NATIONAL REGISTER OF
RF WORKERS

CONNECTING THE DIGITAL WORLD

Modelling exposure in a spatially dynamic world

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Agenda

- Existing safety limits and verification methods
  - Base station
  - Mobile phone
- What's changing with 5G?
  - Use cases
  - Air interface
  - Frequencies
  - Exploitation of the spatial domain
  - Impact of 5G on existing verification methods
- Observations on the evolving health debate
- Thought experiment – do we engineers trust the numbers?

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Some context

- I have no opinion on the safety of RF radiation, deferring to the authorities who have that responsibility
- Throughout my 33 year career I have never considered the signals typical in mobile communication systems to be a concern
- Anecdotal recollections of the “Ferranti girl syndrome” from a small group of RF engineers I worked with
- Recently became aware of growing scientific and public concern about RF safety via private Facebook group and was concerned at the low quality of the debate
- Intent is to provide a scientific explanation of the principles of cellular communication to inform the debate about safety
- Will publish an article this month in Cambridge Wireless Journal

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Cambridge Wireless Journal 5G safety: Myths, Maths and Medicine

- The June 2019 edition of CWJ has its first article on the subject of RF safety written by myself with considerable input and review from many sources
- The focus is primarily technical on the aspects of RF exposure and how 5G will affect this
- The next edition will include a deeper dive into health issues

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Exposure limits

- RF exposure limits defined by FCC (US) and ICNIRP (EU) are based on the ability of RF signals to raise the temperature of human tissue
- Base station RF exposure is defined in terms of incident power density S_{lim} W/m^2
- Mobile phone RF exposure is defined in two ways:
  - Specific absorption rate (SAR) in W/kg for < 3 GHz (FCC) or < 10 GHz (ICNIRP)
  - Incident power density S_{lim} > 3 GHz (FCC) or > 10 GHz (ICNIRP)
- FCC and ICNIRP limits are not harmonized for levels, f_{tr}, upper frequency, averaging volumes, averaging areas, peak power density and on-body distance*
- There are discontinuities between FCC and ICNIRP limits in the permissible transmit power at the transition frequency f_{tr}
- Both FCC and ICNIRP limits are being revised for levels, f_{tr} and averaging areas

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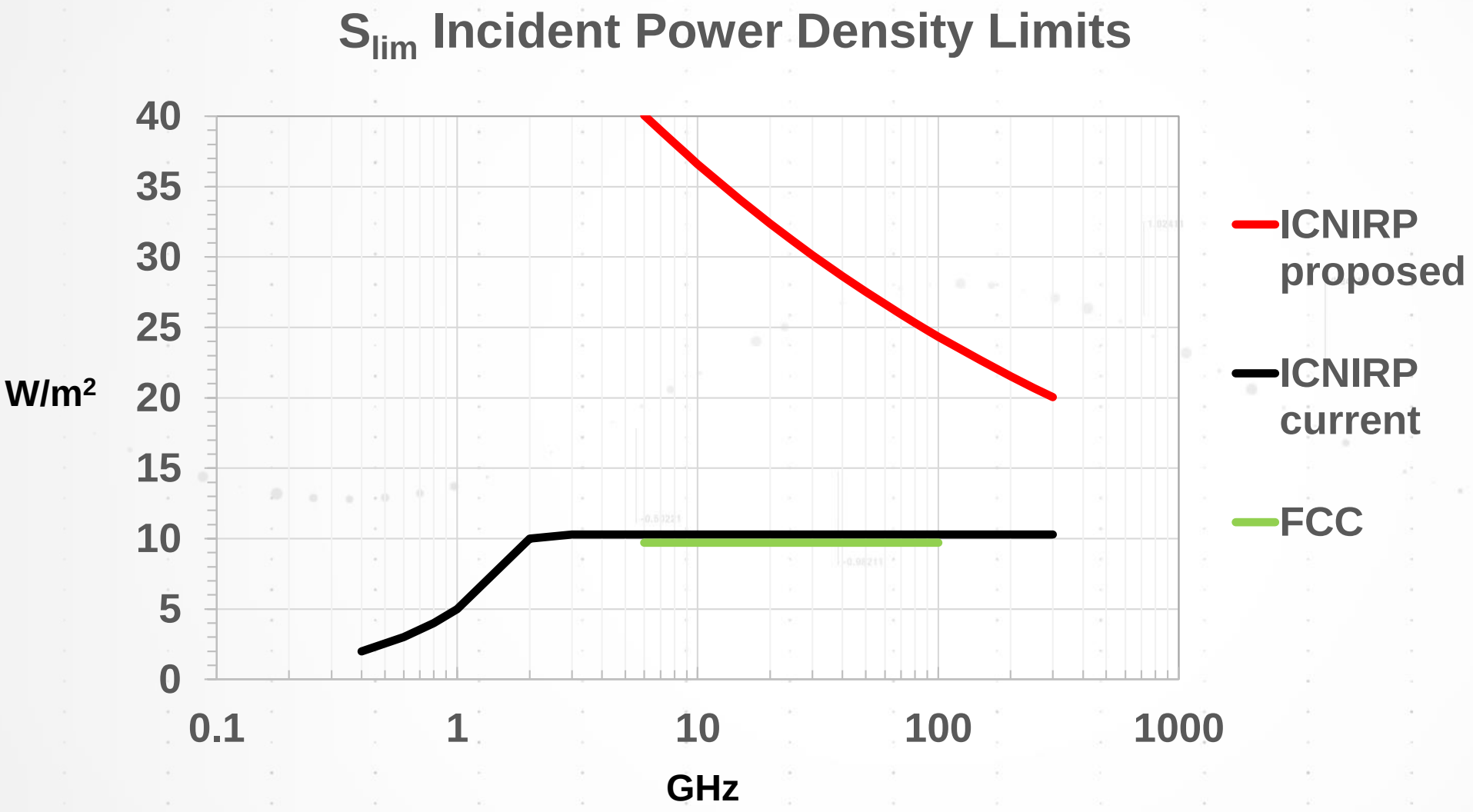
* Thors et al., "Exposure to RF EMF From Array Antennas in 5G Mobile Communication Equipment", IEEE Access, 2016.

