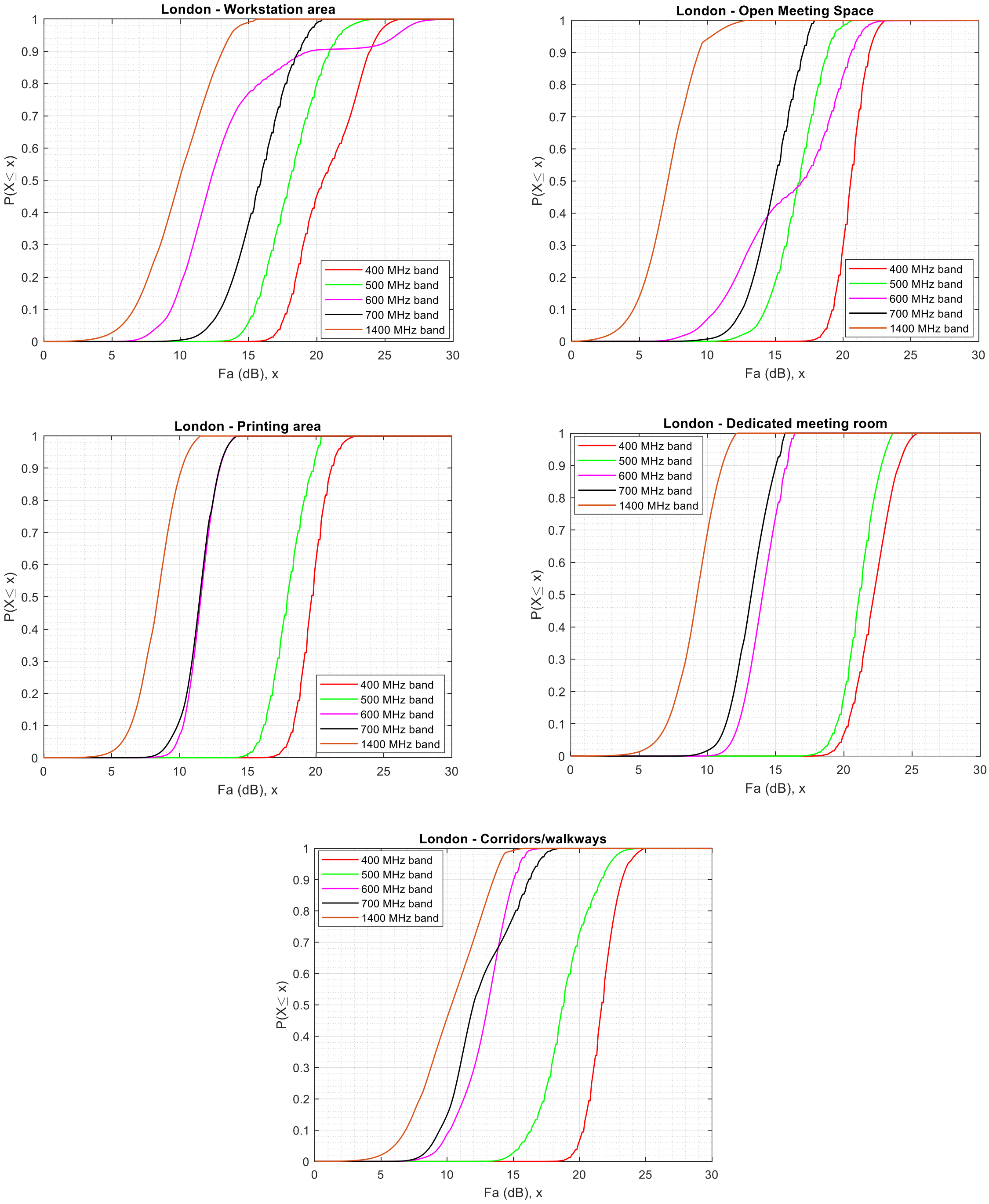
Category	Location number	List of Equipment in proximity (~1-2 m) of the monitoring system
Workstations/ Desk spaces	London (1, 2, 3, 4, 5, 15, 17, 19, 20, 21, 22, 24, 25, 26, 32, 33, 34, 35, 36) Edinburgh (1, 2, 3)	LAN switches, Laptops, PC monitors, LED lighting panels, Mains cable
Open meeting space	London (9, 13, 18, 23, 27)	LAN switches, Large screens, Audio/Video conferencing systems, WiFi access points, LED lighting panels, Underfloor and under-table mains cables/charging points
Printing space	London (7, 29)	Office printer/scanner, paper shredder
Dedicated Meeting rooms	London (8, 10, 16, 30) Edinburgh (4)	Large screens, Audio/Video conferencing systems, LED lighting panels, Underfloor and under-table mains cables/charging points
Corridors/ Walkways/ Aisle	London (6, 11, 12, 14, 28, 31)	Underfloor electrical wiring and sockets, LED lighting panels
Canteen	Edinburgh (5, 6)	Large screen Television units, Vending machine, LED lighting panels, Kitchen appliances like Microwave oven, Convection oven, and kettle

