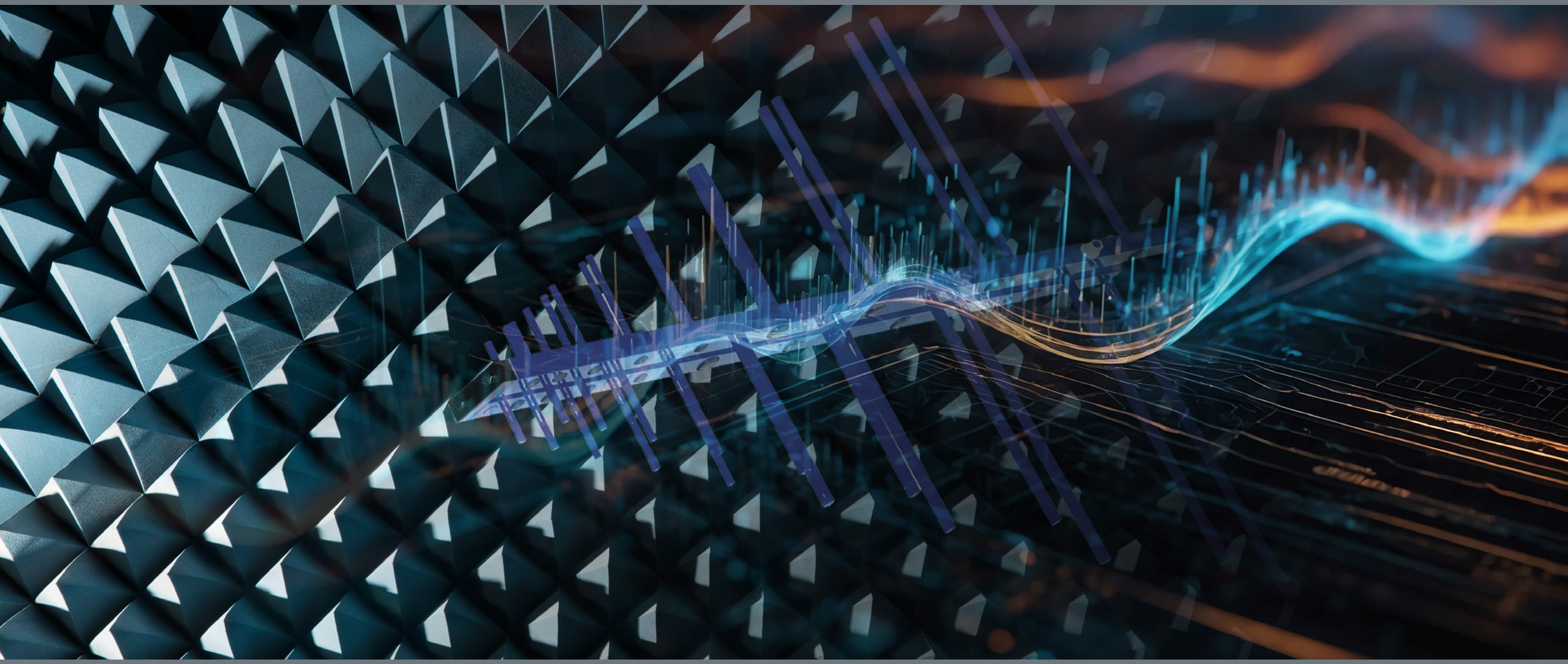
Insights and best practice

EMC COMPLIANCE KNOW-HOW



TECHNICAL NOTE 0121

emtest / TESEQ / AMETEK

A PRACTICAL GUIDE TO ANTENNAS FOR EMC COMPLIANCE

This technical note serves as an essential guide for understanding antenna behavior in EMC testing by exploring key concepts like antenna gain, directivity, and polarization, and their practical implications. Topics covered include:

- The fundamentals of electromagnetic waves, including their composition, properties, and propagation.
- The concept of antennas and their role in transmitting and receiving electromagnetic waves.
- Important antenna parameters, including reflection coefficient, VSWR, antenna gain, directivity, effective aperture, radiation pattern, beamwidth, and polarization.
- The concepts of radiated and received power are discussed, along with the Friis transmission equation, which relates these powers to antenna gains and distance.
- A explaination of antenna factor, a crucial parameter for converting between measured voltage and electric field strength in EMC testing.
- Practical examples, including immunity testing using CBL6111D and emission testing according to CISPR 11, are provided to illustrate the application of these concepts
- An annex covering logarithmic equations used in RF measurements, explaining their significance and providing conversion formulas for various parameters.

This comprehensive guide is an invaluable resource for engineers and technicians involved in EMC testing, providing them with the necessary knowledge to understand and work with antennas effectively.

AMETEK CTS GmbH Sternenhofstrasse 15 4153 Reinach, Switzerland info.cts@ametek.com

AMETEK
COMPLIANCE TEST SOLUTIONS

LIST OF TERMS

TERMS

TERM	DESCRIPTION	UNIT
E	Electric field	V/m
Et	Transmitted Electric field	V/m
Er	Received Electric field	V/m
H	Magnetic field	A/m
Ht	Transmitted Magnetic field	A/m
Hr	Received Magnetic field	A/m
S	Poynting vector	W/m^2
P	Power	W
Pd	Power density	W
Pt	Power transmitted	W
Pr	Power received	W
G	Gain of an antenna	
Gt	Transmitter antenna Gain	
Gr	Receiver antenna Gain	
D	Directivity of an antenna	
e	Efficiency of an antenna	
η	Free space impedance	120 pi = 377 Ohm
Z	Impedance	Ω
Zr	Receiver impedance	Ω
Zt	Transmitter impedance	Ω
Zl	Load impedance	Ω
Zs	Source impedance	Ω
Γ	Reflection coefficient	
	permittivity of free space	
	permeability of free space	
Vmax	Maximum voltage	
Vmin	Minimum voltage	

ELECTROMAGNETIC WAVES

Electromagnetic waves are a form of energy that can travel through space or a medium. They are commonly used to transmit RF energy stored in their electric and magnetic fields. Instead of thinking of them as waves with electric and magnetic field components, let's consider them as interconnected fields that propagate together.

