May 17, 2022

Mayflower Wind Energy LLC
110 Federal Street
Boston, MA 02110

Re: Magnetic Field Analysis Report for Massachusetts (MA) Energy Facilities Siting Board (EFSB) Application Submittal

Dear Sir or Madam:

This cover letter accompanies the Magnetic Field Analysis Report for the Mayflower Wind Brayton Point Project Cable Systems that was prepared by POWER Engineers, Inc. (POWER Engineers). The Magnetic Field Analysis Report summarizes model-predicted reasonable maximum magnetic field (MF) levels for the proposed Mayflower Wind offshore and onshore export cables that will deliver approximately 1,200 MW of clean, renewable energy from offshore wind generated in federal waters to a point of interconnection (POI) to the regional transmission system at Brayton Point in Somerset, Massachusetts. The export cable system includes two high-voltage direct current (HVDC) power cables at a nominal voltage of +/-320 kV DC and one dedicated communications cable. A Mayflower Wind HVDC converter station at Brayton Point will convert power to high-voltage alternating current (HVAC) at a nominal voltage of +/- 345 kV AC for interconnection to the regional transmission system.

The POWER Engineers modeling analysis is focused on magnetic fields because the electric fields arising from the voltage on the offshore export cables will be completely shielded by cable materials, and there will also be no aboveground electric fields from the onshore underground conductors due to shielding by the cables. This cover letter was prepared to compare the model-predicted MF levels for the onshore underground HVDC and HVAC transmission route segments in Massachusetts to health-protective exposure guidelines, and to assess the potential for harmful impacts to marine organisms, including commercially and recreationally important fish species and benthic organisms, from the MF levels predicted for the HVDC offshore export cables.

In Massachusetts, the proposed onshore transmission route includes a short underground HVDC route segment (approximately 0.6 mile [1.0 km]) between the landfall site and the HVDC converter station on the former Brayton Point Power Station property in Somerset, MA. Mayflower Wind also identified a design variation to the Project intended to provide flexibility for the future expansion of the electric system in the Brayton Point area to accommodate the likely need to connect additional new renewable energy generation. This "Noticed Variation" would facilitate the delivery of up to an additional 1,200 MW of renewable clean energy by "right-sizing" certain facilities (primarily trenching and conduits for onshore underground transmission cables) while minimizing overall impacts to the community and environment. The Noticed Variation would involve sizing underground infrastructure on the former Brayton Point Power Station property for the HVDC export cables to include spare conduits at landfall and onshore that would be capable of accommodating an additional 1,200 MW HVDC circuit consisting of an additional two power cables and one communications cable.

Mayflower Wind is committed to fully developing and delivering energy from its offshore Lease Area and believes it is prudent and efficient planning to provide for the potential that all the energy from the Lease Area could be delivered to points of interconnection at or near Brayton Point, pending additional study of regional grid considerations as part of the interconnection process managed by ISO New England. Mayflower Wind wishes to provide for this contingency to do the right thing by not only prudently planning but also avoiding/minimizing impacts to the community and the environment. Developing the project in this way would mean less disturbance of the natural and developed environment by conducting earthwork and civil construction onshore in a single campaign.

Peak maximum DC MF levels ranging from 181 to 433 milligauss (mG) were obtained at 1 meter above the ground surface for the three representative HVDC onshore duct bank configurations that were modeled, including a single circuit duct bank, a double circuit duct bank, and an alternate double circuit duct bank. The Noticed Variation model cases evaluate the double circuit duct bank with one 1,200 MW circuit installed. Although the Noticed Variation does not include a request for approval of additional export cables at this time, for informational purposes only, results are also presented for an indicative future scenario with a second 1,200 MW circuit installed.

For each duct bank configuration, the MF levels drop off very rapidly with increasing lateral distance from the cables, for example, ranging from 3.5 to 30.5 mG at 25 feet (7.6 meters) from the duct bank centerlines and 0.47 to 8.0 mG at 50 feet (15.2 meters) from the duct bank centerlines. At the former Brayton Point Power Station property, the earth's steady (DC) geomagnetic field has a magnitude of approximately 513 mG, meaning that only the MF levels in the immediate vicinity of the onshore underground duct banks will appreciably differ from the earth's DC geomagnetic field.

The state of Massachusetts has not adopted standards for electric and magnetic fields (EMFs) from HVDC transmission lines or other sources that can be compared to the model-predicted DC MFs. There are also no US federal standards limiting general public or occupational exposure to EMFs from HVDC transmission lines. Scientists have not reported any confirmable chronic health risks for the weak steady EMFs associated with HVDC power transmission; this is consistent with the fact that humans have lived for tens of thousands of years in the presence of the earth's DC geomagnetic field, which is not known to adversely interact with biological processes or directly affect human health.

As summarized in Table 1, international health and safety organizations have established health-based exposure guidelines for DC MFs (also known as steady MFs) applicable to both the general public and occupational populations based on preventing transient sensory effects including vertigo and nausea. In particular, ICNIRP has established a general public exposure guideline of 4,000,000 mG for steady MFs (ICNIRP, 2009). This exposure guideline encompasses safety factors in order to be sufficiently protective of the general public. Given potential harms to individuals with implantable medical devices possibly containing ferromagnetic materials (*e.g.*, pacemakers and cardiac defibrillators), ICNIRP recommends that such individuals not be exposed to steady MFs above 5,000 mG (ICNIRP, 2009). More recently, the International Committee on Electromagnetic Safety (ICES) within the Institute of Electrical and Electronics Engineers (IEEE) conducted an updated review of the scientific and medical research literature, and retained its safety guidelines for general public exposure to steady MFs of 1,180,000 mG and 3,530,000 mG for head and trunk exposure and limb exposure, respectively (IEEE, 2019). Importantly, each of these health-protective MF guidelines are far above the modeled DC MFs predicted for the representative onshore underground duct bank configurations.

Table 1 DC MF Guidelines Established by Health and Safety Organizations

Organization	MF Guideline
General Public	
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (exposure to any part of the body)	4,000,000 mG[(a)]
Institute of Electrical and Electronics Engineers (IEEE) Standard C95.6	1,180,000 mG[(b)] 3,530,000 mG[(c)]
Occupational	
International Commission on Non-Ionizing Radiation Protection (ICNIRP)	20,000,000 mG[(d)] 80,000,000 mG[(e)]
American Conference of Governmental and Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs)	20,000,000 mG[(f)] 200,000,000 mG[(g)] 5,000 mG[(h)]

Notes:
DC = Direct Current; MF = Magnetic Field; kV/m = Kilovolts Per Meter; mG = Milligauss.
(a) Applies to exposures to any part of the body (ICNIRP, 2009).
(b) Applies to head and of trunk exposure (IEEE, 2019).
(c) Applies to exposure of limbs (IEEE, 2019).
(d) Applies to head and of trunk exposure (ICNIRP, 2009).
(e) Applies to exposure of limbs (ICNIRP, 2009).
(f) ACGIH TLV for general workplace whole body exposure (ACGIH, 2020).
(g) ACGIH TLV for general workplace limb exposure (ACGIH, 2020).
(h) ACGIH TLV for workers with implanted ferromagnetic or electronic medical devices (ACGIH, 2020).

A short onshore underground HVAC transmission route segment (approximately 0.2 mile [0.3 km]) will connect the Mayflower Wind HVDC converter station and the POI at the existing National Grid 345 kV substation, also located on the former Brayton Point Power Station property. For this short segment, the 345-kV onshore export cables will be buried underground within concrete duct banks. As discussed in the POWER Engineers Magnetic Field Analysis Report, a peak 60-Hz AC MF level of 66.7 mG was obtained at a height of 1 meter directly above the duct bank. The modeling demonstrated that MF levels drop off very rapidly with lateral distance from the cables, with MF levels of 13.9 mG and 1.5 mG at distances of ±10 feet (3.0 meters) and ±25 feet (7.6 meters), respectively, from the duct bank centerline.

The US has no federal standards limiting either residential or occupational exposure to 60-Hz AC MFs. Table 2 shows guidelines established by international health and safety organizations that are designed to be protective against adverse health effects. The limit values should not be viewed as demarcation lines between safe and dangerous levels of MFs, but rather, levels that assure safety with an adequate margin to allow for uncertainties in the science. As part of its International EMF Project, the World Health Organization (WHO) conducted comprehensive reviews of EMF health-effects research and existing standards and guidelines. The WHO website for the International EMF Project (WHO, 2022) notes, "*[T]he main conclusion from the WHO reviews is that EMF exposures below the limits recommended in the ICNIRP international guidelines do not appear to have any known consequence on health.*"

Table 3 lists 60-Hz AC MF guidelines that have been adopted by various states in the United States, including by the Massachusetts Energy Facilities Siting Board (MA EFSB). The MA EFSB has adopted, and long used, an edge-of-ROW guideline level of 85 mG for 60-Hz AC MFs. State guidelines such as those of the MA EFSB are not health-effect based and have typically been adopted to maintain the status quo for MFs on and near a transmission line right-of-way (ROW).

Table 2 60-Hz AC MF Guidelines Established by International Health and Safety Organizations

Organization	MF Guideline
American Conference of Governmental and Industrial Hygienists (ACGIH) (occupational)	10,000 mG[(a)] 1,000 mG[(b)]
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (general public, continuous exposure)	**2,000 mG**
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (occupational)	10,000 mG
Institute of Electrical and Electronics Engineers (IEEE) Standard C95.6 (general public, continuous exposure)	9,040 mG

Notes:
MF = Magnetic Field; mG = Milligauss.
(a) The ACGIH guidelines for whole-body exposure for the general worker (ACGIH, 2020).
(b) The ACGIH guidelines for workers with cardiac pacemakers (ACGIH, 2020).