Ofcom’s London office

A3.3 In Figure 25, we show the CDF plot of the Fa values grouped according to the location categories identified in Table 8. The difference in the plots further highlights how the density and type of electrical equipment have an impact on the noise levels.

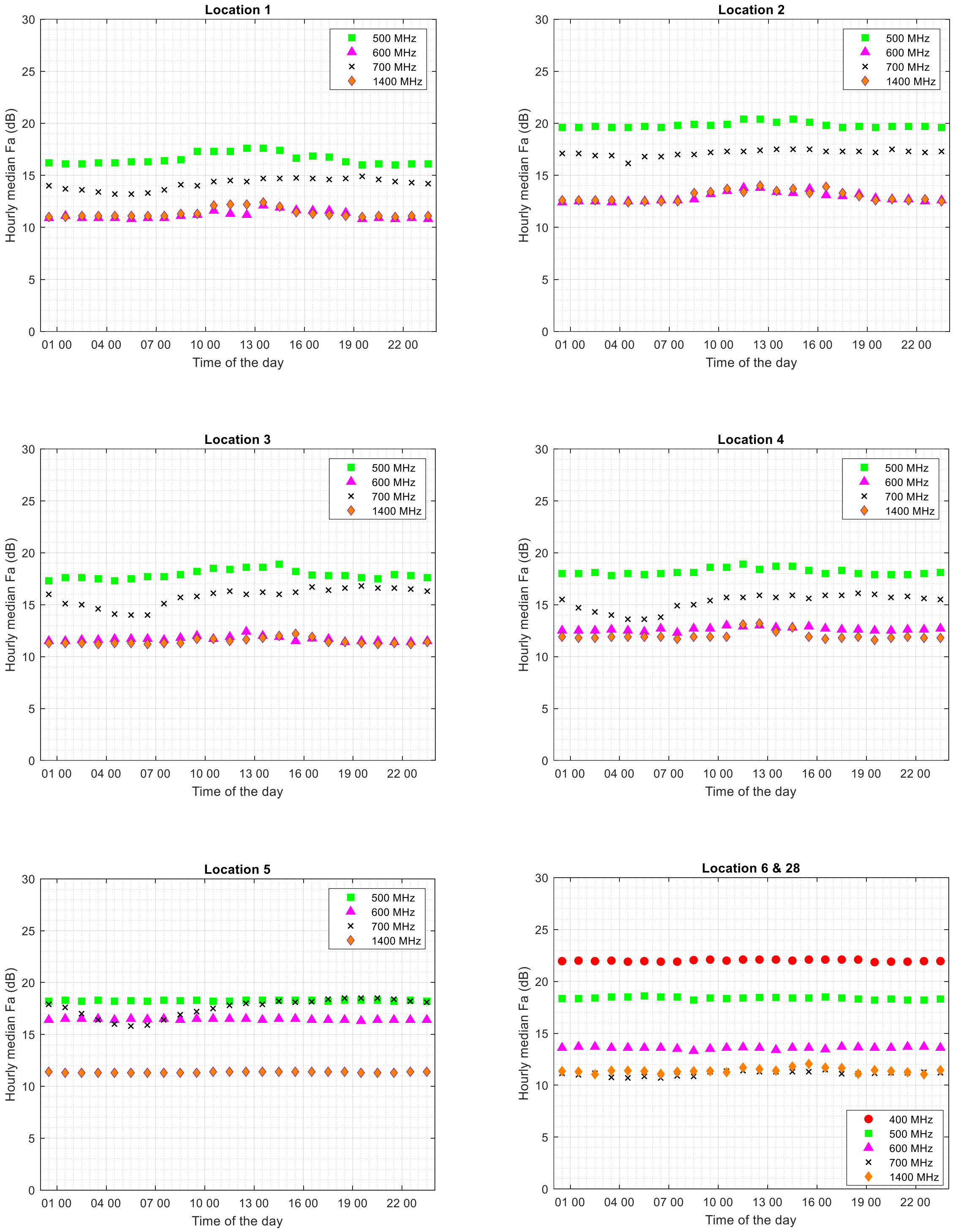
A3.4 It is also noted that some of the CDF plots do not exhibit an ideal “S” shape as would be the case for pure WGN samples. This suggests that in reality, radio noise do not necessarily fit the Gaussian model and may be impacted differently by different devices in the environment.