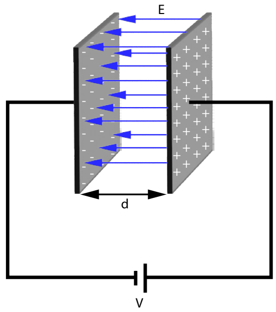
In an electromagnetic wave, there are two fundamental components: the electric field and the magnetic field. These fields are intertwined and mutually dependent on each other. When an electric field changes, it induces a magnetic field, and when a magnetic field changes, it induces an electric field. This continuous interplay between the electric and magnetic fields allows the wave to propagate.

When a source generates an oscillating electric current and send it to an antenna, it creates oscillating electric and magnetic fields that propagate outward from the source. These fields are perpendicular to each other and perpendicular to the direction of wave propagation. This means that if you visualize the wave moving forward, the electric and magnetic fields would be oriented at right angles to that direction.

Electromagnetic waves do not require a medium to propagate. They can travel not only through air or solid material, but also through vacuum in space.

Electric field

An electric field is a region of space around an electric charge or a distribution of charges within which an electric force would be exerted on other charges. The electric field is a vector quantity, meaning it has both magnitude and direction.
For a test charge placed between parallel plates with a large area (A) and a small separation distance (d = 1 mm) connected to a 10 V source, the charge will experience an electric field strength equal to:



$$E = 10\ \text{V}/1\text{mm} = 10\ \text{kV/m} \qquad (1)$$

It is worth mentioning that the electric field between the two plates remains constant anywhere inside the plates, provided the area is relatively large compared to the distance.

Magnetic field

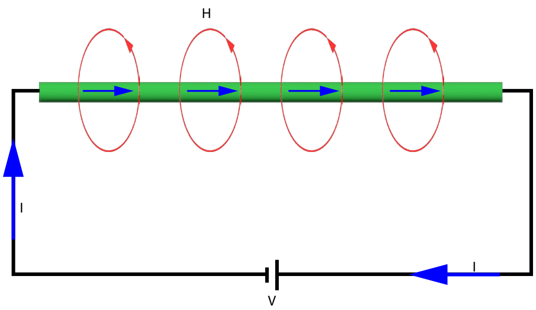
Applying a voltage to a wire causes charges to move, resulting in a current flowing through the wire. This current exerts a force around the wire and produces a magnetic field. The unit of magnetic field strength is Amperes per meter (A/m). The value of the magnetic field decreases as the circumference calculated at increases but remains constant along the circumferential path.

For example, if a long wire carries a current of 5 A, the magnetic field strength at a distance of 1 cm from the wire can be calculated as follows:

$$H = 5\ \text{A}/(2\pi \cdot 1\ \text{cm}) \approx 800\ \text{mA/m} \qquad (2)$$

ELECTROMAGNETIC WAVES *continued...*

When observing the magnetic field at constant distance from the wire, the field strength remains constant for all circles with same size surrounding the wire if the wire is long enough.



Power density and Poynting vector

It is now clear that charges generate an electric field and accelerating charges (flowing current) produce a magnetic field. Both fields can propagate, carrying information in the form of energy. The direction of propagation and its magnitude are described by the Poynting vector. In other words, the Poynting vector indicates the amount and the direction of electromagnetic energy passing through a unit area per unit time and is given by:

$$S = E \times H \qquad (2)$$

The magnitude of the Poynting vector is the power density and can be expressed as:

$$P_d = E \cdot H = E^2/\eta \quad \text{or} \quad P_d = E \cdot H = \eta \cdot H^2 \qquad (4)$$

It has a unit of Watts/meter squared (w/m²).

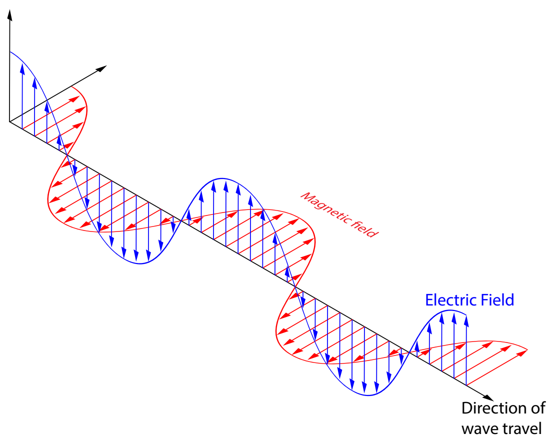
η is the intrinsic free space impedance which is given by:

$$\eta = E/H = \sqrt{(\varepsilon_0/\mu_0)} = 120\pi\Omega \approx 377\Omega \qquad (5)$$

The power density can be converted to dBm as:
Where

- ε_0 is the permittivity of free space, which is a measure of a material's ability to support the formation of an electric field within itself in response to an applied electric field. It is equal 8.854×10^(-12) F/m (farads per meter)
-
- μ_0 is the permeability of free space, which is a measure of a material's ability to support the formation of a magnetic field within itself in response to an applied magnetic field. It is equal to 4π×10⁷ H/m (henries per meter)

The Poynting vector is a fundamental concept in understanding the propagation of electromagnetic waves, as it describes how energy is transported by electromagnetic fields through space. It plays a crucial role in various applications, including the design of antennas, transmission lines, and electromagnetic radiation.



ANTENNA

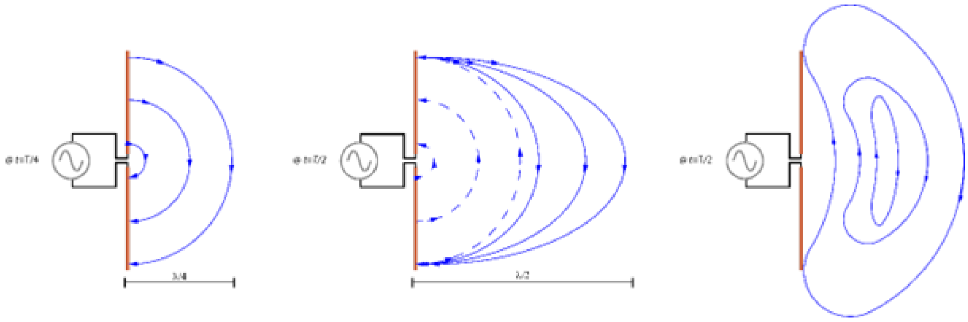
An antenna is a device that enables the transmission and reception of electromagnetic waves in wireless communication systems. It achieves this by converting guided electromagnetic energy of the feed line into a radiated wave in space and vice versa.

