Biological response to pulsed microwave radiation from wireless communication systems: implications for current and future exposure and safety levels

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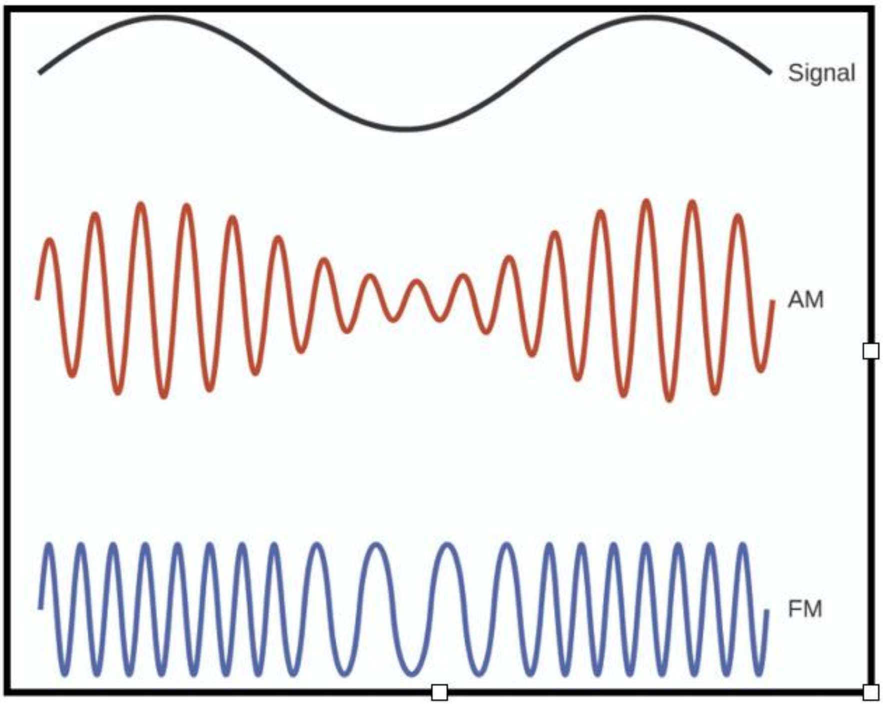
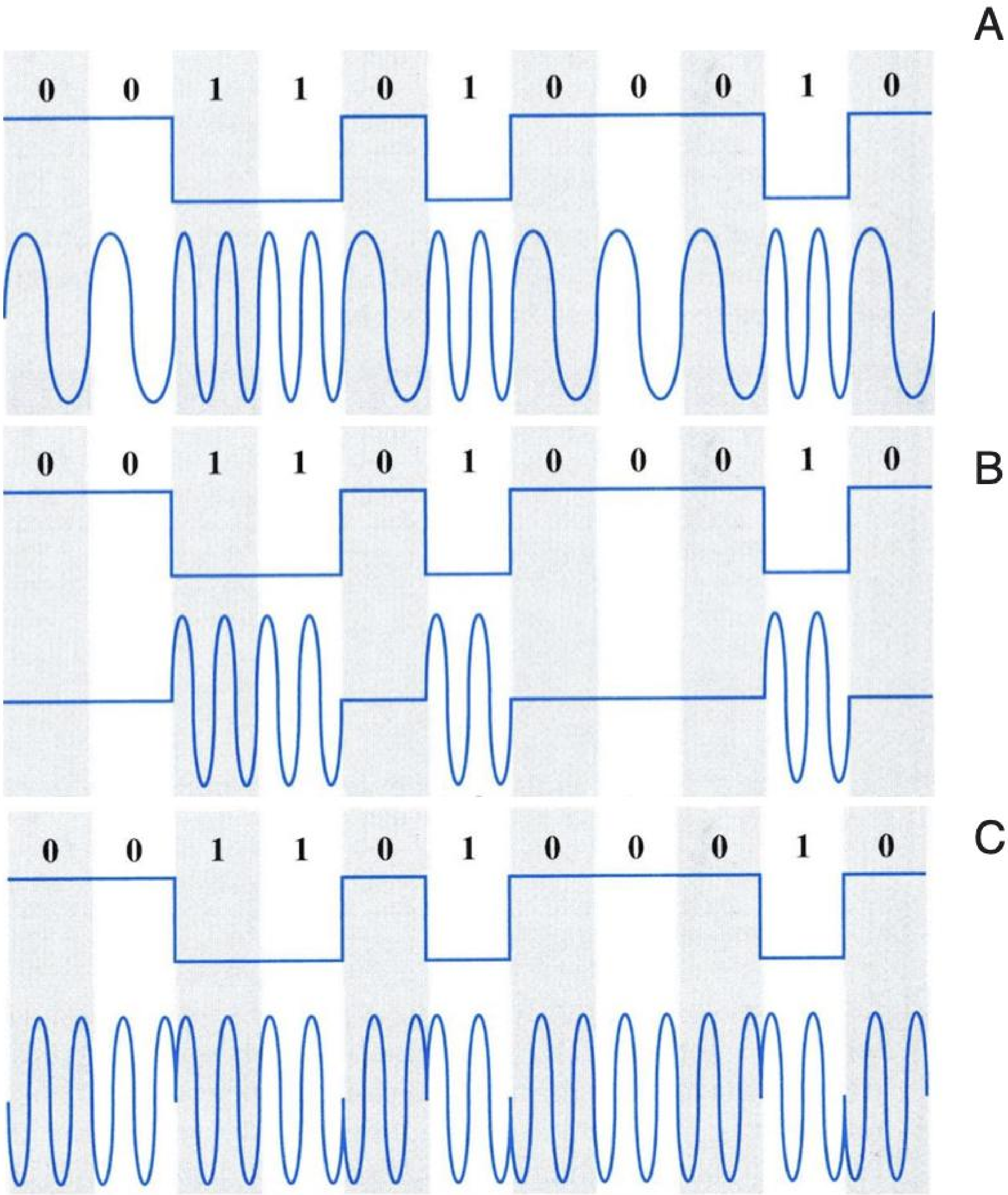
1. Wireless transmission systems

