Exposure assessment of Electromagnetic Fields from Wireless Computer Networks (Wi-Fi); Phase 1 Laboratory Measurements

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Abstract: In order to assess the electromagnetic field exposure from wireless computer networks, the most popular Wi-Fi devices used in the schools were identified. The regulatory standards in the UK limit the radiated power from Wi-Fi at 2.4 GHz to a maximum of 100 mW and this limit increases to 200 mW for Wi-Fi devices in the most popular part of the 5 GHz band. The results showed radiation pattern measurements for all of the laptops were similar, with a minimum in the direction away from the front of the laptop. Generally, two maxima were observed, symmetrically opposed across a vertical plane bisecting the screen and keyboard. The maximum electric field strength recorded at 1 m varied from 719 mVm^{-1} to 1306 mVm^{-1}. Measurements of electric field strength as a function of distance along the direction of maximum field showed that devices had power density values well below the 100 mW (EIRP) limit. The highest EIRP was 57 mW.

1. Background

There has been a rapid expansion in the use of wireless computer networks (WiFi) in homes, businesses and schools. The WiFi systems involve antennas mounted on computers, known as clients, which transmit and receive radio waves. The radio waves travel to and from, access point antennas, usually located within a few tens of metres and in the same building. WLAN offer flexibility and mobility to the users and that made the technology popular amongst a wide range of users, including the education sector. The survey report commissioned by the British Educational Communications and Technology Agency [8] suggests that 50% of primary schools and 82% of secondary schools use wireless network technology. People using WiFi, or in proximity to the equipment, are exposed to the radio signals and will absorb some of the transmitted energy in their bodies. The strength of the radio signals at a given position can be measured as their power density and the absorbed energy can be calculated as the specific energy absorption rate (SAR). These quantities are addressed in guidelines [7] for limiting exposure from the International Commission on Non-Ionizing Radiation Protection (ICNIRP), which are recommended by the HPA for adoption in the UK. WiFi is a rapidly developing technology and there is a lack of quantitative information on exposures, particularly for installed systems. Moreover, given the existing precautionary advice from the Chief Medical Officer and from the NRPB (now part of HPA) to discourage non-essential use of mobile phones my children, it is important to consider how exposure from WiFi equipment, as used by children in schools, compares with that from mobile phones.

2. Objective

The aim of the work was to measure field strength emitted from Laptops in 802.11g in the laboratory in a controlled environment. Review the available information and survey reports to select WLAN devices representing 802.11g standard. Procure WLAN devices and measurement equipment required for experimental measurements. Develop and modify protocol for electromagnetic field measurements and set up test facilities in the laboratory. Measure electromagnetic field strength around the selected devices during transmissions and calculate radiated powers. The majority of the experimental work in the project was laboratory-based to understand the electromagnetic radiation pattern and any electromagnetic directivity with reference to the device position. It is expected that these measurements in the controlled environment would form a basis for the development protocols for school measurement for the next phase of the project.

3. Regulatory standards and ICNIRP guidelines

The most commonly used IEEE standard is 802.11g [6]. This standard uses 2.4 GHz and supports data rates up to 54Mbps. The scheme used for modulation is OFDM and is also compatible with 802.11b by dropping to lower data rates. The standard 802.11a [5] uses the 5 GHz band which is less crowded as compared with 802.11g standard. The radio interface used in this standard is based on OFDM but the coverage range is less than that of 802.11g standard due to the higher carrier frequency. The European Telecommunications Standards Institute (ETSI) deals with harmonising the equipment in terms of compliance with regulatory requirements for use of the radio spectrum. The standard [2] limits the maximum power for any system operating in the 2.4 GHz band to 100 mW. The output power is defined in terms of the maximum equivalent isotropic radiated power (EIRP) and is limited to 100 mW in the 2.4 GHz band and 200 mW in the most popular part of the 5 GHz band (indoor). The ICNIRP guidelines [7] advise reference levels that are based directly on established health effects and it is stated that protection against adverse health effects requires that these reference levels are not exceeded. If the measured or calculated values are below the reference levels then compliance with the guidelines is then ensured. Table 1 contains the ICNIRP reference level values for electric field strength and power density at frequencies between 2 and 10 GHz.

TABLE 1. Reference level of ICNIRP guidelines.

Guidelines	Reference level at 2-300 GHz	
	Electric Field strength (Vm^{-1})	Power density (Wm^{-2})
ICNIRP occupational	137	50
ICNIRP general public	61	10

4. Equipment selected for testing

According to the C3 education report [8], commissioned by BECTA, the majority of the WLAN devices used in school are Access Points and Laptops and therefore most of the electromagnetic exposure would come from these devices. It was decided that, in the first phase of the work, the experimental measurements would begin by testing laptops and access points that are most commonly used in schools. Several manufacturers and models of these devices were identified and the most popular devices were then short listed for experimental measurements. Table 2 contains general information on the laptops that have been obtained for testing.

