Radio Society of Great Britain
Advancing amateur radio since 1913

EMF Technical Note
No. 1

# What You Need to Know about Electromagnetic Fields

## for compliance with ICNIRP Exposure Guidelines

New regulations from Ofcom will require all UK radio amateurs to comply with the international guidelines for limiting exposure to electromagnetic fields (EMFs). The guidelines are provided by ICNIRP, the International Commission on Non-Ionizing Radiation Protection [1, 2].

In *RadCom* for March 2021, RSGB has published the first in a series of articles on how to meet these requirements. This online Technical Note is a background reference to fill in some detail about the fundamental nature of electromagnetic fields.

All UK radio amateurs can download these materials from the EMF pages of the RSGB website [3]. Other digital media such as animations, high-resolution images and videos will be added to the website from time to time.

### What are electromagnetic fields?

As licensed radio amateurs, most of our acquaintance with EM fields concerns their use in radio communication over long distances. This distant region is called the **far field** of the antenna. However, when assessing the EMF exposures arising from our own transmissions, the more important region is likely to be the **near field**, very much closer to the antenna where the field strengths are much greater.

The near-field region has historically been of little concern to radio amateurs; but it is now, and there are some important differences from the far field. This Technical Note aims to fill that gap in our knowledge about EMFs, and to introduce some technical terms that will be relevant to ICNIRP compliance.

### Need To Know

Each section ends with a **Need To Know** summary, covering the main points at the various technical levels that will be needed for compliance with the new UK licence requirements. Because higher RF power levels create stronger EM fields, the **Need To Know** material roughly follows the classes of the UK licence.

- **Foundation** licensees should only need a basic awareness that the major concepts exist.
- **Intermediate** licensees should probably be able to recognise the major terms, along with some technical detail.
- **Full** licensees should require a proportionately deeper knowledge.
- **Anyone trying to help other amateurs** will always need some additional depth of understanding to deal with questions.

# 1. Basic Physics

Almost everyone will find new information in this Technical Note – so the best place for everyone to start is here, at the beginning [4].

## Ancient Greece to Alternating Current (in four paragraphs)

Almost everything we need to know today about the basic properties of EM waves had already been discovered in the 19th century, long before radio communication began to be developed.

Static electricity was discovered by the Ancient Greeks some 2500 years ago. Although they didn't know what 'electricity' was, they gave it the name that we still use today. By the 19th century the chemical battery had also been discovered, and this made it possible to experiment with continuously flowing electricity; in other words, with Direct Current (DC). The concepts of electrical conductors and insulators were also well established. Even in those days, it seemed quite likely that an "electric current" might actually be a stream of tiny charged particles, but the Victorian scientists and engineers didn't need to wait for the electron to be identified in 1897. They already knew enough basic physics to start an avalanche of new discoveries and inventions.

For our purposes, that knowledge still holds good today. An electric charge creates an **electric field** around itself. A moving charge is an electric current, and in 1831 Michael Faraday discovered that an electric current flowing in a wire – a conductor – will also create a **magnetic field** around the wire (**Figure 1**). Faraday then discovered that the reverse also applies: when a conductor is moved through a magnetic field, a voltage is induced. Another major discovery was that the shape and layout of the wire carrying an electric current also affects the *shape* of the fields around it. For example, if we wind many turns of wire into a spiral coil (a solenoid), the magnetic fields line up along the axis of the coil, creating an electromagnet.

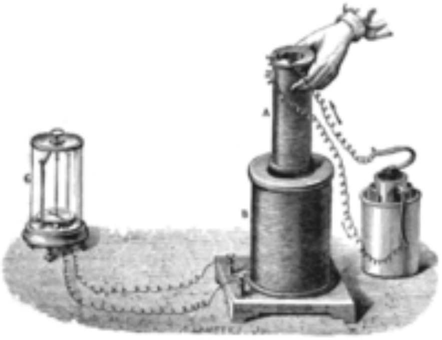

**Figure 1: Faraday's electromagnetic induction experiments**

That was enough basic physics to develop both the DC electric motor and the generator (**Figure 2**). With continuous supplies of electricity at ever-increasing voltages and currents, the race was on for those Victorian scientists, engineers and entrepreneurs to develop all the other building-blocks of 19th and 20th century electrical engineering. Most important among those developments was Alternating Current (AC).