As mentioned previously at this site, the roll-out of the new 5G telecommunications (telecom) standard for mobile devices is encouraging many of us to reconsider the extent to which our microwave environment might be affecting our health. By 'us', I mean thousands of biomedical professionals and tens of thousands of individuals around the world. But what could be the problem- the population of most countries around the world has been exposed to radio and television 'waves' for the best part of 75 years. Whilst this is true, there is a fundamental differences between telecom broadcasts from say the 1970s and those from the 1990s onwards. Signals transmitted in 1970 were analogue, now they are digital and carried by microwaves. Why does this make a difference?



Before answering this question, let's briefly explore the mysteries of wireless transmission using radio as an example. In broadcasting sound, all program 'information' is encoded onto an electromagnetic (EM) 'carrier wave'. In the early days of radio, long wave and medium wave frequencies of the EM spectrum were used as carriers. These covered frequencies from around 150kHz to just under 2MHz. The encoding of information/sound was by amplitude modulation (AM), where in real time, the signal or audio information was the change in amplitude of the carrier wave (see Figure). From 1955, the BBC began broadcasts with FM encoding, where the amplitude stayed the same but the carrier frequency was modulated (Figure above). In the UK, the carrier wave for FM covered the range, 88.0 – 94.6 MHz (FM now extends to 108MHz). Up until 2012, television signals in the UK were transmitted over the range 470–862 MHz where the picture information was transmitted using AM and the sound by FM. From 2012 all television transmission in the UK went digital, meaning that sound and vision 'information' was encoded by a digital algorithm.



Whilst digital transmissions use a sinusoidal carrier wave, the wave is modulated to represent digital information in the form of 0s and 1s. Three fundamental 'digital' modulation techniques are shown in the figure to the left. ‘A’ represents a technique called Frequency shift keying (FSK), whilst ‘B’ and ‘C’ are Amplitude shift keying (ASK) and Phase shift keying (PSK) respectively. Most mobile communication systems use a combination of techniques. For example, combining ASK and PSK gives Quadrature amplitude modulation (QAM). This mode uses two waves phased 90 degrees apart (orthogonal waves). With other sophisticated methods, QAM is one of the modes of modulation that provides the highly complex waveforms necessary to carry large amounts of data (for useful overview see: https://www.open.edu/openlearn/science-maths-technology/exploring-communications-technology/content-section-1.7).

So the fundamental difference between now and 1970, is that almost all 'information', whether sound, picture, text or data, is now sent as highly complex, multi-channel pulsed phase-modulated EM waves.

