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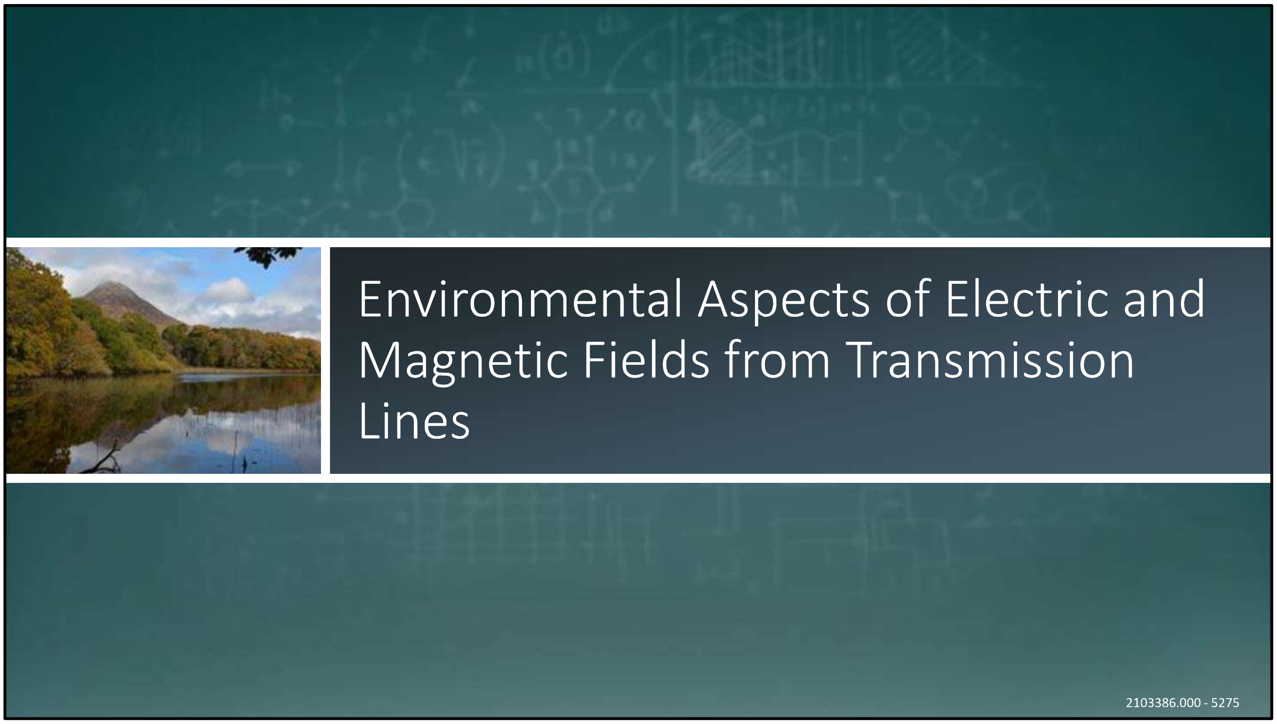


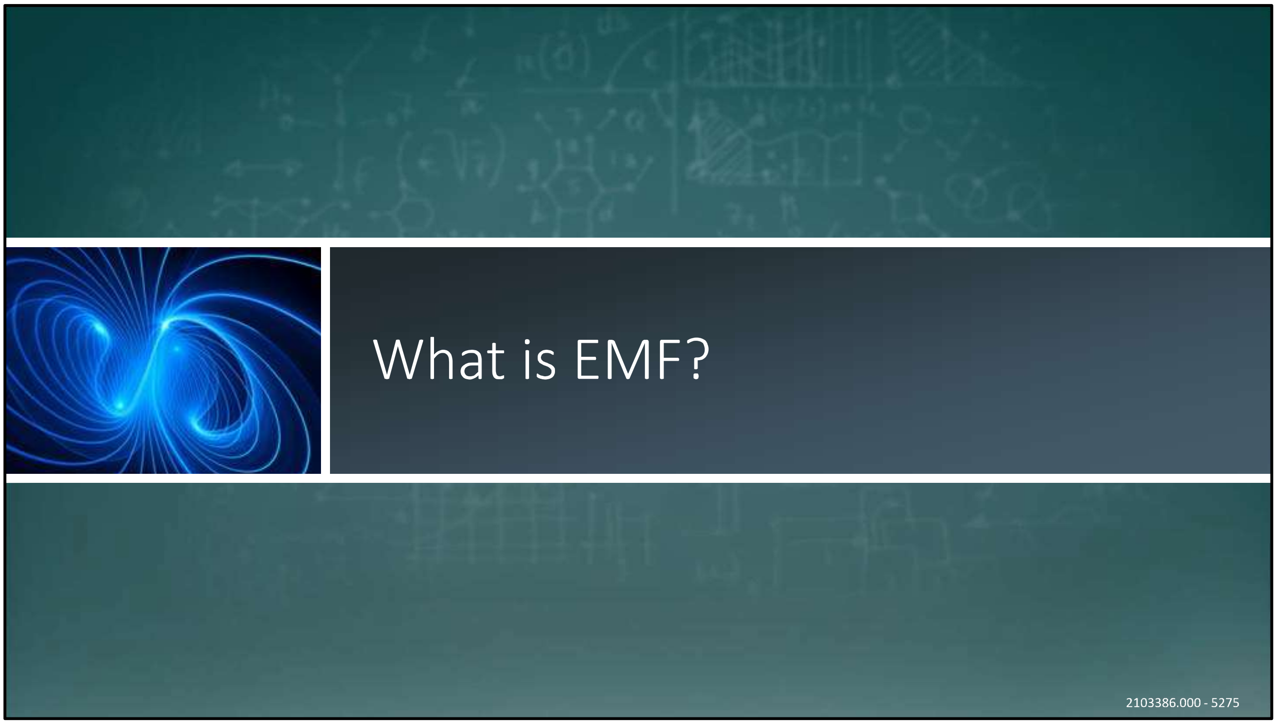
Members of the public have asked Eirgrid about electric and magnetic fields from its transmission lines, so we have asked some outside experts to share their knowledge with you on environmental aspects of electric and magnetic fields of our transmission lines.

Outline

- Introduction
  - What is EMF?
  - EMF sources and levels
- EMF Research
  - Human health
  - Livestock, wildlife, crops
  - Implanted medical devices
- Best Practice Guidelines and Regulations
- Case Study Examples
  - Case examples: Alternating current (AC) overhead and underground transmission lines
  - Case examples: Underground direct current (DC) transmission lines
- Summary

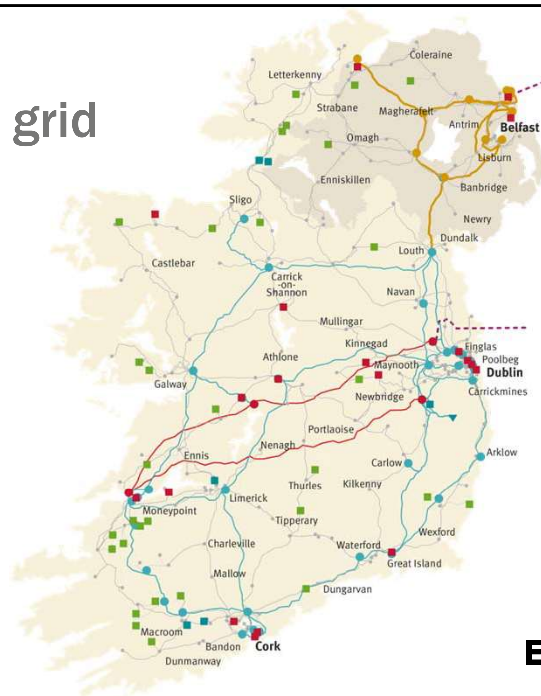
Given the questions the public has asked us in the past, we put together a list of topics to address today relating to the fields associated with two types of transmission lines.

We have divided the topics into sections, and the dashed lines on the screen indicate where the discussion was followed by short Q&A sessions before moving on to the next group of topics.



EMF as an abbreviation for electric and magnetic fields. EMF is a topic that everyone has heard of, but few have had the opportunity to learn more about. So, we'll go over some basics.

Ireland's electricity grid



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One reason for interest in EMF arises because the delivery and use of electricity is the primary source of public exposure to power-frequency EMF. This EirGrid map shows the breadth of its transmission grid of 110 kilovolt (kV), 220 kV, 275 kV, and 400 kV lines across Ireland.

However, the most common sources of exposure to power-frequency EMF are the lower voltage network of distribution lines operating at 2 kV to 38 kV that connect this grid. These distribution lines connect ultimately to every building in the country and are so numerous they would fill in the map if we added them here.

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Electromagnetic Fields

- Key Characteristic is FREQUENCY
- Frequency refers to the number of times per second that the field changes direction

Low Frequency High Frequency

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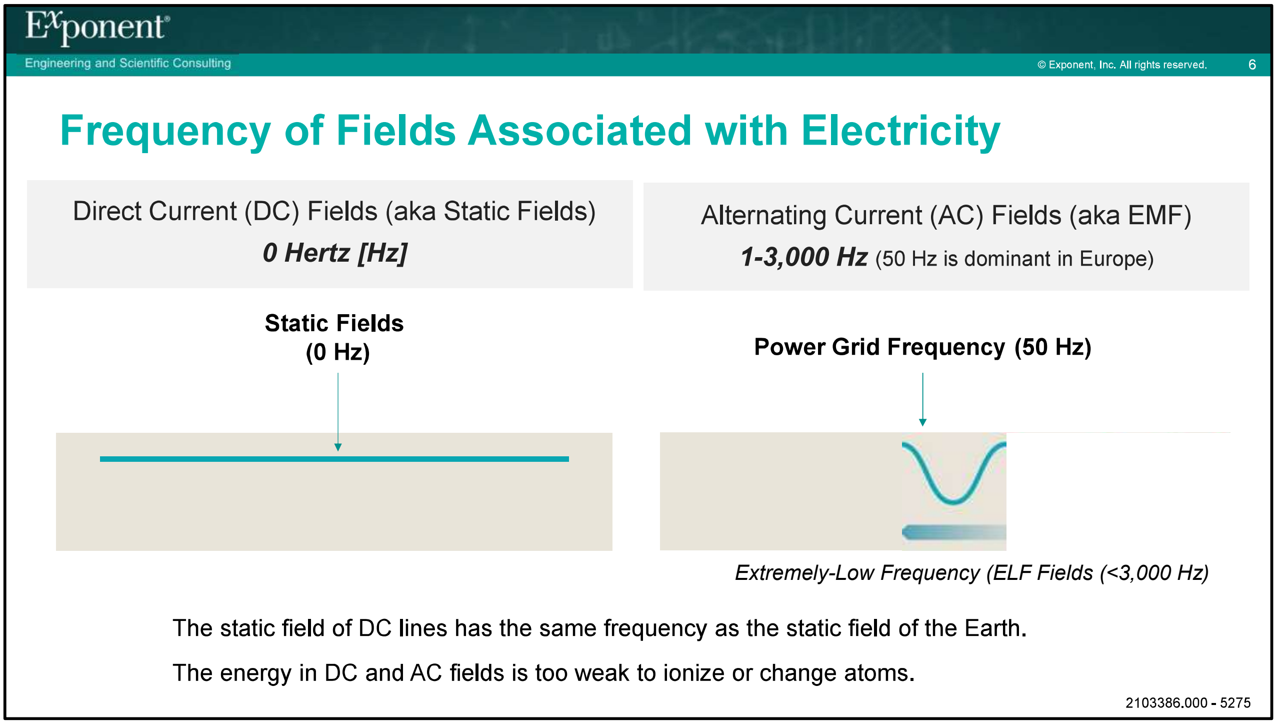
The term electromagnetic field spectrum is used in general to refer to electromagnetic fields that vary across a wide range of frequencies, not just those from our electrical system. Frequency is the number of times per second that the electromagnetic field changes direction (oscillates). This figure shows that low-frequency fields oscillate slowly. As the rate of oscillation increases, the frequency increases. Frequency is specified in units of Hertz (Hz).

