What is Signal Leakage Field Strength?

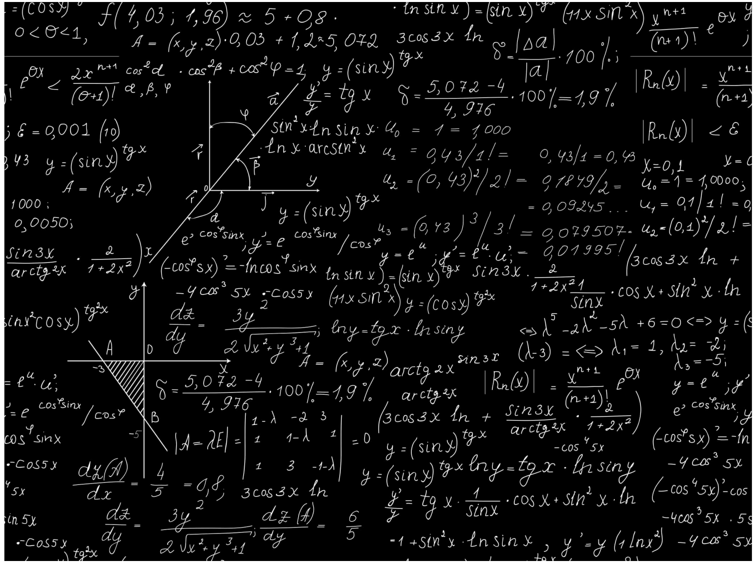
Ron Hranac

What is Field Strength?

- The measurement of signal leakage field strength often is taken for granted. The procedure is fairly straightforward: Using a dedicated leakage detector with a resonant half-wave dipole antenna (or equivalent), orient the antenna to get a maximum reading and see what value the leakage detector reports.
- The measured field strength is stated in microvolts per meter (µV/m),[1] and hopefully is below the maximum limit defined by the FCC.

1. Outside of the North American cable industry, field strength measurements are more commonly stated in decibel microvolt per meter, or dBµV/m.

Uh-oh…



What is Field Strength?

The field strength in µV/m can be converted to a dBmV value at the dipole antenna’s terminals using the formula

$$dBmV = 20log_{10}\left[\frac{\left(\frac{E_{\mu V/m}}{0.021 * f}\right)}{1000}\right]$$

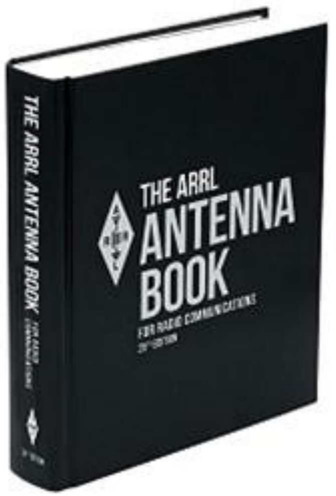
where $E_{\mu V/m}$ is the field strength in microvolts per meter, and f is frequency in MHz.

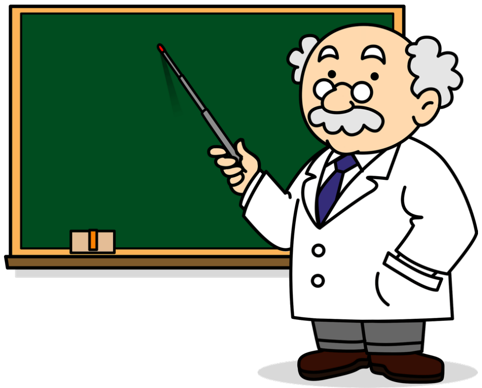
But that still doesn’t explain what field strength is.

What is Field Strength?

From the *ARRL Antenna Book for Radio Communications, 25th Edition*:

“A measurement of the strength of a wave at a distance from the transmitting antenna is its field strength (or field intensity).”





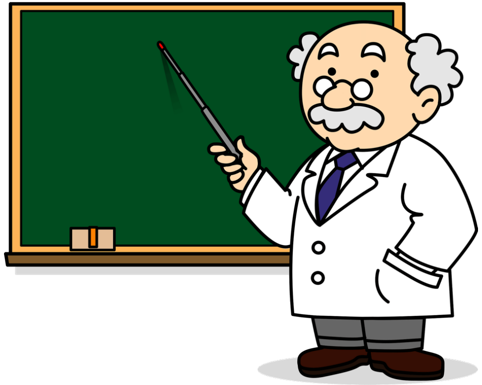
What is Field Strength?