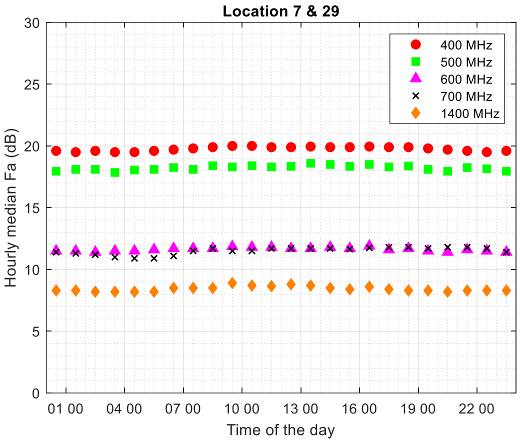
Figure 25: CDF of Fa measured in Ofcom`s London office, grouped by location category in Table 8

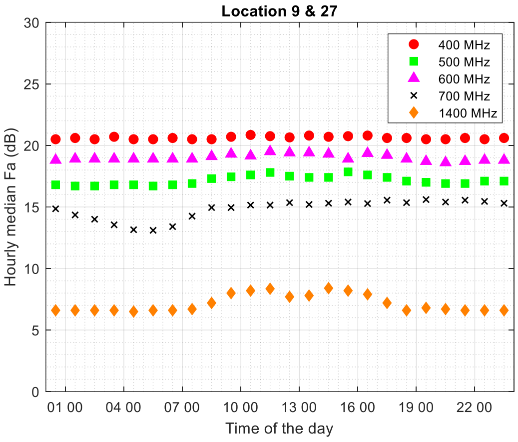


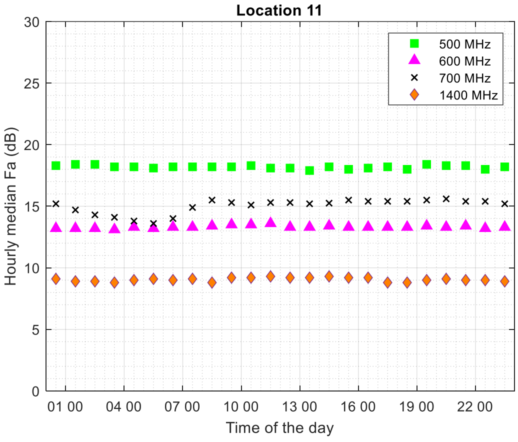
A3.5 In Figure 26, the hourly median Fa value plots, showing how the noise levels change during the hours of the day are shown. From the results, we can infer that the radio noise levels vary according to (1) the measurement location and the device density around the measuring equipment, and (2) the time and human/device activity over the period of the day.

