



F A R A D A Y

**Notes on the use of radars
whilst alongside**

11th March 2006

Ocean Village Marina
Southampton

Faraday's use of radars whilst alongside

and a consideration of any risks involved

Bill Mullarkey – 11th March 2006

Summary

Faraday is doing work that promises to improve marine safety but her radars have caused concern to some of her neighbours.

Those concerns are understood but are caused by a perception of risk rather than its determination. Although her antennae look threatening, their effect is miniscule when compared to other sources of electromagnetic radiation. By way of example, were she to operate her three most powerful radars for eight hours, that would be equivalent to the nearest house holder using a mobile telephone for a few thousandths of a second or being in the kitchen with a switched-on microwave for about three seconds.¹ As might be expected from such figures, the radiation is one millionth of the legal limit.²

On route to establishing that, the document analyses how we all routinely manage and treat risk and how, whilst it is mathematically impossible to say anything useful about risks that are too small to assess directly, they can be compared with much greater ones which share a risk mechanism, such as exposure to radio signals. It also briefly discusses why humanity's experience of lightning storms throughout our period on this planet explains why, counter-intuitively, we are little affected by our own puny attempts to create similar radio signals.

Various outcomes from the situation are considered and preferences stated.

Background

Faraday's prime purpose is to try to improve the safety of life at sea. She carries her name with the express consent of the Royal Institution, where her namesake did his best work, and her commissioning plaque, presented by them at her naming ceremony, includes the phrase

"She will follow Michael Faraday's example by using science to improve the safety of navigation and the wellbeing of seafarers."

I am passionate in my pursuit of that objective.

Her main task at the moment is to try to improve the performance of low power radars so that useful performance could be offered to vessels not previously able to carry radar either because of power or weight constraints.

Sadly—and as Managing Director of her owners I greatly regret this—she has caused concern to a few of her house-holding neighbours in Ocean Village who are worried by the possibility of adverse health effects being caused by her turning radar antennae whilst alongside.

1 One caution we must have is that the word "radiation" is an emotive one because it is also used to describe the very dangerous radiation from radio-active materials. Those concerned with the safety issues associated with both refer to "electromagnetic radiation", when they are discussing the issues concerning us here. That may be satisfactory for those who use the phrase every day of their working lives but it can still seem emotive to others because the word "radiation" remains. It needs to be remembered, however, that we are simply discussing radio signals.

2 The world in which we live has many powerful radio transmitters: from the Radio 4 one at Droitwich and its even more powerful military equivalent at Rugby, to taxi radios and the VHF sets installed in yachts and the Marina Harbour Office, all of which are deliberate transmitters. Added to those are the pieces of electronic equipment, such as laptop computers, television sets and microwave ovens, which radiate "accidentally" as a consequence of their main purpose. It is inevitable that people's concerns about such will have led to expert review and the establishment of regulations which ensure that they are safe. Bizarrely, some of the greatest radiators are those that do so by accident, it may well be those that drove the need for legislation.

I met with the Chairman of their Resident's Association some time ago and believed that I had assuaged those fears and, to help reduce the perception of risk had instructed those working in Faraday not to turn antennae that were not in use.

Since then, I have been told by the marina's Manager that he has received a letter from the Chairman expressing concern so I have clearly failed in my reassurances.³ One possible reason is that there were a couple of weeks in February when she did operate two antennae almost continuously during the working day and I suspect that might have exacerbated the situation.

The purpose of this document is to move on by analysing the nature of any risk in its statutory and environmental contexts. Although I have been asked by scientific colleagues to publish the analysis for a wider audience, I am deliberately writing it in the style of a letter rather than of a scientific paper, because the concerns people have are personal and not scientific.⁴ However, given that I am defending my right to earn a living by contributing to the safety of seafaring whilst not harming others, some of the things needing to be considered are, by their nature, scientific: to help manage that, the main body will concentrate on narrative with the supporting legal and mathematical stuff put in three appendices.