TABLE 2. List of laptops selected for testing.

Wi-Fi Project ID	Wi-Fi modes	Dimensions LxWxD (cm)	Available frequency channels		Settable power levels
			2.4 GHz	5–6 GHz	
LT01	b/g	34 x 24 x 4	Not selectable	Not available	Not selectable
LT02	b/g	36 x 27 x 4	Not selectable	Not available	Not selectable
LT03	b/g	36 x 27 x 4	1–13	Not available	25, 50, 75, 100%
LT04	a/b/g/n	37 x 27 x 4	1–11	36–48	1–5
LT05	a/b/g/n	37 x 28 x 4	1–11	36–48	1–5
LT06	b/g	34 x 25 x 4	1–14	Not available	Not selectable
LT07	a/b/g	32 x 24 x 4	1–11	36–48	1–6
LT08	a/b/g	30 x 25 x 4	1–11	36–48	1–5
LT09	a/g/n	33 x 23 x 3	1–14	36–64, 100–140, 149–165	25, 50, 75, 100%
LT10	a/b/g/n	33 x 25 x 4	1–11	36–48	1–5
LT11	a/b/g	26 x 17 x 5	1–14	36–64, 100–140, 149–165	25, 50, 75, 100%
LT12	b/g	23 x 17 x 4	Not selectable	Not available	Not selectable
LT13	b/g	23 x 12 x 3	Not selectable	Not available	Not selectable
LT14	a/b/g	40 x 29 x 5	1–11	36–48	1–5
LT15	b/g	28 x 24 x 4	1–13	Not available	1–6

5. Experimental facilities and measurement protocols

An anechoic chamber was constructed in the EMF Laboratory at HPA's Chilton site. The room has dimensions of 3.6 m × 2.4 m × 2.4 m. The internal walls of the anechoic chamber are fitted with radiofrequency absorber material with a reflection coefficient of −20 dB at Wi-Fi frequencies. The electric field measurements from each laptop were performed in this controlled environment to minimise field disturbance due to reflections and interference. The transmitting device was mounted on a manual positioning device, known as a goniometer, which allowed rotation in two orthogonal planes so the measuring antenna could sample the radiation pattern at any angle. The distance of the measuring antenna could also be varied to profile electric field strength as a function of distance. The reference point of the rotational coordinate system was at the centre of the hinge-line connecting the laptop screen and keyboard. A single access point was used to receive the Wi-Fi transmissions for all the laptops under test. This access point was enclosed in absorber blocks to weaken the acknowledgment signals it transmitted back to the laptops, which were found to affect the measurements during preliminary investigations. A communication link with sustained data rate was established between the transmitter and receiver using software called LanTraffic.

Figure 1. Screen shot showing the interface to the data acquisition program.

A purpose built computer program was written to automate the measurement and control the vector network analyser. It uploads the specified measurement configurations and acquires the measurement samples for storage in an Excel spreadsheet. The angular position of the device was varied from -90°< θ < 90°, −180°< Φ < 180° and the distance was varied 0.5 m to 1.9 m. The program acquires 50 samples burst power measurements from the Vector Signal Analyser (VSA) for each measurement position. The acquired parameters included, burst power, occupied band power, modulation scheme and Error Vector Magnitude (EVM). The burst power is the key parameter used to calculate the RMS electric fields during the transmitted burst. The band power is the spectral power of the burst. The modulation scheme and EVM are acquired to understand various relationships between radiated power for selected data rates and quality of signal.

6. Measurement results

The laboratory measurements were performed to establish the radiation pattern (i.e. the angular distribution of electric field strength around each laptop) and to identify the angles at which the field was a maximum. The electric field strength at these angles was then measured as a function of distance. Communication was established between laptop and the access point.

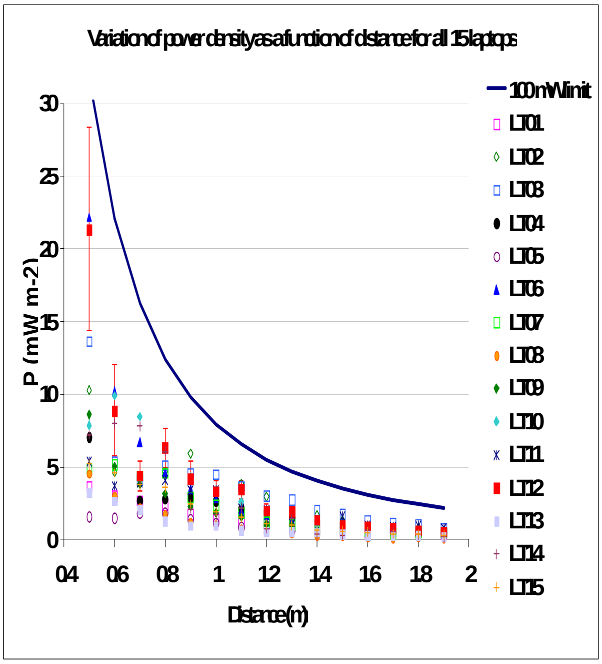

Figure 2. Power density as function of distance.

