

Appendix I
QinetiQ Report on EMF Analysis of the Proposed
PdV Wind-Farm with Respect to the Tejon Range

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EMF Analysis of the Proposed PdV Wind-Farm With Respect To the Tejon Range

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QINETIQ/D&TS/SES/TR0706218/3
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Abstract/Executive Summary

The following report provides a brief analysis of the impact of a proposed PdV wind-farm on the Northrop Grumman facility, with respect to Electromagnetic Fields (EMF).

With respect to the requirements of the FCC EMC specification¹ [1] there are no defined susceptibility or immunity requirements to be met. This study does not assess how EMF emissions may affect wind turbine performance.

The proposed wind-farm is to be located 10 miles west-north west of Willow Springs, California, 3 miles from the Northrop Grumman Facility (Tejon).

The Tejon facility operates both a radar cross section (RCS) and antenna performance measurement ranges. A more detailed overview of the Tejon facility is presented further within this analysis.

Based on the limited data and associated assumptions it is anticipated that the Wind Farm will be unlikely to have an adverse impact on the Northrop Grumman facility with respect to Electromagnetic Fields.

¹ Within European Electromagnetic standards, and within US Military EMC standards requirements exist for electrical/electronic equipment to operate within the defined Electromagnetic environment without exhibiting degradation in specified performance. This implies that when an interference signal is applied to the product or system, it shall continue to operate within its defined design/operating parameters. As the present FCC Regulations do not specify such requirements, wind turbine immunity considerations have not been addressed within this analysis.

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1 Introduction

1.1 Description

1.1.1 The following report provides a brief analysis of the impact of a proposed PdV wind-farm on the Northrop Grumman facility, with respect to the radiation of Electromagnetic Fields (EMF). It should be noted that within equipment test standards, the term EMF is synonymous with Electromagnetic Compatibility (EMC).

1.1.2 With respect to the requirements of the FCC's EMC specification² [1] there are no susceptibility or immunity requirements specified, as such this study concentrates on anticipated emissions from the wind-farm and how this may affect Northrop's adjacent testing facilities.

1.1.3 The proposed wind-farm is to be located 10 miles west-north west of Willow Springs, California, located 3 miles from the Northrop Grumman Facility (Tejon). The Tejon facility operates both radar cross section (RCS) and antenna performance measurement ranges.

1.1.4 This report draws from publicly available information from Northrop Grumman's web-site description of the Tejon facility and how the wind-farm could potentially adversely affect the Tejon facility, by means of EMF generated by the operation of the proposed wind farm.

1.1.5 The following is narrative extracted from the Tejon website:-

“Tejon Test Facility Overview - The Tejon Test Site is a remote test facility located in California and is owned and operated by the Northrop Grumman Corporation. It encompasses over 1400 acres and is self-contained and self-sufficient. Its primary function is to conduct electromagnetic testing utilizing two outdoor Radar Cross Section (RCD) ranges, two outdoor antenna ranges, and one indoor RCS Compact range. Available RCS test frequencies range from 145 MHz to 18 GHz, with imaging capability provided on all bands. These ranges can handle targets up to 8,000 pounds on a 14 foot or 26 foot target support and a range length of 1,500 feet or 3,000 feet. The antenna ranges include a fully automated state-of-the-art antenna and radome test facility covering selected frequencies from 100 MHz to 40 GHz. One antenna range has unobstructed 360 degree capability and can handle target weights up to 75,000 pounds. A model shop is available for target assembly and/or modification and secure target storage is provided.

Facilities - The Tejon Test Site includes a 1200 sq. ft. paint booth with the required federal, state, and local permits. A machine shop and fabrication area are available for target assembly and/or modification. There are six segregated model storage/work areas totaling approximately 30,000 sq. ft.

² Within European Electromagnetic standards, and within US Military EMC standards requirements exist for electrical/electronic equipment to operate within the defined Electromagnetic environment without exhibiting degradation in specified performance. This implies that when an interference signal is applied to the product or system, it shall continue to operate within its defined design/operating parameters. As the present FCC Regulations do not specify such requirements, wind turbine immunity considerations have not been addressed within this analysis.