The nature and measure of risk

From time to time, we all make a judgement to accept a small risk in return for some benefit. Our use of road and air transport are the classical examples, but let us consider a few that are more relevant to the lifestyles we share. We live in a marina and are exposed to sea-air containing microscopic quantities of water droplets that, in their turn have toxic chemicals and the body parts of marine animals. That is a known but tiny health risk which we choose to accept. Similarly, our marina is on the flight path of the airport and we all know that exhaust debris is washed down by the rain and stains everything black.⁵

We breathe the same air and live in the same rain and the debris is known to include carcinogenic components. Again, however, the quantities are small and the risk tiny. As an aside, what about the diesel fumes from various yachts and motor vessels, the pollution caused by people flushing toilets into the marina pond (against MDL's regulations but it clearly happens—just consider the size of the fish)⁶ or the collision risk of large vessels using the Itchen to carry goodness-knows-what cargos.

All of these cause risk but we balance those risks against those we might experience elsewhere, such as by living on a main road and being at risk of a lorry joining us in the front room, or living an isolated existence in the countryside and being at risk of a violent attack in our homes. We choose the life we want and accept its risks.

Whilst the risks of marina life are so small that they can be essentially disregarded, there are greater ones that people routinely take in return for the benefit they confer. By way of example, it is believed that organically grown vegetable are more flavoursome than those grown using synthetic fertilisers and many people prefer them. Let us not forget, however, that they are grown using fertilisers made from animal faeces and rotted vegetables, whose chemical and bacteriological constitution is unknown, rather than from those that are analytically determined and whose risks are quantified. I have no idea how dangerous that is and choose to eat factory-farmed vegetables.

3 I have occasionally met the Residents' Chairman, know a little of his pre-retirement background, and have no doubt that he has behaved entirely properly. He comes from an evidence-based, analytical profession but his members have expressed concerns, which he must bring to the table.

4 Old habits die hard so, although I write informally, I have followed the scientist's custom of having others review the work before publication. Those who played a particularly important role will recognise themselves in the Acknowledgement paragraph.

5 I love this marina, but it the first one I have ever occupied where black stains form on the sides of boats that become ingrained if not washed off within a week or so.

6 If I was given to worry, then the biological pollution would cause me great concern. During the winter months, I have often walked down pontoons and breathed the wind-driven spray, some of which is made up of tiny droplets. I hate to think what has passed into my body. The fact is that I enjoy living around a marina, know that doing so has its consequence and accept the risk.

What the above examples have in common is that, although the risks are tiny they are significant enough to be quantified if the evidence were available. The difficulty arises when the risks are so small as to be practically incalculable: the smaller they are the greater the difficulty until, at limit, we hit the boundary that it is mathematically impossible to prove that any particular risk is zero. To take an extreme example, I have seen the marina Manager sit in his office wearing a blue shirt. There is no way of proving that doing so poses no risk to somebody sat in an apartment half a mile away.

Importantly, all we can do in such circumstances, where the risk is too small to determine directly, is to search for a mechanism that might induce risk and then make comparisons with other risk inducers that use the same mechanism.

The Manger's shirt example is intended to make a point and might seem trite: consider, then, a related risk. If that shirt has synthetic fibres, they are made of complex molecules that probably pass the skin barrier and get into the blood stream: similar complex molecules are known to be carcinogenic as are some dyes so, perhaps, whilst the shirt poses no threat to someone half a mile away, it does to him.

Similarly, the ink of ballpoint pens consist of dye particles carried by a volatile solvent, which evaporates quickly as a line is drawn on the page. Such solvents are related to other chemicals that are health hazards and it is inevitable that a few molecules will be inhaled as the writer sits over the page.

When faced with such "too-small-to-calculate" risks the best we can do to reassure ourselves is to determine the risk that much higher exposures might cause and then make a comparison. Perhaps, for example, we would discover that a lifetime's use of a ballpoint pen is equivalent to using some household cleaning agent for a few minutes a month.

Faraday's radar transmissions

That brings us to the electromagnetic energy from Faraday. I accept that her radar antennae look large and powerful and can understand people's concern about their emissions: in fact, they are large because they are not powerful.⁷ For the record, Appendix One summarises some statutory evidence about how they compare to international standards that are designed to keep people safe by forcing her radars (separately and in combination) into the too-small-to-calculate-the-risk region. Even under worst-case circumstances, Faraday's contribution to the electromagnetic radiation experienced by the nearest householder is about one millionth of the legal limit.