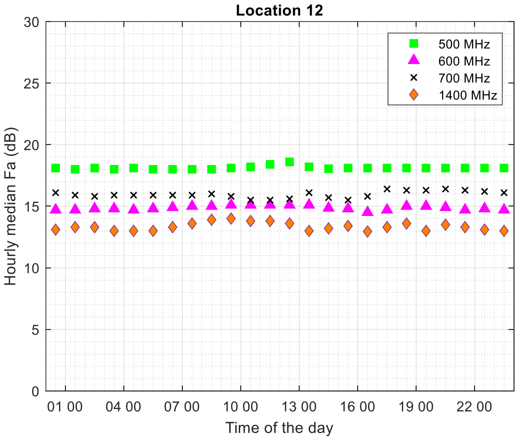
Figure 26: Hourly median Fa value plots in Ofcom`s London office

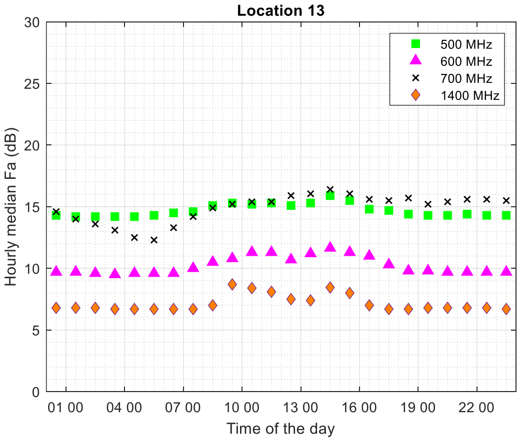


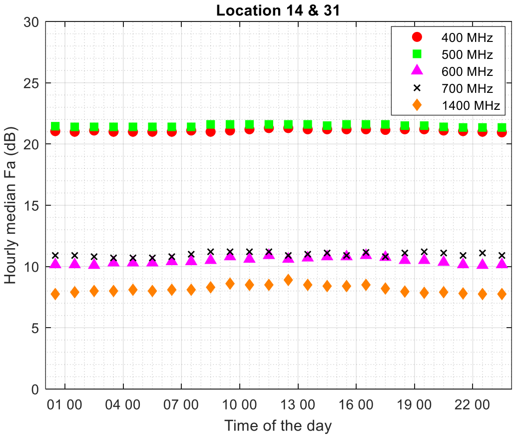

Location 7 & 29

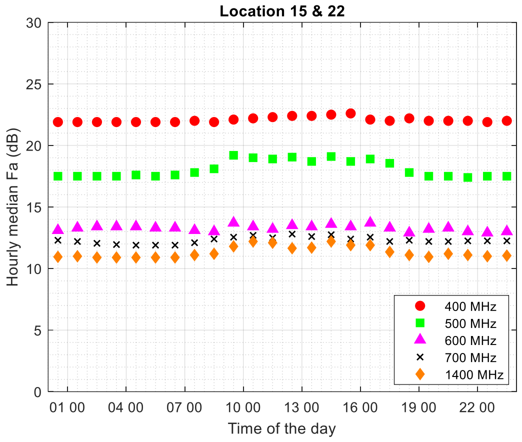

Location 9 & 27

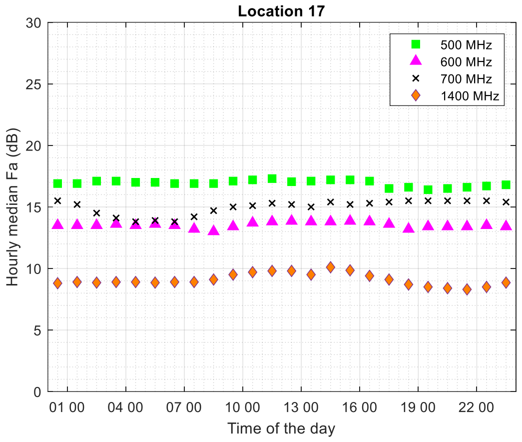

Location 11

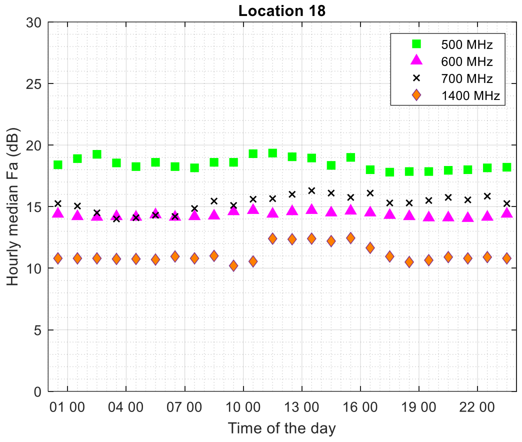