RCS Outdoor Range Capabilities - There are two outdoor RCS ranges with available test frequencies from 145 MHz to 18 GHz in Vertical and Horizontal polarizations. Data acquisition is accomplished using the SPC Mark IV format. In the coherent mode, the range is capable of obtaining eight discrete frequencies per rotation with simultaneous multi-band acquisition. FFT imaging is available in all bands. Frequency sweeps can be set for 128, 256, or 512 frequencies per Chirp. The outdoor RCS range uses a new SPC Mark V radar, ISAR Recon III Data Acquisition software, and ISAR Knowbell Data Processing software. Data output is available in numerous formats including hardcopy, magnetic, and optical. Pattern types available include rectilinear coherent plots, polar coherent plots, medianized coherent plots, sector statistics, ISAR images, Pixel dumps, image edit and reconstruct, and global plots. The Tejon Test Site has several outdoor range model supports available for use. These include 14 foot pylons with 8000, 1500, and 500 pound capacities; a 26 foot pylon with 1500 pound capacity; and a 50 foot pylon with 10000 pound capacity. Foam poles are also available. These typically have a 2000 pound capacity with machining equipment on site to tailor these to meet customer requirements. Positioners are adaptable to custom poles.

RCS Compact Range Capabilities - The RCS Compact range at Tejon was completed in December of 2000. The 20 ft. x 20 ft. x 40 ft. long chamber is configurable for RCS or antenna measurements. It has a 6 foot long by 6 foot diameter cylindrical quiet zone. It is capable of performing RCS measurements at frequencies from 2 to 18 GHz. The target rotator has a capacity of 500 pounds. Active RCS or antennas can be tested. Raw and processed data as well as range video is available via a secure data link at El Segundo, California as well as worldwide using Quest Phone Service. Segregated, secure target storage areas are available. Easy target access and realtime and near-realtime data processing and analysis capabilities allow quick target changes and re-test.

Outdoor Antenna Test Range Capabilities - The outdoor antenna test range is capable of testing at frequencies from 45 MHz to 18 GHz with CW or Frequency Step/Frequency List. Pattern types available include great circle and conic. The antenna range uses HP8510 based Flam & Russell 8003 Antenna/Radome measurement system, Adam Plot plotting software, and the Flam & Russell 8003 analysis software. Data acquisition is simultaneous dual channel absolute/relative gain, absolute/relative phase. The monopulse null seeking software includes boresight error and radome insertion loss. The Flam & Russell analysis package includes beam peak location, beam width at specified level, monopulse null depth and location, and side lobe location and magnitude. The outdoor antenna range positioner is a 10,000 pound Azimuth Over Elevation Over Azimuth positioner. Accuracy is guaranteed at +/- 0.03 degree peak error. Resolution is 0.001 degrees. Pedestal motion is selectable for continuous or step with azimuth limits at +/- 180 degrees and elevation at -40 degrees to +70 degrees.”

- 1.1.6 Tejon facility receiver sensitivity specification and hence EMF limitations are unknown. Assumptions are therefore made in the analysis. Some detail relating to the RCS compact Range facility, however, is provided. From its description this appears to be screened EMC enclosure (Faraday Cage), in which measurements are conducted. Within this type of chamber any interference signals produced by the wind-farm will be attenuated by the chamber, and as such emissions emanating from the wind-farm are highly unlikely to effect the measurements with the chamber. However, there is also an outdoor RCS range which is the focus of this report.