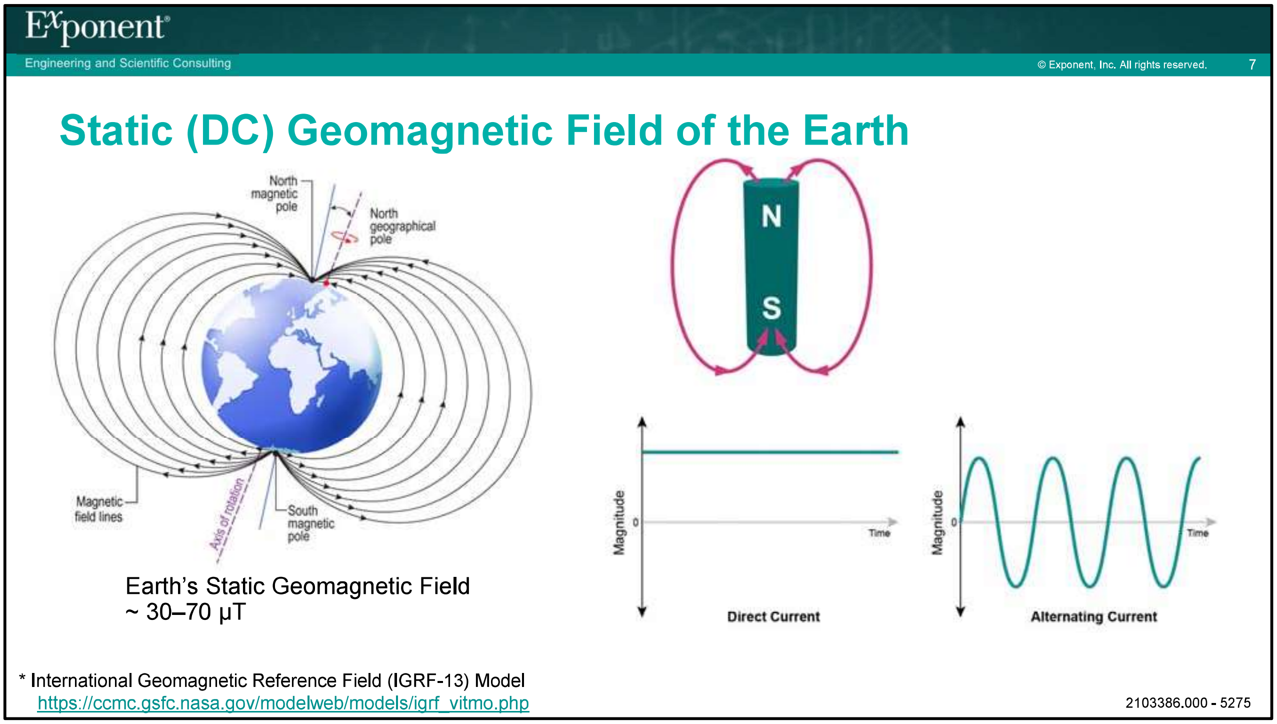
The electromagnetic fields associated with power lines are at the low end of this spectrum. Higher frequency fields produced by radar and mobile phones, are separate and unrelated to power frequency fields. Still higher frequency fields that we see as visible light also are unrelated, as are the still higher frequencies from x-ray machines.

The important point is that frequency determines the characteristics of electromagnetic fields, how they interact with the environment, and their effects.



This slide illustrates the difference between DC fields and AC fields. The direction of a static (DC) field is constant, as shown at the left, whilst AC fields change direction every second, as shown on the right. Fields with frequencies of 1 to 3,000 Hz are in the extremely low frequency (ELF) range. At the lower end of ELF frequencies are the 50 Hz fields associated with electricity.

Two points are important here. First, static fields from DC lines are the same as the natural fields in the environment, and second, a distinguishing feature of both static and ELF AC fields is that their energy is too weak to ionize or change atoms.



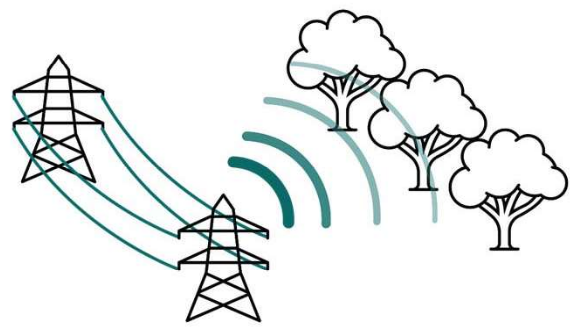
On the left of this slide we see the earth and the lines around the earth that illustrate its static geomagnetic field. Where the lines of the geomagnetic field come closer together at the north and south poles, the magnetic field is higher; the magnetic field is lowest at the equator where the field lines are further apart. This range of values is between 30- 70 microtesla (µT).

The strength of the geomagnetic field in Ireland is about 49 µT.

On the right of the slide, a diagram is used to show the static magnetic field from a bar magnet is exactly like the geomagnetic field of the earth. For both, the direction of the field is constant over time.
In contrast, the magnetic field from an AC source varies in magnitude and direction each second.

AC Electric Fields from Electricity Infrastructure

- Electric fields result from electric charges on wiring
- Measured in units of volts per metre (V/m) or kilovolts per metre (kV/m) 1,000 Volts = 1 kilovolt (kV)
- Strength of the field diminishes as one moves away from the source
- Shielded by common objects such as trees, shrubs, or walls
- Shielding of underground cables effectively blocks the electric field



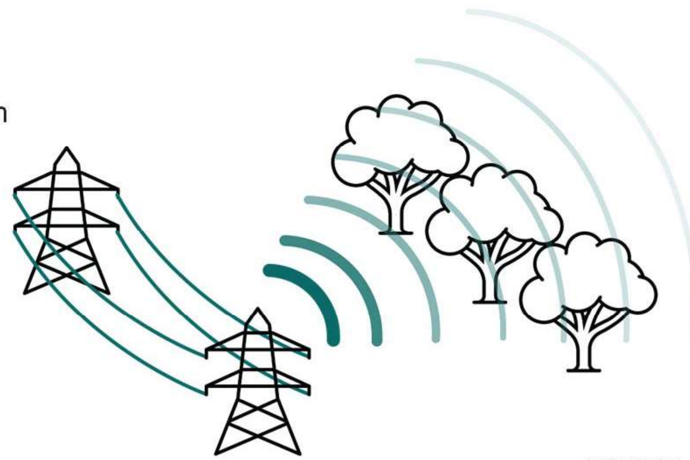
Both the electric field and the magnetic field from the electrical grid, and all other sources of electricity, have a dominant frequency of 50 Hz. This puts them in the ELF range; they are also referred to as power-frequency fields.

The greater the voltage, the greater the electric field. For example, the electric field from a wall outlet in a home will be weaker than from the distribution line on the street, and much weaker than the electric field under a high-voltage transmission line.

The illustration at the right shows that trees are effective at blocking an electric field. Placing the conductors of overhead lines underground eliminates the electric field because of shielding around the cables.

AC Magnetic Fields from Electricity Infrastructure

- Magnetic fields result from the movement of charges (i.e., current flow)
- Measured in microtesla (μT), or for larger fields, millitesla (mT)
- Strength diminishes as one moves away from the source
- Not shielded by common objects such as trees, shrubs, or walls



In contrast to electric fields, magnetic fields are produced by the current flow on wiring, not the voltage. Also, in contrast to electric fields, common objects or materials do not block magnetic fields.

In the same way that trees do not block the magnetic field from electricity infrastructure, the static geomagnetic field of the earth will continue to give a compass reading when the compass is placed inside a thick wooden box. This is because the box does not block the static geomagnetic field of the earth.

What are the most common sources of EMF in our communities?