From https://www.giangrandi.org/electronics/anttool/rx-field.shtml

"…the strength of an electromagnetic wave can be expressed in terms of electric field strength E (measured in V/m), or magnetic field strength H (measured in A/m) or of power density S (measured in W/m²). The most common is the electric field strength, but in the far field region, they are all equivalent and related by the following two equations:

$$E = Z_0 * H \quad \text{and} \quad S = \frac{E^2}{Z_0} = Z_0 * H^2$$

Where Z_0 is the characteristic impedance of vacuum that is $Z_0 = 120\pi\ \Omega \ \approx 377\ \Omega$"

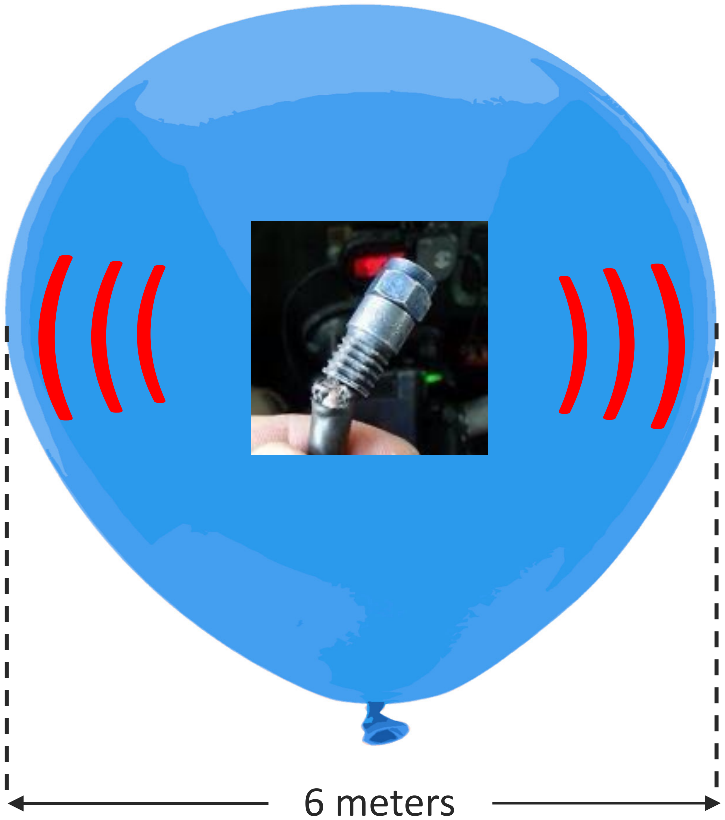


What is Field Strength?

Visualize an improperly installed connector radiating RF into the space around it.

What is Field Strength?

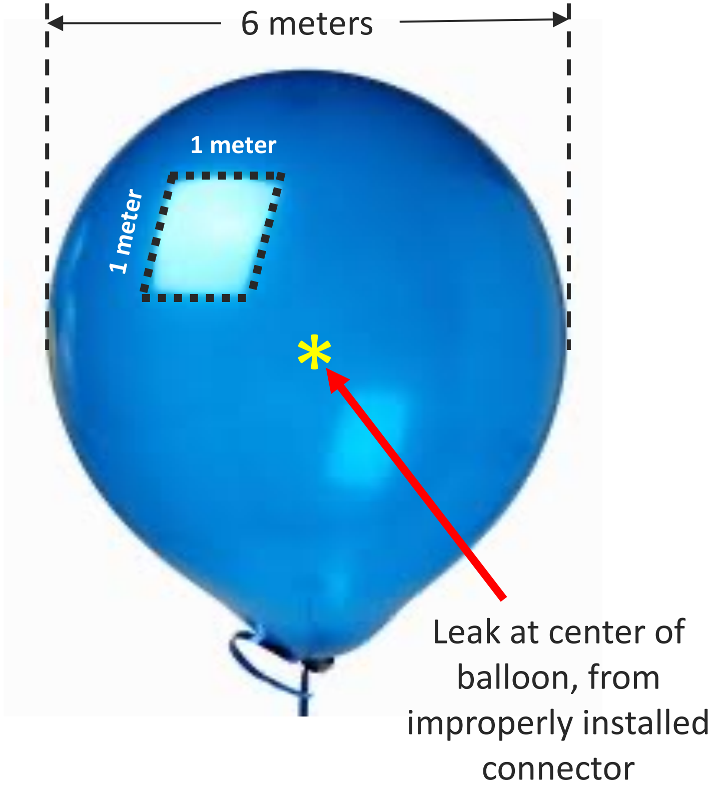
- Now imagine a 6 meters diameter balloon surrounding the improperly installed connector, with the connector at the center of the balloon.
- Assume the RF leaking from the connector is uniformly "illuminating" the entire surface of the balloon from the inside.