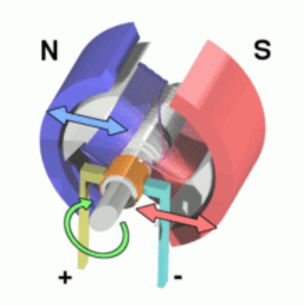

**Figure 2: An electric motor can also act as a generator**

## Alternating Current and RF

Alternating current is the next step on our journey towards RF engineering as we know it today. The key feature that distinguishes AC from DC is that the current varies with time, reversing in polarity on every half-cycle (**Figure 3**). In order to do that, the electrons that carry the charge have to speed up, slow down and also reverse direction.

In other words, the moving charges are accelerating and decelerating – and this turns out to be profoundly important. In 1864, James Clerk Maxwell predicted that an accelerating electric charge creates electric and magnetic fields that do not remain entirely anchored to the conductor carrying the current. Part of those fields will **propagate through space** as an **electromagnetic wave**.

Maxwell noted three other important things about electromagnetic waves. First, that a propagating EM wave must contain both electric and magnetic components. Second, that visible light is just another form of EM wave, with a very short wavelength. And third, that all EM waves must propagate at the same speed – namely, the speed of light [4].

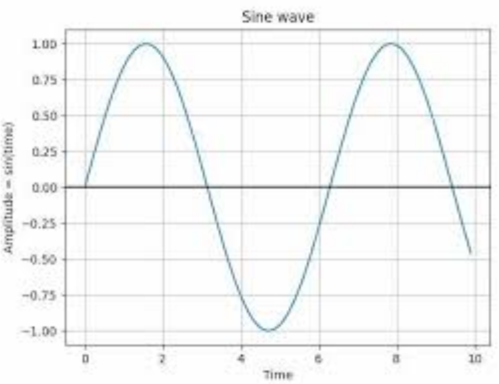

**Figure 3: An alternating current involves accelerating / decelerating electric charges.**

At that time, radio waves were still unknown, but based on the emerging 'laws of physics' and the logic of pure mathematics, Maxwell was able to make the firm prediction that EM waves of much longer wavelengths than light **had** to exist. They were merely waiting to be generated and discovered.

In 1887, Heinrich Hertz was the first to confirm Maxwell's predictions, in a bench-top experiment at a frequency not far from the 144MHz band (**Figure 4**). The first experiment used a spark transmitter with primitive dipole antenna (C-C), a loop as a receiving antenna, and a spark gap (M) as a very primitive RF detector. Hertz also used dipole antennas to demonstrate plane polarization and the reflection of radio waves, creating the first directional antennas and confirming that radio waves do indeed behave like visible light.

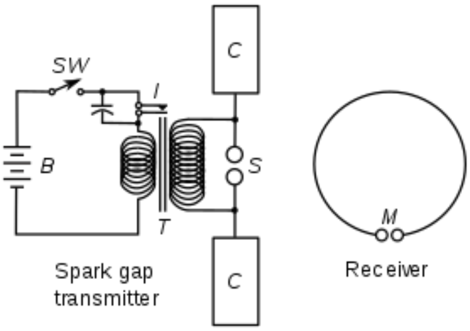

**Figure 4: First practical demonstration of communication using EM waves (Hertz, 1887)**

That in turn set the stage for engineers like Marconi to put these new radio waves to practical use over much longer distances in the early 20th century. The main advances at the time were the move to much longer wavelengths and larger antennas, and the development of much more sensitive RF detectors than Hertz's primitive spark gap. Then came the discovery of short waves (HF) and the ionosphere, followed by the exploitation of ever-higher frequencies, all of which we now broadly group together as "RF".

Today's RF technology would be unrecognisable to the Victorians, but they would still recognise the underlying physical behaviour of EM waves, exactly as Maxwell had predicted [4].

## Need to Know

**This section was mainly to remind you that most radio amateurs already know something about the basic physics of EM waves – so we already have something to build on.**

## 2. Near Field and Far Field

The total EM field radiated by an antenna can be divided into three regions:

- **The far field**, at a long distance from the antenna. This is the region we almost always use for radio communication.
- **The near field**, very close to the antenna. The size of the near-field region is measured in wavelengths, so there are enormous practical differences between the near field at 1.8MHz (wavelength = 160m) and the near field at 10GHz (wavelength = 3cm) for example.
- A transition region between the near and far field regions, sometimes called the **radiative near field**.

These three regions have their own distinctive characteristics, but they blend into each other with no sharp boundaries [5].

Field strengths are greater in the near field and transition regions because they are closer to the antenna. At amateur power levels, the boundaries for EMF compliance will often occur in the near field and transition regions, depending on the type of antenna and its physical size.

The near field and transition regions are not familiar to most radio amateurs, so let us try to build on what we already know about the far field.

### The Far Field

If you create an alternating electric field on its own, said Maxwell, it will not propagate very far through space before the missing magnetic field grows into existence too, and then the two will continue to propagate together as a fully developed electromagnetic field. The reverse also applies: an alternating, propagating magnetic field will soon be accompanied by its companion electric field.