2 Electromagnetic Fields (EMF)

2.1 Compliance for EMF and EMC

- 2.1.1 It is assumed that individual wind turbines at the proposed Wind Farm will have been designed and demonstrated to be compliant with the Electromagnetic Compatibility (EMC) requirements for radiated emissions applicable for unintentional radiators defined by FCC EMC regulations; CFR47 Part 15 Subpart B Section 15.109 [1], radiated emission limits, sub paragraph (a) and (b). The rationale for this assumption is that under the FCC regulations all electrical/electronic equipment must comply with the EMC requirements of the FCC.
- 2.1.2 The FCC does not provide product specific radiated emission requirements for wind turbines. A search of Euronorms (Harmonized European Standards) within the Official Journal of the European Union has been undertaken to establish whether there exists a European product specific standard for wind turbines/farms. No such standard has been identified. The only EMC standards which would apply from the European Union (EU) are noted below in Table 1.
- 2.1.3 The FCC radiated emissions limits are less onerous than the nearest equivalent European Standard BS EN61000-6-4 [2] (invoking the test requirements of BS EN 55011 [3] over the frequency range 30MHz to 230MHz, and 960MHz to 1000MHz). If the emissions from an individual wind turbine meet the European Standard then the FCC requirement will also be met. Figure 1 illustrates a comparison of the European Union (EU) standard with the FCC standard [1]. It should be noted that the requirements have been extrapolated to 30m, as this would be the preferred measurement distance given the physical size of a Wind Turbine if testing was to be performed for the full system configuration.
- 2.1.4 This comparison has been included since it is recognized that the manufacturer of the Wind Turbine may have sourced component parts from other countries. It is likely that these parts will comply with standards other than those of the US. Relevant information will be detailed in one or all of the following documents: certificates of conformity, statement of conformity or build standard. See paragraph 2.1.2.

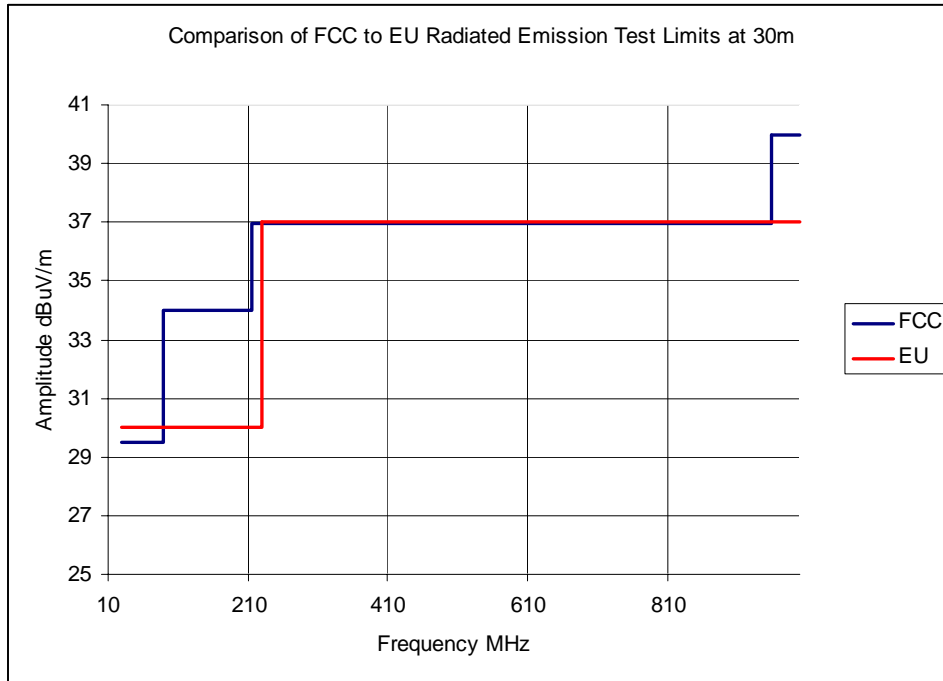


Figure 1: Comparison of FCC EMC test to EU test requirements

Body	Standard	Identifier
CENELEC [4]	EN 61000-6-2:2001 [4] Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments (IEC 61000-6-2:1999 (Modified))	EN61000-6-:1999
CENELEC [5]	EN 61000-6-2:2005 [5] Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments (IEC 61000-6-2:2005)	EN61000-6-:2001
CENELEC [6]	EN 61000-6-3:2001 [6] Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments (CISPR/IEC 61000-6-3:1996 (Modified))	EN50081-1:1992
CENELEC [7]	EN 61000-6-4:2001 [7] Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments (IEC 61000-6-4:1997 (Modified))	EN50081-2:1993
FCC [1]	FCC; Subpart B Section 15.109, radiated emission limits, sub paragraph (a) and (b) for 3m or 10m test measurement distances respectively	