Location 12

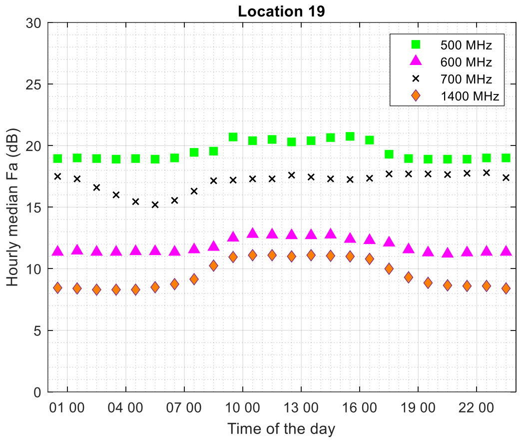

Location 13

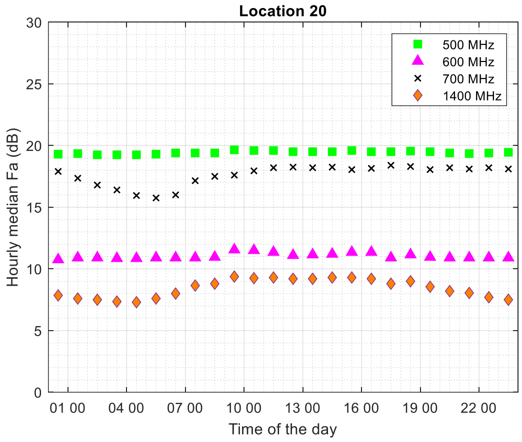

Location 14 & 31

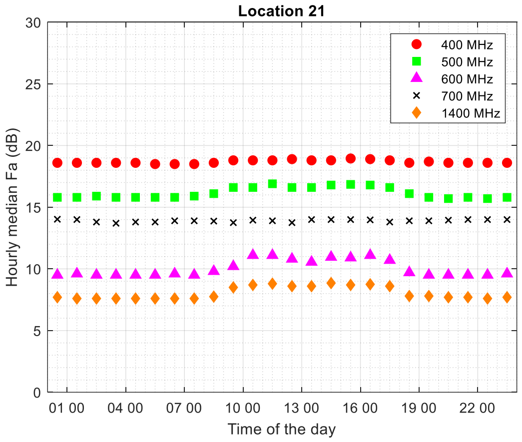

Location 15 & 22
Hourly median Fa (dB)
Time of the day
30
25
20
15
10
5
0
01 00
04 00
07 00
10 00
13 00
16 00
19 00
22 00
400 MHz
500 MHz
600 MHz
700 MHz
1400 MHz