2. Biological targets for digital wireless signals

Whilst we might think are bodies are animated by biochemical processes, in reality, we function on bioelectrical principals. Our physiological functions are shaped by pulses. Signalling happens by the opening of ion channels in membranes, allowing a pulse or influx of small ions like, sodium, potassium and calcium into (or out of) cells. With this in mind, pulsed microwaves are considered to be more biologically active than non-pulsed sinusoidal waves (Panagopoulos et al., 2015). There is now overwhelming evidence that pulsed EM waves target what is termed the Voltage Gated Calcium Channel (VGCC) in the membrane of most mammalian cells (with a similar system in plants). Much of the evidence for this has been accumulated by Professor Martin Pall. His review from 2013 outlined numerous studies where the effects of low-intensity EM waves, both at microwave frequencies and at lower frequency, could be prevented by calcium channel blockers.

The molecular composition of the VGCC, coupled with its cell membrane location, greatly increases the sensitivity of this ion channel to pulsed EM waves (Pall, 2018a, b). In his numerous articles, Pall has outlined how activation of the VGCC by pulsed EM waves leads to multiple 'down-stream' effects, such as Nitric oxide (NO) formation, reduced mitochondrial function, oxidant formation and DNA damage (see caption above for overview). The latter, in particular, is not widely acknowledged. Cancer Research UK at their site state that, '*The radiofrequency electromagnetic radiation they* (mobile phones) *transmit and receive is very weak. This radiation does not have enough energy to damage DNA, and cannot directly cause cancer*'. Whilst it is true that pulsed microwaves don't have high enough photonic energy to damage DNA directly (unlike the higher frequencies of high UV, X-rays and gamma rays), they cause damage indirectly, via increasing intracellular oxidants. The evidence for this is now overwhelming (Panagopoulos, 2019).

The statement by Cancer Research UK is incorrect on both counts. Pulsed microwaves do damage DNA and there is good evidence that pulsed microwaves do increase cancer risk (Morgan et al., 2015 *with further overview by* Pall, 2018a and b).

Of great concern should be the effect that phase-modulated pulsed microwaves might be having on children and young people. We expose most children in school and at home to WiFi and mobile device and pulsed microwaves have been shown to affect DNA repair and embryonic stem cells [Belyaev et al., 2009, Markovà, 2010]. As stem cells occur at much higher densities in children (most abundant in the foetus), impacts on young children are likely to be higher than in adults. EM wave effects on stem cells may also disrupt brain development and function in young children [Bhargav et al., 2015]. This may play a role in autistic spectrum disorders.

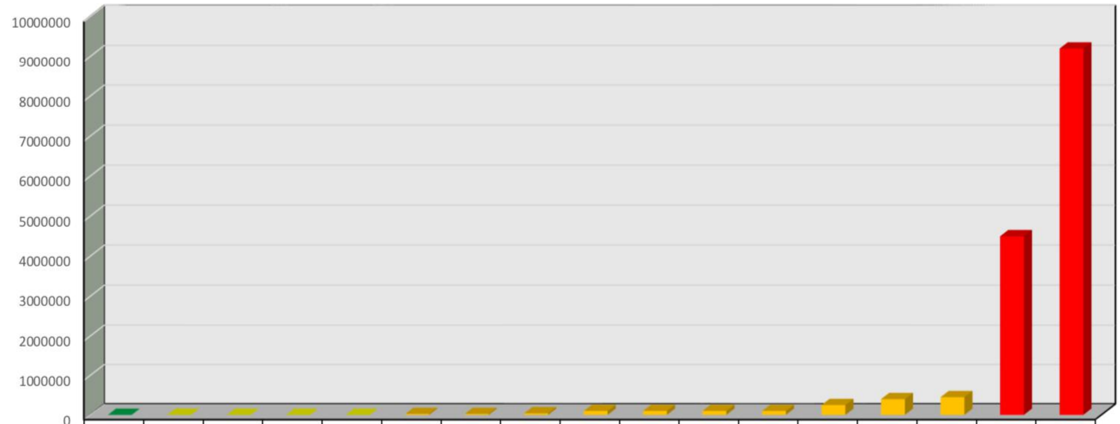
3. Current exposure to pulsed microwave sources

Whilst there is absolutely no doubt that phase-modulated pulsed microwaves cause adverse biological effects, it is not so easy to make studies on overall health (with the exception of cancer studies, as they relate to mobile phone use). Unless we used wired connections, laptops, tablets, WiFi, cordless phones and Bluetooth devices all emit pulsed EM waves at microwave frequencies. Add to this transmissions from mobile phone masts (antenna) and one can appreciate that it is impossible to conduct case-control studies; *we are all part of the 'experiment'*. This means that we can only look at trends over time. Before taking a look at some trends in health, the next paragraphs discuss exposure levels in terms of national and international guidelines.