Base station incident power density limits



- ICNIRP occupational limits are 5X public limits
- FCC* moving from 1 cm^2 averaging to 4 cm^2
- ICNIRP* moving from 20 cm^2 averaging to 4 cm^2

* 3GPP R4-1814719 Ericsson, Sony Mobile “Update on RF EMF regulations of relevance for handheld devices operating in the FR2 bands”

Mobile phone SAR and S_{lim} / MPE limits

- FCC
  - 1.6 W/kg SAR averaged over 1g of tissue < 3 GHz
  - 1 mW/cm^2 maximum permissible exposure (MPE) 3 GHz to 100 GHz
- ICNIRP
  - 2 W/kg SAR averaged over 10 g of tissue < 10 GHz
  - 1 mW/cm^2 S_{lim} 10 GHz to 300 GHz S_{lim}
- FCC & INCIRP whole body SAR 0.08 W/kg
- Whole body SAR of 0.08 W/kg and S_{lim} of 10 W/m^2 (1 mW/cm^2) are largely similar:
  - 10 W/m^2 with body area of 0.5 m^2 and body weight of 70 kg = 0.07 W/kg (ignoring reflection coefficient)

Compliance with incident power limits

- Verification is carried out using a passive receiver with omnidirectional antenna system – consistent with the use of static antenna patterns in 2G/3G/4G
- Evidence that existing infrastructure operates well within safety limits was provided in a study by Jack Rowley and Ken Joyner, published in the Journal of Exposure Science and Environmental Epidemiology
  - “Comparative international analysis of radiofrequency exposure surveys of mobile communication radio base stations”,
- It is unusual for street-level incident power to reach as high as10 % of ICNIRP limits and are usually much lower

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Compliance with SAR limits

- All mobile phones are individually type-approved to meet requirements for SAR, and MPE/ S_{lim} for higher frequencies
- Head SAR is measured using fixed (left and right) talk position against an anthropomorphic (phantom) head – consistent with static mobile phone antennas
- The head is filled with an electrolyte that represents human tissue at the frequency of measurement
- A field strength probe scans the liquid to find the peak absorption over the required volume
- On-body SAR is measured at a distance of 5 mm from a phantom limb
- This means that on-body SAR is not measured for use cases where the phone is touching the body (e.g. in a pocket) – see manufacturer warnings

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What's changing with 5G?

- 5G is the broadest scope "G" ever
- Use cases:
  - Enhanced mobile broadband (eMBB)
  - Massive machine type communications (mMTC)
  - Ultra-reliable low latency communications (URLLC)
- Enhanced air interface based on LTE
- Increased use of time domain duple (TDD)
- Wider channel bandwidths (up to 400 MHz)
- Low/mid frequencies from 600 MHz to 7.125 GHz (frequency range 1 FR1)
- Millimetre-wave (mmWave) frequencies from 24.25 GHz to 52.6 GHz (FR2)
- Increased exploitation of the spatial domain – particularly for mmWave

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What's changing with 5G?

- Of all the new things with 5G, three stand out as being significant in terms of RF exposure
  1. The continued trend towards smaller cells / more dense networks
  2. The increased exploitation of the spatial domain
  3. The addition of mmWave frequencies
- Number 1 & 2 are relevant to FR1 but are inevitable for FR2
- Other factors such as the flexibility of the OFDM numerology and frame structure, and wider channels are not significant in terms of RF exposure
- URLLC remains a future topic and anyway is an expensive niche market similar to eMBB in exposure terms
- mMTC is also a future market and primarily concerned with low power devices so is not of particular interest

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Small cells

- The public and even the medics associate with the 5G Appeal (www.5Gappeal.eu) are primarily concerned with proximity to what looks like a base station rather than being curious about the actual exposure
- The reality is that small cells lead to lower exposure, partly from the base station but particularly from the mobile which can vary output by 63 dB (2,000,000)
- To an audience not familiar with the physics of radio wave propagation the concerns about proximity are not unreasonable but they are scientifically incorrect
- This can more easily be explained using an acoustic analogy

Small cells – Glastonbury style

The old days

Speaker arrays to improve coverage

Distributing 1000 speakers throughout the crowd would even out and lower average exposure

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Exploiting the spatial domain

- As with small cells, received wisdom about exploiting the spatial domain through use of directive beams is not obviously unreasonable but it is again not founded on a correct understanding of the physics of propagation
- Existing < 3 GHz cellular deployments rely on base station and mobile phone antennas with fixed antenna patterns
  - The base station typically covers a 120 degree sector in azimuth and a narrower 5 to 12 degree range in elevation depending on antenna height and cell size
  - The mobile phone is essentially omnidirectional although may employ simple antenna switching
- The use of narrower (more directive) beams is one area of considerable development as a means of exploiting the spatial domain for increased capacity
- It is an essential feature for mmWave but < 6 GHz only realistic for the base station due to the large antenna size