The **far field** is the region where the relationship between the electric and magnetic components of an EM wave is fully developed. Because the far field is the only region of importance for normal radio communication, we tend to assume that all electromagnetic fields look like the classic textbook image in **Figure 5** – but in fact, this image is only valid in the **far** field.

The **electric field** is often called the **E-field** and is shown in blue. Its companion **magnetic field** is often called the **H-field** and is shown in red. The orientation of the E-field defines the plane of polarization, so the EM wave drawn in Figure 5 is horizontally polarized.

Figure 5 is a still from an animation that can be viewed on the RSGB EMF pages [3]. The animation shows much more clearly why the wave propagates, and why direction of propagation in this example will be from left to right.

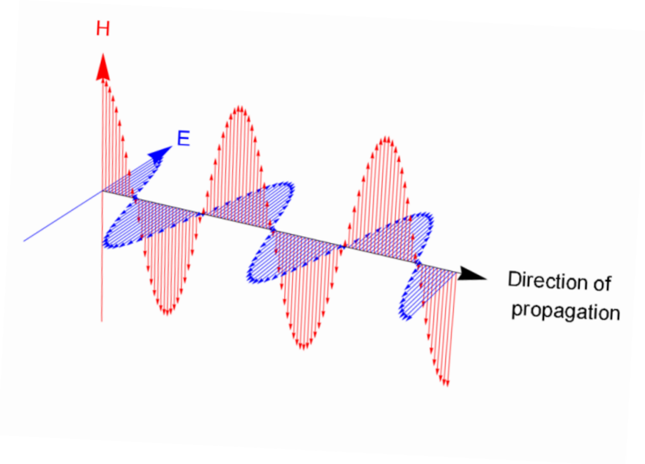

**Figure 5: EM wave in the far field.**

In the far field, the E and H fields are always at right-angles, always in phase, and always in a constant ratio of E/H. This means the two fields can be treated together. Knowing only one component, either E or H, the other one can easily be calculated. So too can the power density (see Section 3), which will decrease with distance according to the well-known inverse square law.

In the far field, these simple relationships are independent of the type of antenna.

### The Near Field

The near field is the region closest to the antenna. The near-field region will cover the entire physical structure of the antenna and some way beyond, eventually merging into the transition region and finally into the far-field region.

The near-field and transition regions are difficult to visualize. The electric and magnetic fields in the near field do not have the simple relationship that will eventually develop in the far field. In the near field, that relationship is much more complex. It depends on the specific type of antenna, and also on the distance and the direction from the feedpoint; and in most situations the effect of ground will also need to be considered. This also means that the short-range directivity of the antenna within the near field is likely to be different from the radiation pattern in the far field.

Think of a stone dropping into a still pool of water (**Figure 6**). At the point of impact, the disturbance is complex and very strong, but waves in this region do not travel very far. It is only farther out that the wave pattern becomes much more uniform, and these are the waves that propagate over much greater distances. Also notice that the distance between peaks and troughs varies considerably in the region close-in, but farther out in the propagating region the peak-to-trough distance becomes constant.

**Figure 6: Visualization of the near and far fields.**

EM waves radiated from an antenna display similar features to Figure 6. The imagery is obviously not exact, but it may help you to understand how there can be significant differences in the behaviours of EM waves in the near field, the far field, and the transition region in between.

The complicated relationship between the E and H fields in the near field and transition regions means that the E and H components must be treated separately. These individual fields reduce with distance much faster than the familiar inverse square law for power density in the far field.

When estimating or measuring individual fields close to antennas, care must be taken not to assume an inappropriate far-field model which incorrectly estimates individual field strengths. Fortunately, there are well-tried computer programs that allow the E and H fields close to an antenna to be modelled in some detail when necessary [5].

### Need to Know

- **The basic nature of an electromagnetic field.**
- **Names and general characteristics of the near field, transition and far field regions.**
- **Field strengths are greatest at short distances from the antenna and decrease rapidly over short distances; but the inverse square law only applies in the far field.**
- **Radio communication uses the far field; but EMF compliance boundaries (at amateur power levels) will more commonly be in the near-field or transition regions – especially at HF.**
- **The near field can be unfamiliar territory where existing amateur knowledge based on the far field may no longer be accurate.**

## 3. Terminology

This final section gives more details about commonly-used terms and symbols, and how these quantities are related [4].

### E-field and H-field

An electromagnetic wave has both electric and magnetic components (see above).

- The alternating electric field is commonly called the **E-field**.