When connected to a transmitter, the antenna converts the electrical energy into electromagnetic waves, allowing them to propagate through space. This conversion occurs through the acceleration of charges, which are driven by time-varying voltage and current applied to the antenna's input terminal. As a result, the antenna radiates the electric field into the surrounding region, facilitating the transmission of power from the transmitter to the electromagnetic wave traveling towards the receiver.

To ensure efficient transmission, the length of the antenna is designed to match the wavelength of the signal being transmitted. This length is typically half the wave¬length and varies with the frequency. By optimizing the antenna length, the radiation fields from each wave cycle add up in phase, preventing the cancellation of the previously sent signal.

Reflection coefficient and VSWR

In the context of antennas, the reflection coefficient (Γ) quantifies the amount of electromagnetic energy reflected back towards the source due to impedance mismatches between the antenna and the transmission line or between different components of the antenna system. It measures the efficiency of energy transfer between the antenna and the transmission medium.
The reflection coefficient for the circuit shown in the following Figure can be expressed at different locations as:



$$\mathit{\Gamma}_L = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad (6)$$

$$\mathit{\Gamma}_S = \frac{Z_{in} - Z_S}{Z_{in} + Z_S} \qquad (7)$$

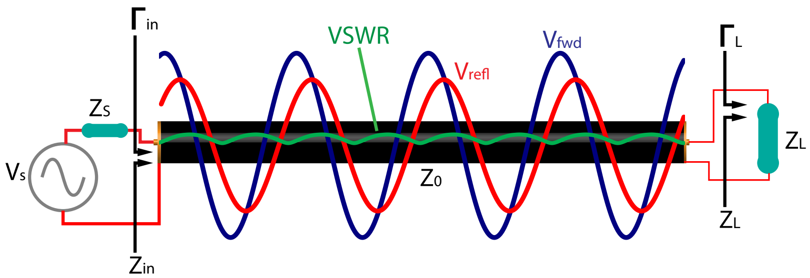
A reflection coefficient close to zero indicates a well-matched system where most of the energy is transferred to the antenna, while a reflection coefficient close to 1 or -1 indicates significant energy reflection due to poor impedance matching.

ANTENNA *continued...*

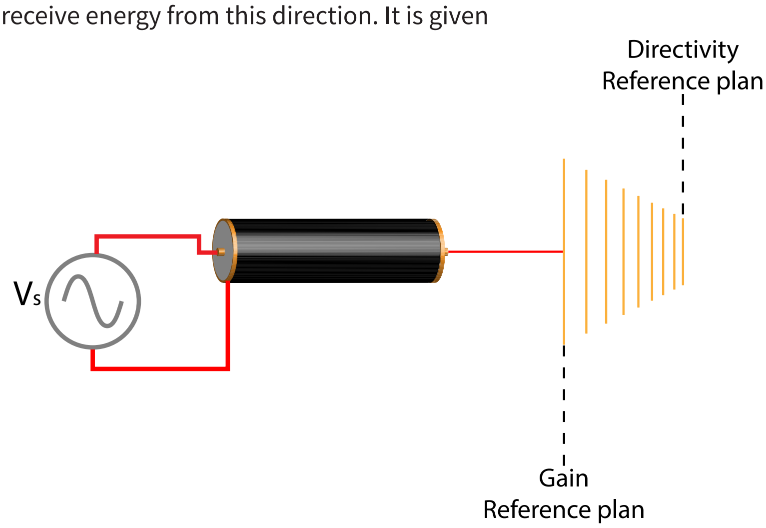
On the other hand, Voltage Standing Wave Ratio (VSWR) is a related parameter used to quantify the quality of impedance matching in an antenna system. VSWR is defined as the ratio of the maximum voltage to the minimum voltage along a transmission line connected to an antenna:
VSWR provides an indication of the efficiency of power transfer between the transmitter and the antenna. A VSWR of 1 indicates perfect impedance matching, while higher values indicate poor impedance matching and greater power loss due to reflections.
In summary, while both the reflection coefficient and VSWR provide insights into the impedance matching of an antenna system, the reflection coefficient specifically quantifies the ratio of reflected to incident power, whereas VSWR quantifies the ratio of maximum to minimum voltage along the transmission line.

$$VSWR = \frac{V_{\max}}{V_{\min}} \qquad (8)$$

Antenna Gain and Directivity



Directivity describes how much power is sent in the maximum power directions compared to lossless isotropic antenna (a fiction antenna where it radiates power equally in all directions without any loss.). For example, Ideal dipole antenna can radiate power in the Horizontal direction with 2.15 dB (64%) more power than the isotropic antenna. Directivity defines how well the antenna can concentrate its energy in one direction or receive energy from this direction. It is given relative to the isotropic antenna.



The radiation pattern is more directional as the Directivity increases. Usually, antenna have some losses and cannot send all energy received from a source to free space, or vice versa, with 100% efficiency. This efficiency is defined as the total power delivered to the antenna from a source to the total power radiated from the antenna. It does include also the mismatch loss which occur if the source is not matched to the antenna. Gain, hence, show how much power is sent from an antenna in its maximum peak of directivity. Gain is more common term because it includes the losses and can be directly related to power.

The gain can be calculated as: $G = e \cdot D$ (9)

ANTENNA *continued...*

Effective aperture

The effective aperture of an antenna is a measure of how well an antenna can capture electromagnetic energy from an incident wavefront and convert it into electrical power. It is directly related to the antenna's gain and is a critical parameter in determining the efficiency of an antenna in receiving signals. The effective aperture is calculated using

$$A_e = \frac{\lambda^2}{4\,\pi} G \qquad (10)$$

In EMC (Electromagnetic Compatibility) testing, the effective aperture is important because it influences the accuracy and sensitivity of measurements. High-gain antennas with larger effective apertures are better at detecting weak signals and can provide more precise measurements of electromagnetic emissions from devices under test. This is crucial for ensuring that the emissions do not exceed regulatory limits and for identifying potential sources of interference.

Radiation pattern

A radiation pattern is a graphical representation of the distribution of radiated energy from an antenna. It's a three-dimensional plot, but it's often simplified to a 2-dimensional plot in the horizontal and vertical planes. The radiation pattern of an antenna depends on several factors, including the frequency of the transmitted signal, the design of an antenna and the environment in which the antenna is operating.