As outlined in previous articles, the UK defers to ICNIRP 1998 (International Commission for Non-Ionizing Radiation Protection). For radio-frequency transmissions (frequencies up to 300GHz), the upper limit for permissible exposure is set around 60V/m. As this is transmitted through free space (air), this electric field strength can be converted to a power level of around 10W/m^2 (*see *Note below for conversion from V/m to Watts/m^2*). To put this into perspective, a mobile phone emits intermittent signals of at least 6V/m (measured at 3-5cm from phone) in standby mode (this equates to around 100 mW/m^2) . When dialling and sending, the signal strength will go up considerably. An Apple MacBookPro emits intermittent pulses of at least 6V/m when the detection device is held 5cm to the right of the keyboard. Tablets are similar. When 1m from a WiFi router (in UK), one can detect pulses of up to 6V/m. If you live within 200m of a mobile phone antenna, you will be exposed to a constant stream of pulses anywhere between 0.3 and 1 V/m (0.24 mW/m^2 - 2.7 mW/m^2, depending on power of antenna). So all these transmissions are within permissible levels in the UK.

RADIO FREQUENCY RADIATION SAFETY LIMITS

Power Flux Density (a heating metric) – micro Watt per metre squared (*μW/m^2*)



	Natural	Building Biology	EURO-PAEM: Wifi, 2.5G	Bioinit-iative	Seletun	Brussels	Poland	Switzer-land	Bulgaria	Italy	Lithuan-ia	Russia	Turkey	China	India	UK, ICNIRP, 900 MHz	UK, ICNIRP, 1.8 GHz
Heating Limits																4,500,000	9,200,000
Non-thermal Limits						24,000	25,000	42,000	100,000	100,000	100,000	100,000	250,000	400,000	450,000		
Biological Limits		0.1	10	6	170												
Biol. Sensitive Limits		0.1	0.1	3													
Natural Levels	0.000001																

The peak electric field (Volts per metre: V/m) is the appropriate metric for biological effects.

Natural: 0.000001 μW/m^2 = 0.00001 V/m

Sensitive and Biological: 0.1 μW/m^2= 0.006 V/m; 10 μW/m^2 = 0.06 V/m

Non-thermal: 24,000 μW/m^2 = 3 V/m; 100,000 μW/m^2 = 6 V/m

Heating: 4,500,000 μW/m^2 = 41 V/m; 9,200,000 μW/m^2 = 61 V/m

Paris in 2017 adopted 5 V/m (75,000 μW/m^2), down from 7 V/m, for 900 MHz indoor limits. Values are based on information currently available but mainly not specifying the relevant RF frequencies.
Michael Bevington, 2017.

To make national comparisons, the table above has been extracted from the Powerwatch website (divide microW by 1000 to get mW). The levels set by ICNIRP are only advisory and are upper limits, based on heating tissues. It is alarming to note that whilst several Western European nations and the US (via the FCC) use the 9-10W/m^2 limit, China and Russia limit maximum exposure to 0.1W/m^2 (6V/m). A more detailed summary of power limits was recently prepared by Bevington 2017. These data largely support Powerwatch and quite clearly show that the UK, like the US, has the highest power limits. Of particular note from the Powerwatch data is reference to the power level at which a mobile phone can function- 2picoWatts/m^2! If this value can be corroborated, then why are we using such relatively high power transmissions? One assumes this has something to do with data integrity, in other words, to assure high data rates (bits/s) and low latency.4. What level of exposure to pulsed microwaves is safe?

From the perspective of biological effects, recent work has demonstrated marked increases in oxidant formation and DNA damage with pulsed microwaves (from a mobile phone) at average strengths of 0.32microW/cm^2 or (3.2 mW/m^2)*, around 1V/m (Yakymenko et al., 2018). The Bioinitiative report (2012), from its extensive review of earlier literature, suggests a precautionary limit of 1mW/m^2 or 0.64V/m (see **Note below). This is entirely consistent with current literature on biological effects and suggests that much of our current exposure is too high by at least a factor of 10.