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Environmental Sources of Electric and Magnetic Fields

- **Alternating Current Fields** (dominant frequency is 50 Hertz (Hz) in the ELF range)
  - AC power lines
  - Home appliances
  - Building wiring
  - Grounding systems (e.g., water pipes)
- **Static Fields** (0 Hz)
  - Static magnetic field from the earth, static electric field from clouds
  - Magnets, headphones
  - Electric trains
  - DC power lines

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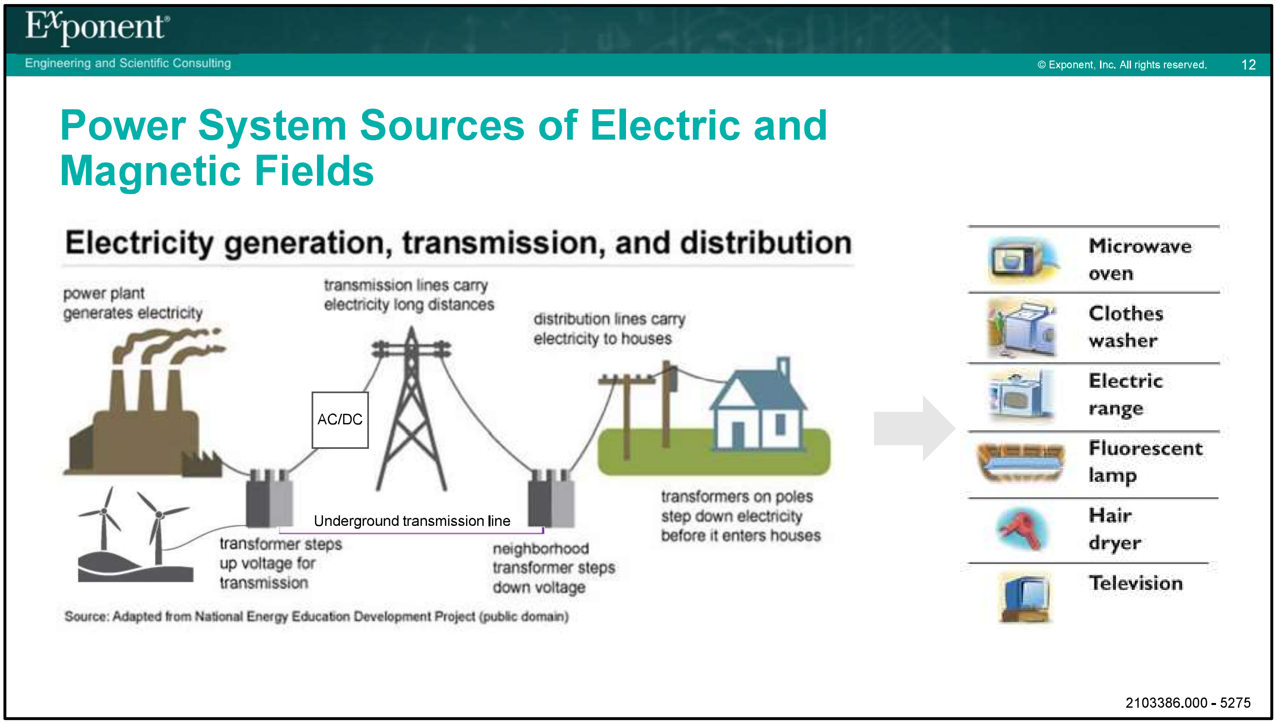
There are two types of power-frequency EMF we encounter in our environment are of 2 types: AC fields and static (DC) fields.

The dominant frequency of electricity in Ireland and the rest of Europe is 50 Hz, so 50 Hz fields are present around power lines, appliances, building wiring, and sometimes even our water pipes.

Static fields are common from natural sources. As noted, static magnetic fields are what cause a compass needle to orient in a north-south direction. These fields are produced by magnets on our refrigerators, and in toys and in headphones, for example. Static fields are also associated with the operation of electric trains, such as those in Dublin, are produced by DC power lines.



Electricity is distributed to EirGrid from electrical generating plants and wind farms as shown at the left. The voltage of the electricity is stepped up to be carried on transmission lines across the country. In each region, the Electricity Supply Board steps down the voltage before delivering electricity over distribution lines, and the voltage is stepped down again by transformers before electricity is supplied to homes.

In our homes, house wiring and all the appliances connected to that wiring are sources of EMF.

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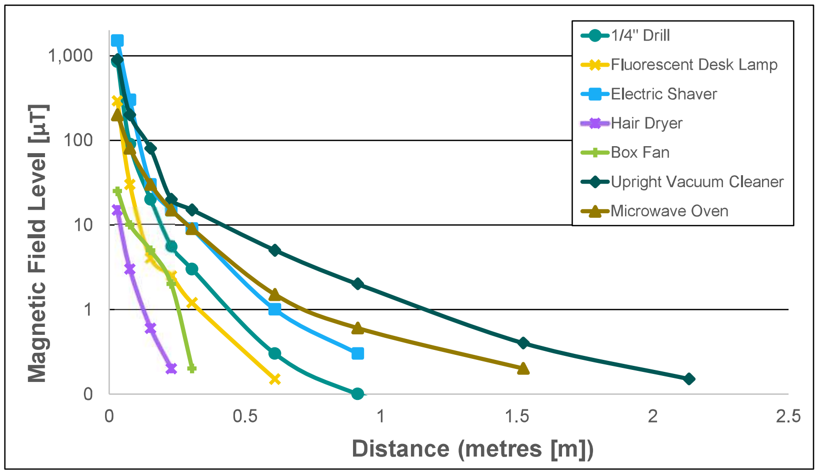
AC Magnetic Fields from Home Appliances



[1] Gauger JR. Household appliance magnetic field survey. IEEE Trans Power App Syst 104:2436-2444, 1985.

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The strongest sources of magnetic fields we encounter are from items that we use every day in our homes or at work that are closest to us.

This graph shows the levels of AC magnetic fields measured around common appliances in the home. The strength of the field is measured along the vertical scale and the distance from the appliance is measured along the horizontal scale.

The highest fields are measured at the surface of these sources, but these magnetic fields diminish quickly with distance — so that the magnetic field is much lower, up to 1,000 times lower, within a few metres.

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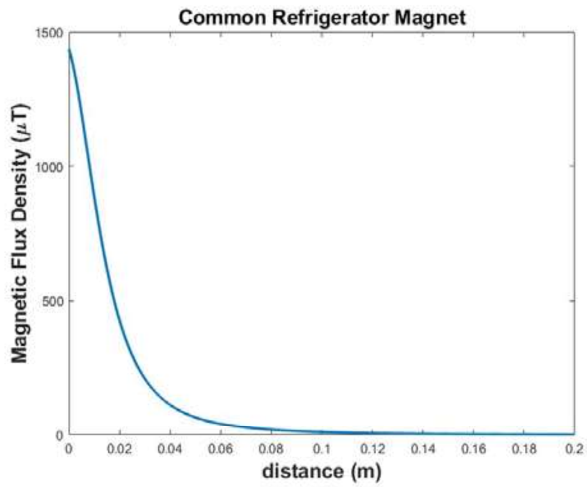
Static Magnetic Field from a Permanent Magnet



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For comparison to the AC fields from household appliances on the previous slide, here is the static magnetic field of a common refrigerator magnet. At the surface the field is strongest—close to 1,500 μT—but for a magnet, the strength of the field drops even more quickly with distance than from AC powered appliances.

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Typical Static Magnetic-Field Levels from Common Natural and Man-made Sources

Source	Magnetic Field Level (µT)
Man-made Sources	
Battery operated appliances	300 – 1,000
Electrified railways	< 1,000
MRI machines	1.5 million – 4.0 million
1 m above ground at EWIC DC transmission line	13
Natural Sources	
Earth's geomagnetic field in Ireland	~ 49

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This table compares the strength of static magnetic fields produced by a variety of sources in our environment.

The levels produced by the earth and the East West Interconnector (EWIC) transmission line are much lower that other common sources. The static magnetic above the proposed Celtic Interconnector, 15 µT, will be similar to the existing EWIC DC transmission line.

We'll first talk about EMF research related to human health, including how this research is evaluated and the overall conclusions that have been drawn by reputable scientific and health agencies.

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How Health Agencies Review Scientific Studies

- Independent, consensus evaluation of research
- Large panels of experts in multiple disciplines
- Assessments focused on integration of <u>all</u> relevant scientific evidence ("weight-of-evidence" review)
  - Epidemiology studies – people
  - Laboratory studies – animals (in vivo)
  - Laboratory studies – cells and tissues (in vitro)

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When we want to find out more information about anything today many of us search the Internet. While fast and convenient, the quality and accuracy of information can be inconsistent, inaccurate, or incomplete. That is why when you search for information about any exposure or health outcome, you want to get the information from informed, authoritative sources that have properly reviewed and evaluated the research. This includes independent health and scientific agencies, such as the World Health Organization (WHO).

In order to arrive at a scientific conclusion about a potential cause-and-effect relationship between any environmental exposure and an adverse health effect, these scientific agencies evaluate the entire body of research on the subject. They convene multidisciplinary panels of experts to provide a comprehensive assessment of the relevant scientific research; this is called a weight-of-evidence review. In a weight-of-evidence review, research studies on humans (called epidemiology studies), as well as laboratory studies of animals or human cells and tissues, are each evaluated for their strengths and limitations, and the results of the relevant studies are assessed together to form a conclusion, with more weight given to studies of better quality. This is done because conclusions about health risks cannot be drawn from any single study; every study has limitations in one way or another.

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Summary of EMF Health Research

- Over the past 40 years, the large body of scientific research on electric power EMF has been reviewed by many national and international public health and scientific agencies, including:
  - International Agency for Research on Cancer (2002)
  - World Health Organization (2007)
  - International Commission on Non-ionizing Radiation Protection (ICNIRP) (2010)
  - Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) (2009, 2012, 2015)
  - Swedish Radiation Safety Authority (2006-2021)
  - Health Council of the Netherlands (2015)

IARC
World Health Organization
ICNIRP INTERNATIONAL COMMISSION ON NON-IONIZING RADIATION PROTECTION
European Commission

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Research on the topic of EMF exposure and health has been on-going since the late 1970s. Over this period, thousands of studies have been published, leading to a very large body of available research. This research has been reviewed by several international scientific and health agencies, including the International Agency for Research on Cancer (IARC), the WHO, the European Commission's Scientific Committee on Emerging and Newly Identified Health Risks, and the Health Council of the Netherlands. Many of these agencies have conducted weight-of-evidence reviews.

The focus of the next few slides, and the focus of much of the EMF health research, is on exposures to magnetic fields rather than electric fields, for a few reasons:
First, electric fields from overhead lines are easily blocked by conductive materials, including trees, fences, buildings, so generally they do not result in significant exposure levels inside nearby residences and buildings.
Second, electric fields from underground cables are so low as to not be measurable above ground due to the protection around the cable.

Finally, while electric fields can sometimes be perceived directly underneath higher voltage overhead AC transmission lines, and higher levels can result in nuisance shocks and discharges, there is no body of evidence showing that long-term exposure to electric fields has any adverse biological or health effects.

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Summary of Scientific Consensus on ELF Fields

- None of the reviewing agencies have concluded that ELF (power-frequency) EMF cause or contribute to cancer or other adverse health effects

"No consistent evidence for an association between any source of non-ionizing EMF and cancer has been found."