Beamwidth

Beamwidth specifies the angular region or direction where the power meet defined value.

> Main lobe

The main lobe of an antenna radiation pattern is the direction in which the antenna radiates the most energy. The main lobe is typically the largest and most important loop in the radiation pattern.

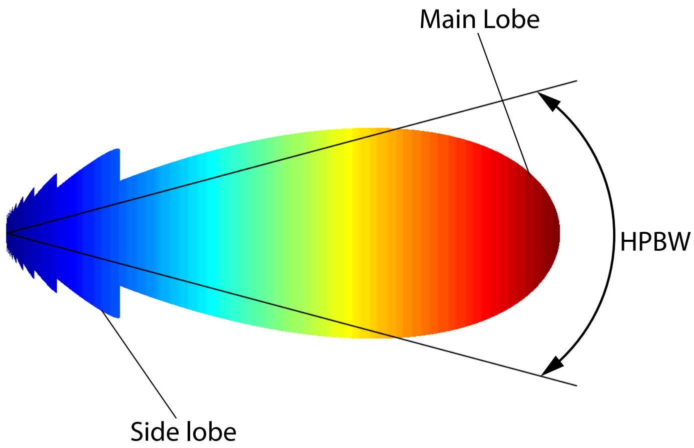
> Side lobe

side lobs are smaller lobes in the radiation pattern that radiate energy in directions other than the main lobe. Side lobes are typically unwanted and can cause interference with other antenna and systems.

ANTENNA *continued...*

> *Half power beamwidth*

Half power beamwidth (HPBW) is a measure of the angular width of the main lobe of an antenna's radiation pattern. The HPBW is defined as the angle between the two points on the main lobe where the power radiated is half of the maximum power radiated.
The HPBW is an important parameter of an antenna because it determines the directionality of the antenna another one HPBW indicates a directional antenna, while a wide HPBW indicates an omnidirectional antenna.



HPBW is important parameter for the antenna when it is used for radiated immunity to fulfil the homogeneous plane of power. However, wider half power beamwidth is achieved with lower gain, which requires high power for EMC immunity testing. Hence, a trade-off between gain and beamwidth must be taken carefully.

Polarization

Antenna polarization refers to the orientation of the electric field vector of the electromagnetic wave radiated by an antenna. It describes the direction in which the electric field oscillates as the wave propagates through space. The three main types of polarization are:

1. Linear Polarization:
   Vertical Polarization: The electric field vector oscillates in a plane perpendicular to the Earth's surface (vertical direction).
   Horizontal Polarization: The electric field vector oscillates parallel to the Earth's surface (horizontal direction).
2. Circular Polarization:
   Right-Hand Circular Polarization (RHCP): The electric field vector rotates in a right-hand (clockwise) direction as the wave propagates.
   Left-Hand Circular Polarization (LHCP): The electric field vector rotates in a left-hand (counterclockwise) direction as the wave propagates.
3. Elliptical Polarization:
   A combination of linear and circular polarization, where the electric field vector traces an ellipse in the plane perpendicular to the direction of propagation.

ANTENNA *continued...*

In EMC testing, standards require the use of a linearly polarized antenna, with measurements taken in both vertical and horizontal polarizations by rotating the antenna by 90 degrees. This ensures a comprehensive assessment of electromagnetic emissions and susceptibilities, capturing emissions and responses in all possible orientations for accurate and reliable results. To ensure thorough EMC testing, both horizontal and vertical polarizations are typically tested. This helps to capture emissions and susceptibilities in all possible orientations, providing a comprehensive assessment of the device's EMC performance.

It is worth noting that even if the antenna has a dominant polarization, it will still send/receive power on the other polarization. This term is called cross polarization. So, if a horizontally polarized antenna has a cross polarization of -25 dB as in CBL 6112D, it will receive a signal in the vertical polarization 25 dB lower than the horizontal polarized signal.

RADIATED AND RECEIVED POWER

Radiated power is the total electromagnetic power emitted by an antenna into the surrounding space. It is a fundamental parameter in determining an antenna's effectiveness in transmitting signals.
The power transmitted from an antenna spreads out depending on its radiation pattern. The radiation intensity at a distance r is given by the power radiated in the direction of maximum gain divided by the surface area of the sphere of radius r, and is given by:

$$P_d = \frac{P_t \cdot G_t}{4\,\pi\, r^2} \qquad (11)$$

The radiated electric and magnetic fields can be found by substituting (4) in (11):

$$E_t = \frac{\sqrt{30 P_t G_t}}{r} \qquad \text{Or} \qquad H_t = \frac{\sqrt{P_t G_t/30}}{4\pi r} \qquad (12)$$

Let's assume that at distance R there is a receiving antenna. The received power, hence, is the power density at that distance multiplied by the effective area of the receiving antenna:

$$P_r = P_d \cdot A_{er} = P_d \cdot \frac{\lambda^2 G_r}{4\,\pi} \qquad (13)$$

Then the receiving power can be calculated from the field components. From (4) in (13)

$$P_r = \frac{E_r^2}{120\,\pi} \cdot \frac{\lambda^2 G_r}{4\,\pi} = \frac{E_r^2 \lambda^2 G_r}{480\,\pi^2} \qquad \text{Or} \qquad P_r = 120\,\pi \cdot H_r^2 \cdot \frac{\lambda^2 G_r}{4\,\pi} = 30 H_r^2 \lambda^2 G_r \qquad (14)$$

Friis transmission equation

The Friis transmission equation calculates the power received by one antenna when another antenna transmits power to it, accounting for the gains of both antennas and the distance between them. It is crucial for understanding the link budget in communication systems to calculate the power between the base station and receiver. It can be derived by applying (11) in (13)