Table 1: Related FCC and European standards

3 Electromagnetic Impact of the Wind-Farm

3.1 Wind Turbines

- 3.1.1 The proposed wind-turbines are between 77.9m and 61.4 m in height, measured from ground level to the hub. The construction essentially is a metal tower, supporting a rotor, 3 phase motor/generator and gearbox, with its associated control and data processing equipment (typically used for remote PC control).
- 3.1.2 The hub supports 3 rotor blades. In the case of the PdV wind-turbines each blade will be of the order of between 44m and 30 m in length. Each of the rotor blades may vary in pitch according to the speed of the prevailing wind during operation. The blade is constructed from a GRP/Polycarbonate or fiber-glass material treated with liquid epoxy and connected to a rotating steel mandrel which is in turn connected to the central hub.
- 3.1.3 The radiated emissions generated from devices fall into two emissions categories, narrowband and broadband. Both types of emissions are measured in terms of dB μ V/m (decibels relative to 1micro volt per meter).
- 3.1.4 Wind Turbine emissions are likely to comprise both broadband and narrowband signals ('noise').
- 3.1.5 Broadband emissions can be of two forms, coherent and incoherent. For a signal or emission to be coherent the adjacent frequency components of the signal are related in amplitude and phase. For broadband signals the adjacent frequency components of the signal are equal in amplitude and in phase and when measured, the amplitude of the measured signal is directly proportional to the measurement bandwidth.
- 3.1.6 For a signal or emission to be incoherent, the adjacent frequency components are random in either phase or both phase and amplitude and when measured the amplitude of the measured signal is proportional to the square root of the measurement bandwidth.
- 3.1.7 Typical coherent broadband sources can be digital systems and strobe lamps, while typical incoherent broadband sources are noise diodes, corona discharges, brush/commutator arcing, and internal receiver noise.
- 3.1.8 A narrowband signal is a signal which does not vary in amplitude with change in detector bandwidth (In this case the RF detector bandwidth would be 120kHz, over the frequency range 30 MHz to 1000 MHz). This type of signal tends to have little or no modulation, and is typically produced by clock circuits (Harmonics), crystals, controllers and speed governors.

3.2 Power Generation

3.2.1 There is only one mode of operation for the wind-turbine which is power generation.

3.3 EMC and Earthing

3.3.1 Based on QinetiQ experience of conducting Electromagnetic site surveys on wind-farms it is anticipated that the majority of the electromagnetic emissions generated by the wind-turbine will be below 1GHz. Only high frequency clock signals related to controlling PCs/control systems may produce clock fundamentals and harmonics emanating above 1GHz. The level of emissions generated will depend on the following factors, although it should be noted that this is not an exhaustive list:

- Compliance of the controllers and governors with the relevant FCC specification
- Compliance of the controllers and governors with the relevant EU Specification
- Ensuring all cables and connectors are properly screened with 360 degree screening
- Ensuring all sub systems are bonded using earth braid as opposed to earth wire used as a safety connection
- The earthing philosophy of the wind turbine. *A safety earth connection is there to prevent electric shock in the event of an electrical fault, and to provide an electrical earth return path. This is more than satisfactory for low frequencies i.e. 60Hz. An RF earth is one which has a maximum 5:1 (length to width) aspect ratio which will allow Radio Frequency signals to flow to ground. These RF earths will typically be in the order of ½ inch wide (10mm).*

3.4 Predicted EMF at the Tejon Facility from the Proposed Wind Farm

3.4.1 With reference to table 1 of the Evans Associates report [8], there are a number of microwave data links which operate in the area, over the frequency range 2.1 GHz to 11 GHz. There is no data available for these transmitters from which field strengths can be predicted. However, as these data links are line of sight, and their frequency band of operation exceeds the expected emissions from the wind-farm, they are unlikely to interfere with the Tejon facility when the wind-farm is introduced. This is because the Tejon facility appears to be operating with no interference from the line of sight data links. It is highly unlikely that the wind turbines will perturb the line of site transmission to cause interference at the Tejon facility.

3.4.2 The wind farm is proposed to be located 3 miles east of the Tejon facility. Assuming that the design of the wind-turbines is such that they meet the general test requirements for FCC radiated emissions, then the EMF incident on the Tejon facility can be estimated.