If that is not sufficient to reassure, then we are left with comparing that too-small-to-calculate risk with others, which is easier to do for Faraday's radars than for a ballpoint pen because the mechanism of risk is clear: electromagnetic radiation causes heating at high enough levels and, some say—but continually fail to find evidence to prove—that it might damage DNA.⁸

Obviously, there will be some power so large that it produces effects and the international standards force everything from mobile telephones to television sets to radiate powers that are so much less than that to get them into the too-small-to-calculate risk region.

Obvious candidates for comparison are mobile telephones and microwave ovens, et cetera. In that context, if Faraday used her three most powerful radars for eight hours a day, the effect in the closest house would be equivalent to:

- using a mobile telephone for 7.5 thousandths of a second (Para 2 Appendix Two), or
- sharing a kitchen with a microwave oven for about 3 seconds (Para 3 Appendix Two).

Similar comparisons could be made with television sets, portable Playstations, cordless phones, computers, et cetera: all radiate and all have international standards which specify how much.

Even outside of our homes, modern life forces us to accept living in an environment bathed in electromagnetic radiation. Permit a few examples.

7 A comparison could be made with Owl's ears. They are large because they need to hear very weak sounds. Some of Faraday's antennae are large because they need to pick up very weak echoes.

8 It may well be that such effects are discovered, as may others: what is certain is that all will be dose related.

- Our marina is next to one of the most powerful mobile-telephone base stations in the region with the enormous antennae farm on top of the National Oceanographic Centre.⁹
- It is difficult now to get a cup of coffee or go into a modern hotel without being close to a WiFi Access point, there are even a few around the marina (including the one on the veranda of the RSYC).
- And, finally, being within a mile or two of a lightning strike subjects the body to an electromagnetic pulse which puts everything else discussed in this document into the shade.

That last is actually reassuring and goes some way to explaining why human beings are, counter-intuitively, so little influenced by electromagnetic radiation. We were being bombarded with electromagnetic radiation long before Marconi discovered wireless and simple survival required us to be fitted to live on our planet.

Lightning strikes that ground a few hundred metres away, crash computers, stop many modern cars and sometimes damage domestic equipment, so powerful are the emissions. We see the light, hear the thunder and never even notice the electromagnetic pulse. It is as natural a part of our environment as sunlight and rain.

Importantly, nor do we ever worry about it.

In summary, compared to the electromagnetic radiation that those living around the marina already experience, Faraday's contribution is miniscule, unnoticeable and irrelevant.

So what next?

We clearly need to resolve this difficulty and, logically, I can think of only three outcomes:

- The contents of this document provide sufficient reassurance that Faraday's radars pose no practical risk to people living nearby and everyone again becomes relaxed about her presence. Faraday has always had an open-door policy to visitors and I would be delighted to welcome anyone interested onboard to explain the work we do and to discuss any concerns they had.

This is her home port and there is a strong sense in which she belongs to our marina: some people have been kind enough to say that she adds to its environment and that they looked forward to sharing in her achievements. I would like as many others as possible to understand enough of what she is doing to feel some shared pride in her work.

- There is a move to suppress Faraday's work, which would inevitably leave the matter to be resolved elsewhere. Whilst I want to do everything I can to help with people's natural and understood concerns, I would be ethically bound to ensure that harmless and potentially beneficial scientific research is not prevented because of a perception of risk rather than its determination.

It is very easy to live in our own time and lose sight of the fact that it is science and technology that have brought human kind from the caves. Without it we would all be sat naked and hungry in an uncultivated field, suffering from toothache and waiting for death at the hands of the next predator or infection. Many would face this fate nearly blind.¹⁰

Faraday will not discover the next antibiotic or cancer treatment: what she may do is add a little to the safety of seafaring and save a few lives. That must be worth defending.

⁹ There are 121 others in the City of Southampton.

¹⁰ Ploughs, clothes and glasses were once as remarkable achievements as the latest medical advance that might be made today. Consider the magic-like properties of window glass: it keeps out the rain and wind but lets in the sun.

- My obvious preference would be for the first. If, however, even that does not provide sufficient reassurance, then perhaps there is something else I could offer.

This document has considered the effect of Faraday operating three radars for eight hours a day, which she has never actually done. Perhaps those interested could meet together informally, under the chairmanship of the marina Manager, and agree a maximum average use that was less than that. I would voluntarily and gladly accept a reasonable constraint as a gesture of neighbourliness.