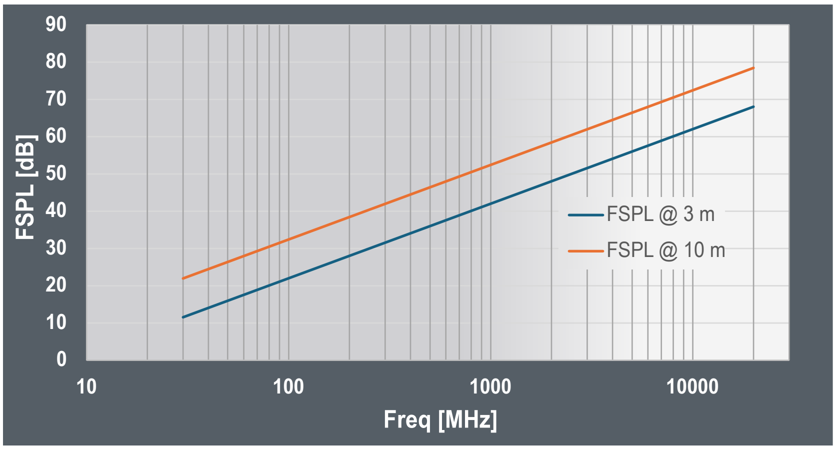
$$\frac{P_r}{P_t} = \frac{G_t \cdot G_r \cdot \lambda^2}{(4\pi r)^2} \qquad (15)$$

RADIATED AND RECEIVED POWER *continued...*

This equation shows that if the received power decreases by 4 times (6 dB) when the received antenna is moving apart from the transmitter. Additionally, the same is valid if the frequency doubles. That is why in EMC testing, it is important to have a high Gain antenna for higher frequencies. The losses due to frequency and distance in (15) Is referred to as a free path loss (only accounts for one path losses), which is given by:

$$FPL = \left(\frac{\lambda}{4\pi r}\right)^2 = \left(\frac{c}{4\pi r f}\right)^2 \qquad (16)$$

It is worth noting that (16) does not count the losses due to polarization and the absorption or dispersion by the atmosphere.



Antenna factor

The antenna factor (AF) is a conversion factor that relates the field strength component received by an antenna to the voltage produced at its terminals. It is a critical parameter in EMC testing for converting between the measured voltage and the corresponding electric field strength.
For electric field it has a unit of m^(-1) and for magnetic field it has a unit of Ωm^{-1} or S/m

$$AF_E = \frac{E}{V} \quad \text{Or} \quad AF_H = \frac{H}{V} \qquad (17)$$

The received power is calculated using (18)

$$P_r = \frac{V_r^2}{Z_r} \qquad (18)$$

For 50 Ω system and using (14) in (18), the electric and magnetic field antenna factor become:

$$AF_E = \frac{\sqrt{4\pi\eta/50}}{\lambda\sqrt{G_r}} = \frac{9.73}{\lambda\sqrt{G_r}} = \frac{E_r}{V_r} \quad \text{Or} \quad AF_H = \frac{\sqrt{4\pi/50}}{\lambda\sqrt{\eta G_r}} \frac{1}{38.73\lambda\sqrt{G_r}} = \frac{H_r}{V_r} \qquad (19)$$

The conversion between electric and magnetic antenna factor is:

$$AF_E = AF_H \cdot \eta \qquad (20)$$

RADIATED AND RECEIVED POWER *continued...*

Antenna Factor in Far Field (Transmit Antenna Factor)

Transmit antenna factor (TAF) is a measure of how well an antenna converts electrical signal into electromagnetic waves. It is defined as the ratio of the transmitted field strength component to the input voltage of the antenna. TAF has the same unit as the AF.
Similar to the received power in (18), the transmit power is calculated as:

$$P_t = \frac{V_t^2}{Z_t} \qquad (21)$$

Substituting (21) in (12) the transmit Electric and magnetic field at a distance of r is calculated using:

$$E_t = \frac{\sqrt{30V_t^2 G_t / Z_t}}{r} \quad \text{Or} \quad H_t = \frac{\sqrt{V_t^2 G_t / (30 \cdot Z_t)}}{4\pi r} \qquad (22)$$

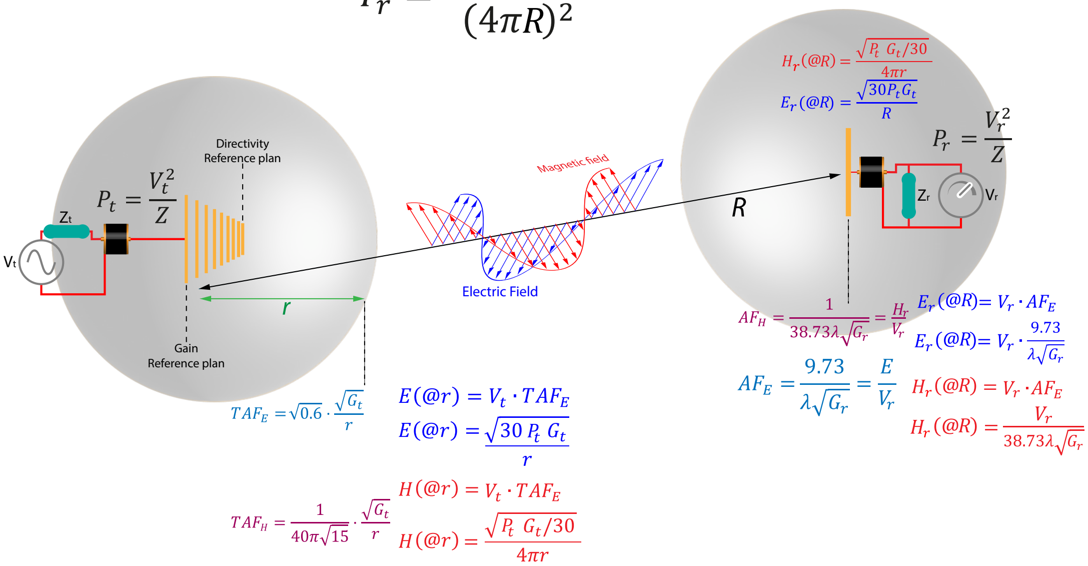
Rearranging (22) and calculating for 50 Ω system, the transmitted antenna factor for magnetic and electric field become:

$$TAF_E = \frac{E_t}{V_t} = \sqrt{0.6} \cdot \frac{\sqrt{G_t}}{r} \quad \text{Or} \quad TAF_H = \frac{H_t}{V_t} = \frac{1}{40\pi\sqrt{15}} \cdot \frac{\sqrt{G_t}}{r} \qquad (23)$$

The Friis equation can be written as (24) if both antenna factor is known:

$$\frac{P_r}{P_t} = \left(\frac{TAF_E}{AF_E}\right)^2 = \left(\frac{TAF_H}{AF_H}\right)^2 \qquad (24)$$