– U.S. National Cancer Institute
2019

*"Despite the feeling of some people that more research needs to be done, **scientific knowledge in this area is now more extensive than for most chemicals**. Based on a recent in-depth review of the scientific literature, the WHO concluded that **current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields**. However, some gaps in knowledge about biological effects exist and need further research."*

– World Health Organization
2016

https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/electromagnetic-fields-fact-sheet
https://www.who.int/news-room/q-a-detail/radiation-electromagnetic-fields

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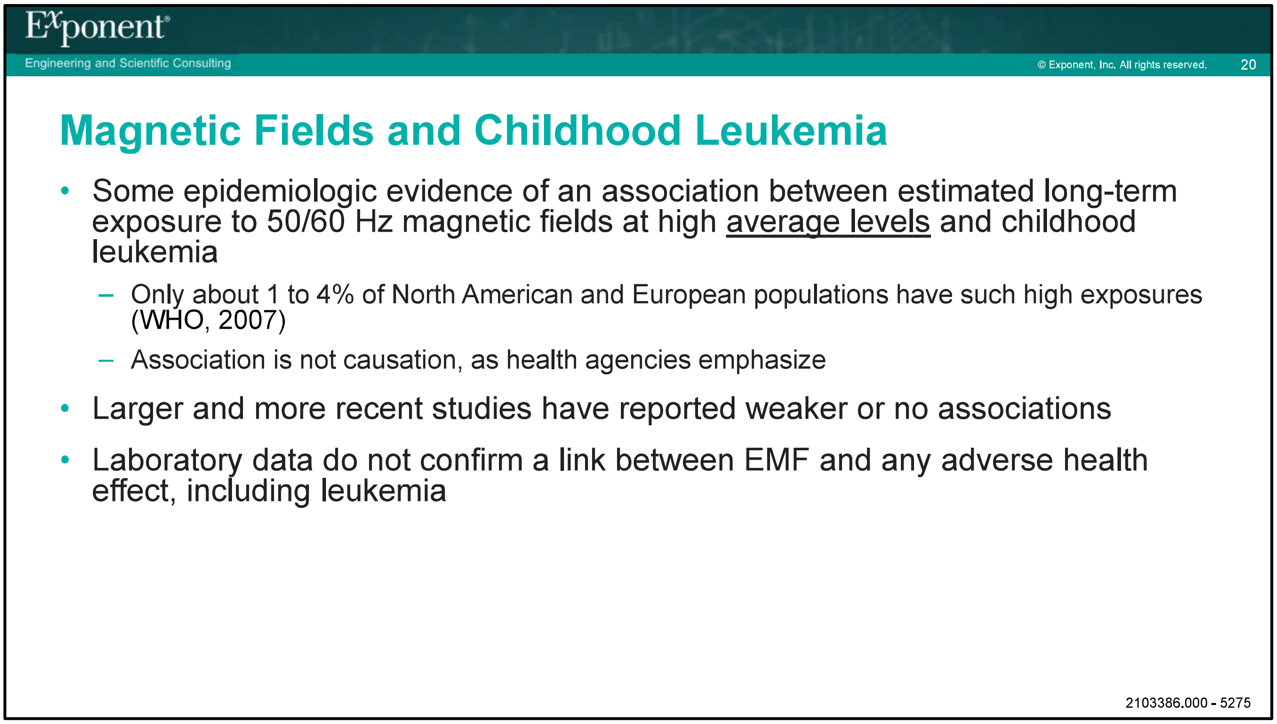
The conclusions of agencies that have evaluated EMF health research have largely been consistent. None of these agencies have concluded that power-frequency ELF EMF cause or contribute to cancer or other adverse health effects.

In Ireland, while also relying on these authoritative sources, the Irish Department of Environment, Community and Local Government also commissioned scientists to "report on the current scientific knowledge on the possible health effects of exposure to electromagnetic fields," including those from high-voltage overhead power lines. The scientists' conclusion was that "The current scientific evidence does not support long-term health effects, such a cancer, due to exposure to EMF."

Both the U.S. National Cancer Institute and the WHO have websites dedicated to providing information on EMF exposure and health and are good resources for anyone interested in more information.
It is important to note that research on EMF continues and likely will continue, as described by the WHO, not because we have a problem, but because everyone with electricity has exposure to EMF, meaning billions of people are exposed, and thus the scientific community should strive to make sure that they have identified even the smallest potential for a health risk, should it exist.



Among the many studies that have been conducted looking at magnetic-field exposure and health, some have reported an association between high long-term average exposure to magnetic fields and childhood leukemia. It is important to understand, however, that an observed association between an exposure and an outcome does not mean that the exposure caused that outcome or even has a direct effect on that outcome; rather, it simply indicates that the two are somehow related.

Regarding research on magnetic fields, none of the reviewing agencies that we introduced previously have concluded that magnetic-field exposure causes childhood leukemia. Larger and more recent human studies have reported weaker or no associations between EMF and childhood leukemia. In addition, laboratory studies on animals, as a whole, do not show adverse effects, and studies of cells and tissues have not confirmed any biological mechanism explaining how magnetic fields could cause harm in the body.

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Authoritative Health Agency Reviews of DC Electric- and Magnetic-Field Health Research

- International Agency for Research on Cancer (2002)
- National Radiological Protection Board (2004)
- World Health Organization (2006)
- Health Protection Agency of Great Britain (2008)
- ICNIRP (2009)
- SCENIHR (2015)

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Many of the same agencies that have evaluated the health research on AC EMF have also evaluated the research on DC fields. This includes both the IARC and the WHO, as well as the United Kingdom's National Radiation Protection Board, which is now part of Public Health England.

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Summary of DC EMF Research

- Research on DC fields, including those related to DC transmission lines, has not confirmed that exposure to these fields, even at high levels, has any long-term health effects on people or pose safety risks.
- Some studies have indicated that short-term exposure to DC magnetic fields at levels about 4,000 times greater than the ICNIRP guideline for static fields may be perceived in magnetic resonance imaging (MRI) devices.

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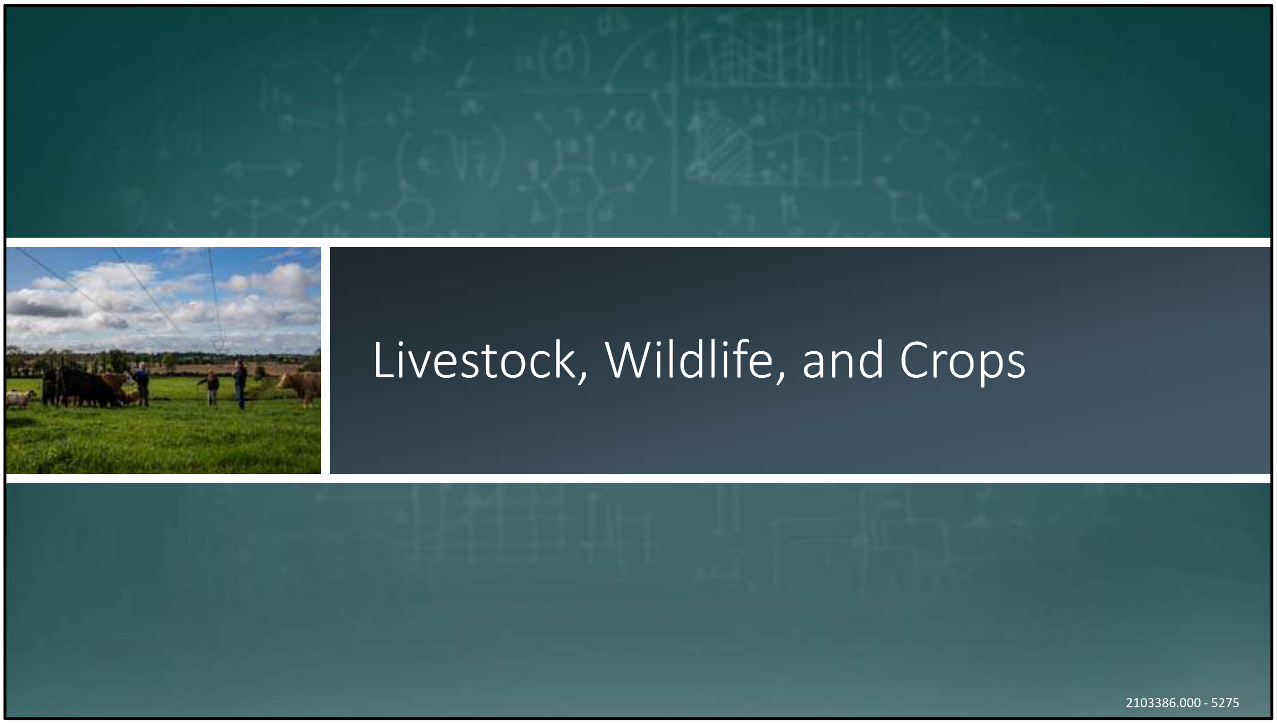
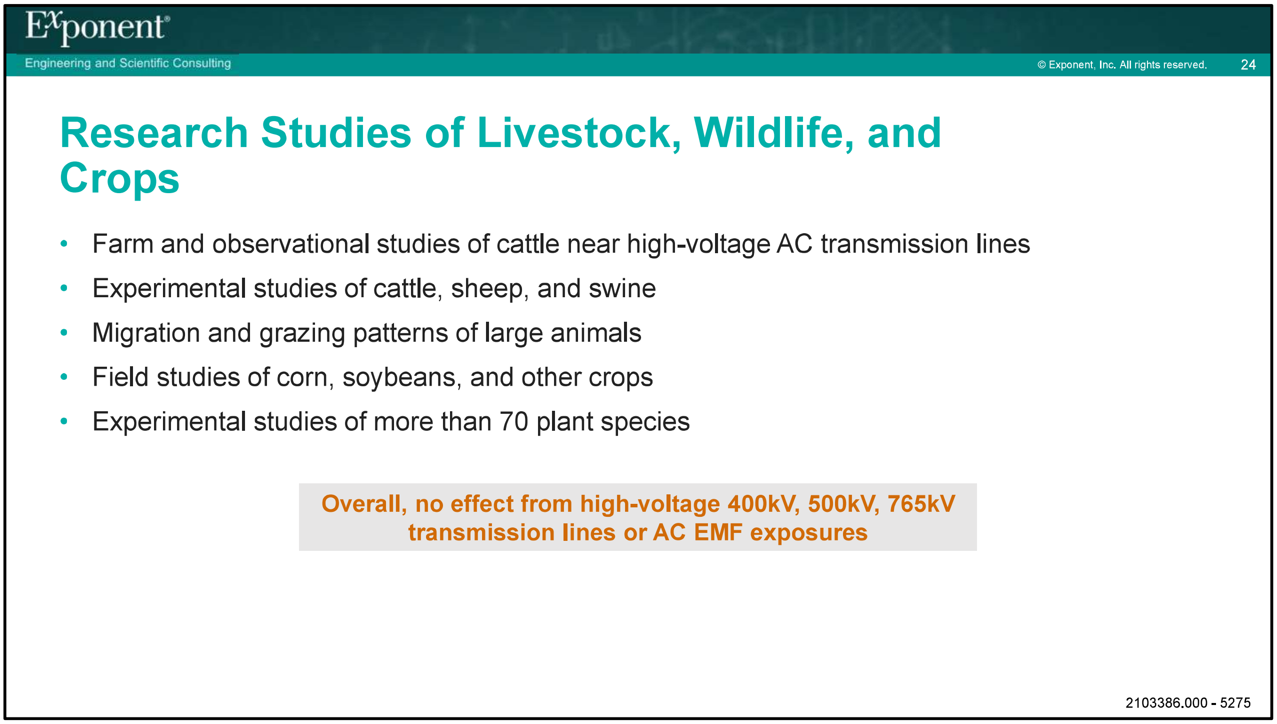
Similar to research on AC fields, research on DC fields, including research related to DC transmission lines, has not confirmed that exposure to these fields, even at high levels, has any long-term health effects on people or pose safety risks.