The telecom industry will point out that extrapolation from isolated biological systems is not valid in terms of human exposure, as microwave penetration into tissues has to be taken into consideration. For this reason, SAR values or Specific Absorption Rates are often quoted in the context of mobile phones. SAR is calculated from the average field strength emitted by a device such as a mobile phone (*one assumes, at distance from the head when phone in use*), the density of the tissue and its conductivity (as if the tissue were an electrolyte). The equation is given below with an example of SARs at field strengths of 4V/m and 1V/m.

$$Specific\ Absorption\ Rate\ (SAR) = \frac{\sigma \times E^2}{m_d}$$

σ = Conductivity of Material E = Electric Field(RMS)

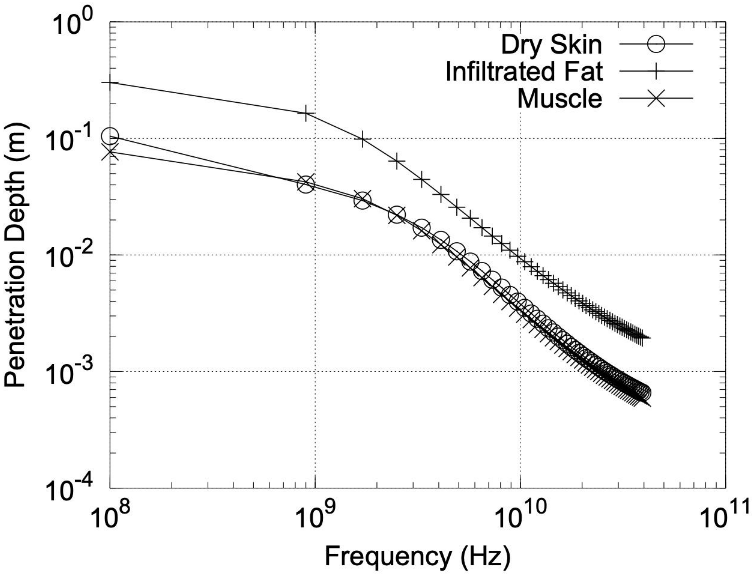
md = Mass Density

If the (rms) field strength is 4V/m, the overall conductivity of the brain is estimated as 0.4 S/m* and the mass density is 1300Kg/m3, then the Specific Absorption Rate (SAR) is 0.005 W/Kg. At 1V/m the SAR is 0.0003 W/Kg.

* McCann H, Pisano G Beltrachini L. (2019) Variation in Reported Human Head Tissue Electrical Conductivity Values .Brain Topography Volume 32(5): 825–858

The limit for SAR set by the FCC is 1.6W/Kg. One can calculate, based on the equation above, that this is equivalent to a field strength of around 70V/m, the electric field strength limit set by ICNIRP and the FCC. One can see that SAR is not particularly useful as it relates to a reference value based on heating and not biological effects.

Another way to consider the problem is to look at tissue penetration as a function of frequency. The graph on the left below shows the calculated penetration into three tissue types (Melia, 2013). At between 700MHz and 3GHz penetration into skin and muscle is between 5 and 2cm. So whilst it is theoretically possible for microwaves to penetrate to a depth that most certainly could cause health problems, one has to assume that the actual penetration depends on power as energy will be lost as the microwaves pass through tissues. The only solution to bridge the divide between biological responses determined experimentally and health, is to do experiments. The problem is how, as we are already in the *experiment* and so case- control studies are technically difficult. Consider smoking for example. Many individuals in the 1970s were part of the *experiment* due to 'passive smoking'. Studies were eventually performed on animals. In rather the same way, experimental studies (on the effects of pulsed microwaves) have now been conducted on animals (*for review see* Bioinitiative report 2012 and Pall, 2018a, 2018b). Perhaps the most alarming are those on fertility.



For mice exposed to pulsed EM waves, fertility was diminished for consecutive litters until the third generation, where progeny demonstrated either low fertility or were completely sterile (Magras and Xenos, 1997). Whilst one has to make a species leap, there is cause here for concern regarding male fertility. As shown in the graph on the left, microwave penetration is inversely proportion to tissue depth. The reproductive organs of the male (unlike the female) are relatively unprotected by tissue layers and so depending on power levels (as discussed above), are likely to be vulnerable to microwave-induced oxidative DNA damage. Children work/play for hours a day, often within one to several meters of WiFi routers (30mW devices emit microwaves at a power level of 1mW/m^2 at around 1.5m), both a school and at home. Add to this mobile devices and antennae placed within 200m of dwellings and one quickly realizes this could be a recipe for reproductive disaster.