TABLE 3. EIRP, integrated radiated power and maximum E-field strength for each laptop.

Laptop No.	EIRP,(mW)	Power, (mW)	E-field, (mVm^{-1})
LT01	36	10	1045
LT02	49	19	1216
LT03	57	17	1306
LT04	37	13	1048
LT05	17	6	719
LT06	44	12	1153
LT07	37	13	1055
LT08	20	9	766
LT09	34	18	1009
LT10	37	11	1054
LT11	32	10	1144
LT12	43	17	1142
LT13	22	8	837
LT14	31	12	970
LT15	28	9	909

Data traffic was maintained at roughly 22 Mbps, the maximum sustained rate that could be reliably maintained using the IEEE 802.11g standard. During the measurement the laptop screens were set at 115 degrees, a typical angle in which users operate their devices. The transmitted signal was analysed using the Vector Signal Analyser which has the ability to decode the burst and reassemble it back for detailed analysis. The instrument captures individual Wi-Fi bursts in the time domain and demodulates them to identify the burst power, and many other parameters. At each position 50 measurement samples were acquired and then analysed in terms of the statistical distribution. To establish the radiation pattern, the spherical measurements were made around the device at 1 m distance from the laptop in horizontal and vertical polarisations for azimuth and elevation rotations in 30° steps. The acquired electric field data were then analysed to identify angles of maximum radiation. In order to perform measurement as function of distance, the manual positioning system was then set up at the angles, where electric field had maxima, and the electric field strength was measured in 10 cm steps from 0.5 m to 1.9 m. The measurement results showed similar radiation pattern measurements for all 15 devices with a minimum in the direction from the front of the laptop as shown in Figure 2. The power level varied between distinct levels and this was considered to be due to the use of antenna diversity. Generally, two angular maxima were observed that were symmetrically opposed across a vertical plane bisecting the screen and keyboard. The measurement results showed that electric field strength values for all the devices were below the specified output power limits of 100 mW (EIRP) limit. The highest value of the measured EIRP was 57 mW as shown in Table 3.

7. Conclusions and further Work

The regulatory standards in Europe and the UK limit the radiated power from WiFi at 2.4 GHz to a maximum of 100 mW (EIRP). This limit increases to 200 mW in the most popular part of the 5 GHz band. Various surveys carried out by project partners showed that laptops are the most popular wireless devices used in schools, with IEEE 802.11g as the most widely utilised standard. This resulted in choosing a total of 15 laptops from the most commonly used devices in schools. The results showed radiation pattern measurements for all of the laptops quite similar, with a minimum in the direction away from the front of the laptop. Generally, two maxima were observed, symmetrically opposed across a vertical plane bisecting the screen and keyboard. The maximum electric field strength recorded at 1 m varied from 719 mVm^{-1} to 1306 mVm^{-1}. Measurements of electric field strength as a function of distance along the direction of maximum field showed that devices had power density values well below the 100 mW (EIRP) limit. The highest EIRP was 57 mW. The next phase of experimental measurements will include the assessment of the electric field strength around access points operating at 2.4 GHz. Measurements will be carried out on a selection of laptops and access points operating in the 5 GHz band before performing measurements in schools. The internal structure of the antennas and devices will also be simulated to predict the electromagnetic exposure. Finally, the review of the health risk will be carried out.

References

[1] CENELEC EN 50383 (2002) Basic Standard for the calculation and measurement of electromagnetic fields related to human exposure from radio base stations and fixed terminal stations for wireless telecommunications systems (11 MHz – 40 GHz).

[2] CENELEC pr EN 50400 (2004) Basic standard to demonstrate the compliance of fixed equipment for radio transmission (110 MHz - 40 GHz) intended for use in wireless telecommunication networks with the basic restrictions or the reference levels related to general public human exposure to radio frequency electromagnetic fields, when put into service, Second draft.

[3] EN 301 489 Electromagnetic compatibility and Radio spectrum Matters (ERM) Electromagnetic Compatibility (EMC) standard for radio equipment and services Part 17 Specific conditions for Wideband data and HIPERLAN equipment.

[4] IEC 62209-2 (2007) Human exposure to radio frequency fields from handheld and body-mounted wireless communication devices – Human models, instrumentation, and procedures – Part 2: Procedure to determine the specific absorption rate (SAR) for mobile wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz) .

[5] IEEE Std 802.11a (1999) Supplement to IEEE Std 802.11-1999, Supplement to IEEE Standard for Information technology. Telecommunications and information exchange between systems. Local and metropolitan area networks. Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications High-speed Physical Layer in the 5 GHz Band.

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[7] ICNIRP (1998) Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz)

[8] Wireless Technology in Schools 2007 C3 Education for the National Education Research Panel (NERP)