Table 3 State 60-Hz AC MF Standards and Guidelines for Transmission Lines

State	Line Voltage (kV)	Magnetic Field (mG)
		Edge of ROW
Florida[(a)]	69-230	150[(b)]
	>230-500	200[(b)]
	>500	250[(b,c)]
Massachusetts		**85**
New York[(a)]		200

Notes:
Blank = Not Applicable/Not Available; FLDEP = Florida Dept. of Environmental Protection; kV = Kilovolt; MA EFSB = Massachusetts Energy Facilities Siting Board; MF = Magnetic Field; mG = Milligauss; NIEHS = National Institute of Environmental Health Sciences; ROW = Right-of-Way.
Sources: NIEHS (2002); FLDEP (2008); MA EFSB (2009).
(a) Magnetic fields for winter-normal loading (*i.e.*, at maximum current-carrying capability of the conductors).
(b) Includes the property boundary of a substation.
(c) Also applies to 500-kV double-circuit lines built on existing ROWs.

The modeled MFs for the onshore 345-kV HVAC cables, including those directly above the underground duct bank, are all well below the ICNIRP health-based guideline of 2,000 mG for allowable public exposure to 60-Hz AC magnetic fields (ICNIRP, 2010). In addition, all 60-Hz AC MF levels are also below the Massachusetts guideline of 85 mG for MFs at ROW edges. As noted above, this guideline is not health-based and was instead adopted in the 1980s to maintain the *status quo* for MF levels on and near overhead transmission line ROWs.

Modeled MF levels for the 345-kV HVAC cables are overestimates of the expected MF levels for actual Project operations due to several conservative assumptions in the modeling analysis, including the lack of accounting for the partial MF cancellation associated with induced currents in the ground continuity conductors that will act to reduce MF levels from the cables, and the use of cable currents based on maximum wind farm output (100 percent capacity) at 95% per unit voltage and 0.95 power factor, rounded to the nearest ten amps.

The entire offshore export cable route will consist of HVDC submarine cables, and the POWER Engineers Magnetic Field Analysis predicted DC MF levels at the seafloor (or above the concrete mattress for the unburied installation case) associated with three representative installation scenarios for the HVDC offshore export cables: (1) the typical installation case that will be used wherever practicable, where the two DC conductors are bundled together (along with a communications cable) and buried at a target depth of 2 meters, (2) a worst-case installation case where the bundled conductors are laid directly on the seafloor surface and covered by a concrete mattress, such as at a cable crossing location, and (3) an unbundled installation case where the two DC conductors are separately buried approximately 50 meters (164 feet) apart at a target depth of 2 meters– to be used as needed to ensure safe installation and repair of the separate cables, as well as to minimize risk of damage to both cables from threats such as anchor strike. As shown in the POWER Engineers Magnetic Field Analysis Report, the highest modeled MF levels for these offshore export cable installation scenarios would occur directly above the cables (peaking at 123 mG for the typical installation case, and ranging from 1,909 to 3,785 mG across the two other possible installation cases), with a rapid reduction in MF levels with increasing lateral and vertical distance from the cables, *e.g.*, decreasing proportional to the square of the distance from the bundled cables. For example, for the two bundled cable installation scenarios where MF cancellation is increased by the bundling of two cables with current in equal but opposite polarity, the analysis shows 93->99% reductions in MF levels at lateral distances of ±25 feet (±7.6 meters) from the cable bundle centerlines as compared to the maximum MF levels directly above the cable bundles; and at lateral distances of ±25 feet, there is little difference in MF levels for the buried *versus* the surface-laid cables. Only for the two atypical installation cases, cases (2) and (3), will MF levels above the offshore export cables appreciably differ from the earth's steady (DC) geomagnetic field, and only within short distances from the cables.

No regulatory thresholds or guidelines for allowable EMF levels in marine environments have been established for either HVDC or HVAC transmission. There is a growing body of evidence suggesting that EMFs from HVDC cables may be perceptible to some electromagnetic (EM)-sensitive marine species, but there remains a lack of evidence indicating potential harmful impacts at the population- or community-level for the various types of marine species which may experience exposure to DC EMFs from submarine export cables (CSA Ocean Sciences Inc. and Exponent, 2019; Gill and Desender, 2020; SEER, 2022; Taormina *et al*., 2018). Several different types of studies have been conducted in recent years, including experimental field studies, experimental laboratory studies, and field surveys, with a limited number of inconsistent findings of subtle behavioral responses and physiological changes from some studies. For example, Hutchison *et al*. (2020) observed minor behavioral responses of both Little skates (*Leucoraja erinacea*) and American lobsters (*Homarus americanus*) for *in situ* enclosure experiments conducted on top of the Cross Sound Cable (CSC), a buried submarine HVDC cable (330 MW, ±150 kV) that runs between Connecticut and Long Island. They did not report evidence of a barrier effect as both species were observed to freely cross over the cable, but their findings included several responses indicative of increased exploratory/foraging behavior for the Little skate, and more limited evidence of a subtle behavioral exploratory response for the American lobster. Despite the usage of highly elevated DC MF levels, laboratory experimental studies have frequently reported an absence of evidence of adverse biological responses. For example, Taormina *et al*. (2020) conducted laboratory experiments of juvenile European lobsters (*Homarus gammarus*) for higher DC MF gradients (as high as 2,250 mG), observing no changes in sheltering behavior or exploratory behavior. For a laboratory study where several different types of marine benthic (seafloor) species were exposed to highly elevated DC MFs (37,000 mG) over several week time periods, Bochert and Zettler (2004) observed no differences in survival between exposed and control test organisms that included North Sea prawn (*Crangon crangon*), round crab (*Rhithropanopeus harrisii*), glacial relict isopod (*Saduria entomon*), blue mussel (*Mytilus edulis*), and young flounder (*Plathichthys flesus*).

It is important to distinguish the types of subtle behavioral responses and physiological changes that have been observed in some research studies from evidence of potential harmful impacts at the population- and community-level (Taormina *et al*., 2018). Moreover, since exposures to elevated MF levels from submarine cables will be limited to small areas along the seafloor in the immediate vicinity of the submarine export cables, it is important to consider the low exposure potential of most marine species. For example, because they breathe at the sea surface and have large migratory ranges, marine mammals such as sea turtles and whales would not be expected to spend significant amounts of time at the seafloor in the vicinity of specific submarine export cables. Overall, although knowledge gaps remain and there is a need for continued research, the weight of the currently available evidence does not provide support for concluding there would be population-level harms to marine species from EMF associated with HVDC submarine transmission.

This conclusion regarding a lack of evidence of population-level harms to marine species from HVDC-related EMFs is supported by findings from recent governmental reports and expert state of the science reviews. For example, the U.S. Bureau of Ocean Energy Management (BOEM) released a report in 2019 aimed at summarizing what is currently known about potential EMF impacts in coastal marine environments, with a specific focus on fish species of commercial or recreational importance in southern New England (CSA Ocean Sciences Inc. and Exponent, 2019). This report includes an 8-page executive summary, a 36-page technical discussion, and a 7-page reference list with 92 specific citations. It addresses potential risks to marine species posed by both AC and DC fields. Overall, based on its review of the state of the knowledge regarding potential EMF-related impacts on marine life, the authors concluded, "The operation of offshore wind energy projects is not expected to negatively affect commercial and recreational fishes within the southern New England area. Negligible effects, if any, on bottom-dwelling species are anticipated. No negative effects on pelagic [*i.e.*, in upper layers of the open sea] species are expected due to their distance from the power cables buried in the seafloor" (CSA Ocean Sciences Inc. and Exponent, 2019). This conclusion is based on the growing number of recent research studies published by US and European researchers, as well as information available from fish surveys conducted in Europe where both AC and DC submarine export cables have been operated in coastal environments for more than a decade. With respect to findings from fish surveys in Europe, the study authors concluded, "During this time, many surveys have been conducted to determine if fish populations have declined following offshore wind energy project installation. The surveys have overwhelmingly shown that offshore wind energy projects and undersea power cables have no effect on fish populations [72,80,81,82]. Fish assessed as part of these surveys include flounder and other flatfish, herring, cod, and mackerel. These are similar to species harvested along the U.S. Atlantic coast" (CSA Ocean Sciences Inc. and Exponent, 2019).

Another recent example is the review of the current knowledge relevant to EMF-related risks to marine organisms from electric cables and marine renewable energy devices that was included in the Ocean Energy Systems (OES)- Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. OES-Environmental, which currently consists of 16 partner nations, was established in 2010 by the International Energy Agency (IEA) Ocean Energy Systems (OES). The 2020 EMF review, which was authored by Andrew B. Gill and Marieke Desender of the United Kingdom's Centre for Environment, Fisheries and Aquaculture Science, discussed how a number of targeted studies have contributed to an increase in the knowledge base since the analogous publication in the 2016 State of the Science Report, which highlighted significant gaps in the knowledge base. Gill and Desender (2020) observed that new research, including both field and laboratory studies, has included some detectable EMF-related effects and responses (*e.g.*, behavioral, physiological, developmental, and genetic) on a limited number of individual species, but emphasized that these findings are not generally for EMF strengths associated with marine renewable energy (MRE) projects. Overall, based on their updated review of the available science, Gill and Desender (2020) concluded, "Based on the knowledge to date, biological or ecological impacts associated with MRE subsea power cables may be weak or moderate at the scale that is currently being considered or planned. It is important, however, to acknowledge that this assessment comes from a handful of studies and that data about impacts are scarce, so significant uncertainties concerning electromagnetic effects remain." While this conclusion is not specific to DC cables, many of the recent studies discussed in the review were for DC fields. Gill and Desender (2020) highlighted the continued lack of conclusive evidence as to any harmful effects and the need for additional research targeting other receptor species, sensitive life stages, and different EMF exposures (sources, intensities).