Exploiting the spatial domain

- The use of directive antennas at mmWave frequencies is a necessary response to overcome much higher propagation losses
- It is also practical to implement since the size of the antenna arrays necessary to generate narrow beams reduces linearly with the wavelength of the signal
  - At 3 GHz an 16x16 array at half λ spacing will be 150 cm^2, at 30 GHz it will be 15 cm^2
- At 1 GHz the free space path loss at 10m is 52 dB
- At 3 GHz the free space path loss at 10m is 62 dB
- At 30 GHz the free space path loss at 10m is 82 dB
- A 16x16 array has 29 dBi gain at 6.4 degree half power beamwidth
- This is used to overcome increased path loss to enable similar field strengths on the street as was possible using less directive antennas at low frequencies

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Exploiting the spatial domain

- There are two important consequences of using more directive antennas:

1. The system is harder to operate as the antennas need to be dynamically pointing in the correct direction at both ends of the link as the user moves
2. There is a reduction in collateral RF exposure since the required energy is only transmitted in the direction where it is useful for communication

- Thus it can be concluded that use of higher directivity antennas leads to overall lower RF exposure
- The particular exposure in close proximity to a base station may be higher than for static antenna patterns but still well inside existing limits.
- At other locations the exposure would be lower than for static antenna systems
- The exposure for the active user would be similar to static antenna systems

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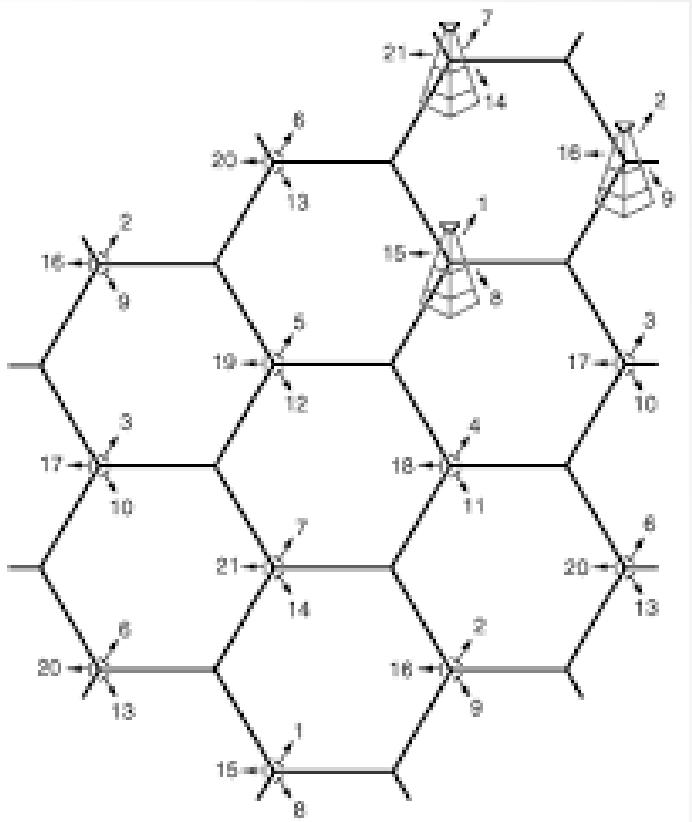
From honeycombs to starfish

- The traditional tri-sectored cell is based on the principle of interlocking hexagons where the cell edge is equidistant from each site