What is Field Strength?

Next, imagine a 1 meter x 1 meter square drawn somewhere on the surface of the balloon. The task at hand is to measure the RF power density in within the 1 meter x 1 meter square.

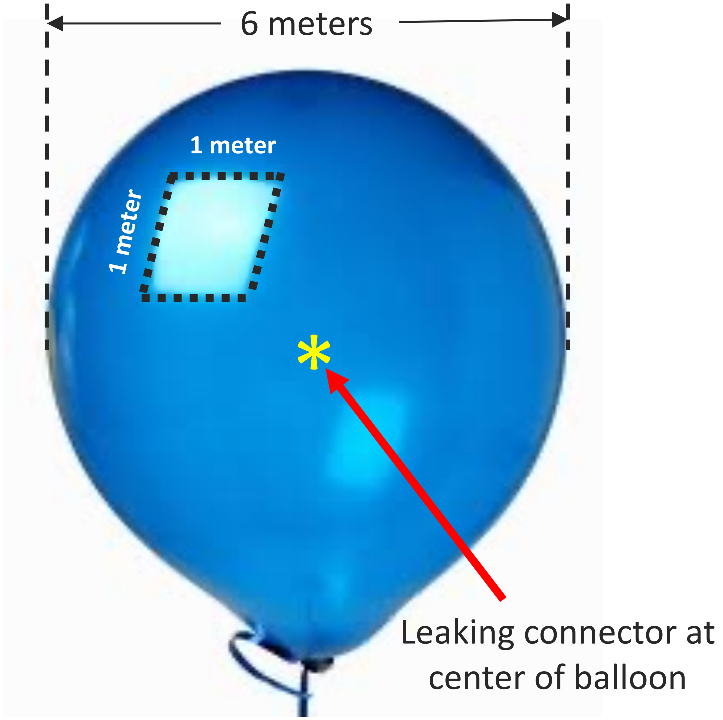
Note: Power density is the power per unit area. As mentioned previously, power density is typically measured in watts per square meter, or W/m^2 (it's also measured in units such as milliwatts per square centimeter, or mW/cm^2).



What is Field Strength?

Let’s call the RF power transmitted (leaked) by the improperly installed connector in the center of the balloon the source power, and designate it P_t.

Assume P_t = 0.00000000012 watt or $1.2 * 10^{-10}$ watt.