3.4.3 The FCC radiated emission limit [1] is stated in Table 2. Figure 3 illustrates the free-space loss with distance for a number of frequencies, on the basis of a 1/r dependence (where r is distance in meters (m)) which is valid for this assessment since far field conditions apply. The free space loss graph presented in figure 3 illustrates graphically how radio frequency energy dissipates with distance from the source of the radiated emission. As an example: a 1GHz signal (the fifth line from the top of the graph) measured at 100 miles from its source will be attenuated by approximately 140dB.

Frequency (MHz)	FCC Specification Limit (dB μ V/m)
30	29.5
88	29.5
88	34
216	34
216	36.94
960	36.94
960	40
1000	40

Table 2: Specification limit for FCC Specification at 30m

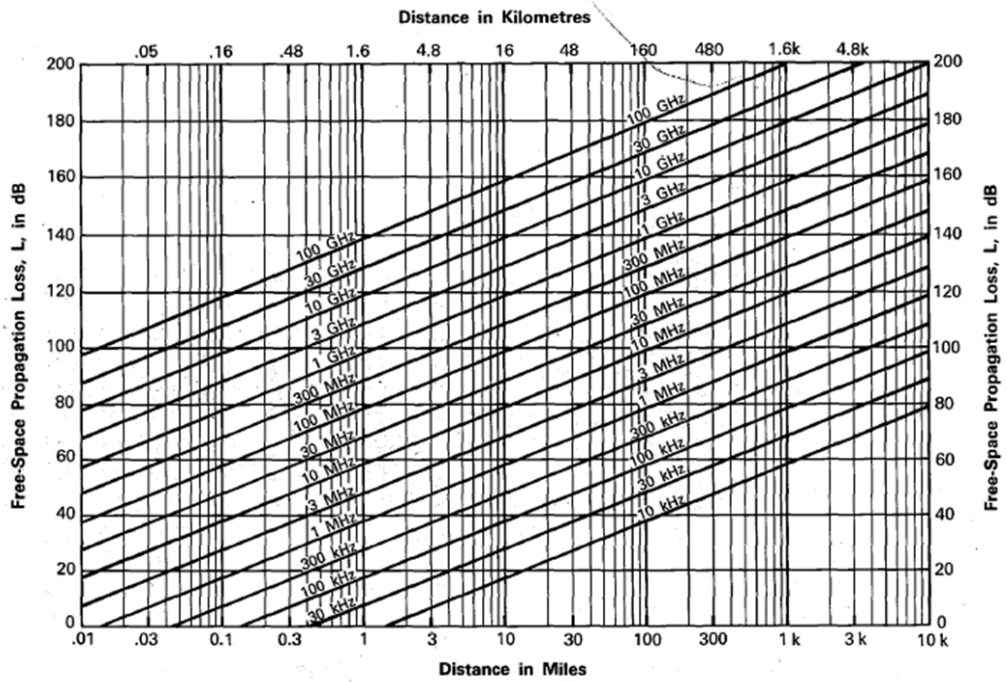


Figure 3: Free-Space Propagation Loss graph

Frequency (MHz)	Specification Limit (dB μ V/m)	Path loss from Figure 1 dB	Predicted Emissions at 3 miles (dB μ V/m)
30	29.5	77.5	-47.5
88	29.5	88.75	-59.25
88	34	88.75	-54.75
216	34	91.25	-57.25
216	36.94	92.25	-54.31
960	36.94	107.5	-70.56
960	40	107.5	-65.50
1000	40	107.5	-65.5

Table 3: Predicted RF Field at the Northrop facility at a distance of 3 miles from the Wind Farm

3.4.4 The predicted values in column 4 of Table 3 are extremely low and would be difficult to measure with current EMC test equipment. It would be helpful if the Tejon facility could provide information on the Radio Frequency sensitivity levels they are currently operating to, and the frequency band of operation.