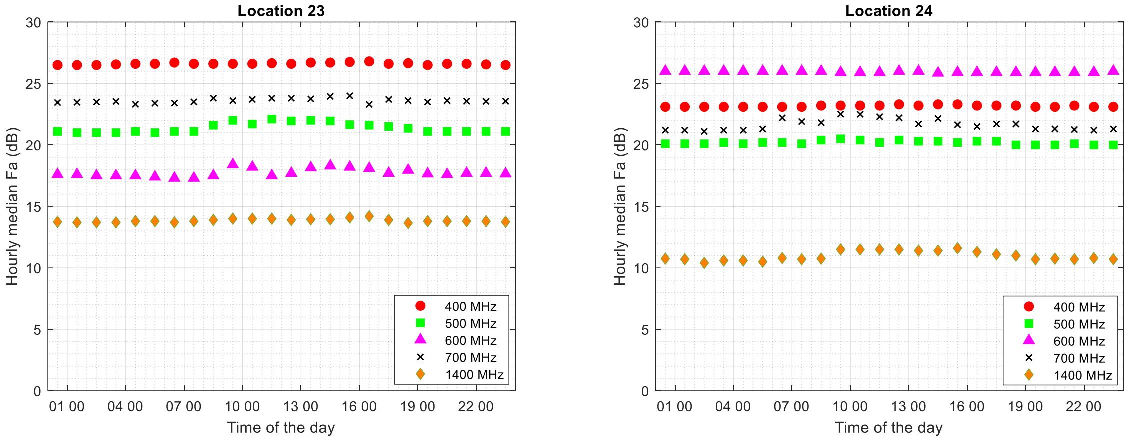

Location 17
Hourly median Fa (dB)
Time of the day
30
25
20
15
10
5
0
01 00
04 00
07 00
10 00
13 00
16 00
19 00
22 00
500 MHz
600 MHz
700 MHz
1400 MHz


Location 18
Hourly median Fa (dB)
Time of the day
30
25
20
15
10
5
0
01 00
04 00
07 00
10 00
13 00
16 00
19 00
22 00
500 MHz
600 MHz
700 MHz
1400 MHz


Location 19
Hourly median Fa (dB)
Time of the day
30
25
20
15
10
5
0
01 00
04 00
07 00
10 00
13 00
16 00
19 00
22 00
500 MHz
600 MHz
700 MHz
1400 MHz


Location 20
Hourly median Fa (dB)
Time of the day
30
25
20
15
10
5
0
01 00
04 00
07 00
10 00
13 00
16 00
19 00
22 00
500 MHz
600 MHz
700 MHz
1400 MHz