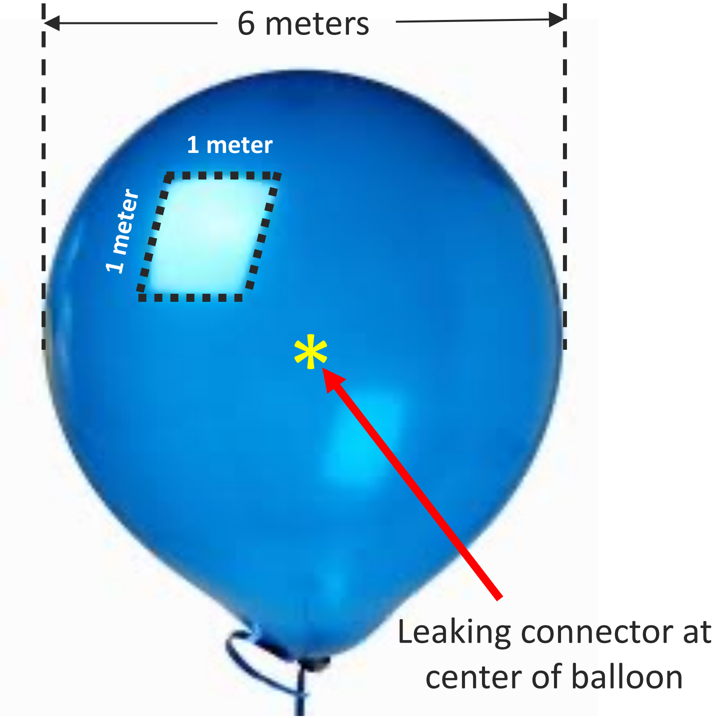


What is Field Strength?

Because the RF source power P_t is uniformly illuminating the entire balloon (an analogy is a light bulb at the center of the balloon), the power density P_d on the surface of the balloon in watts per square meter is simply the source power P_t divided by the surface area of the balloon (assumed for this example to be spherical), or

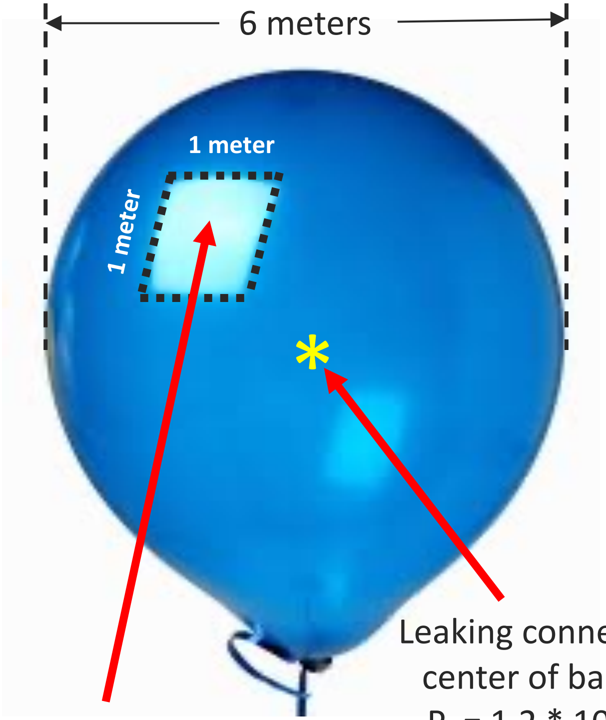
$$P_d = \frac{P_t}{4\pi r^2}$$

where r is the radius of the balloon, or 3 meters.



What is Field Strength?

Plugging the just-discussed values for P_t and r into the previous formula, the calculated power density on the surface of the balloon is equal to about $1.06 * 10^{-12}$ watt per square meter (the actual value is 0.00000000000106103295 W/m²).



P_d on the surface of the balloon is about $1.06 * 10^{-12}$ W/m²

Leaking connector at center of balloon, $P_t = 1.2 * 10^{-10}$ W

What is Field Strength?

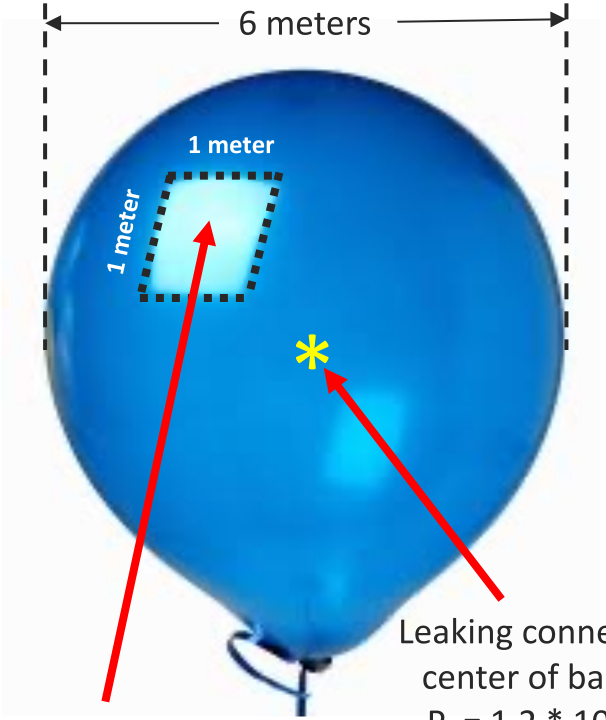
The impedance Z_0 of free space is 120π ohms, or about 377 ohms. Using the formula