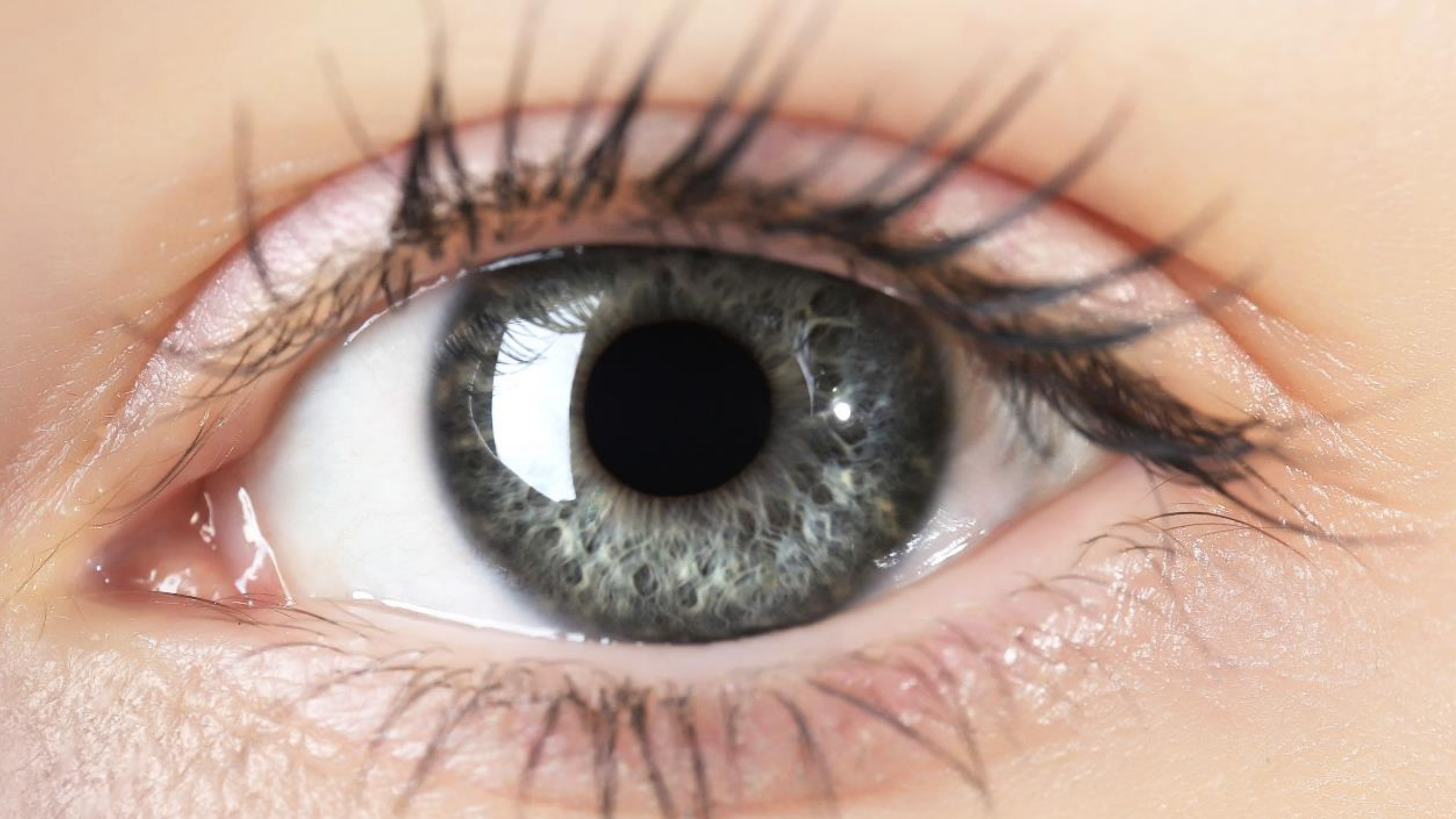
- But with the shrinking of cells and use of directive antennas the future may look more like interlocking starfish as cells reach into each others' territory
- Use of dynamically steered beams also mandates changes to the way base station exposure is verified

mmWave frequencies

- The move to include mmWave frequencies in 5G is not inherently indicative of an increase in RF exposure
- The current guidelines for field strength (MPE) are constant from 6 GHz to 300 GHz
- However, there are implications for portable and mobile devices in terms of how meeting existing exposure limits will require reduction in equivalent radiated power due to the use of antenna arrays
- There is also a change in how user devices will be verified since the controlled metric changes form SAR at low frequencies to radiated field strength (S_{lim} / MPE) at higher frequencies

UE S_{lim} / MPE aspects

- Moving from a SAR regime to field strength density (S_{lim} / MPE) requires a complete change to the way user devices are verified
- Existing SAR verification methods require only a small number of static setups followed by 3D probing of field strength inside a phantom head or limb
- At mmWave frequencies body penetration is negligible so it is appropriate to move to a surface area power density metric based on a 2D scan of field strength
- Although this may sound simpler the actual situation has considerably more complexity since the antennas being probed will be actively steering based on the direction of arrival of the downlink signal
- In addition, the distance at which to measure is unclear since near-field probing of antenna arrays may not yield the highest field strength



UE S_{lim} / MPE aspects

- In the closing stages of 3GPP Release 15 which defines the New Radio (NR) air interface for 5G, a problem was discovered with how to ensure MPE was not exceeded if the user put a finger over an active antenna array
- Previous assumptions had suggested this would not require more than around 3 dB power back off but more recent analysis showed that 15 dB may be required
- This led to the introduction of a new maximum power reduction (MPR) mechanism called Permitted-MPR, or P-MPR where the UE can autonomously decide (based on proximity detectors) that it is necessary to reduce transmitted power by up to 15 dB
- In addition an alternative approach was investigate based on limiting the uplink duty cycle such that average power is reduced to similar levels

UE S_{lim} / MPE aspects

- Unfortunately due to the late nature of this new understanding, both the P-MPR and maximum uplink power reduction mechanisms are not fully integrated into Release 15
  - There is no signalling support for the UE to inform the network that P-MPR is being applied
  - There is no dynamic signalling to support modifying the uplink duty cycle after a call has been established
- Consequently, if a user puts a finger over an active antenna array, there is a significant chance of dropping the link
- More advanced solutions for managing P-MPR and dynamic uplink duty cycle reduction are being considered for Release 16 but are not guaranteed
- So in effect, a Release 15 UE has an additional off switch – Antennagate for 5G