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2}$$



RADIATED AND RECEIVED POWER *continued...*

The Gain for the receiver antenna can be found from the antenna factor in (19) as:

$$G_r = \frac{4\pi\eta}{50\lambda^2 \cdot AF_E^2} \quad \text{Or} \quad G_r = \frac{1}{30 \cdot 50\lambda^2 \cdot AF_H^2} \qquad (25)$$

Similarly, the gain for the transmit antenna can be found from the transmit antenna factor in (23) as:

$$G_t = \frac{50}{30} \cdot r^2 \cdot TAF_E^2 \quad \text{Or} \quad G_t = 15(40\pi)^2 \cdot r^2 \cdot TAF_H^2 \qquad (26)$$

The antenna factor and the transmit antenna factor are two different terms for the same antenna. The gain for one antenna is similar in the transmit or receive mode, i.e. G_t=G_r=G. Hence, from (25) and (26) both antenna factor can be related to each other as in (27):

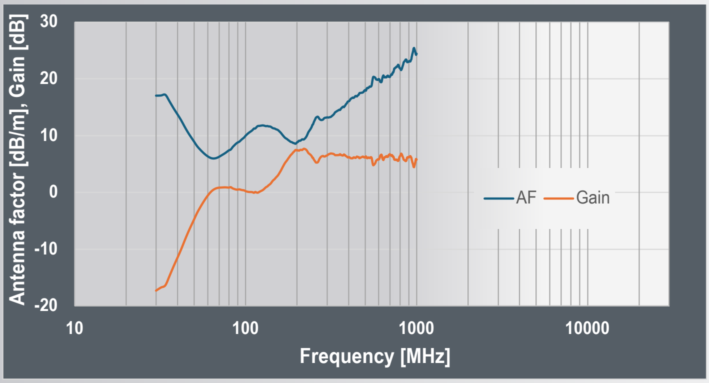
$$TAF_E = \left(\frac{12\pi}{5\lambda \cdot r \cdot AF_E}\right) \quad \text{Or} \quad TAF_H = \left(\frac{1}{6000\pi\lambda \cdot r \cdot AF_H}\right) \qquad (27)$$

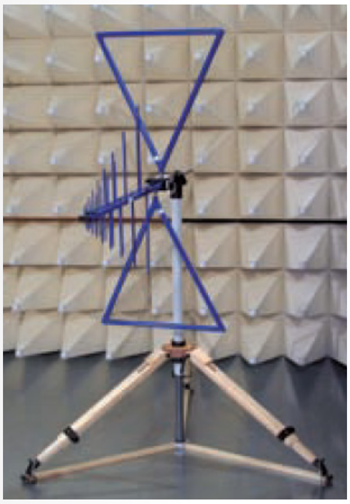
EXAMPLE 1: IMMUNITY USING CBL6111D

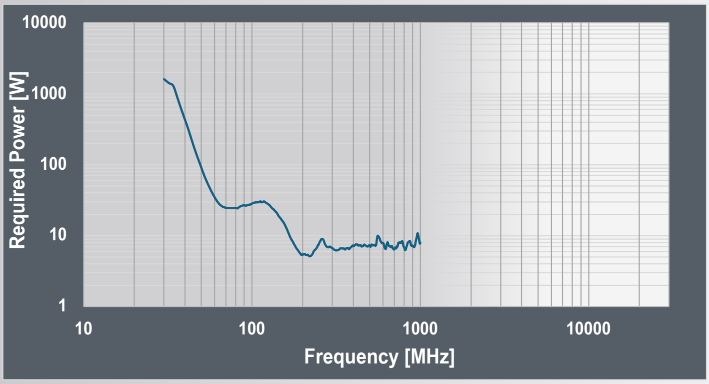
EXAMPLE

IEC 61000-4-3 addresses the testing and measurement techniques for assessing the immunity of electrical and electronic equipment to radiated radio-frequency electromagnetic fields from 80 MHz to 6 GHz. IEC 61000-4-3 specifies different test levels for evaluating the immunity of electrical and electronic equipment to radiated radio-frequency electromagnetic fields. AMETEK CTS offers different antenna for this standard. For example, the antenna CBL 6111D is an ultra-wideband BiLog combining two antennas in one, is suitable for both emission and immunity testing. It works from 30 MHz to 1 GHz. The antenna Gain and its Electric antenna factor is shown in the following figure.

For level 3 (10 V/m) test according to IEC 61000-4-3, the required power is shown in the following figure.