$$E = \sqrt{P_d Z_0}$$

the voltage E on the surface of the balloon in volts per meter (V/m) is

$$E = \sqrt{([1.06103295 * 10^{-12} watt] * 120\pi)}$$

= 0.000020 volt per meter, or 20 µV/m.



P_d on the surface of the balloon is about $1.06 * 10^{-12}$ W/m²

Leaking connector at center of balloon, $P_t = 1.2 * 10^{-10}$ W

What is Field Strength?

- Things get confusing when measuring leakage on more than one frequency. Assuming the same field strength – say, 20 µV/m – at two frequencies and the use of separate resonant half-wave dipoles for the measurements, the dBmV values at the two dipoles' terminals will be different.
- For example, a field strength of 20 µV/m at 121.2625 MHz will produce -42.1 dBmV at the terminals of a resonant half-wave dipole for that frequency. A field strength of 20 µV/m at 782 MHz will produce -58.29 dBmV at the terminals of a resonant half-wave dipole for that frequency.
- The field strength is the same for both frequencies (20 µV/m), as is the power density ($1.06 * 10^{-12}$ W/m^2), yet the dBmV values at the terminals of the two dipoles are different!

What's going on?

Let’s Start With the Following Assumptions:

Measurement frequencies are 121.2625 MHz and 782 MHz
Antennas for the two frequencies are lossless resonant half-wave dipoles
Field strength at the point of measurement is 20 µV/m for both frequencies
Measurement distance from the leak is 3 meters, which is in the far-field for both frequencies
Each antenna is terminated by a load equal to its radiation resistance (approximately 73 ohms for a half-wave dipole)
Each dipole is oriented for maximum received signal level
Each antenna does not re-radiate any of the intercepted signal
The polarization of the RF coming from the leak is linear and is the same as the orientation of the dipoles when the field strength measurements are made

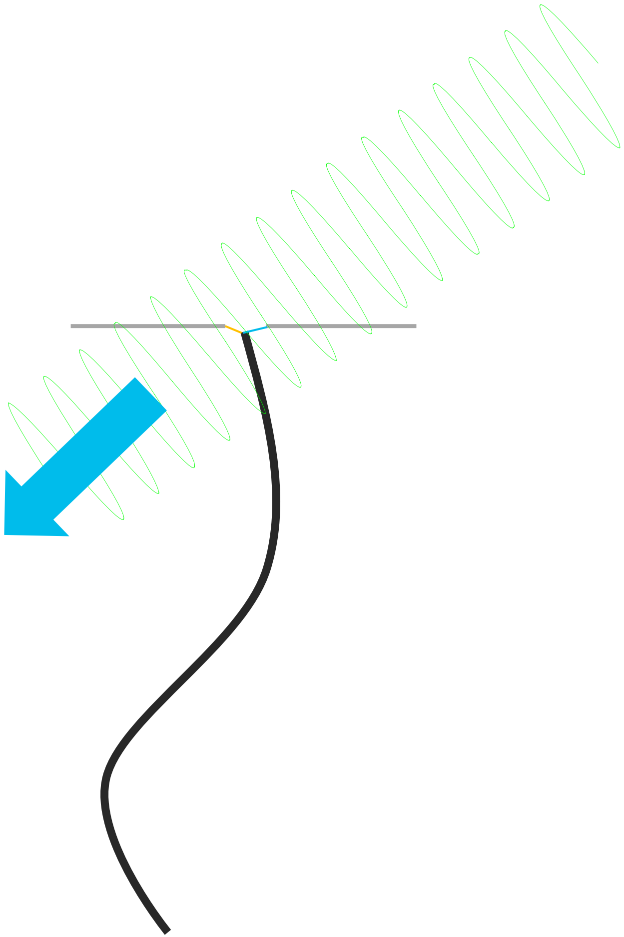
What is Field Strength?