Some studies have indicated that short-term exposure to DC magnetic fields at levels many times greater than the recommended exposure guidelines may be perceived while in magnetic resonance imaging (MRI) devices. The results of this ongoing research help guide international regulations and exposure limits related to DC EMF – and we'll talk more about those regulations a little later in the presentation.

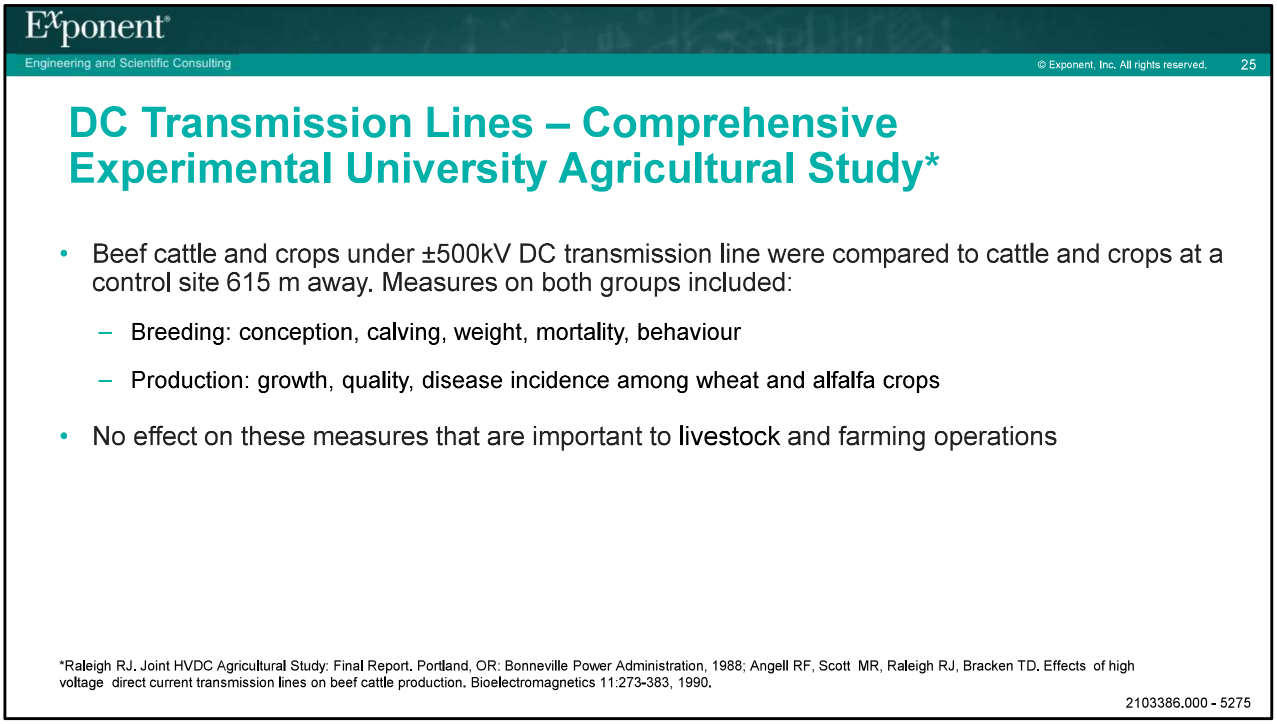


Now we shift focus to research related to livestock, wildlife, and crops, since they can all be located under overhead lines for lengthy periods of time.



Similar to research on human health, a substantial number of studies have been conducted to evaluate the possible effects of EMF exposure from high-voltage AC transmission lines on the health of both wildlife and livestock, including cattle, sheep, swine, and poultry. Overall, the research does not conclude that exposure to EMF from high-voltage transmission lines results in adverse effects on the health, behavior, or productivity of domestic or wild animals, including on their migration or grazing patterns.

Additionally, the results of studies conducted on crops and plants exposed to EMF do not provide any consistent or reliable evidence that EMF at levels typically found under transmission lines is harmful to crop yield or production.



A comprehensive experimental study on DC transmission lines and cattle was conducted by a university in the United States in which herds of beef cattle were maintained beneath a 500 kV DC transmission line over a 30-month period; these cattle were then compared to similar herds maintained 600 metres away from the transmission line. The researchers found that productivity, health status, and breeding behavior were similar between the two groups and concluded that beef cattle permitted to graze in the vicinity of a high-voltage, DC transmission line were not expected to experience any decrease in frequency of conception, calving, growth rate, or survival. The same study also compared wheat and alfalfa crops grown under the DC line to those grown away from the line—here, the researchers found no effects on the growth or yield of the crops.

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DC Transmission Lines and Wildlife

- Studies of overhead DC transmission lines suggest that habitat change from construction is the critical factor, not static fields.
- There are reports that some varieties of birds and bees can detect and use some aspect of the earth's magnetic field as a supplementary travel aid for moving within or between habitats.
- Research does not suggest that the behavior of birds or other species would be adversely affected by the relatively small change in the magnetic field from DC transmission lines in Ireland.

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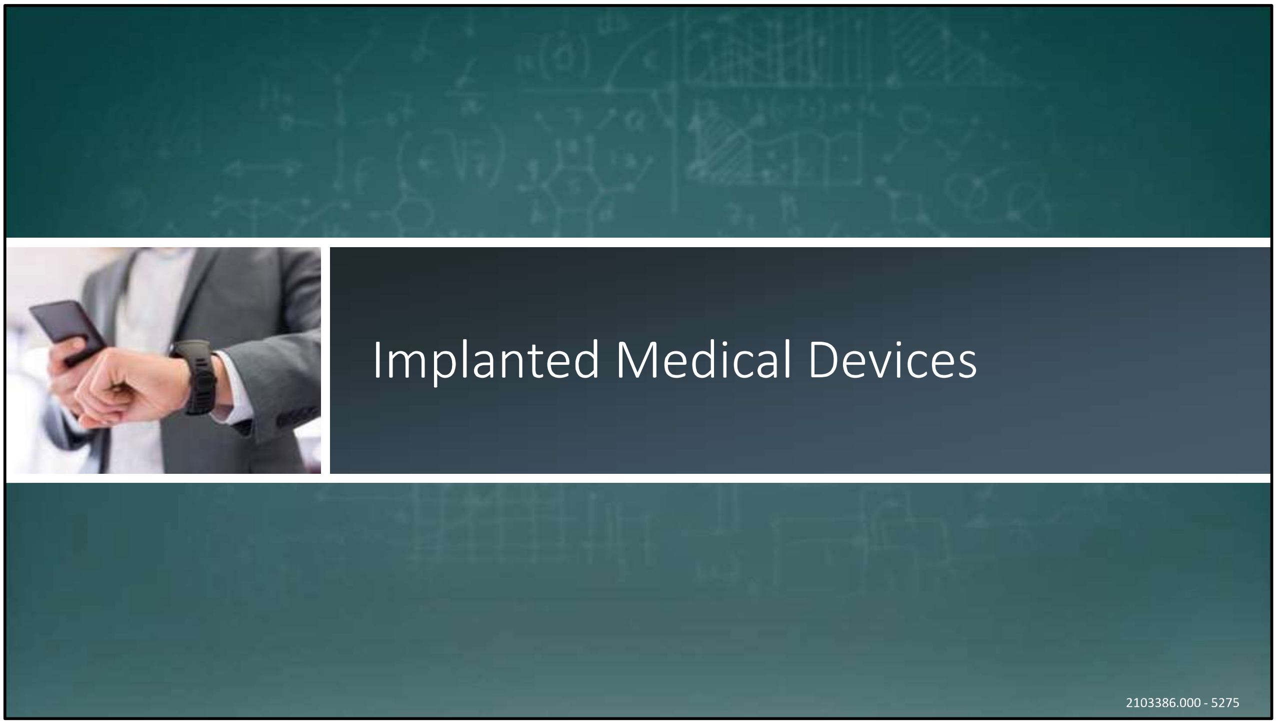
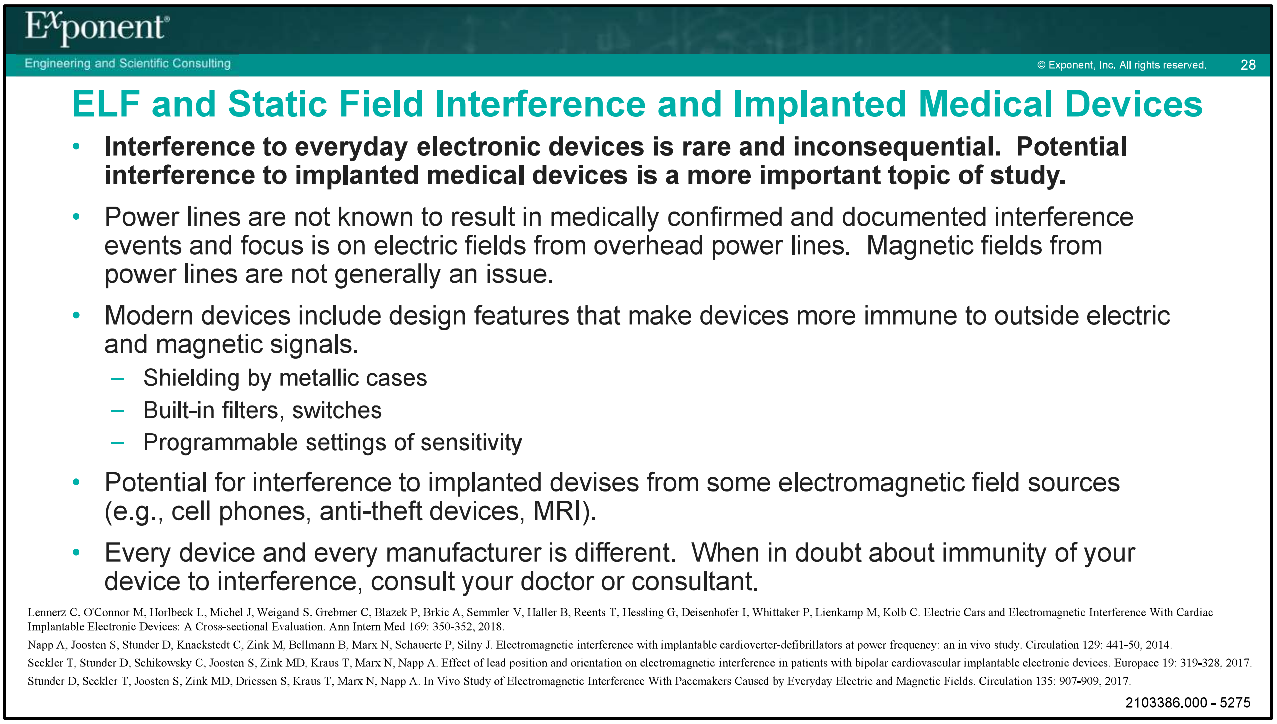
Studies of overhead DC transmission lines and wildlife suggest that, in fact, it is habitat change from construction that is the critical factor impacting wildlife, not DC fields. There are reports that some varieties of birds and bees can detect and use some aspect of the earth's geomagnetic field as a supplementary travel aid for moving within or between habitats. However, research does not suggest that the behavior of birds or other species would be adversely affected by the relatively small change in the magnetic field from DC transmission lines in Ireland. It is important to note too that the only DC transmission lines in Ireland are underground lines.