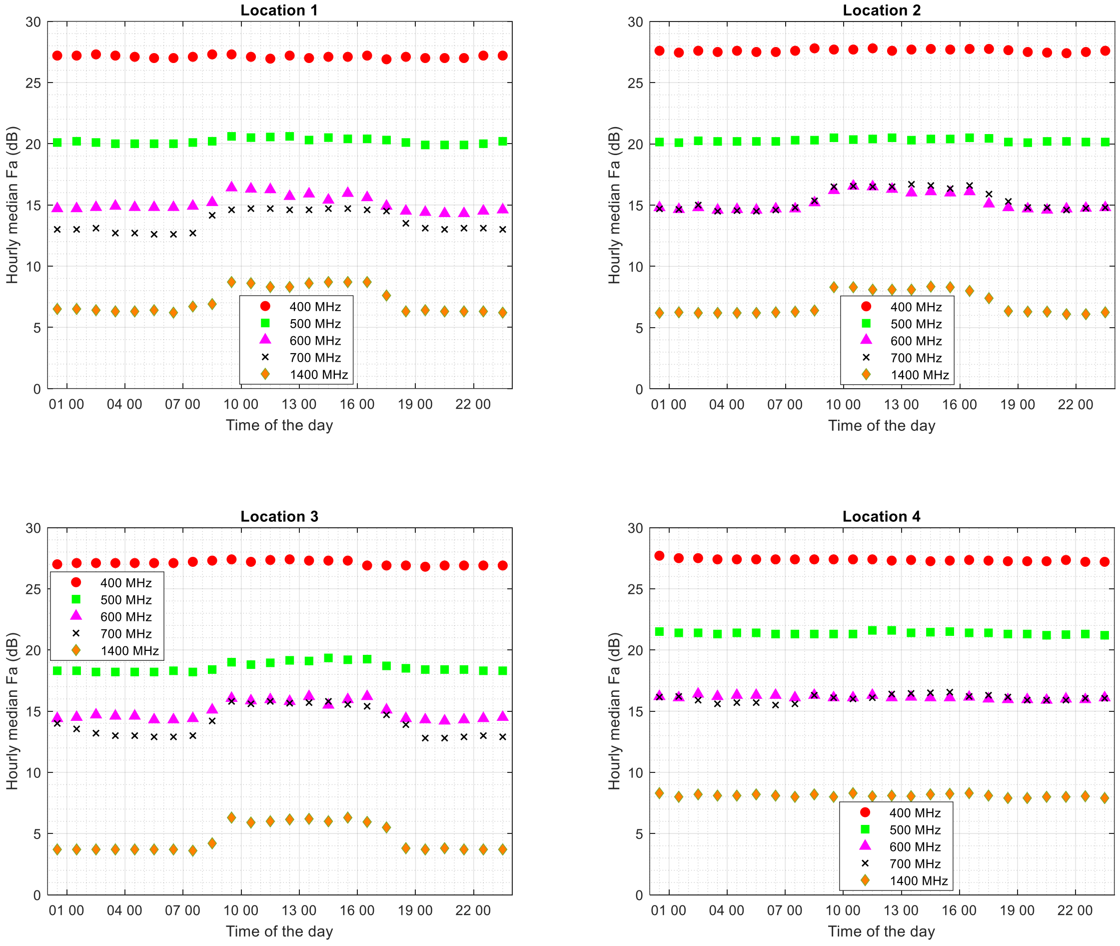

Location 21
Hourly median Fa (dB)
Time of the day
30
25
20
15
10
5
0
01 00
04 00
07 00
10 00
13 00
16 00
19 00
22 00
400 MHz
500 MHz
600 MHz
700 MHz
1400 MHz

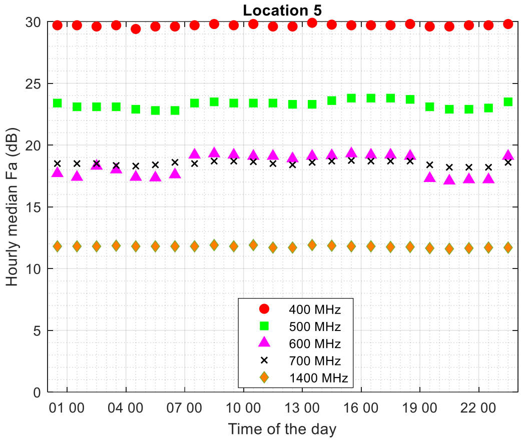


Ofcom's Edinburgh office

A3.6 The hourly median noise levels recorded in Ofcom's Edinburgh office are shown in Figure 27.

Figure 27: Hourly median Fa value plots in Ofcom's Edinburgh office





Residential environment

A3.7 The hourly median noise levels recorded in the residential environment are shown in Figure 28. The four locations reported in numerical order represent the living room (Location 1), a utility room (Location 2), the dining room (Location 3) and one serving as a music room (Location 4).

Figure 28: Hourly median Fa value plots in the residential environment