Acknowledgements

The label “scientist” hides the fact that we are all really specialists in some particular subject with only a general understanding of things outside of our own field of expertise. Recognising this and recognising also that anything I wrote had to be impeccably defensible; I have sought the help of various colleagues, a few of whom are worth a special mention.

Thanks to mathematician, Dr Colin Wright, for advice on how to treat risks that are too small for direct assessment; to Dr Chris Jones, a world-renowned expert on the effect of lightning and other pulsed forms of radiation on machines and human beings and to Dr Richard Jales, a broad-spectrum engineer currently involved in radar design.

Appendix One

Statutory requirements of radars and other electromagnetic radiators operated in the vicinity of the general public

The prime authority in determining the safety of exposure to electromagnetic radiation is the International Commission on Non-Ionizing Radiation Protection

The technique adopted by them to set the statutory safe limits, is to consider the average intensity over the whole of the body. That is referred to as the “Specific Absorption Rate (SAR)”, which is dimensioned in Watts per kilogram of body mass. To provide a safety margin, the figure allowed for the general public is one fifth of that allowed for a worker and the worker level is one that has not been known to cause adverse effects.¹¹

In practice, the SAR is difficult to measure, so a reference level is substituted dimensioned in Watts per square metre. Any equipment which has less electromagnetic radiation than that reference level at a place that a member of the general public can access is guaranteed to at least meet the SAR requirement.

The reference level changes with frequency because the body is less vulnerable to higher frequencies. By way of example, the general public requirements on mobile telephone base stations are:

- 4.5 W/m² in the 900 MHz GSM frequency band,
- 9 W/m² in the 1800MHz GSM frequency band, and
- 10 W/m² in the 2000 MHz frequency band used for the emerging 3G systems¹²

Marine equipment is specified by IEC60945 and a general public level of 10W/m² is the norm. Qualification to that standard requires testing by an accredited third party. The QinetiQ test certificate for the Raymarine radars that Faraday carries¹³ shows that the 10W/m² distances of the antennae in which we are interested are:

- 4kW 23cm
- 10kW 34cm

The corresponding 10W/m² distance for the 25kW Furuno radar is less than

- 25kW 50cm

In short, the standard is easily met and—by the standards established in law—the greatest danger from any of Faraday’s radars is being hit by the antenna, not irradiated by it! We should not be surprised by this because there is nothing to stop several vessels running their radars at the same time and we would expect that those on the pontoons must be guaranteed their safety.¹⁴

Given the inverse square law that establishes the W/m² at different distances from the source, it is clear that the effects of Faraday’s antennae when seen in the nearest home are within the legal requirements by a factor of about one million.¹⁵

11 The logic is that a worker will have much greater exposure and any adverse effects would manifest unambiguously.

12 The data are quoted from the Health Protection Agency’s website (www.hpa.org.uk/radiation/understand/)

13 A copy has been included in a report sent to MDL, but is not published here because I do not own its copyright.

14 If for no other reason than that skippers are required to check all of their navigation equipment before leaving the berth and activities such as yacht races will have many vessels doing their checks at the same time.

15 The amount is derived in Appendix Two.

Appendix Two

Comparisons between of the effect of Faraday's radars and other electromagnetic radiators

1 As a first step, establish a worst-case view of Faraday's radiation

1.1 Effect of an antenna's beamwidth

The antenna has a gain (which increases the power experienced when in its beam, that is given by:

$$Gain = \frac{360^2}{BW_{(vert)} \times BW_{(horiz)}}$$

Set against that is that as the antenna rotates, it spreads its power over a whole 360 degrees of azimuth so that anyone in its beam is only illuminated for:

$$Illum = \frac{BW_{(horiz)}}{360} \quad \text{of the time}$$

The overall effect of the antenna is thus:

$$\begin{aligned} AE &= Gain \times Illum \\ &= \frac{360}{BW_{(vert)}} \quad \text{regardless of the horizontal beamwidth} \end{aligned}$$

With a 30 degree vertical beamwidth that increases the power in the beam by a factor of 12.