Most recently, in February 2022, the U.S. Offshore Wind Synthesis of Environmental Effects Research (SEER) webinar #4 "Electromagnetic Fields & Vessel Collision: Effects on Marine Life from Offshore Wind Energy" included the following conclusion: "Overall, the effects of EMF have been considered minor to negligible and a less significant issue than other environmental effects at OSW [offshore wind] farms, but confidence remains low" (SEER, 2022).

In summary, for a conservative modeling analysis that assumed cable currents based on maximum (100 percent capacity) wind farm output[1], both modeled DC and 60-Hz AC MFs predicted at a height of 1 meter on the former Brayton Point Power Station property in Somerset are well-below health-based exposure guidelines for DC and 60-Hz AC MFs, respectively. In addition, MF modeling for the offshore export cables showed that DC MF levels will be increased only for small areas along the seafloor around certain localized cable locations where conservative (and atypical) installation conditions are present, contributing to highly localized deviations from the earth's DC geomagnetic field. As discussed above, the weight of the currently available scientific evidence does not provide support for concluding there would be population-level harms to marine species from EMFs associated with HVDC submarine transmission.

Sincerely,

GRADIENT

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Principal
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[1] The wind farm is expected to operate at an annual-average capacity factor of around 50 percent; thus, much of the time, the actual output and MF attributable to the Project export cables will be correspondingly lower than the values discussed in this letter, which are for maximum output.

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MAYFLOWER WIND

Brayton Point Project Cable Systems

Magnetic Field Analysis

Revision 0

PROJECT NUMBER:
174444

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MAGNETIC FIELD ANALYSIS

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REVISION HISTORY						
REV.	ISSUE DATE	ISSUED FOR	PREP BY	CHKD BY	APPD BY	NOTES
A	2022-04-14	Prelim	JTL	ELB	CMB	Issued for preliminary review
B	2022-05-06	Appvl	JTL	ELB	CMB	Issued for Appvl
0	2022-05-12	Record	JTL	CWC	CMB	

"Issued For" Definitions:

- "Prelim" means this document is issued for preliminary review, not for implementation
- "Appvl" means this document is issued for review and approval, not for implementation
- "Impl" means this document is issued for implementation
- "Record" means this document is issued after project completion for project file

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INTRODUCTION

This report documents a magnetic field study completed by POWER Engineers, Inc. (POWER) for Mayflower Wind Energy, LLC (Mayflower). The study examines eight (8) cable configurations associated with the portions of the Mayflower Wind project in the Rhode Island and Massachusetts jurisdictions, both offshore in state waters and onshore on Aquidneck Island and Brayton Point. These configurations are listed below and described in the Cable Installation Scenarios section. Preliminary cable sizes and drawings of the circuit configurations are located in Appendix A and Appendix B.

1. HVDC offshore, bundled configuration, 6.6 ft (2.0 m) burial depth[1].
2. HVDC offshore, bundled, on seafloor under a 1.0 ft (0.3 m) thick concrete mattress.
3. HVDC offshore, non-bundled, cables separated by 164 ft (50 m), 6.6 ft (2.0 m) burial depth.
4. HVDC landfall horizontal directional drills (HDD), beach case under Island Park Beach near Boyd's Lane and Park Avenue. Cable depths are 25 ft (7.6 m) and 40 ft (12.2 m) below the surface with a 15 ft (4.6 m) horizontal separation.
5. HVDC onshore, single circuit duct bank, 3.2 ft (0.96 m) burial depth.
6. HVDC onshore, double circuit duct bank, 3.3 ft (1.01 m) burial depth.
7. HVDC onshore, alternate double circuit duct bank, 3.4 ft (1.03 m) burial depth.
8. HVAC onshore, single circuit duct bank (two cables per phase), 3.3 ft (1.01 m) burial depth.

POWER has calculated magnetic field in milligauss (mG) for the above configurations. Interpretation of results and comparison to industry limits will be performed by others. Human exposure to electric fields is negligible when a cable includes a grounded sheath and/or armor. This is the case for the Mayflower wind project. Therefore, calculation of the small external electric fields due to voltages induced on cable sheaths and/or armor is not included in the study.

METHODOLOGY AND INPUT DATA

Magnetic fields are the result of electron flow (current) in conductors. DC current produces a static magnetic field and AC current produces a time varying magnetic field. POWER used the COMSOL Multiphysics finite element software (version 5.6) for the analysis and verified results with hand calculations. Currents in each case are assumed to be balanced. This means that the currents for all conductors in each case sum to zero.

Magnetic field results for the seabed installation scenarios were reported at the sea floor. The offshore exception to this is Case 2 where fields are reported at the surface of the cement mattress. Per typical industry practice, onshore magnetic fields are reported at 3.28 ft (1.0 m) above ground. The onshore exception is the landfall beach case. While it is standard practice to report EMF values at a height of 1 meter above the ground surface, we assumed that a person could be lying flat on the beach. Therefore, we conservatively reported the landfall magnetic field results at the ground surface. Magnetic fields are proportional to current and inversely proportional to the distance from the current carrying conductor. Therefore, magnetic fields at any non-zero height above the surface will be lower than what is reported at the surface.

[1] Burial depths in this document are from the surface of the seafloor or surface of the earth to the top of the respective cable.

When conductor groups include currents flowing in opposite directions, they can be arranged so that external magnetic fields partially cancel. Better cancellation of magnetic fields is achieved by reducing the spacing between the conductors. However, spacing between conductors is sometimes constrained by other factors. For example, the cable spacing of the un-bundled cables offshore in Case 3 is determined to facilitate safe installation and repair of the separate cables, as well as to minimize risk of damage to both cables from threats such as anchor strike. Conductor spacing within onshore duct banks is also constrained by thermal considerations. Multi-circuit results reported in the next section are based on geometric arrangements that maximize magnetic field cancellation. Table 1 summarizes the study inputs.

Table 1. Study Inputs

Parameter	Value	Comments
AC Frequency	60 Hz	
Nominal AC voltage	345 kV	Line-to-line rms. Maximum voltage is 362 kV.
Total AC Power	1200 MW	
AC current per cable	1120 Amps rms [a]	Based on two cables per phase.
Nominal DC voltage	±320 kV	Pole-to-ground
Total DC Power	1200 MW	600 MW on each pole.
DC current per cable	1974 Amps DC	Based on one cable per pole and 5% reduced pole voltage.
AC cable sheath current	0 Amps	Based on single point sheath bonding.
GCC current	0 Amps	Induced voltage and current in the GCCs are neglected [b].
DC sheath and armor current	0 Amps	No voltage induced due to static magnetic fields.
Non-magnetic material μ_r	1.0	Magnetic permeability of soil, air, water, Al, Cu, stainless steel.

[a] Calculated at 0.95 per unit voltage, 0.95 power factor, and rounded up to the nearest 10 amps. Total current per phase is 2240 Amps rms.

[b] GCC currents have minor cancelling effects that would slightly reduce surface level magnetic fields. Neglecting these currents results in a slightly overestimated magnetic field.

CABLE INSTALLATION SCENARIOS

Submarine Cable Scenarios Offshore and at Landfall

Mayflower Wind selected Model Cases 1-4 to capture representative configurations for the HVDC submarine transmission systems offshore and in the sea-to-shore transition at landfall. Some or all of these configurations will be present in the installed project equipment.

Case 1: HVDC offshore, bundled configuration, 6.6 ft (2.0 m) burial depth

This model case represents the typical configuration offshore, with all offshore export cables (two submarine power cables and one submarine communications cable) installed together in a bundled configuration and buried in the seabed. Mayflower Wind will install the offshore export cables in a bundled configuration where practicable.