- To find out what's going on, let's start by placing the resonant half-wave dipoles one at a time on the 1 meter x 1 meter square on the balloon, and the field strength within that square measured.

- The question is how much of the power in the square is intercepted by each dipole and delivered to the load connected to each antenna's terminals? All of it? Only an amount occupying an area equal to the physical dimensions of each antenna? Or some other amount?

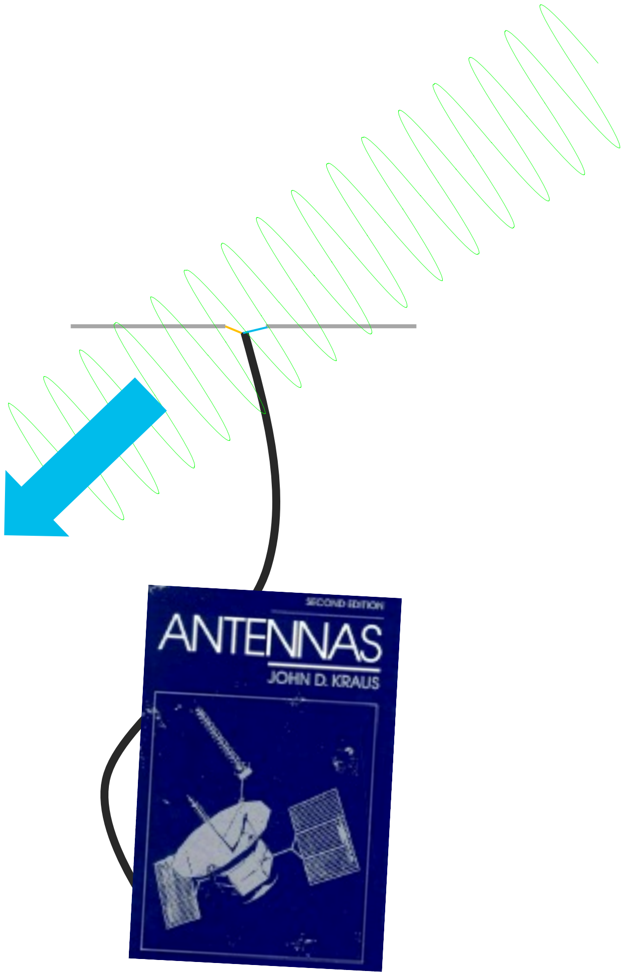
What is Field Strength?

- Visualize what happens when a dipole is placed at the surface of the balloon, where RF from the improperly installed connector 3 meters away is passing by at the speed of light. The RF field induces a voltage *V* in the dipole, resulting in a current *I* through the ~73 ohms impedance at the antenna terminals.
- What's of interest is the power *P* delivered by the antenna to that impedance, where $P = I^2 R_T$. Here R_T is the sum of the antenna's radiation resistance (~73 ohms) and loss resistance, the latter assumed to be zero for this example.