1.2 Effect of Faraday using her three most powerful radars

Her three most powerful radar are 25kW, 10kW and 4kW, corresponding to the 8ft, 6ft and 4ft antennae. However, salesmen always quote the peak powers (P_p) of pulse radars because that makes them sound more powerful. In reality, they transmit short pulses having some width (P_w) at some Pulse Repetition Frequency (PRF). The average power, which is accepted by all the statutory authorities as being the significant "threat" is the product of P_p , P_w & PRF . The product of the last two of which are approximately a constant that is determined by physics and by the magnetron rating.

Taking account of the antennae effect (AE), the average power of a particular radar is:

$$Av = AE \times P_p \times P_w \times PRF \quad [Eq1]$$

Taking a worst-case view of these worst-case antennae, they cannot combine to provide a greater total effect than being summed. That assumption would have a total power from Faraday (P_{far}) of:

$$\begin{aligned} P_{far} &= AE \times (P_{p(1)} + P_{p(2)} + P_{p(2)}) \times P_w \times PRF && [Eq2] \\ &= 12 \times (39 \times 10^3) \times (350 \times 10^{-9}) \times 2000 \\ &= 327.6 \text{ Watts} \end{aligned}$$

That already seems a lot less threatening than 39kW and becomes even less so after we take account of time and distance when making comparisons. Time because the biological effect is heating and that is determined by energy not power: distance because electromagnetic radiation experienced at some distance from a radiator is proportional to the inverse square of that distance.

2 Compare to the use of a mobile telephone

The nearest home to Faraday's current berth at A8 is approximately 45 metres away ($D_{far} = 45$). Consider how her radiation experienced from 8 continuous hours of exposure ($T_{far} = 8$) compares to that from a mobile telephone 2cm away ($D_{tel} = .02$) for some time (T_{tel}).¹⁶

There will be significant attenuation of Faraday's field as it passes through the structure of any building (that is why even powerful and sensitive radars only ever show the outer walls of a building with no hint of the internal structure). Glass attenuates by between 10dB and 20dB and brick by over 50dB. However, to maintain the "worst-case of the worst-case" philosophy, let us use a figure of only 30dB—such would reveal internal structures so we can be sure that it is no less: ($Atn = 30$).¹⁷

We can now establish the equation

$$P_{tel} \times T_{tel} \times D_{tel}^{-2} = P_{far} \times T_{far} \times D_{far}^{-2} \times 10^{-(Atn/10)} \quad [\text{Eq3}]$$

From which we can solve for T_{tel}

$$T_{tel} = \frac{P_{far} \times T_{far} \times D_{far}^{-2} \times 10^{-(Atn/10)}}{P_{tel} \times D_{tel}^{-2}} \quad \text{hours} \quad [\text{Eq4}]$$

T_{tel} provides the comparison we want. It is the number of hour's use of a mobile telephone that would subject the user to the same amount of electromagnetic radiation as Faraday using her three most powerful antennae 45 metres away from the nearest Marina home for eight hours.

$$T_{tel} = 2.071 \times 10^{-6} \quad (\text{about 2 millionths of an hour})$$

Which, in seconds, is:

$$T_{tel} \times 60 \times 60 = .007455 \text{ seconds} \quad (\text{or about 7.5 milliseconds})$$

To be fair, someone sitting on the balcony for eight hours would experience one thousand times more radiation than has been calculated here, because there would not be the attenuation effect of the building's structure. The equivalent mobile phone use would be about 7.5 seconds.

In summary

If Faraday were to use her three most powerful radars for 8 continuous hours and if we take the most pessimistic view of how their outputs combine and of the attenuation of building structures, the total radiation experienced by the occupier of the home nearest to her berth would be equivalent to using a mobile telephone for 7.5mS.

3 Compare to the use of a microwave oven

Of course not everyone uses mobile telephones—even though we cannot avoid their base stations—so let us make another comparison: this time with a domestic microwave oven.¹⁸

A typical oven has an average power of 600 to 800 Watts and there is no practical way to keep all of the radiation inside the oven: in particular, the door and its seals leak.

Two international standards set the limit on how much leakage is allowed and the tighter of them, which we might expect of an oven manufactured and sold in the EU to meet, is BS EN 60335-2-25, last modified in 2002.