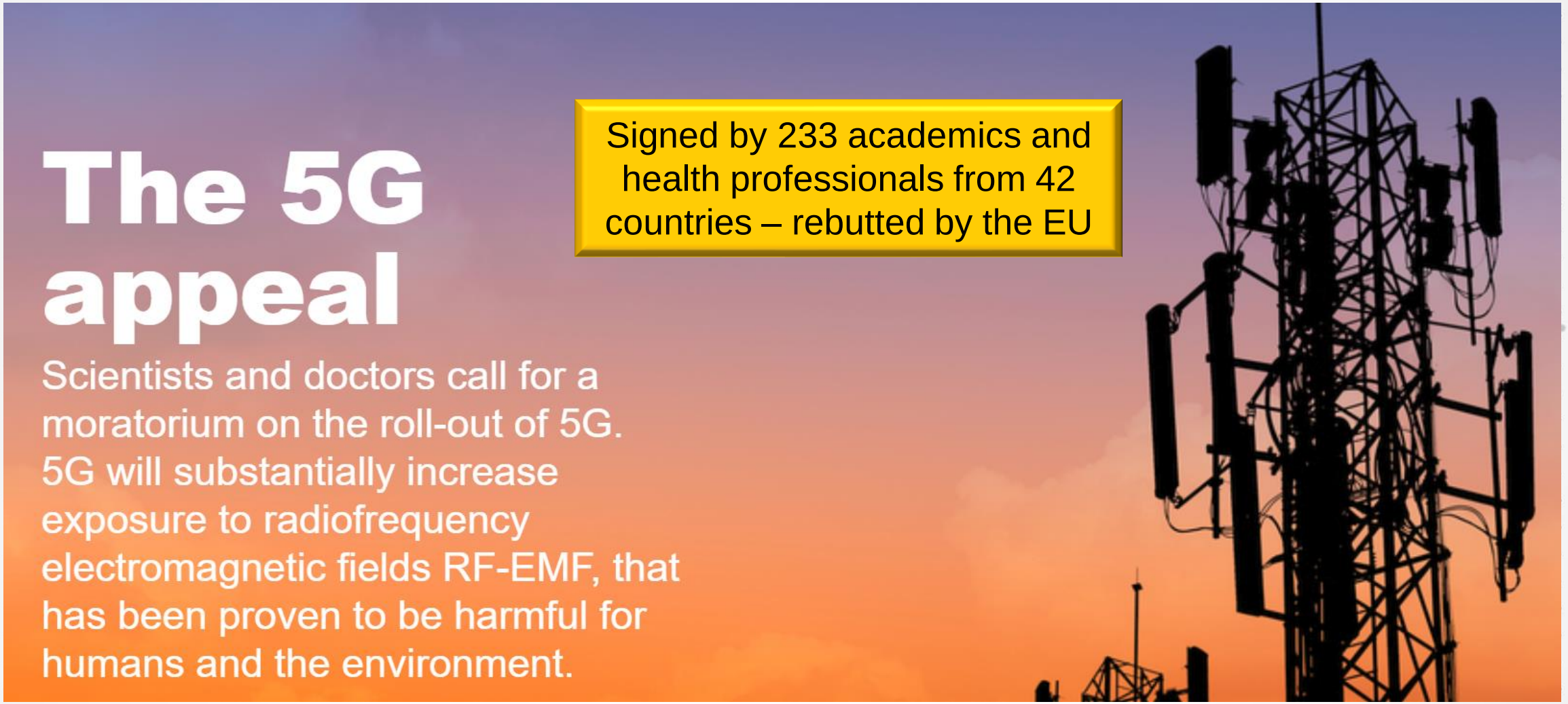
High power CPE deployment issues

- Fixed Wireless Access (FWA) is one of the key early use cases for 5G @ mmWave, particularly in the US
- CPE for internal use may need to have an exclusion zone depending on their EIRP
- External CPE up to and including the 3GPP 55 dBm power class will b externally mounted and aligned to eh base station
- This presents challenges in implementing safe exclusions zone e.g. for building maintenance etc.

Growing evidence of concern about RF safety

- Seen this week in the gents toilets at the Cobham service station on the M25:
- Of all the things I have seen this is probably the most indicative that we are approaching a tipping point in terms of public backlash against 5G
- Promotes “5G THE FACTS” conference, 28th September, London https://www.radiationresearch.org/wp-content/uploads/2019/05/Slide1.jpg