3.4.5 Based on currently known information it is highly unlikely that such low emission levels would interfere with the Northrop Facility systems. If the EMF collectively generated by the turbines was summed incoherently, the predicted EMF emissions could be increased by as much as 23 dB, as incoherent emissions may be summed using the following formula, where 191 is the number of turbines on the wind farm:

$$dB = 10\text{Log}(191)$$

3.4.6 At worst, if the EMF collectively generated by the turbines is summed coherently, the emissions could be increased by as much as 46 dB, as coherent emissions may be summed using the following formula:

$$dB = 20\text{Log}(191)$$

3.4.7 Even with the worst case example, the highest predicted emission from a compliant wind farm, at 30 MHz would be in the order of -1.5 dB μ V/m, which equates to 0.84 μ V/m (micro volts per meter).

3.4.8 If the emissions from a wind-turbine are unknown and the assumption of compliance with the requirements of the FCC EMC specification [1] is incorrect then prediction could only be possible using actual test data.

3.4.9 Power distribution lines currently exist at the proposed location. As a result, the electrical noise they already present to the Tejon facility will not increase with the introduction of a wind farm. Electromagnetic emissions from power lines at the intentional grid transmission frequency of 60 Hz, intuitively, could be considered likely to be higher than emissions at the same frequency from individual Wind Turbines. Distribution lines will carry higher current at a higher voltage than associated with a single turbine and therefore the magnetic and

electric fields in the immediate vicinity of the power line are likely to be higher than the magnetic and electric fields in the immediate vicinity of the wind farm.

- 3.4.10 Additional confidence in these predictions could be provided using measurement data from existing wind farm and power distribution sites.

4 Recommendations

- 4.1.1 It is assumed that Wind Turbine manufacturers comply with FCC EMC regulations of radiated emissions for unintentional radiators. The validity of this assumption should be confirmed with the proposed supplier.
- 4.1.2 If demonstrated that the proposed Wind Turbine does not comply with the assumed emission limits then in order to confirm the anticipated impact of the wind-farm on the Northrop Grumman facility it would be desirable to survey a similar wind farm with a view to establishing if broadband and narrowband emission profiles are within FCC requirements.
- 4.1.3 The Tejon facility operates over a frequency band of 100MHz to 40GHz, as stated on its web page. It would be helpful if Northrop Grumman could provide information on “selected” frequencies currently in use. With this information a more definitive analysis could be produced.
- 4.1.4 Based on current understanding of the proposal, and subject to the associated assumptions, it is anticipated that the Wind Farm will be unlikely to have an adverse impact on the Northrop Grumman facility systems with respect to Electromagnetic Fields.

5 References

- [1] FCC Regulations; CFR47 Part 15 Subpart B Section 15.109 , radiated emission limits, sub paragraph (a) and (b) for 3m or 10m test Measurement distances respectively
- [2] BS EN 61000-6-4 Generic standards — Emission standard for industrial environments October 2001
- [3] BS EN 55011 Industrial Scientific and Medical Limits and Methods of Measurement May 1998+A1 August 1999
- [4] EN 61000-6-2: October 2001 Electromagnetic compatibility (EMC) - Part 6-2: Generic standards Immunity for industrial environments (IEC 61000-6-2:1999 (Modified))
- [5] EN 61000-6-3: October 2001 Electromagnetic compatibility (EMC) - Part 6-3: Generic standards Emission standard for residential, commercial and light-industrial environments (CISPR/IEC 61000-6 3:1996 (Modified))
- [6] EN 61000-6-4: October 2001 Electromagnetic compatibility (EMC) - Part 6-4: Generic standards Emission standard for industrial environments (IEC 61000-6-4:1997 (Modified))
- [7] EN61000-6-2:2001 Generic standards — Immunity for industrial
- [8] Evans Associates Engineering report Concerning the effects upon FCC Licensed RF Facilities due to the construction of a wind turbine Farm March 19, 2007
- [9] Impact of the Pdv wind farm on RCS measurements at the Tejon range QinetiQ/D&TS/SEA/TR0703730/1.0, Steve Turner 05/04/3007

6 List of Abbreviations

Abbreviation	Description
dB	Decibel
dB μ V	Decibels Relative to 1 microvolt
E-Field	Electric Field
EMC	Electromagnetic Compatibility
EMI	Electro Magnetic Interference
Hz	Hertz
GHz	Gigahertz
MHz	Mega Hertz
N/A	Not Applicable
RF	Radio Frequency
EU	European Union
EN	Euro Norm
EMF	Electromagnetic Fields

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