We are sometimes asked about the potential for EMF to interfere with the normal operation of implanted medical devices, such as pacemakers and cardioverter defibrillators. In general, for these devices and ordinary electronic devices, the likelihood for interference is low, as we’ll now discuss.



Electronic devices are useful tools for many people. We are often asked whether AC or DC transmission lines will interfere with mobile phones and other common devices. The answer is no.

We also get asked about the potential for interference with implanted medical devices. It is theoretically possible, but highly unlikely, for power lines to have an effect on implanted medical devices. Power lines are not known to result in medically confirmed or documented interference events.

Furthermore, modern implanted cardiac devices incorporate many technological and design features to minimize the potential for interference. This includes shielding through the use of a metallic casing and filters to specifically block 50- or 60-Hz fields.

While electrical signals from outside sources (such as anti-theft devices or medical equipment), may in principle interfere with the normal operation of implanted cardiac devices, the signals from most of these sources where patients may encounter them are too weak to affect the standard operation of these devices. However, ultimately, every device and manufacturer is different and when in doubt, patients should consult with their doctor if they have concerns about the compatibility of their devices with any source of EMF.

Best Practice Guidelines and Regulations

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What Agencies in Ireland are Responsible for EMF Policies?

Agency	Remit
Department of Environment, Climate and Communications	National policy including adherence to EU Directives based on exposure limits to EMF recommended by ICNIRP
Health & Safety Authority	Regulates workplace EMF exposure
Environmental Protection Agency	Advice and guidance on exposure of public

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In Ireland, there are several agencies that are responsible for developing and implementing polices related to EMF. The Environmental Protection Agency monitors public exposure to EMF and provides scientific advice and guidance, while the Health and Safety Authority regulates workplace EMF exposure. The Department of Environment, Climate and Communications is responsible for national policy regarding EMF, including adhering to the European Union Directives on exposure limits.

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Ireland Has Implemented the "Precautionary Principle" (DCMNR, 2007)

- Adopted internationally recognised EMF and radiofrequency standards.
- Participates in international bodies and fora that address concerns, such as the World Health Organization, and following agency reviews of scientific weight of evidence.
- Implement no-cost or low-cost measures consistent with current WHO recommendations (WHO, 2021)*
  - Route transmission lines as far from existing residences as reasonably possible; optimise the phasing of adjacent lines and incorporate stakeholder input during consultation on new lines.
  - Plan the transmission infrastructure in as sensitive a way as is reasonable, including consideration of overhead and underground lines, use of new technologies, and optimisation of existing infrastructure.

*https://www.who.int/teams/environment-climate-change-and-health/radiation-and-health/non-ionizing/elff

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In addressing EMF exposures, Ireland has implemented a precautionary principle approach, which is closely related to the EMF policy of "prudent avoidance" in the United States. The goal of these policies is to identify strategies to minimize or prevent exposure, but to only adopt or implement those strategies that are considered to represent a reasonable balance between cost and the current scientific understanding about the possible risks from exposure. Such policies are based on the idea that we should not spend more money to avoid a speculative or unknown risk than we would spend on known public health risks. Ireland has followed this approach by:

1. Adopting internationally-recognised EMF exposure standards participating in international bodies that address EMF concerns, such as the WHO, and following agency reviews of scientific research.

2. Implementing no-cost or low-cost measures to reduce exposure such as routing transmission lines as far from existing residences as reasonably possible and incorporating stakeholder input during consultation on new lines. This policy of adopting low- or no-cost measures is also consistent with the current recommendations of the WHO.

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EMF AC Guidelines Published by ICNIRP

ICNIRP EMF Guidelines for 50-Hz		
	ICNIRP (2010)	**ICNIRP (1998)**
Basic Restrictions		
Magnetic Field	606 µT*	360 µT*
Electric Field	9.9 kV/m*	9 kV/m*
Reference Levels		
Magnetic Field	200 µT	100 µT
Electric Field	5.0 kV/m	5.0 kV/m

International Commission on Non-Ionizing Radiation Protection (ICNIRP). Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz – 100 kHz). Health Physics 99:818-826, 2010.

International Commission on Non-Ionizing Radiation Protection (ICNIRP). Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). Health Physics 74:494-522, 1998.

* Calculated from Dimbylow P. Development of the female voxel phantom, NAOMI, and its application to calculations of induced current densities and electric fields from applied low frequency magnetic and electric fields. Phys. Med. Biol 50, 1047–1070, 2005. https://doi.org/10.1088/0031-9155/50/6/002.

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Internationally-recognized guidelines for exposure to EMF for both workers and the general public have been developed by several scientific organizations following their review of the EMF health research. The organization that has established the health and technical basis for EMF and static magnetic field standards in Europe is the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

This slide presents ICNIRP's guidelines for exposure of the general public to 50-Hz fields from AC electricity. ICNIRP last updated their guidelines in 2010. For the general public they set a Reference Level of 200 µT for magnetic fields and 5.0 kV/m for electric fields. For magnetic fields the Reference Level is double what had previously been recommended in the 1998 guidelines. While the 2010 ICNIRP guidelines replace the 1998 guidelines, it is the 1998 guidelines and standard that remain in place for European and Irish regulations.

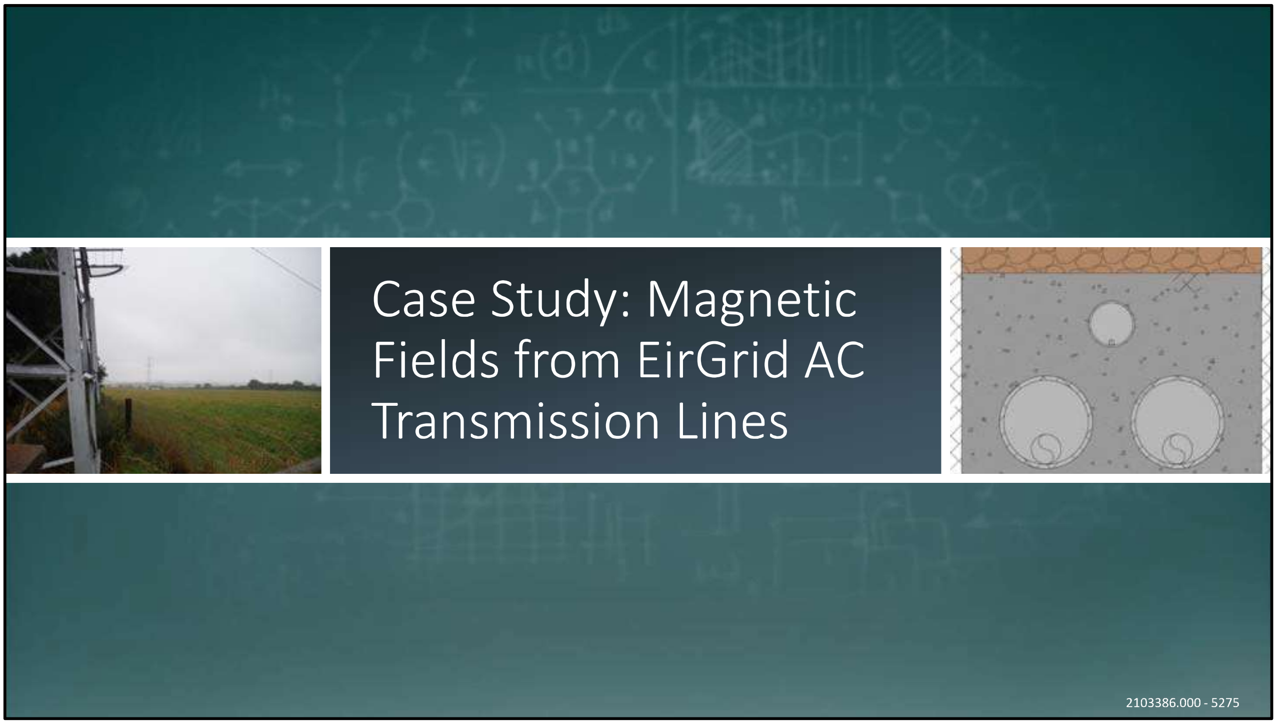
Exposures below the Reference Levels have assured compliance with ICNIRP's limits on fields and currents inside the body (Basic Restrictions). Exposures to external field values greater than the Reference Levels also are compliant if dosimetric modeling demonstrates that Basic Restriction limits are not exceeded. The environmental field levels in the slide were calculated to produce internal fields and currents equal to the Basic Restrictions values based on Dimbylow (2005).