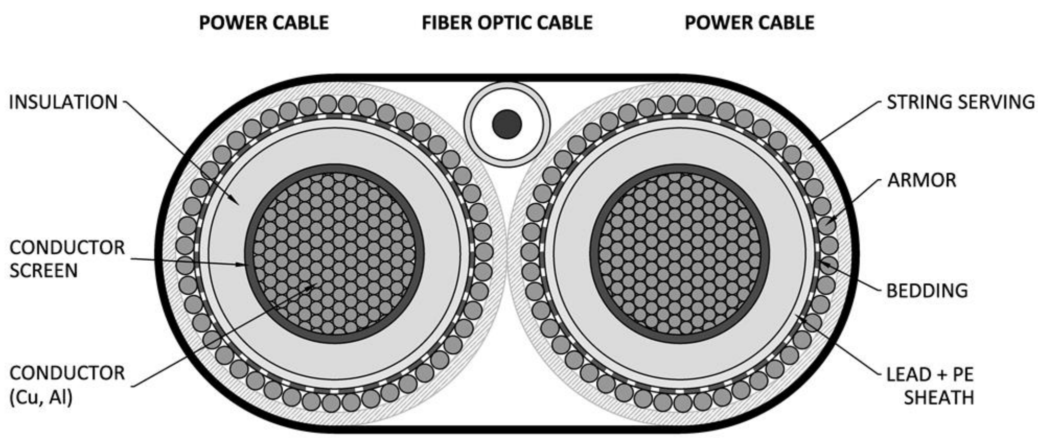

Figure 1: Typical HVDC Offshore Export Cable Bundled Configuration

Case 2: HVDC offshore, bundled, on seafloor under a 1.0 ft (0.3 m) thick concrete mattress

This model case represents the bundled configuration offshore, as described in Case 1 and illustrated in Figure 1. However, in certain local areas (including at crossings of existing pipelines such as those in the Sakonnet River), cable burial in the seabed may not be possible. In this case, the cables will be protected by means of secondary protection material (i.e., mattresses, rock) placed on top of the cables after installation. A typical example with representative geometry and thickness of cover is presented in this model case.

Case 3: HVDC offshore, non-bundled, cables separated by 164 ft (50 m), 6.6 ft (2.0 m) burial depth

As noted in Case 1, Mayflower Wind will install the offshore export cables in a bundled configuration where practicable. However, there may be portions of the route, including the approach to the landfall HDDs, where the cables must be installed separately (non-bundled). In this case, adequate separation will need to be maintained between the cables to ensure that they can be safely installed, maintained, and repaired (if needed). This model case represents a typical horizontal spacing between separately installed offshore export cables.

Case 4: HVDC landfall horizontal directional drills (HDD), beach case under Island Park Beach near Boyd's Lane and Park Avenue.

One cable is at a depth of 25 ft (7.6 m) below the surface and the other is at a depth of 40 ft (12.2 m). The horizontal spacing between cables is 15 ft (4.6 m). The offshore export cables will be brought to shore at each landfall location via HDD. Each submarine power cable will be installed in a separate HDD borehole and conduit. The trajectory of the HDDs will result in deeper burial of the cables beneath sensitive nearshore areas, including under Island Park Beach which is depicted in this model case. The cable depth represented in this model case is the current preliminary design depth of the cables at the landfall location at Boyd's Lane on Aquidneck Island.

Onshore Cable Scenarios

Mayflower Wind selected Model Cases 5-8 to capture representative configurations for the HVDC and HVAC underground transmission systems onshore. These configurations were evaluated as part of the preliminary engineering effort for the Project.

Case 5: HVDC onshore, single circuit duct bank, 3.2 ft (0.96 m) burial depth

This Model Case captures a typical configuration for an underground, concrete-encased duct bank that can accommodate two HVDC power cables and one dedicated communications cable.

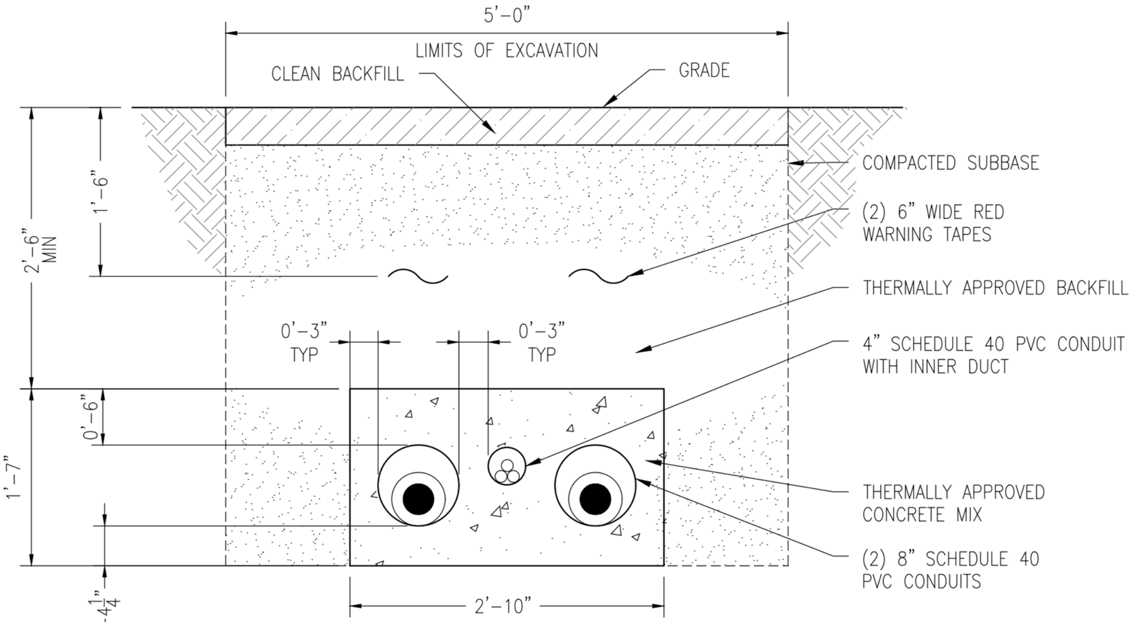

Figure 2: Typical HVDC Onshore Trench without the Noticed Variation

Case 6: HVDC onshore, double circuit duct bank, 3.3 ft (1.01 m) burial depth

This Model Case captures Mayflower Wind's Noticed Variation.

Mayflower Wind has identified a design variation to the Project, referred to as the Noticed Variation, which would involve the design and conditional construction of certain right-sized transmission facilities along the same onshore routes to enable the delivery of up to an additional 1,200 MW of renewable clean energy. The Noticed Variation would involve sizing underground infrastructure to include spare conduits and vaults at landfall and onshore, capable of accommodating an additional 1200 MW HVDC circuit.

Model Case 6 represents a typical configuration for an underground, concrete-encased duct bank that can accommodate four power cables and associated communication and ancillary cables in a single trench.

The Magnetic Field Results section reports results for the Noticed Variation, which includes two spare conduits for an additional circuit, as shown in Figure 3**.** Although the Noticed Variation does not incl ude a request for approval of additional export cables at this time, for informational purposes only, results are also presented for an indicative future scenario with a second 1200 MW circuit installed.

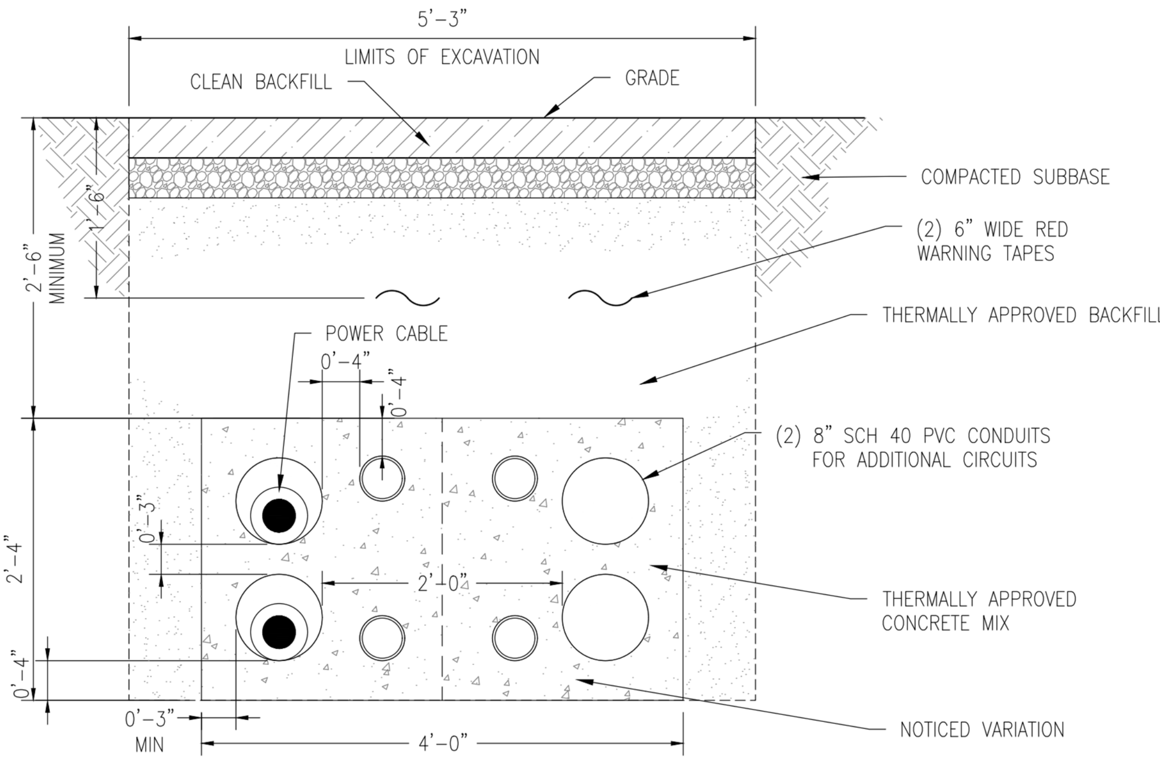

Figure 3: Typical HVDC Onshore Trench with the Noticed Variation

Case 7: HVDC onshore, alternate double circuit duct bank, 3.4 ft (1.03 m) burial depth

This Model Case captures an alternate configuration for Mayflower Wind's Noticed Variation.