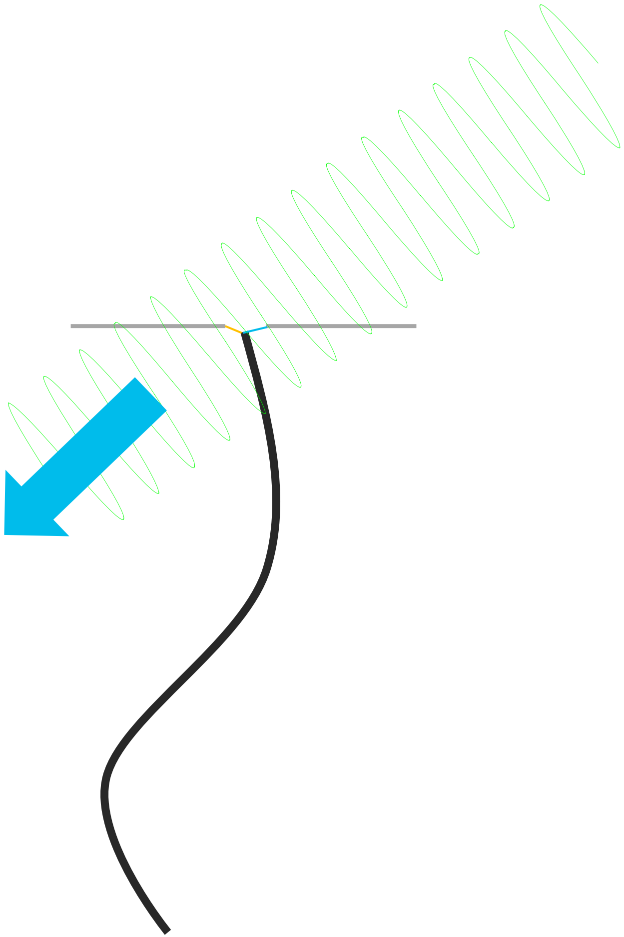
Antenna Aperture

- A dipole antenna can be regarded as an aperture with a specific area that extracts power from a passing wave and delivers it to the load connected to the antenna terminals. Defining aperture isn’t quite as simple as one might assume, though.
- According to the book *Antennas* (J. Kraus), three types of aperture describe “…ways in which power collected by the antenna may be divided: into power in the terminal resistance (effective aperture); into heat in the antenna (loss aperture); or into reradiated power (scattering aperture).”



Antenna Aperture

A fourth aperture, called collecting aperture, is the sum of the three previous apertures. Finally, physical aperture is basically "a measure of the physical size of the antenna," but surprisingly doesn't have all that much to do with how much power is intercepted by an antenna.

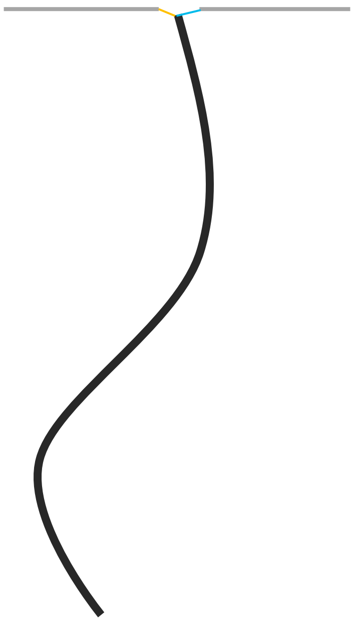


Antenna Aperture

Since the dipoles in this example are assumed to be lossless, effective aperture – more specifically, maximum effective aperture A_{em} – is the criteria that can be used to describe how much of the RF power in the 1 meter x 1 meter square is intercepted and delivered to the load at the antenna terminals. Mathematically

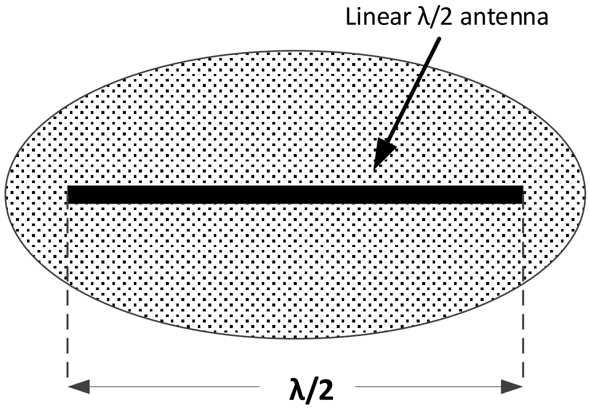
$$A_{em} = (\lambda^2/4\pi)G$$

where λ is wavelength in meters ($299.792458/f_{MHz}$) and G is the antenna's numerical gain (1.64 for a half-wave dipole).



Antenna Aperture

A linear half-wave dipole's maximum effective aperture is an elliptically shaped aperture with an area equal to $0.13\lambda^2$, as shown in the graphic.