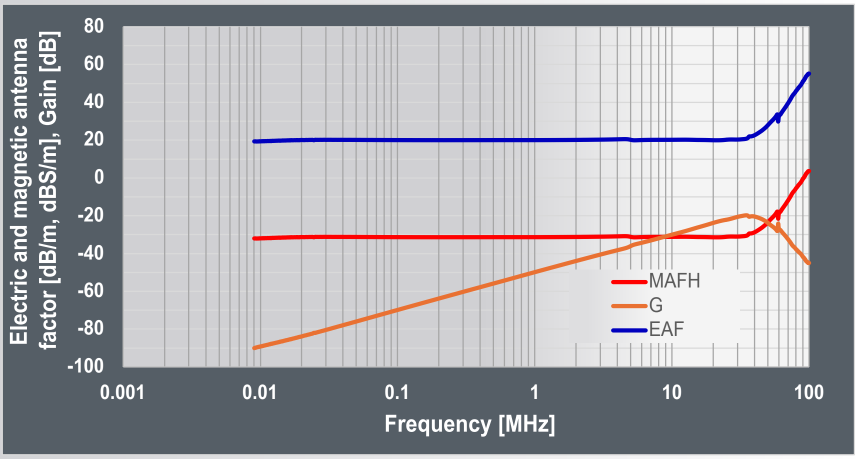




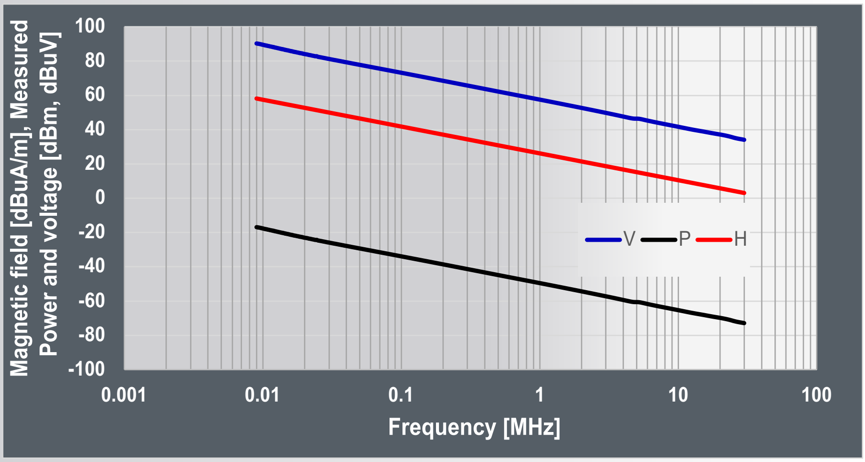
EXAMPLE 2: EMISSION TESTING ACCORDING TO CISPR 11

EXAMPLE

CISPR 11 specifies limits and methods of measurement for the radio frequency disturbances generated by industrial, scientific, and medical (ISM) equipment. It sets the permissible emission levels of electric and magnetic field strength to ensure that ISM equipment does not interfere with radio communications and other electronic devices.
A suitable loop antenna for magnetic field strength in the frequency from 150 kHz to 30 MHz is offered by AMETEK CTS. The active loop antenna HLA 6121 has a constant factor over the whole its operating frequency range, making it ideal for swept measurement systems. The HLA 6121 has another version for outdoor use. The typical characteristic is shown in the following figure.



For class B group 2 equipment measured on a test site, CISPR 11 define a maximum magnetic field as shown the following figure



The measured power and voltage at the receiver with this limit is shown also in the graph. Due to the constant antenna factor of the HLA 6121, it can be seen that the measured level is linearly proportional to the limit magnetic field level, which makes it convenient to use this antenna for this type of measurements.

ANNEX I LOGARITHMIC EQUATION

ANNEX I

Measuring the electrical parameters in RF usually is represented in logarithmic scale. Using a logarithmic scale in RF (Radio Frequency) measurements offers several advantages:

1. **Wide Dynamic Range:** RF signals often have a wide range of power levels. A logarithmic scale, such as decibels (dB), can represent both very large and very small values compactly, making it easier to analyze signals with a wide dynamic range.
2. **Multiplicative Relationships:** RF systems often involve multiplicative processes, such as gain, attenuation, and power ratios. A logarithmic scale converts these multiplicative relationships into additive ones, simplifying calculations. For example, combining gains or losses is easier in dB since you can simply add or subtract the dB values.

Basic parameters

The power is usually represented in dBm which means power relative to 1 mW. For example, 20 dBm is 100 100 times above 1 mW.

$$P[dBm] = 10\log_{10}\frac{P[W]}{0.001} = 10\log_{10}P[W] + 30 \qquad \text{(I. 1)}$$

In EMC testing, the voltage and current are usually represented in dBµV and in dBµA. This allows more precision and is suitable for low values in the EMC world.

$$V[dB\mu V] = 20\log_{10}\frac{V[V]}{10^{-6}} = 20\log_{10}V[V] + 120 \qquad \text{(I. 2)}$$

$$I[dB\mu A] = 20\log_{10}\frac{I[A]}{10^{-6}} = 20\log_{10}I[A] + 120 \qquad \text{(I. 3)}$$

The reason for using factor 20 in the (I.2) and (I.3) for converting voltage to decibels (dB) is rooted to the fact that power is proportional to the square of voltage or current in electric circuits and the calculations based on power.

The power in logarithmic scale can be calculated using:

$$P[dBm] = 10\log_{10}\frac{V^2[V]}{Z[\Omega]} + 30 = \underbrace{V[dB\mu V] - 120}_{\text{to convert from dBµV to dBV}} - 10\log_{10}Z[\Omega] + 30 = V[dB\mu V] + 10\log_{10}Z[\Omega] - 90 \qquad \text{(I. 4)}$$

Similarly with current, the power is given as:

$$P[dBm] = 10\log_{10}(I^2[A]\cdot Z[\Omega]) + 30 = I[dB\mu A] + 10\log_{10}Z[\Omega] - 90 \qquad \text{(I. 5)}$$

For 50 Ω System (I.4) and (I.5) can be written as:

$$P[dBm] = V[dB\mu V] - 107 \qquad \text{(I. 6)}$$
$$P[dBm] = I[dB\mu A] - 73 \qquad \text{(I. 7)}$$

Converting between current and voltage is shown here:

$$V[dB\mu V] = 20\log_{10}(I[A]\cdot Z[\Omega]) + 120 = I[dB\mu A] + 20\log_{10}Z[\Omega] = I[dB\mu A] + 34 \qquad \text{(I. 8)}$$

ANNEX I

ANNEX I LOGARITHMIC EQUATION

Field Strength

Similar to the voltage and current, the field strength is also represented in dBµV/ and dBµA/m.

$$E[dB\mu V/m] = 20\log_{10} E[V/m] + 120 \qquad (I.\ 9)$$
$$H[dB\mu A/m] = 20\log_{10} H[A/m] + 120 \qquad (I.\ 10)$$

Hence the power density of (4) becomes:

$$P_d[dBmW/m^2] = 10\log_{10}\frac{E^2[V]}{\eta[\Omega]} + 30 = E[dB\mu V/m] - 120 - 10\log_{10} 120\pi + 30 = E[dB\mu V/m] - 115.8 \qquad (I.\ 11)$$
$$P_d[dBmW/m^2] = H[dB\mu A/m] - 64.2 \qquad (I.\ 12)$$

Converting between the electric and magnetic field strength in Far field is calculated as:

$$E[dB\mu V/m] = 20\log_{10}(H[A]\cdot\eta[\Omega]) + 120 = H[dB\mu A/m] + 20\log_{10}\eta[\Omega] = H[dB\mu A/m] + 51.5 \qquad (I.\ 13)$$