Model Case 7 represents an alternate configuration for an underground, concrete-encased duct bank that can accommodate four power cables and associated communication and ancillary cables in a single trench.

The Magnetic Field Results section reports results for the scenario with two spare conduits for an additional circuit**.** Although the Noticed Variation does not include a request for approval of additional export cables at this time, for informational purposes only, results are also presented for an indicative future scenario with a second 1200 MW circuit installed.

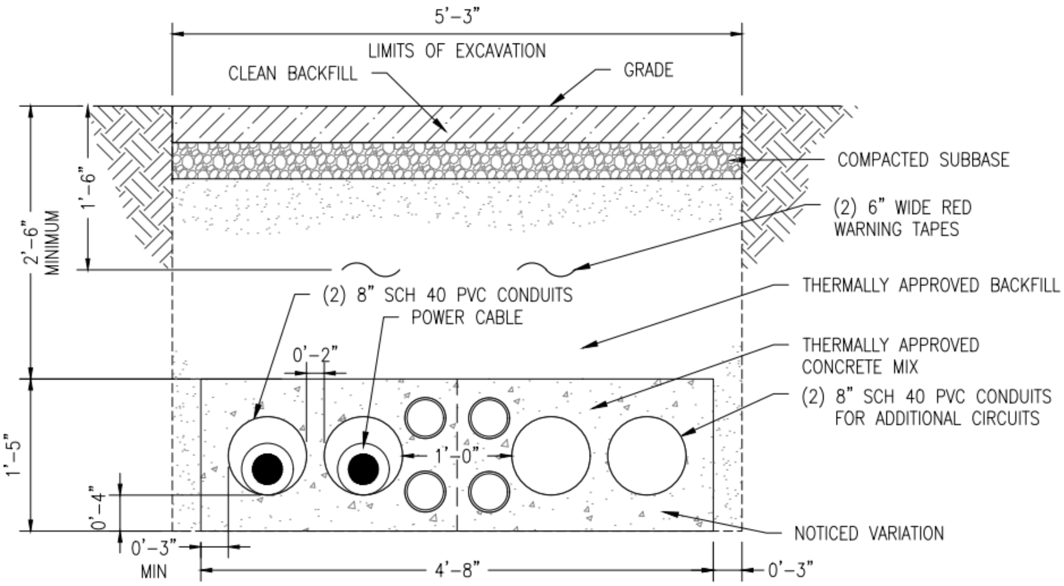

Figure 4: Alternate HVDC Onshore Trench with the Noticed Variation

Case 8: HVAC onshore, single circuit duct bank (two cables per phase), 3.3 ft (1.01 m) burial depth

This Model Case captures the typical configuration of an underground, concrete-encased duct bank that can accommodate three HVAC phases (each with two power cables per phase) and associated communication and ancillary cables in a single trench.

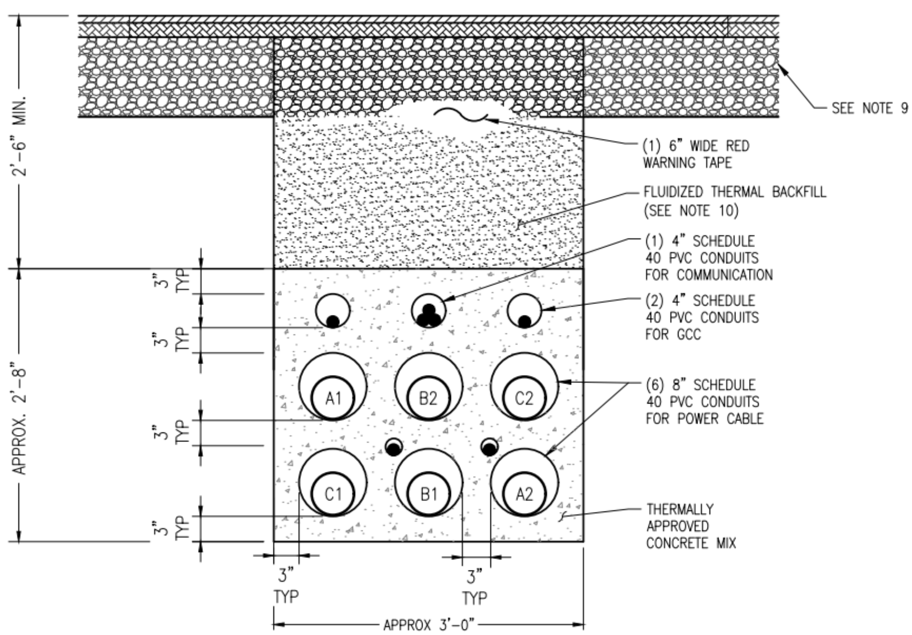

Figure 5: Typical HVAC Onshore Trench

MAGNETIC FIELD RESULTS

Table 2 lists the peak magnetic field results for each case. Corresponding profile plots are located in Figures 6 through 13.

Table 2. Study Results

Case		Magnetic Field [a] (milligauss [b])				Figure
		Max	10 ft	25 ft	50 ft	
1	HVDC offshore, bundled, 6.6 ft burial depth.	123	38.7	8.4	2.2	6
2	HVDC offshore, bundled, on seafloor under a 1.0 ft concrete mattress.	3785	55.7	9.0	2.2	7
3	HVDC offshore, non-bundled, 164 ft cable separation, 6.6 ft burial depth.	1909	1120	579	360	8
4	HVDC landfall HDD, beach case, 25 ft, and 40 ft burial depths.	261	250	174	79.0	9
5	HVDC onshore, single circuit duct bank, 3.2 ft burial depth.	433	140	30.5	8.0	10
6	HVDC onshore, double circuit duct bank, 3.3 ft burial depth.	252 (181) [c]	101 (37.4)	20.6 (3.9)	5.2 (0.53)	11
7	HVDC onshore, alternate double circuit duct bank, 3.4 ft burial depth.	259 (188) [c]	95.8 (34.9)	18.9 (3.5)	4.7 (0.47)	12
8	HVAC onshore, single circuit duct bank (2 cables per phase), 3.3 ft burial depth.	66.7 [d]	13.9	1.5	0.20	13

[a] *Magnetic field results at maximum and at varying distances from the centerline (or from cable in separated offshore case).*
[b] *Milligauss is a unit of magnetic flux density; however, the generic term "magnetic field" is used throughout this document.*
[c] *Values in parenthesis include an additional 1200-MW circuit with identical loading.*
[d] *Field values for the AC case are root-mean-square (rms).*

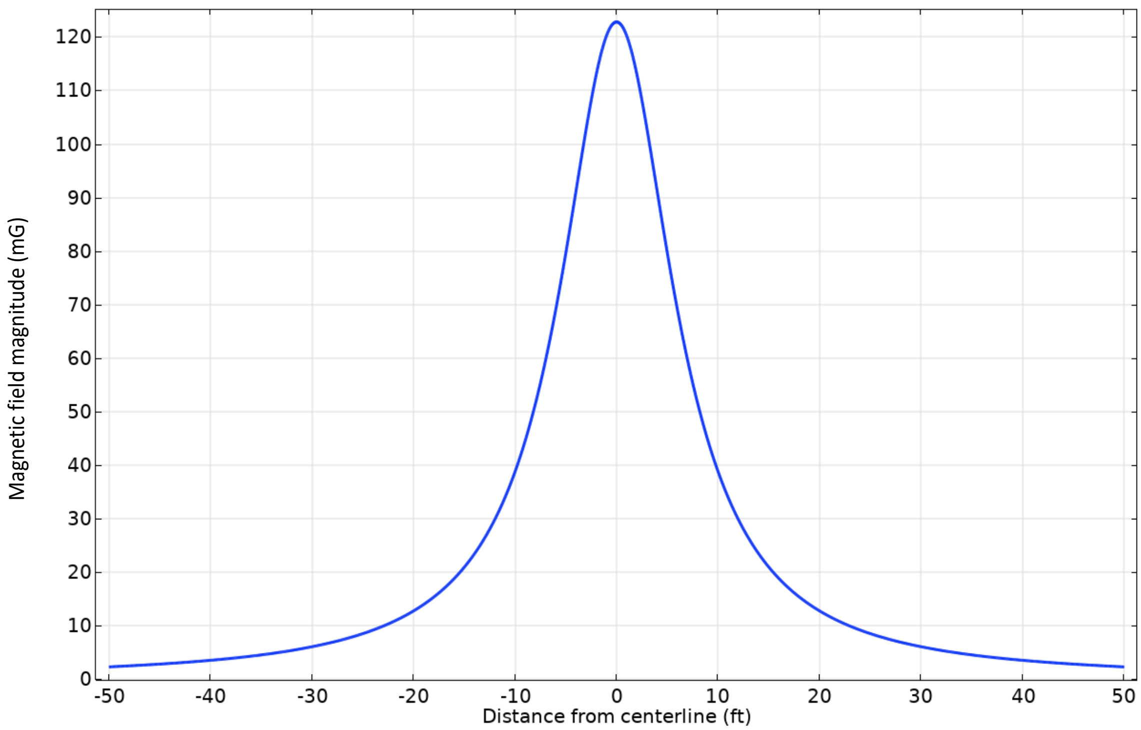

Figure 6. Magnetic field at the seafloor for Case 1: HVDC offshore, bundled, 6.6 ft (2.0 m) burial depth.