DC Magnetic Field Standards Published by ICNIRP

ICNIRP DC Magnetic Field Guidelines (in µT)	
	ICNIRP (2009)
Controlled	2,000,000 µT (head & trunk) 8,000,000 µT (limbs)
General Public	400,000 µT

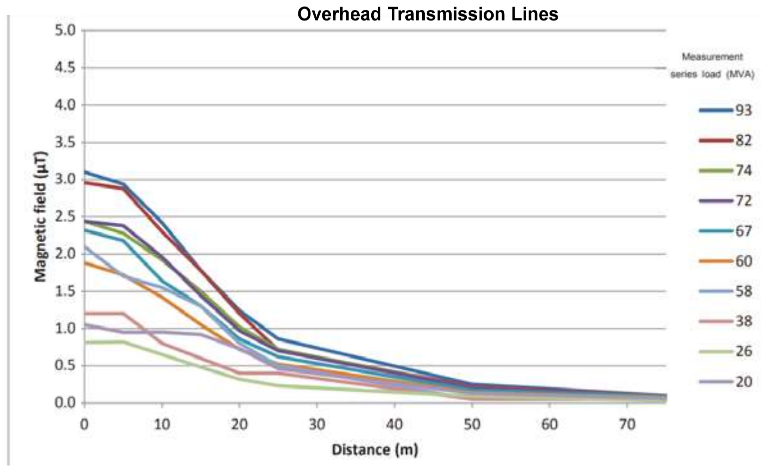
International Commission on Non-Ionizing Radiation Protection (ICNIRP). Guidelines on Limits of Exposure to Static Magnetic Fields. Health Physics 96(4):504-514, 2009.
International Committee on Electromagnetic Safety (ICES). IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz C95. 6-2002. Piscataway, NJ: IEEE, 2002. Reaffirmed 2007.

ICNIRP has also published guidelines for exposure to DC or static magnetic fields. For the general public, the limit is set at 400,000 µT. There is no common source capable of producing magnetic fields even close to that limit on public exposure.



Magnetic fields from AC transmission lines vary depending on a variety of factors including voltage, power level, and design of the transmission line. In this section we will take you through a couple examples of AC transmission lines, both overhead lines and underground lines, and how the magnetic-field levels vary by voltage class and distance from the lines.

Typical AC Magnetic Fields Measured near Overhead Transmission Lines



Magnetic-Field Level at Average Load

Overhead AC Transmission Line Configuration	Distance	
	0 m	25 m
400-kV (Single-Circuit on double-Circuit tower)	2.1 μT	0.79 μT
400-kV (Single-Circuit on Single-Circuit tower)	2.6 μT	1.1 μT
220 kV (Single-Circuit 1)	2.2 μT	0.54 μT
220 kV (Single-Circuit 2)	1.5 μT	0.46 μT
110-kV (Single-Circuit)	1.2 μT	0.18 μT

Data From http://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-Evidence-Based-Environmental-Study-1-EMF.pdf

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This first example covers typical AC magnetic fields from overhead transmission lines. A 2014 study reported the findings of measured magnetic-field levels from different transmission line configurations throughout Ireland. This study included both overhead and underground lines with a variety of voltages and configurations, as summarized by the tables on the right.

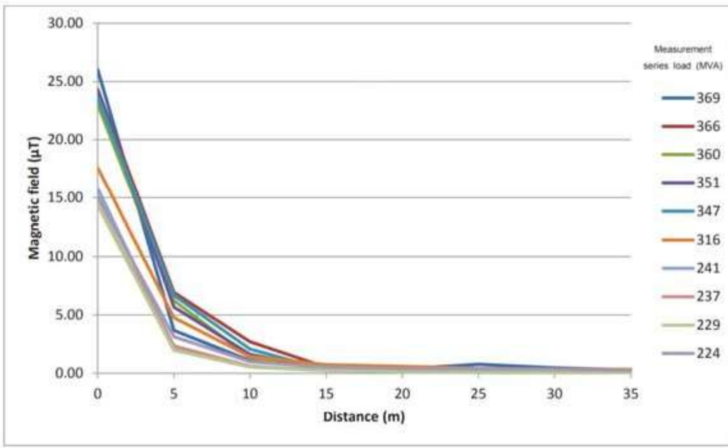
The figure on the left shows the measured magnetic field from a 220-kV single-circuit overhead transmission line. The vertical axis shows the strength of the magnetic field and the horizontal axis shows distance away from the center of the overhead line. The colored lines each represent a different measured level of power flow—as the power flow goes up so, too, does the magnetic-field level. Right beneath the transmission line (0 m as marked on the figure) the magnetic-field level is highest, but as described before, magnetic-field levels decrease rapidly with distance from the source.

The table on the right summarize the measurement results from a number of other overhead lines (from 110 kV to 400 kV) and show the average magnetic-field level at 0 m and 25 m from the transmission line.

In general, the AC magnetic-field levels are higher for the higher voltage lines. This is because higher voltage transmission lines generally carry more current and therefore have higher fields. Consistent among all the measured lines is the rapid decrease with distance away from the line.

Typical Magnetic Fields Measured near Underground AC Transmission Lines

Underground 220-kV Transmission Line



Magnetic-Field Level at Average Load

Underground AC Transmission Line	Distance	
	0 m	4 m
220-kV	16 μT	0.99 μT
110-kV	2.0 μT	0.52 μT

Data From http://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-Evidence-Based-Environmental-Study-1-EMF.pdf

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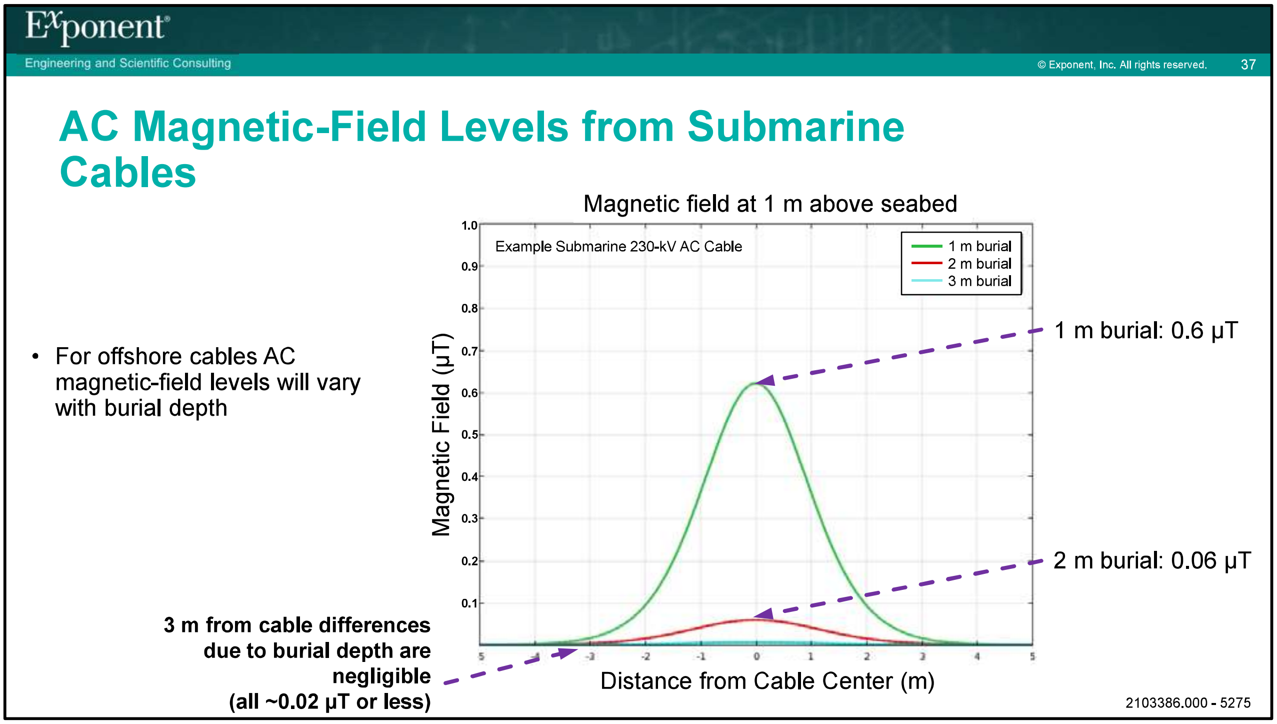
The same 2014 study also measured magnetic-field levels from different underground AC transmission lines.

This figure is similar to that on the previous slide showing the strength of the measured magnetic field on the vertical axis and distance from the center of the duct bank on the horizontal axis. The colored lines are each for a different measured level of power flow; again, as the power flow goes up so, too, does the magnetic-field level.

For the underground lines, the field levels are somewhat higher immediately above the transmission line duct bank but decrease much more rapidly with distance than their overhead counterparts. This is because the three conductors of the transmission line are all so close together, so the magnetic field from each individual cable more effectively cancels out the field from the other two nearby cables. For this reason, the magnetic field levels in the summary table at the right were measured at 0 m and 4 m from the transmission line.

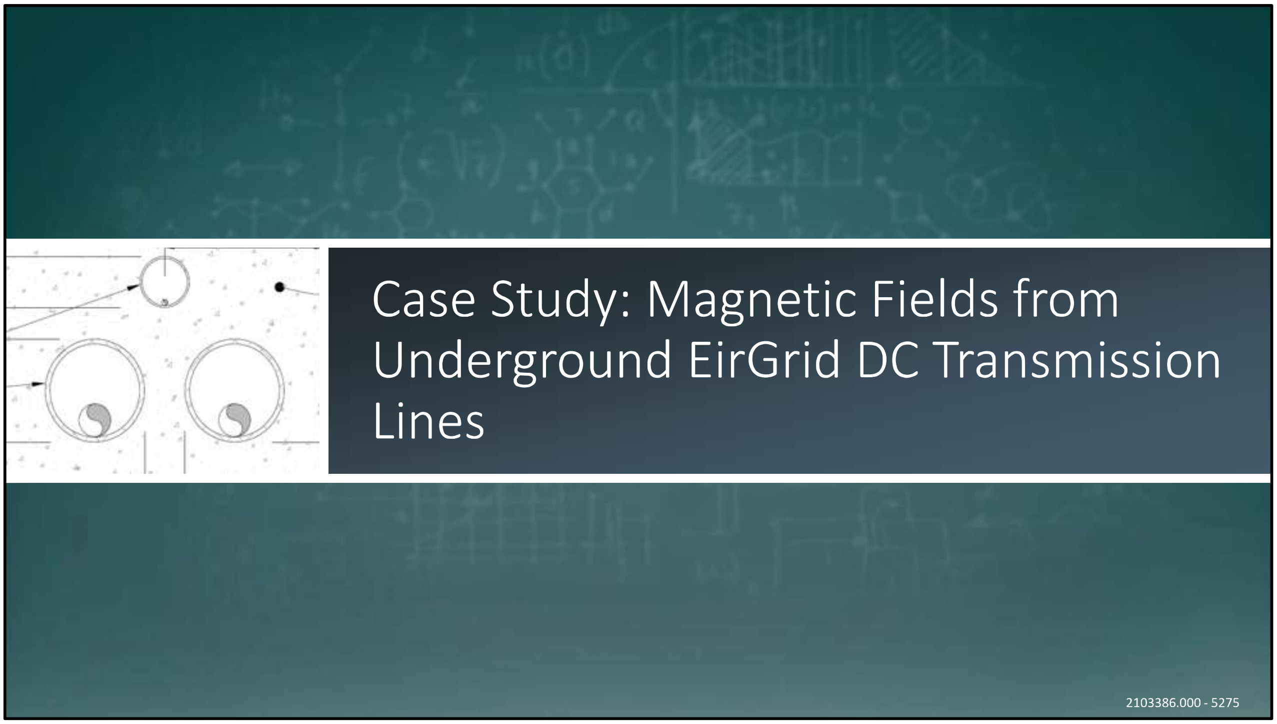


This graph shows the magnetic field from a submarine cable at a height of 1 m above the seabed. Similar to the previous graphs, this shows the strength of the magnetic field on the vertical axis and the distance from the source (here at the center of the figure at 0 m) on the horizontal axis.