¹⁶ he power and distance come from the standards which define and limit mobile phone radiation

¹⁷ onsideration of the measurements reported in Health and Safety Executive's Information note published in Appendix 3 indicates that the figures used in this document are such.

¹⁸ he idea of doing so came from a memory of being in the staff canteen at Jodrell Bank, whilst sorting out a project for a programme at the Royal Institution. The microwave there was in a large, thick, steel container. My colleague explained that this was necessary not for the health or safety of the scientists but because the electromagnetic radiation that leaked from it blocked the receivers connected to the various radio telescopes and stopped them working!

It specifies a maximum leakage of 5mW per square centimetre of the door. Such a door is typically 700 cm², permitting a leakage of 3.5W ($P_{mic} = 3.5$). As one switches it on and then moves around the kitchen, assume that the average distance from that door is 1.5 metres ($D_{mic} = 1.5$).

We can establish a comparison between having Faraday as a neighbour and sharing a kitchen with a microwave oven by repeating Eq3 and rewriting its variables.

$$P_{mic} \times T_{mic} \times D_{mic}^{-2} = P_{far} \times T_{far} \times D_{far}^{-2} \times 10^{-(Atn/10)} \quad [Eq5]$$

From which we can solve for T_{mic}

$$T_{mic} = \frac{P_{far} \times T_{far} \times D_{far}^{-2} \times 10^{-(Atn/10)}}{P_{mic} \times D_{mic}^{-2}} \quad \text{hours} \quad [Eq6]$$

Just as T_{tel} provided us with a comparison with a mobile telephone, T_{mic} does so for a microwave oven. It is the number of hours spent in proximity to a microwave oven that would subject the user to the same amount of electromagnetic radiation as Faraday using her three most powerful antennae 45 metres away from the nearest Marina home for eight hours.

$$T_{mic} = 0.000832 \quad (\text{about } 832 \text{ millionths of an hour})$$

Which, in seconds, is:

$$T_{mic} \times 60 \times 60 = 2.9952 \quad \text{seconds}$$

In summary

If, as with the telephone comparison, Faraday were to use her three most powerful radars for 8 continuous hours and if we take the most pessimistic view of how their outputs combine and of the attenuation of building structures, the total radiation experienced by the occupier of the home nearest to her berth would be equivalent to sharing a kitchen with a microwave oven for about 3 seconds.

4 Compare with legally defined limits

As described in Appendix One, the legal limits for the electromagnetic radiation that sources such as Faraday's radars are permitted to cause to members of the general public, are defined as 10W/m².

The distances at which that level arises for the radars considered in this Appendix are:

25kW 50cm

10kW 34cm

4kW 23cm

As a first step, reference all of these to the W/m² value at a distance of 5 metres.

$$\begin{aligned} Ref &= \frac{10 \times 0.5^2}{5^2} + \frac{10 \times 0.34^2}{5^2} + \frac{10 \times 0.23^2}{5^2} \\ &= 0.1674 \text{ W/m}^2 \end{aligned}$$

Now consider what would be experienced in a home 45 metres away

$$\begin{aligned} Home &= \frac{Ref \times 5^2 \times 10^{-(Atn/10)}}{45^2} \\ &= 10.33 \text{ } \mu\text{W/m}^2 \quad (\text{about } 10 \text{ millionths of a Watt per square metre}) \end{aligned}$$

In summary

If Faraday were to use her three most powerful radars the total radiation experienced by the occupier of the home nearest to her berth is less than that specified by law by a factor of about one million.

Appendix Three

The Health and Safety Executive's consideration of a related perceived risk from high powered radars on vessels in commercial ports

Their Information Sheet was reproduced in full in the original report, because it was treated as a written document.

For this web-based version, it can be linked to on the dBR website by clicking on HSE Report to the left of this page.

It is worth noting that:

- The radar transmitters considered are much more powerful than Faraday's
- It judges risk against 100W/m², which is ten times greater than used in this document
- Measurements against 50 and 60kW radars 10 metres away from a stationary scanner were at no more than 1/100th of the no-threat level. With a rotating antenna that would correspond to about 1/30,000th.

Scaling the HSE's figures as an alternative way to determine Faraday's contribution to the electromagnetic radiation experienced by her nearest neighbour would suggest that the analysis of Appendix Two is indeed "worst case".