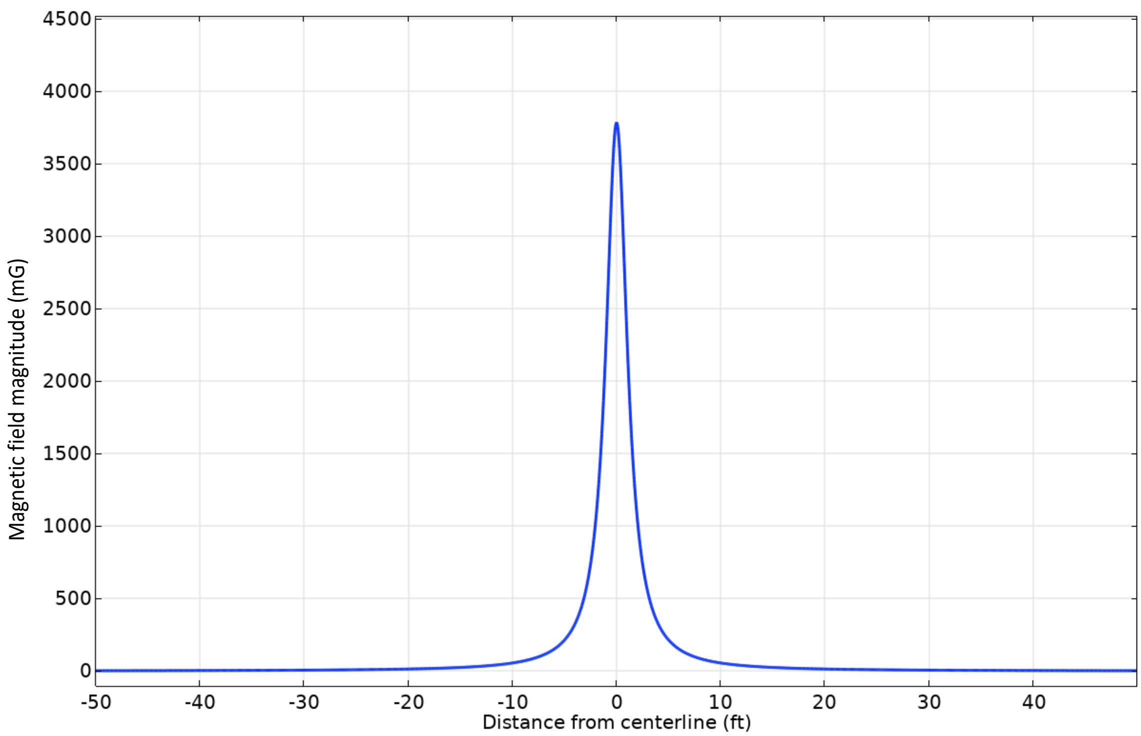

Figure 7. Magnetic field above the concrete mattress for Case 2: HVDC offshore, bundled, 1.0 ft (0.3 m) concrete mattress.

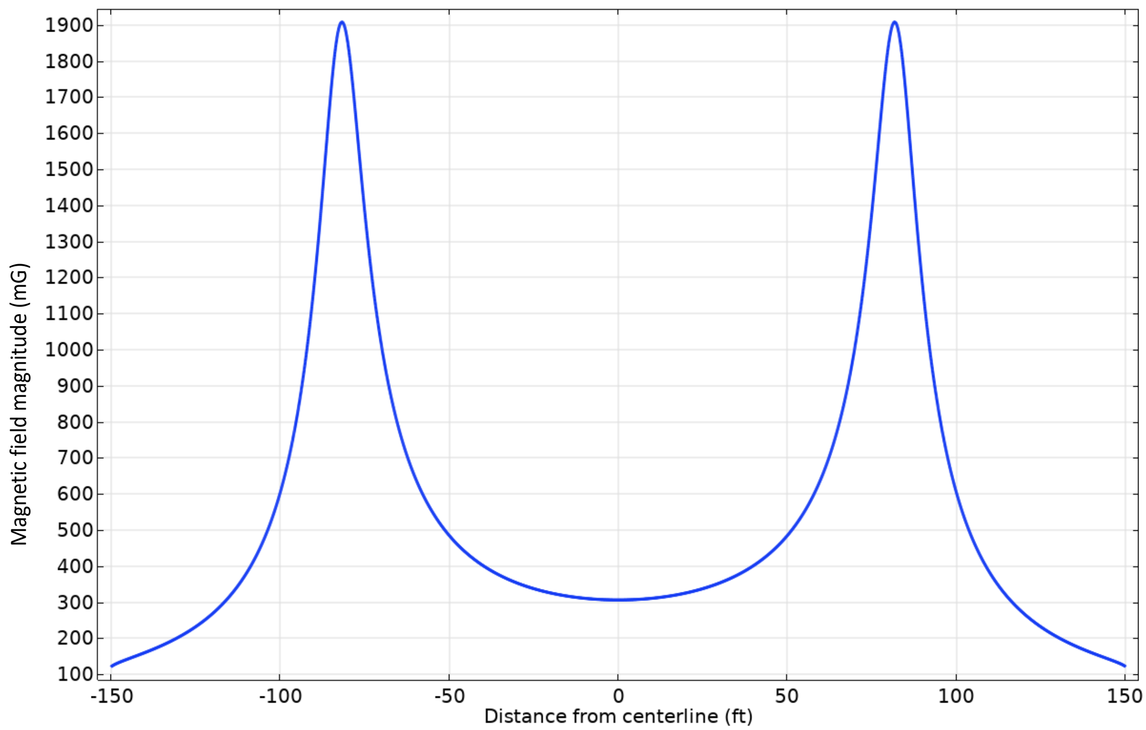

Figure 8. Magnetic field at the seafloor for Case 3: HVDC offshore, non-bundled 164 ft (50 m) separation, 6.6 ft (2.0 m) burial depth.

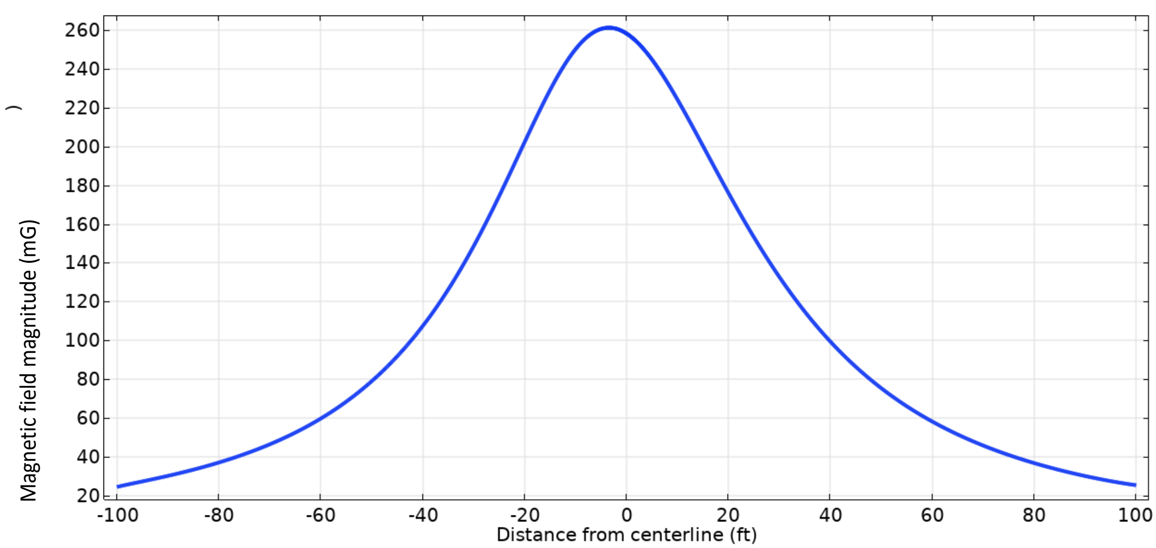

Figure 9. Magnetic field at the surface for Case 4: HVDC HDD landfall case, 25 ft (8.2 m) and 40 ft (12.2 m) burial depths and 15 ft (4.6 m) horizontal spacing.

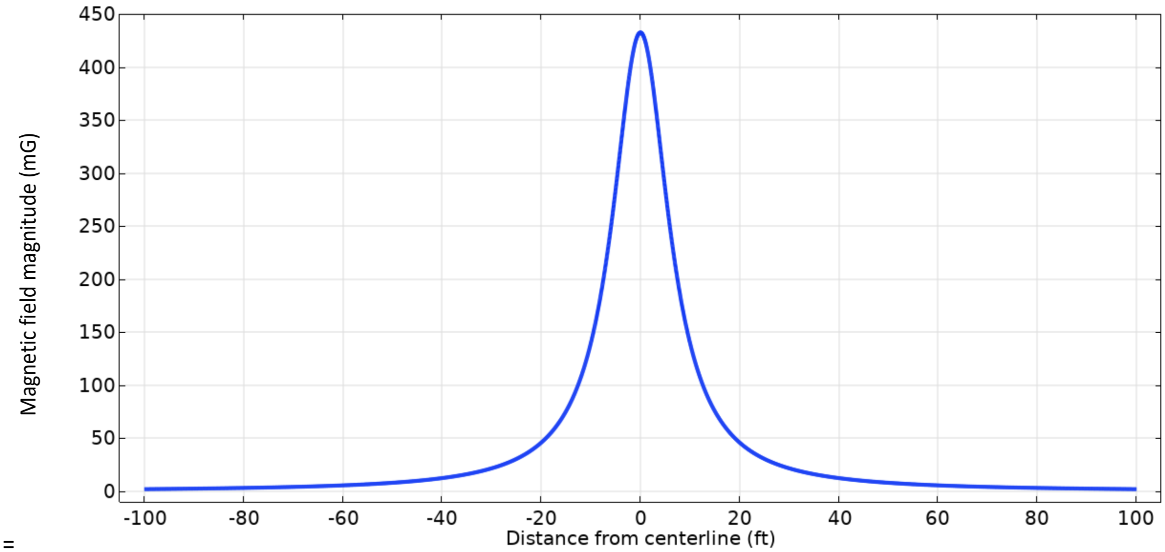

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Figure 10. Magnetic field at the earth surface for Case 5: HVDC onshore, single circuit, 3.2 ft (0.95 m) burial depth. (Model case does not include spare conduits for the Noticed Variation)