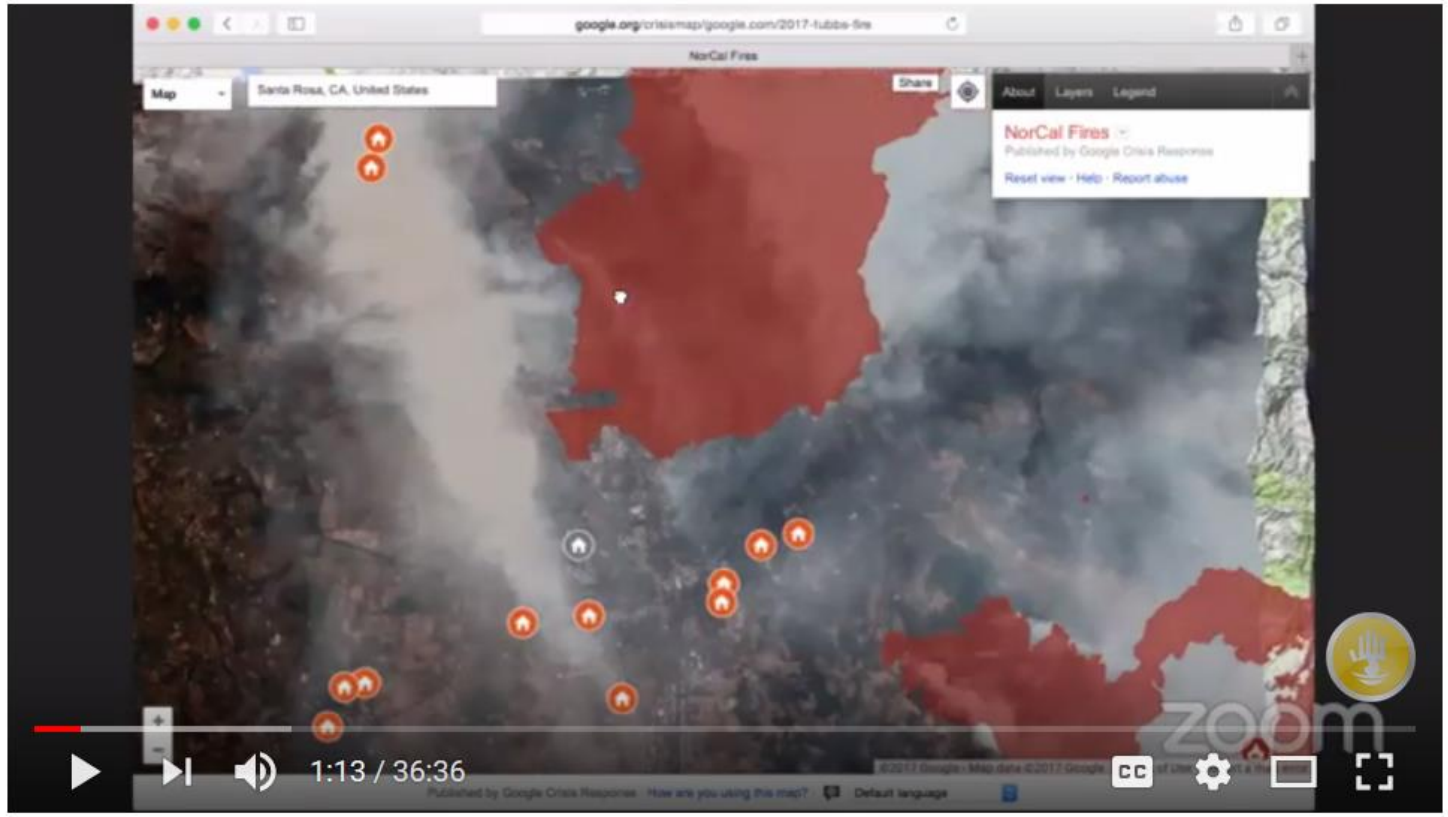
5G Appeal www.5G-Appeal.eu



Signed by 233 academics and health professionals from 42 countries – rebutted by the EU

https://www.youtube.com/watch?v=KAaiSjznt68

Unprecedented California Wildfires Started with Directed Energy Weapons **& 5G**



Unprecedented California Wildfires Started with Directed Energy Weapons & 5G - Latest Analysis

130,417 views 2K 324 SHARE

Dr Martin Pall UoW Portland
Eight biological effects of EMF exposure*

Note: Pall has a business selling anti-oxidant remedies

1. Attack our nervous systems including our brains leading to widespread neurological/neuropsychiatric effects and possibly many other effects.
2. Attack our endocrine (that is hormonal) systems.
3. Produce oxidative stress and free radical damage, which have central roles in essentially all chronic diseases.
4. Attack the DNA of our cells, producing single strand and double strand breaks in cellular DNA and oxidized bases in our cellular DNA.
5. Produce elevated levels of apoptosis (programmed cell death), events especially important in causing both neurodegenerative diseases and infertility.
6. Lower male and female fertility, lower sex hormones, lower libido and increased levels of spontaneous abortion
7. Produce excessive intracellular calcium [Ca2+]i and excessive calcium signaling.
8. Attack the cells of our bodies to cause cancer. Such attacks are thought to act via 15 different mechanisms during cancer causation.