The construction of an AC submarine cable also is somewhat different than most on-shore lines: all three conductors of the transmission line are bundled together inside a single cable, so the conductors are even closer together than for typical onshore underground lines. This means that the magnetic-field level decreases even more rapidly with distance than from an underground line.

One difference for submarine cables is that the burial depth may be slightly more variable than for on-shore transmission lines due to challenges of submarine installation, so three lines are shown in the graph above: 1 m burial in green, 2 m burial in red, and 3 m burial in teal which is almost indistinguishable from the horizontal axis.

As can be seen from the graph, the difference in field level due to burial depth can be seen most easily directly above the cable, but at a distance of 3 m or more from the cable, the magnetic-field levels above the seabed from cables buried to a 1, 2, or 3 m depth are almost identical and very low.



This brief section discusses underground DC transmission lines similar to the EWIC transmission line.

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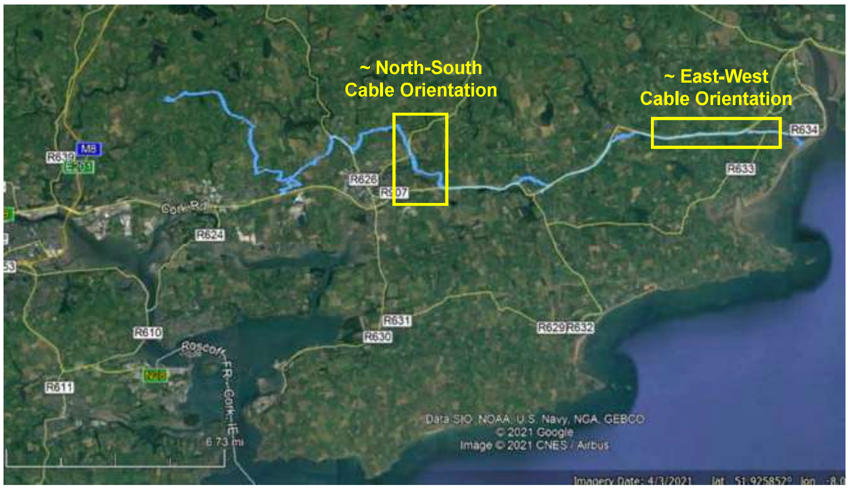
Cable + Earth's Geomagnetic Field



- Earth's DC geomagnetic field has a direction and strength
- DC cables also produce DC magnetic fields with a direction and strength
- Strength of the DC field from cables depends on power transfer
- Orientation of cable determines whether the fields add to or subtract from the geomagnetic field

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This section provides more information about the differences between AC and DC magnetic fields in the case of underground transmission lines.

One of the important differences between AC and DC transmission lines arises because the earth itself is a source of a DC geomagnetic field—everywhere on earth there is already a DC magnetic field between about 30 and 70 µT. Another important thing to note is that these DC magnetic fields (like all magnetic fields) have a strength and a direction. This is why a compass is able to point in the direction of geomagnetic north no matter where you are.

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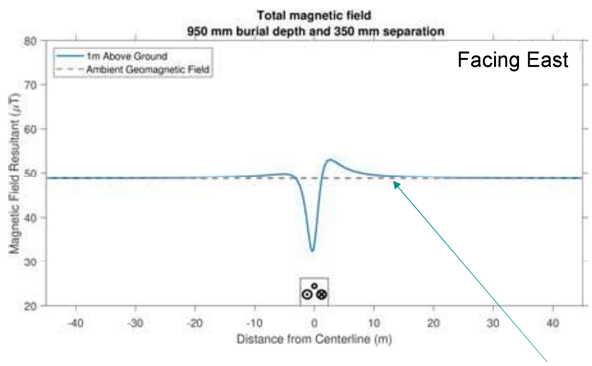
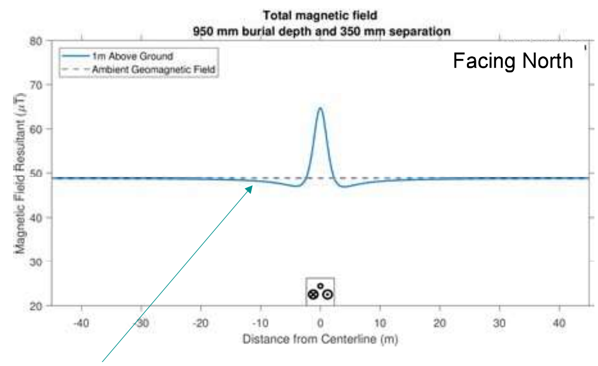
Earth's Geomagnetic Field + Cable Field

Local change in the immediate vicinity of the duct bank -
increase or decrease depends on installation direction and direction of current flow





Local variation:
Field falls to within ~10% of ambient
within 10 m from duct bank

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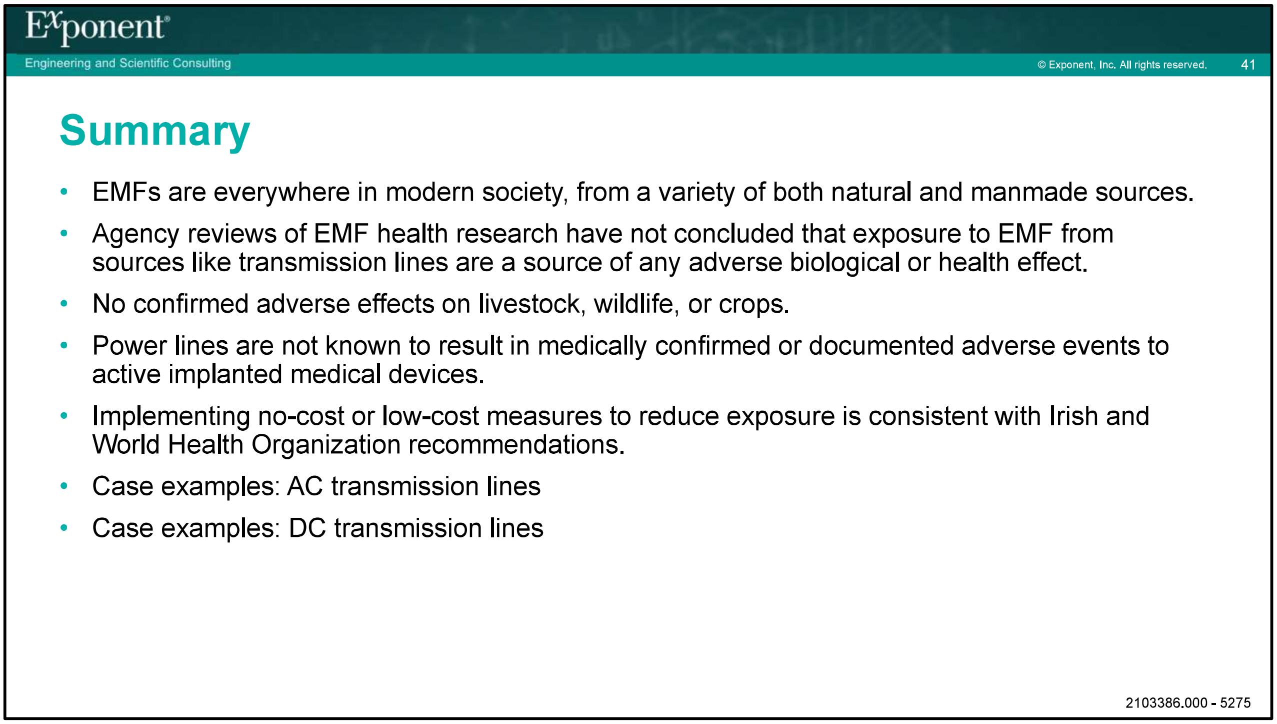
These two graphs show the total magnetic field from the same DC transmission line calculated at a height of 1 m above ground. The vertical axis in both plots shows the strength of the magnetic field and the horizontal axis shows the horizontal distance away from the transmission line. Both graphs show the magnetic field from exactly the same transmission line. The differences are that the one on the left is for a line that is traveling east-west and the one on the right is traveling north-south.

The dashed gray line in each graph is the strength of earth's geomagnetic field in Ireland, about 49 µT. The blue line is the total field from earth PLUS the field from the DC transmission line and shows how the total magnetic-field level changes in close proximity to the transmission line.

For this transmission line design, the total magnetic field decreases directly over the ductbank where it is installed in an east-west direction and increases directly over the transmission line where it is installed in a north-south direction.

Similar to AC transmission lines, however, the magnetic-field level decreases rapidly with distance from the transmission line. Beyond about 10 m from the transmission line, the field decreases to within 10% of the ambient value of the earth's geomagnetic field, whether oriented north-south or east-west.



The case study of AC transmission lines in Ireland shows that measured levels of transmission lines decrease rapidly with distance.

The case study illustrates that DC transmission lines, such as the EWIC, produce DC magnetic fields like the geomagnetic DC field of the earth. The DC fields from transmission lines are generally much weaker than the earth's geomagnetic field and may locally increase or decrease the total geomagnetic-field level, but as shown in this example the change in the earth's geomagnetic field from the DC cable is very close to zero within 10 m of the line.