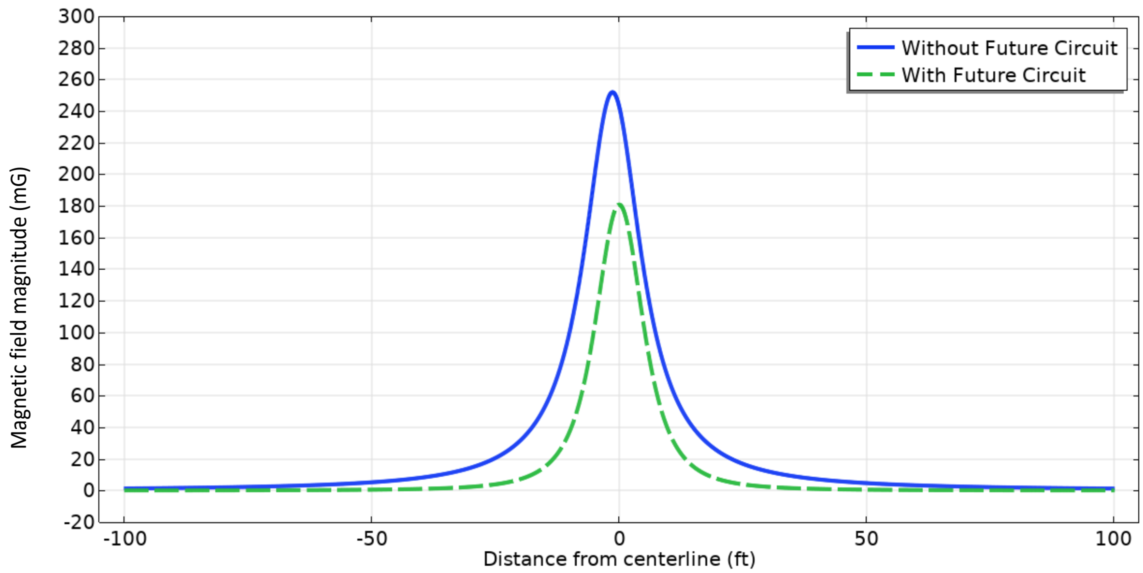


Figure 11. Magnetic field at the earth surface for Case 6: HVDC onshore double circuit duct bank, 3.3 ft (1.01 m) burial depth.

Note: *The blue line predicts MF for the Noticed Variation with empty spare conduits (as proposed). The green dashed line is an indicative future scenario that predicts MF with a second 1200 MW circuit installed. The reduction is due to field cancelling effects introduced by the second circuit.*

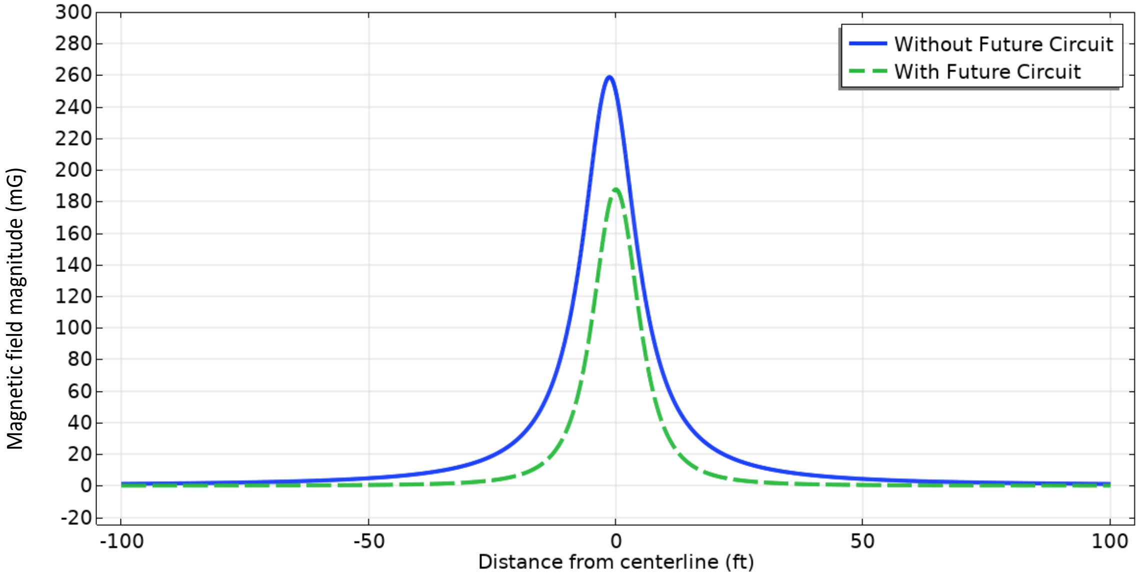


Figure 12. Magnetic field at the earth surface for Case 7: HVDC onshore alternate double circuit duct bank, 3.4 ft (1.03 m) burial depth.

Note: *The blue line predicts MF for the Noticed Variation with empty spare conduits (as proposed). The green dashed line is an indicative future scenario that predicts MF with a second 1200 MW circuit installed. The reduction is due to field cancelling effects introduced by the second circuit.*

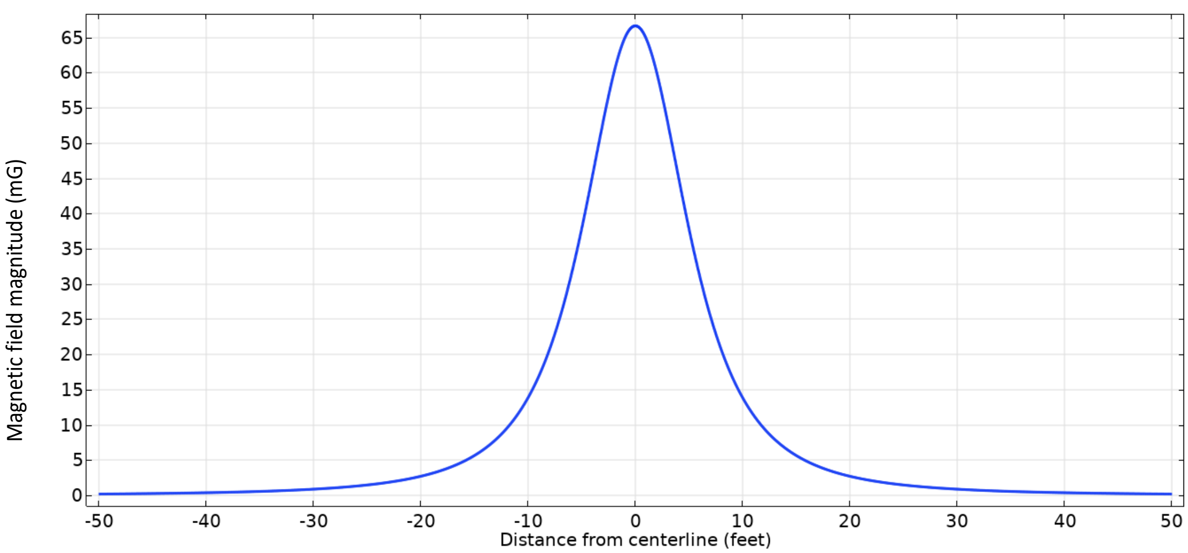


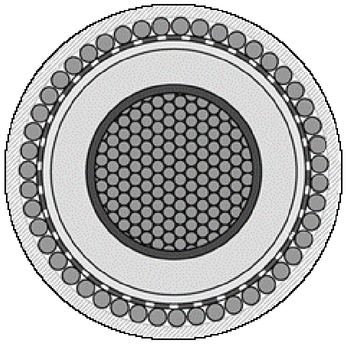
Figure 13. Magnetic field at the surface of the earth for Case 8: HVAC onshore, 3.3 ft (1.01 m) burial depth.

APPENDIX A – CABLE GEOMETRIES

Approximate Submarine ±320 kV DC Cable Geometry (cable size provided by Mayflower)

Conductor core diameter: ≈48 mm (≈1.9 in)

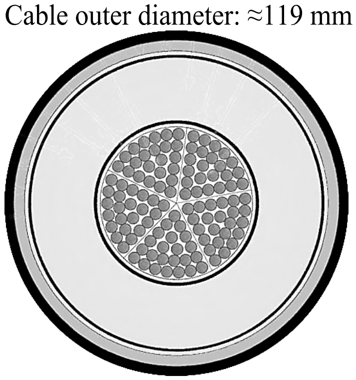
Cable outer diameter: ≈133 mm (≈5.2 in)



Approximate Underground ±320 kV DC Cable Geometry (cable size provided by Mayflower)

Conductor core diameter: ≈63 mm (≈1.9 in)

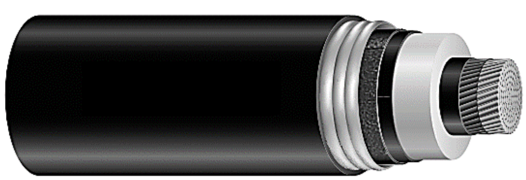
Cable outer diameter: ≈119 mm (≈5.2 in)



Approximate Underground 345 kV AC Cable Geometry (3000 kcmil cable size estimated by POWER based on desired ampacity of 1004 Amps AC rms per cable).