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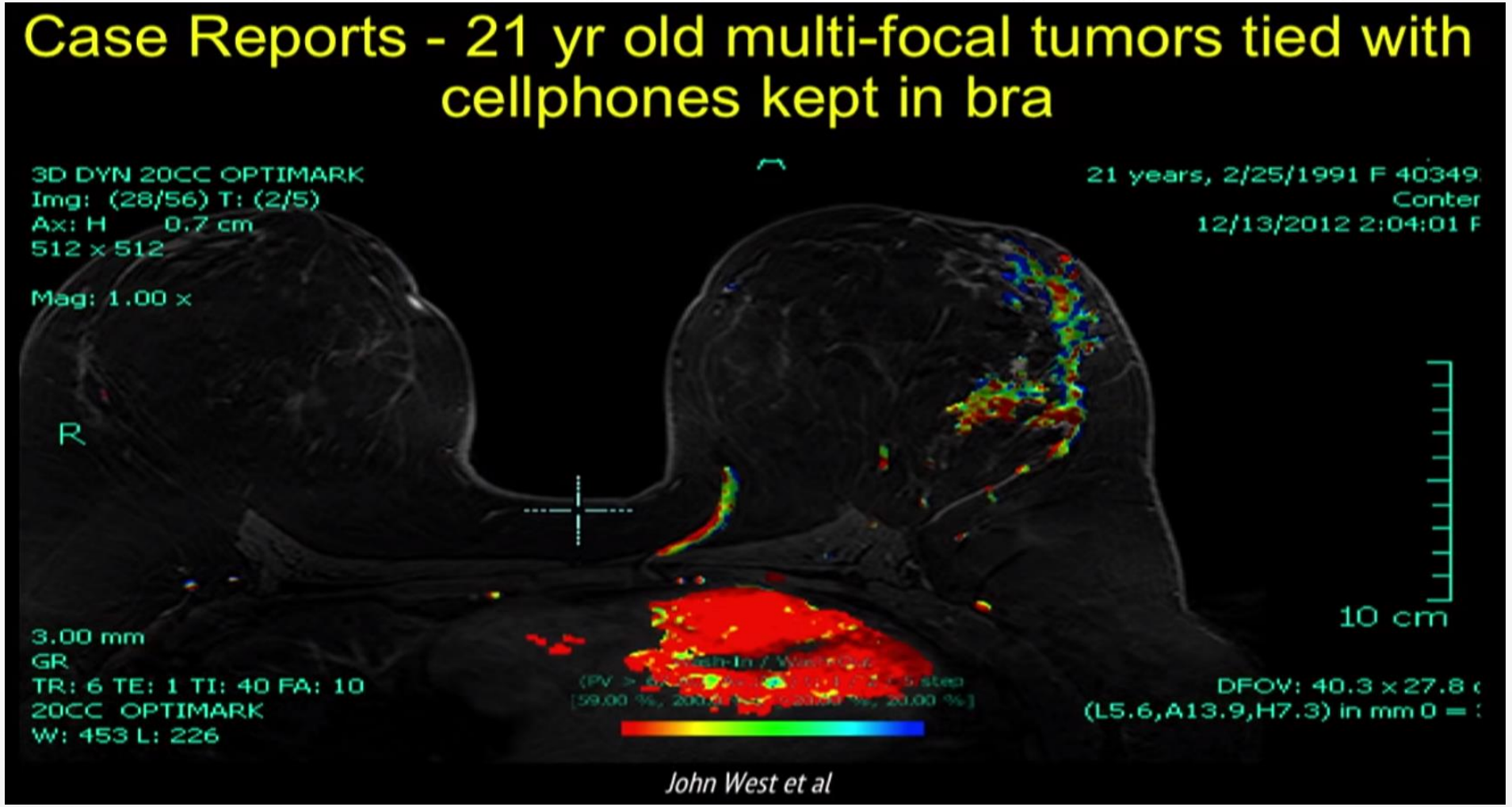
* 5G: Great risk for EU, U.S. and International Health! Compelling Evidence for Eight Distinct Types of Great Harm Caused by Electromagnetic Field (EMF) Exposures and the Mechanism that Causes Them

Dr Devra Davis
Evidence of subcutaneous breast cancer

https://www.youtube.com/watch?v=BwyDCHf5iCY



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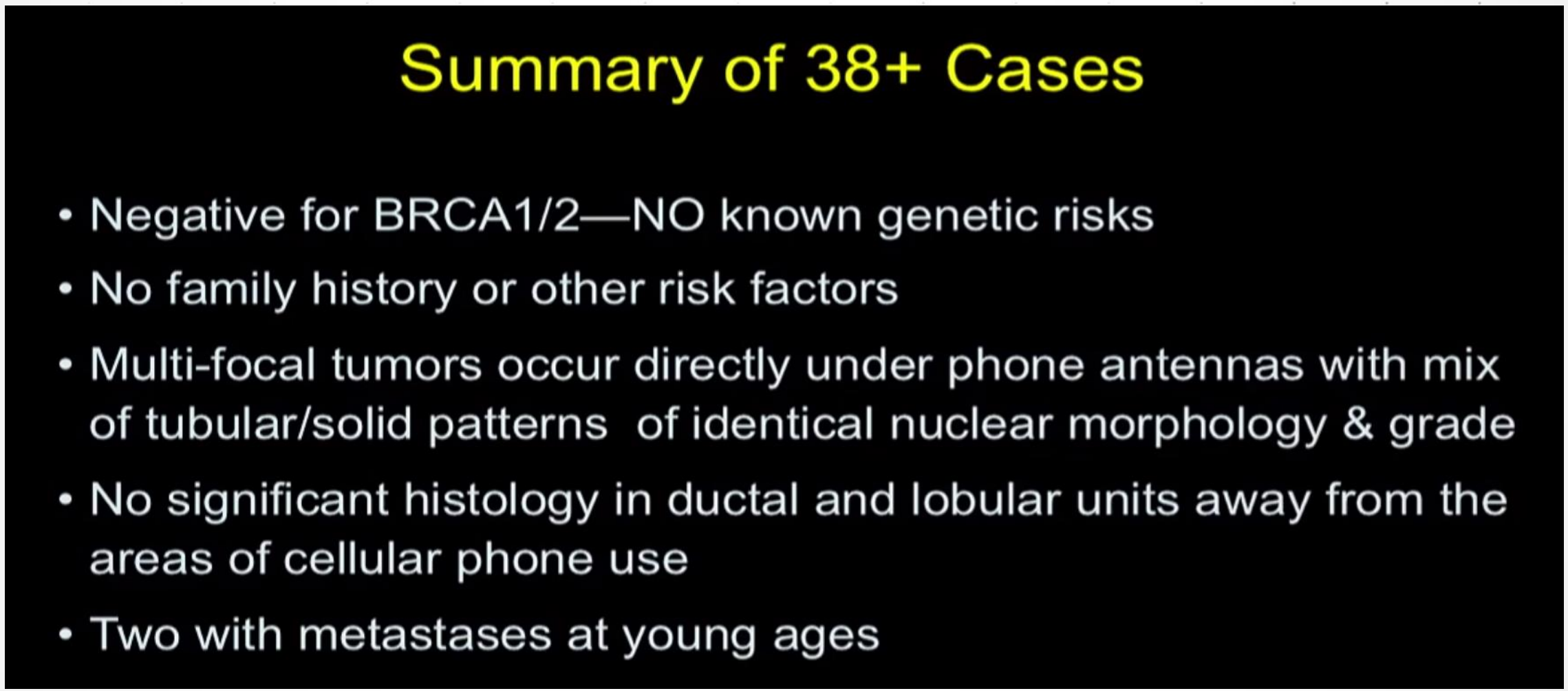