  The usual symbol for electric field strength is **E** and the units are **volts/metre** (V/m).

- Its companion, the alternating magnetic field, is commonly called the **H-field**.

  The usual symbol for magnetic field strength is **H** and the units are **amps/metre** (A/m).

### Power density

The **power flux density** in an EM wave is the amount of energy flowing through unit area of the wavefront in unit time. The name is often shortened to **power density**.

- The usual symbol for power density is **S** and the units are **watts per square metre** (W/m$^2$).

  **S** can be calculated from **S** (W/m$^2$) = **E** (V/m) ★ **H** (A/m)

  That equation follows the same pattern as the equation for power in an electrical circuit, **P** (watts) = **V** (volts) ★ **I** (amps). When calculating **P** in reactive circuits, we need to remember that **V** and **I** are not always in phase, so then we must include the phase angle in the calculation. The same applies when calculating **S** in the near field and transition regions.

## Relationships between E, H, S and the RF power level

At any given point within an EM field, the values of **E**, **H** and **S** will scale exactly according to the RF power level:

- Power flux density **S** at a given location is **exactly proportional** to the RF power level.

  Example: increasing the RF power level by a factor of 10 will also multiply every local value of **S** by 10.

- The local **E** and **H** field strengths at a given point will scale together, both in proportion to **the square root** of the RF power level.

  Example: increasing the RF power level by a factor of 10 will multiply all the local values of both **E** and **H** by a factor of $\sqrt{10} = 3.16$.

## Wave impedance

This is an advanced topic, included only for completeness in recognising the terms and symbols.

- The ratio **E/H** at any given point within an EM field is called the **wave impedance**.

  The symbol for wave impedance is **Z**, and the units of impedance are (of course) **ohms**.

In a similar way to $\mathbf{Z} = \mathbf{V} / \mathbf{I}$ in electrical circuits, the wave impedance a given point in a field can be calculated from $\mathbf{Z} = \mathbf{E} / \mathbf{H}$.

In the far field, the E and H fields are in phase, and $\mathbf{Z} = \mathbf{E}/\mathbf{H}$ has a constant value that is non-reactive. In free space this is usually called $\mathbf{Z_0}$ (“zed-nought”) and has a value of approximately $377\Omega$.

In free space, the relationships $\mathbf{S} = \mathbf{E}^2/\mathbf{Z_0}$ and $\mathbf{S} = \mathbf{H}^2 \star \mathbf{Z_0}$ apply in the same way that $\mathbf{P} = \mathbf{V}^2/\mathbf{Z}$ and $\mathbf{P} = \mathbf{I}^2 \star \mathbf{Z}$ apply in electrical circuits.

In the near field and transition regions where **E** and **H** are not in phase, **Z** must be evaluated as a complex impedance containing a reactive term.

## Need to Know

- **At all levels, be aware of the symbols used to define EMF Compliance levels: E for electric field strength, H for magnetic field strength, and S for power density.**

- **At an intermediate level and beyond, recall the units of E, H and S.**

  **Also recall how E, H and S are related; and be aware that these parallel the relationships between P, V and I in electrical circuits.**

- **At all levels, be aware that E, H and S all increase with the applied RF power.**

- **At an intermediate level, understand how each of those quantities scales with the applied RF power level.**

## References and Notes

[1] UK Amateur Radio Licence: https://www.ofcom.org.uk/__data/assets/pdf_file/0027/62991/amateur-terms.pdf

[2] ICNIRP: https://www.icnirp.org/

[3] RSGB EMF pages: https://rsgb.org/emf

[4] This Technical Note takes a deliberately minimalist ‘Classical Physics’ approach. Many exceptions and elaborations could obviously be added to the explanations given here; but on closer examination, they do not affect what readers **Need to Know** for the purpose of EMF compliance.

[5] Antenna modelling software will usually calculate far-field radiation patterns by default. Far-field radiation patterns are independent of the distance from the antenna, and are also independent of the RF power level.

Many antenna modelling programs can also be configured to calculate the absolute E-field and H-field at any given distance and direction from the antenna, including in the near field. In this mode, the software makes no assumptions about the “near field”, “far field” or “transition” regions, but calculates the magnitudes and relative phase angles of the E and H fields using the same methodology for all locations. The absolute magnitudes of the E and H components will also be scaled according to the specified RF power level (Section 3).

### Artwork

All artwork is acknowledged to be the copyright of its respective owners. It is copied here under ‘fair use’ conditions for educational purposes.

Figures 1, 2, 4 and 5: https://commons.wikimedia.org

Figure 3: https://pythontic.com/sinewave.jpg

Figure 6: http://munnscience.weebly.com/waves-on-earth.html