Conductor core diameter: ≈48 mm (≈1.89 in)

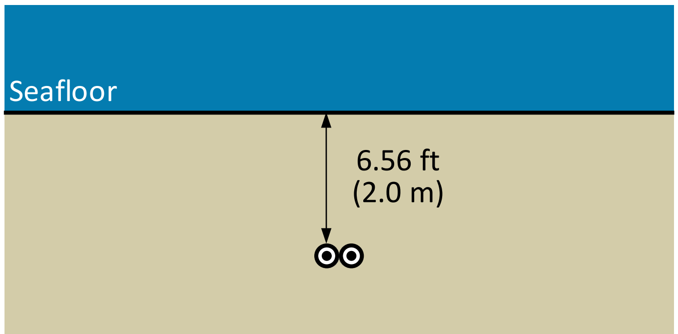
Cable outer diameter: ≈140 mm (≈5.5 in)



APPENDIX B – CIRCUIT GEOMETRIES

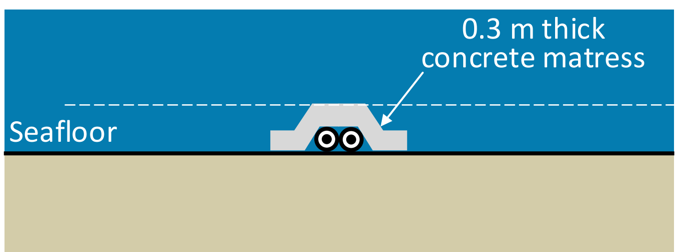
The drawings below are simplified diagrams showing relative cable placement. Depths are measured from the seafloor or earth surface to the top of the respective cable. Horizontal separation is measured from cable centers. Horizontal separation for bundled is therefore equal to one cable diameter.

Case 1: ±320 kV DC offshore, bundled configuration.



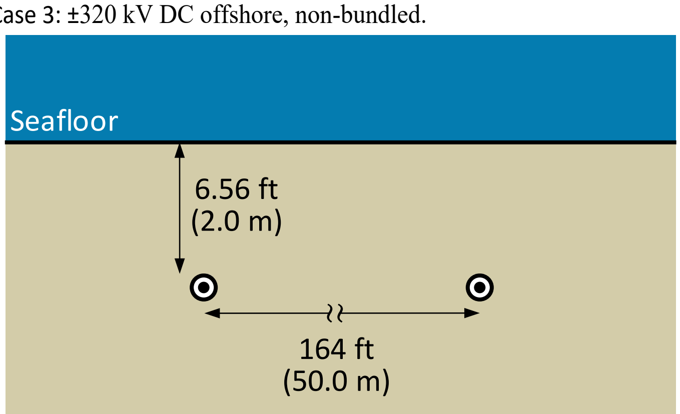
Magnetic field is measured at the sea floor.

Case 2: ±320 kV DC offshore, bundled and covered with concrete mattress.



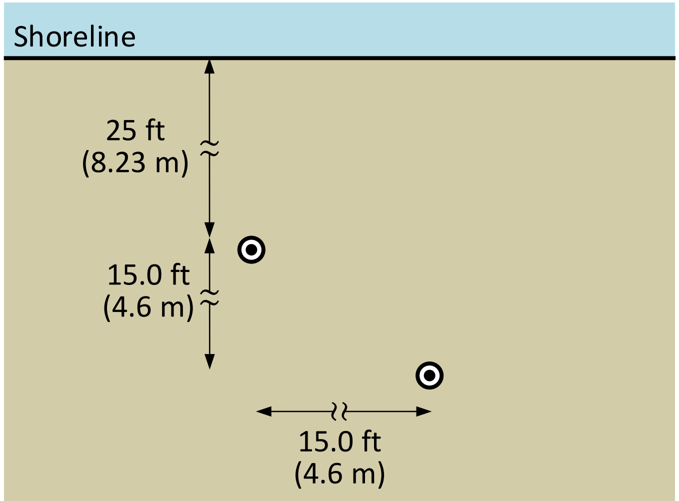
Magnetic field is measured along the dashed line (0.3 meters above top of cables).

Case 3: ±320 kV DC offshore, non-bundled.



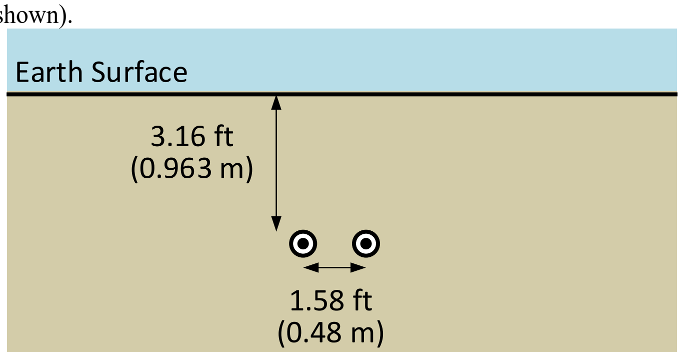
Magnetic field is measured at the sea floor.

Case 4: ±320 kV DC HDD landfall case under Island Park Beach near Boyd's Lane and Park Avenue.



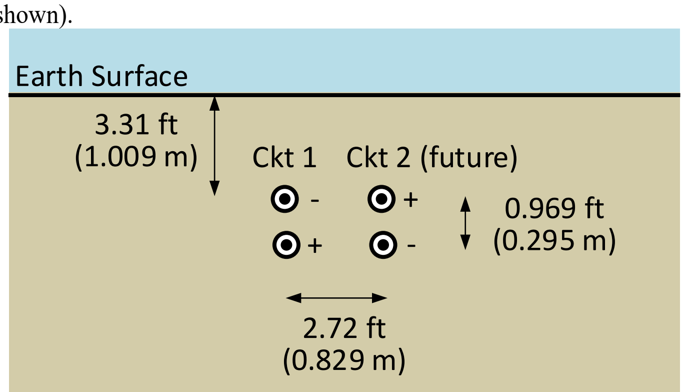
Magnetic field is measured at the beach surface.

Case 5: ±320 kV DC HVDC onshore, single circuit duct bank (conduit, engineered backfill, marketer tape etc. not shown).



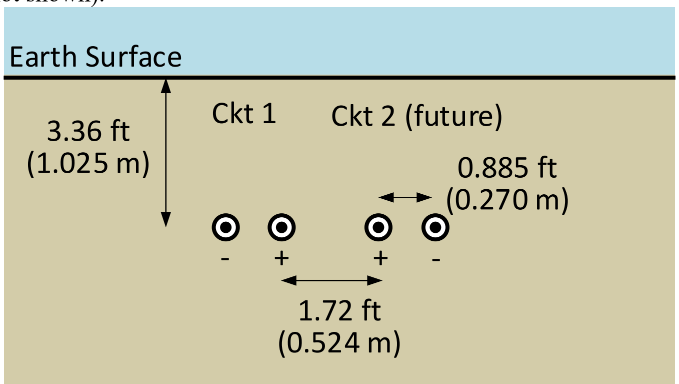
Magnetic field is measured at 3.28 ft (1 m) above the ground surface.

Case 6: ±320 kV DC HVDC onshore, double circuit duct bank (conduit, engineered backfill, marketer tape etc. not shown).



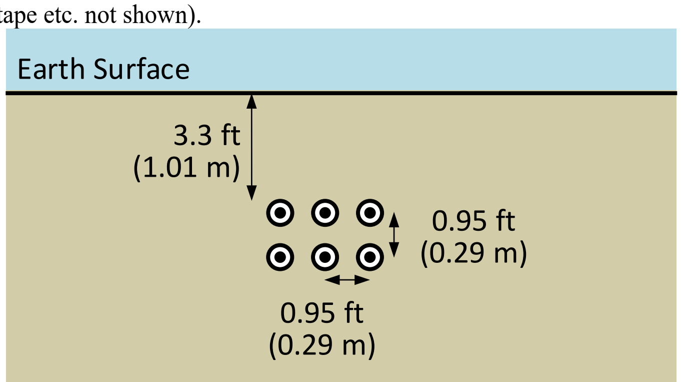
Magnetic field is measured at 3.28 ft (1 m) above the ground surface.

Case 7: ±320 kV DC HVDC onshore, alternate double circuit duct bank (conduit, engineered backfill, marketer tape etc. not shown).



Magnetic field is measured at 3.28 ft (1 m) above the ground surface.

Case 8: 345 kV HVAC onshore single circuit (two cables per phase) duct bank conduit, engineered backfill, marketer tape etc. not shown).



Magnetic field is measured at 3.28 ft (1 m) above the ground surface.
Phasing top: A1-B2-C2, bottom: C1-B1-A2. Results assume the angle of A1 equals the angle of A2; likewise, with B1, B2 and C1, C2.