So what about trends? A recent meta-analysis revealed lowering of sperm counts and sperm quality in many countries around the world, with declines of 40-50% in all advanced technology countries (Levine et al., 2017). As for all correlations, one cannot conclude causation, but given the biology, pulsed microwaves may be playing a part. Other trends might be the gradual rise in autistic spectrum disorders. Despite the biology, it will be extremely difficult to pin this rise on exposing children to pulsed microwaves alone. For this reason, one might suggest that exposing the population to pulsed microwaves is equivalent to the '*perfect crime*'. Unless conducted on an artificial island in the middle of the Pacific ocean, 'clinical trials' to investigate a cause-effect relationship will never be possible.

5. 5G: the new Wild West

Capacity =	Cell density x	Spectral efficiency x	Available spectrum
bits/s/km2	cells/km2	bits/s/Hz/cell	in Hz

The internet of things, driverless cars and mobile data-streaming at speeds 10-100 fold greater than present are apparently on their way. This will require a large increase in capacity, defined as a combination of three factors indicated in the box above. An increase cell density will require more cells or antenna per unit area. Using current antenna, increasing spectral efficiency is a problem, as a two fold increase would require almost a 20 fold increase in power. A solution is to leave the single antenna arrangement and move to multiple antenna in a MIMO (multiple input multiple output) arrangement. The third factor in the box above is to increase the available spectrum. In the UK, sub-1GHz frequencies, around 700MHz (coverage layer), will apparently provide for general coverage and 'deep indoor coverage'. The frequency range 1GHz-6GHz is being described as the ‘coverage and capacity layer’ and frequencies above 6GHz, are described as the ‘super data layer’. For the latter, Europe will use frequencies in the 24.25-27.5GHz band. There are also plans for bandwidths extending all the way to 200GHz.

Implementing these changes will require extended infrastructure and this will become apparent by the appearance of smaller masts and antenna, particularly in massive MIMO arrays, that will allow beamforming and multiplex signal distribution (simultaneous transmissions to receivers). Whilst health fears have been expressed concerning the higher frequency millimetre bands, transmitted by beamforming MIMO arrays (that will target skin and eyes), it may be the lower sub-GHz bands that are the most troubling. These are the ones reserved to provide 'deep coverage' (all areas). At the lower frequency of 700 MHz, microwaves are more penetrating and will pass easily through clothing and deposit energy in tissues. Much, of course, depends on the power transmitted by base stations in the new 5G networks. There is talk about being able to reduce transmitted power by using more base stations. How much this will reduce power density in the indoor environment is entirely unknown (to us) at present.

Despite the belief that penetration will be blocked by skin, higher frequencies (20GHz +) come with their own problems. As data transfer rates approach 10GBits/s, deeper penetration may occur due to the generation of Brillouin precursors (see https://betweenrockandhardplace.wordpress.com/2019/05/24/guest-blog-can-5g-phased-array-antennas-generate-brillouin-precursors-by-don-maisch/). Unlike unidirectional radiation with 4G, MIMO antenna arrays will direct a beam of pulsed microwaves at the user. The massive MIMO arrays will be capable of multiplexing by a combination of antenna number and phase, meaning that multiple users will be simultaneous targets. Without doing the math (or having inside technical knowledge), we simply don't know what the power density will be at the target site (user/mobile device).

Given the lack of any form of technical consultation with the public and given the complete failure of ICNIRP and Public Health England to establish guidelines based on known biological effects of pulsed microwave radiation, it is clear that we are living in the technological incarnation of the *Wild West.*

None of the new 5G technologies (also true for previous Gs) that are being rolled-out have been tested in any sort of 'clinical study'. The industry is flying blind and one might suggest that confirmation of this is the observation that Lloyds of London will not insure any of the service providers. This alone should be a wake-up call, not just to the industry, but government and especially 'us' .....the citizens (particularly the young and on their behalf, the very young).

*Note 1 : To convert power in Watts/cm^2 to power in Watts/m^2 multiply by 1000 e.g. 0.32microW/cm^2 x 10,000 = 3.2 mW/m^2

**Note 2: To convert V/m to Watts/m^2 the equation is E^2/120Pi, where E= V/m . So $(0.64V/m)^2$/ 377= 0.001 Watts/m^2 .

For the other way around i.e. converting Watts/m^2, to V/m, multiply watts/m^2 by 120Pi and find square route. So 0.0032watt/m^2 x 377= E^2 (1.2) and square route 1.2=1.09

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