Antenna Relationships in far field

The gain, directivity and effective area are all related to power. Hence, all the parameters are calculated in logarithmic with a factor of 10, i.e., $G[dB] = 10\log_{10} G$.
Power density of (11) can be written as

$$P_d[dBmW/m^2] = P_t[dBm] + G_t[dB] - 20\log_{10} r[m] - 11 \qquad (I.\ 14)$$

From (I.11) in (I.14) and (I.12) in (I.14) the electric and magnetic field can be written as:

$$E_t[dB\mu V/m] = P_t[dBm] + G_t[dB] - 20\log_{10} r[m] + 104.8 \qquad (I.\ 15)$$
$$H_t[dB\mu A/m] = P_t[dBm] + G_t[dB] - 20\log_{10} r[m] + 53.2 \qquad (I.\ 16)$$

The power received by an antenna is related to the received field strength from (14).

$$P_r[dBm] = E_r[dB\mu V/m] + G_r - 20\log f[MHz] - 77.2 \qquad (I.\ 17)$$
$$P_r[dBm] = H_r[dB\mu A/m] + G_r - 20\log f[MHz] - 25.7 \qquad (I.\ 18)$$

Rearranging (I.15) and (I.16), and using the equation of power from (I.6) The antenna factor is then:

$$AF_E[dB/m] = E[dB\mu V/m] - V[fB\mu V] = 20\log f[MHz] - G_r - 29.8 \qquad (I.\ 19)$$
$$AF_H[dBS/m] = H[dB\mu A/m] - V[fB\mu V] = 20\log f[MHz] - G_r - 81.3 \qquad (I.\ 20)$$

Similarly, the transmit antenna factor is given by:

$$TAF_E[dB/m] = G_t - 20\log r[m] - 2.2 \qquad (I.\ 21)$$
$$TAF_H[dBS/m] = G_t - 20\log r[m] - 53.7 \qquad (I.\ 22)$$

The conversion between the Transmit antenna factor and the antenna factor can be shown below:

$$TAF_E[dB/m] = 20\log f[MHz] - 20\log r[m] - AF_E[dB/m] - 32 \qquad (I.\ 23)$$
$$TAF_H[dBS/m] = 20\log f[MHz] - 20\log r[m] - AF_H[dB/m] - 135 \qquad (I.\ 24)$$

EXAMPLE: PRACTICAL CALCULATIONS FOR THE REQUIRED POWER AS IN IEC 61000-4-3

EXAMPLE

Let's take a practical example. Assume a transmit antenna sends a signal at 1000 MHz with a gain of 1.64 as in dipole antenna. It is required to receive an electric field of 10 V/m at 3 m distance away from antenna. To find the required power transmit power, we can calculate either in logarithmic or in linear scale:

Parameter given:

Gain = 1.64 = 2.1 dB
Frequency = 1000 MHz = 60 dBMHz
Electric field = 10 V/m = 140 = dBµV/m
Magnetic field = 26.5 mA/m = 88.5 dBµA/m

The transmit antenna factors can be calculated from (27) and (I.23) or (I.22):

TAF_E=331.4 mm^{-1} =-9.61 dB/m
TAF_H=879.0 µS/m = -61.1 dBS/m

The transmit voltage and power is calculated from (23)

V_t=30.2 V = 149.6 dBµV
P_t=18.2 W = 42.6 dBm

The power can also be calculated using (12) and it will give the same result.

If we place an antenna similar to the BiLog Antenna from AMETEK CTS (CBL 6112D) at this distance with gain of 6.3 (8 dB), the antenna factors are calculated from (19), (I.19) and (I.20):

AF_E = 12.9 m^{-1} = -22.2 dB/m
AF_H = 34.3 mS/m = -29.3 dBS/m

Hence, the received voltage can be calculated as in (17):

V_r = 775.6 mV = 117.8 dBµV
P_r = 12.0 mW = 10.8 dBm

If the distance between both antennas is increased to 10 m, then the transmit antenna factor will reduces to:

TAF_E = 99.4 mm^{-1} = -20 dB/m
TAF_H = 263.7 µS/m = -71.6 dBS/m

And the required transmit voltage and power is:

V_t = 100.6 V = 160.1 dBµV
P_t = 203.4 W = 53.1 dBm

If the received and transmit antennas are similar with 8 dB and the distance is 10 m, then the Transmit antenna factors are:

TAF_E = 194.8 m/m = -14.2 dB/m
TAF_H =516.8 µS/m = -65.7 dBS/m

And the required transmit voltage and power for the 10 V/m at a distance of 10 m is:

V_t = 51.3 V = 154.2 dBµV
P_t =52.7 W = 47.2 dBm

CONTACT US.

Care to learn more about AMETEK CTS?
We look forward to speaking with you!

Sales & Service Centers

China
AMETEK Commercial Enterprise
(Shanghai) Co. Ltd. Beijing Branch
Western Section, 2nd Floor
Jing Dong Fang Building (B10)
Chaoyang District
Beijing, China, 100015
T +86 10 8526 2111
sales.cts.cn@ametek.com

Shanghai Office:
Part A1, A4, 2nd floor, Building No. 1
No. 526 Fute 3rd Road East
Pilot Free Trade Zone, Shanghai
200131, China
T +86 21 5868 5111

Guangzhou Office:
Room 810, Dongbao Plaza
No. 767, Dongfengdong Road
Yuexiu District, Guangzhou, China
T +86 20 8363 4768

Europe
AMETEK CTS Europe GmbH
Rünther Str. 120
59192 Bergkamen
Deutschland
T +49 2307 26070-0
sales.cts.eu@ametek.com

Japan
AMETEK Co. Ltd.
Tokyo office
3rd floor, Shiba NBF Tower,
1-1-30 Shiba-Daimon, Minato-ku
Tokyo, 105-0012, Japan
T +81 3 6809 2401

AMETEK Co. Ltd.
Nagoya Office
1-329 Kifune Meito-ku Nagoya-shi
Aichi-ken, 465-0058, Japan
T +81 52 709 5501
cts-japan.sales@ametek.com

Singapore
AMETEK Singapore Pte. Ltd.
No. 43 Changi South Avenue 2
#04-01 Singapore 486164
T +65 6484 2388
singaporesales.cts@ametek.com

Taiwan
AMETEK Taiwan Corp. Ltd.
10F-5, No. 120, Sec 2,
GongDaoWu Rd.,
Hsinchu City 30072, Taiwan
T +886 3 57 5099
tw-hsn.cts@ametek.com

USA
AMETEK CTS US
160 Schoolhouse Rd
Souderton, PA 18964
T +1 732 417 0501
For free: +1 888 417 0501
usasales.cts@ametek.com

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