Municipal opposition to 5G

- Local government approach to 5G varies from the early adopters like Bristol and Liverpool, to those who are actively opposing it:
- City of Brussels
- City of Geneva
- City of Rome
- City of Florence
- Parts of The Netherlands
- Public opposition in Bristol and Liverpool to early mmWave adoption

Thought experiment on perceptions of safety

- You are about to buy a new house
- It is located on the edge of a village facing uninterrupted views of the countryside
- In the distance you spot a base station pointing directly at the house
- After some enquiry it turns out this is a medium area base station, 38 dBm (6.3 W) with 18 dBi antenna system transmitting at 2 GHz on one channel only

Question – How does the visible presence of the base station impact your decision on whether or not to buy and at what price?

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Thought experiment on perceptions of safety

1. At what distance would you consider the visible presence of the base station is a “don’t care” factor in buying the house?

   a. 2 km
   b. 500 m
   c. 200 m
   d. 100 m
   e. 20 m
   f. 5 m
   g. 2 m

2. At what distance would you consider the visible presence of the base station is a “don’t care” factor when selling the house to the next buyer?

   a. 2 km
   b. 500 m
   c. 200 m
   d. 100 m
   e. 20 m
   f. 5 m
   g. 2 m

Predicting exposure

- The field strength from a transmitter can be calculated based on three factors:
  - The effective radiated power (ERP) – which is the total power available to the antenna system
  - The directivity of the antenna system – which is the gain available due to directional transmission
  - The distance to the measurement point
- The formula for calculating field strength e from a point source to an area can be found in ITU-R P.525-3:

$$e = \frac{\sqrt{30p}}{d}$$

e : r.m.s. field strength (V/m)
p : equivalent isotropically radiated power (e.i.r.p.) of the transmitter in the direction of the point in question (W)
d : distance from the transmitter to the point in question (m)

Predicting exposure

- For the example given, at what distance does the field strength of the base station reach 80 % of the ICNIRP public safety limit?
  a. 2 km
  b. 500 m
  c. 200 m
  d. 100 m
  e. 20 m
  f. 5 m
  g. 2 m ✓

- Clearly if the base station transmitted more channels at 6.3 W the safe distance would increase
- For example, at 10 m, the base station could transmit 32 channels or 10 channels @ 20W
- Or if this were a high power wide area base station rated at 48 dBm per channel (63 W), at a distance of 10 m it would meet the ICNIRP limit transmitting 190 w over three channels

Are you sleeping comfortably?
If not, why not?

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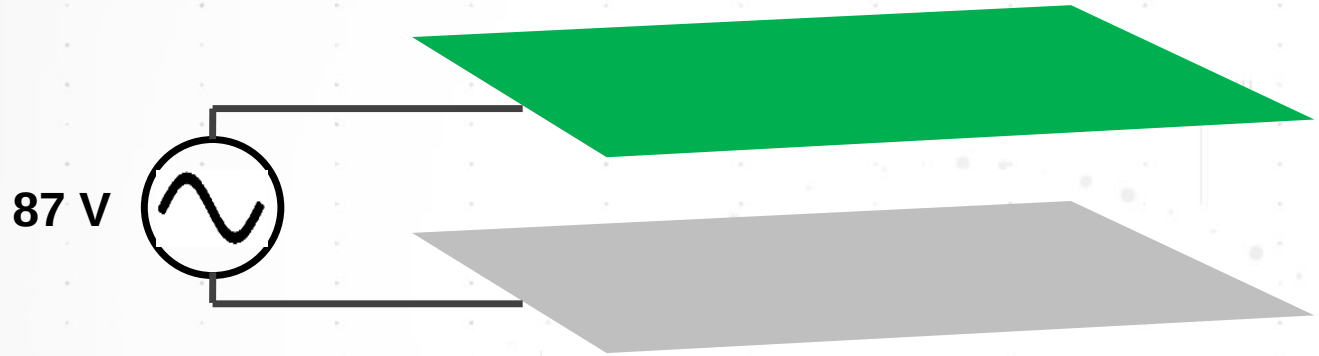
An alternative analysis

- Consider a ground plane 1 x 2 m with another plane above at a distance of 1 m*



- Next connect a 2 GHz 5G signal (50 % duty cycle) at 87 V rms** across the plates
- Then insert your child's bed in between the plates

Are you still sleeping comfortably?
If not, why not?

* This is a simplified analogy that not consider near field effects
** 87 V/m at 50 % duty cycle represents the ICNIRP 10 W/m^2 limit for continuous exposure

Summary

- The opposition to 5G is unprecedented compared to earlier generations
- Opposition is increasingly organized
- The quality of the debate is low and increasingly polarized
- Research into health effects is difficult and time consuming
- Research at mmWave is lagging lower frequencies
- Some concern is based on ensuring existing safety limits are met, other concern is questioning the veracity of current international limits based purely n thermal effects
- On the current trajectory, two undesirable outcomes are possible

1. We miss real health issues or,
2. Democracy will act out of beliefs and fears to unnecessarily limit the growth of the wireless industry

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A collaborative approach is needed to ensure the correct outcome