Antenna Aperture

The free-space wavelength for 121.2625 MHz is approximately 2.47 meters (2.47226024534) and for 782 MHz is approximately 0.38 meter (0.383366314578). Plugging these numbers into the previous formula gives a maximum effective aperture A_{em} of 0.797668339532 m^2 for the 121.2625 MHz dipole, and 0.0191805865422 m^2 for the 782 MHz dipole. The A_{em} values denote what percentage of the power within the 1 meter x 1 meter square is intercepted by each dipole and delivered to the load at the antenna terminals. The difference between the two A_{em} values in decibels is

$$10log_{10}\left({A_{em}}^{(dipole\ 1)}/{A_{em}}^{(dipole\ 2)}\right)$$

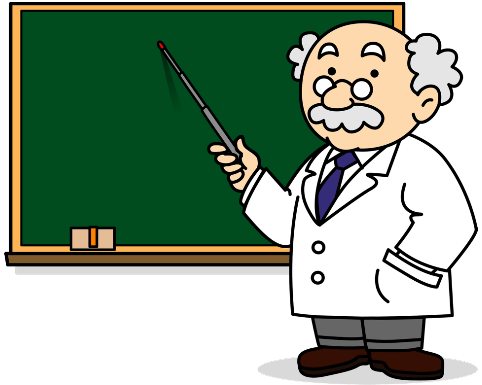
or 16.19 dB, which is equal to the antenna factor difference between the two dipoles.

Quick Detour: What is Antenna Factor?

Antenna factor is the ratio of the field strength of an electromagnetic field incident upon an antenna to the voltage produced by that field across a load of impedance Z_0 connected to antenna's terminals.

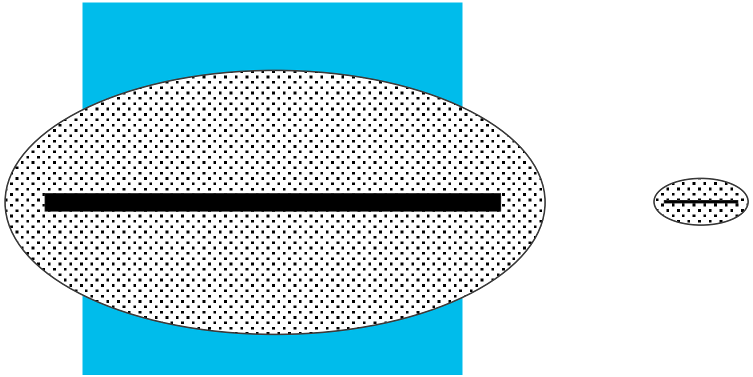
The antenna factors for the VHF and UHF dipoles in this presentation's example are 8.12 dB/m and 24.31 dB/m respectively. For more information about antenna factor, see my July 2012 *Communications Technology* article here:

https://wagtail-prod-storage.s3.amazonaws.com/documents/12-07-0120the20antenna20factor.pdf



What is Field Strength?

- In other words, when measuring a 20 µV/m field strength at 121.2625 MHz and 782 MHz with resonant half-wave dipoles for each frequency, the lower frequency antenna intercepts and delivers more power to its load (~8.46 * 10^{-13} watt) than the higher frequency antenna does (~2.04 * 10^{-14} watt). Here, too, the decibel difference is the same as the antenna factor difference.
- All of this jibes with the two different signal levels at the dipoles' terminals:
  -42.1 dBmV at 121.2625 MHz and -58.29 dBmV at 782 MHz, for identical 20 µV/m field strengths at the two frequencies.



The large ellipse on the left represents A_{em} for the 121.2625 MHz dipole, and the small ellipse on the right the A_{em} for the 782 MHz dipole.

Final Point: Be Sure to Measure Field Strength in the Source’s Far-Field

Left photo: Leakage field strength at 756 MHz and 126 MHz is 180 µV/m, measured about 3 meters from the source (the camera distorts the distance perspective). This measurement is in the far-field region for both frequencies.
Right photo: When measured a little less than 1 meter from the source, the indicated field strengths are 450 µV/m at 756 MHz and 2100 µV/m at 126 MHz. The detector is still in the far-field region for the higher frequency, but is in the near-field region for the lower frequency. Images courtesy of Arni Lundale

Q&A

What is the Far-Field vs. Near-Field?

The far-field is the region of an antenna’s radiation pattern in which the angular distribution of radiated energy is largely independent of distance from the antenna, and in which the power varies inversely with the square of distance. The approximate distance from the antenna to the beginning of the far-field is generally accepted to be $R = 2D^2/\lambda$, where R is distance from the antenna, D is the largest linear dimension of the antenna, and λ is wavelength.