If you want to quote this work:
Ostrowski, K. (2025). Tutoring research notebooks: Radio engineering - Course notes. Zenodo.
https://doi.org/10.5281/zenodo.15341408

Radio Engineering: Analysis of Radio Link Balance,logarithmic scale, isotropic antenna and other antenna types

Radio technology tutoring

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The logarithmic scale and its application

Introduction

The logarithmic scale is a key tool in radio engineering for easy comparison of signals with a large dynamic range. This paper discusses the basics of the logarithmic scale, radio link balance and antenna issues.

Magnitudes in radio engineering are often expressed in **decibels** (dB), which allows for easy handling of large ranges of values.

Formulas for power and voltage

Power on a logarithmic scale is expressed as: $$L = 10 \cdot \log_{10} \left(\frac{P}{P_0} \right)$$ Whereas for voltage or current: $$L = 20 \cdot \log_{10} \$$left(\frac{V}{V_0} \right)$$ For example, a reduction in power by half corresponds to an attenuation of $$-3$ dB: $$10 \dot \log_{10}(0.5) \approx -3 \text{dB}$$. ===== Logarithmic scale diagram ===== {{notatki:pasted:20250507-205231.png}} Logarithmic scale for power in decibels. ====== Radio link balance ====== The radio link balance is an analysis of the signal power gains and losses in the transmission path. An example calculation is shown below. ===== Assumptions ===== * Frequency: 5 GHz

- Distance between antennas: 5 km
- Transmitter power: 20 dBm (100 mW)
- Gain of transmit and receive antenna: 24 dBi
- Cable and connector losses: 2 dB

- Propagation losses: calculated below

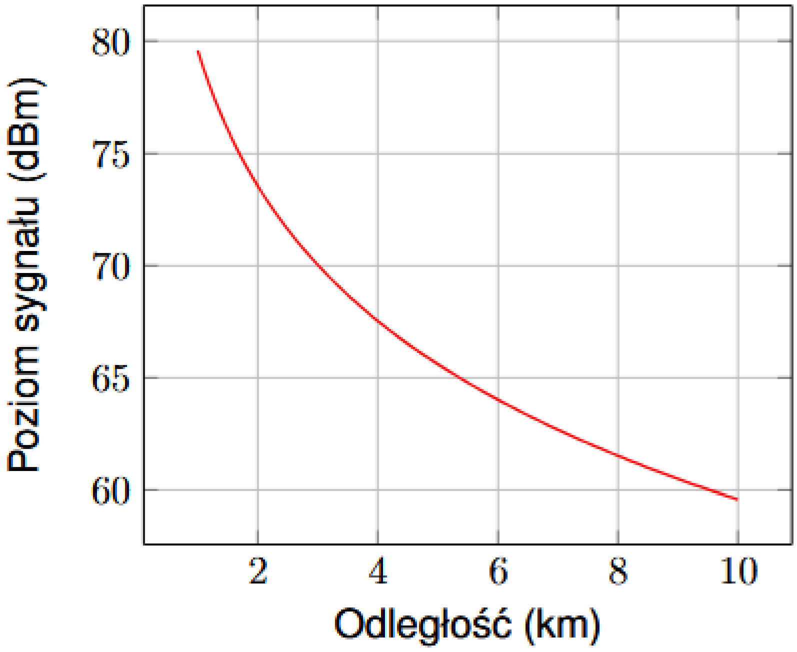
Propagation losses in free space

Propagation losses in free space (FSPL) are determined by the formula: $$FSPL = 20 log_{10}(d) + 20 log_{10}(f) + 20 log_{10} \Λ_{10}(f)$$Based on the values: $$FSPL = 20 \log_{10}(5000) + 20 \log_{10}(5000) - 147.56 = 60.44 \text{ dB}$$.

Power balance at the receiver

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} - FSPL - Loss_{cables}$$ $$P_{RX} = 20 + 24 + 24 - 60.44 - 2 = 5.56 \text{ dBm}$$

Link balance diagram

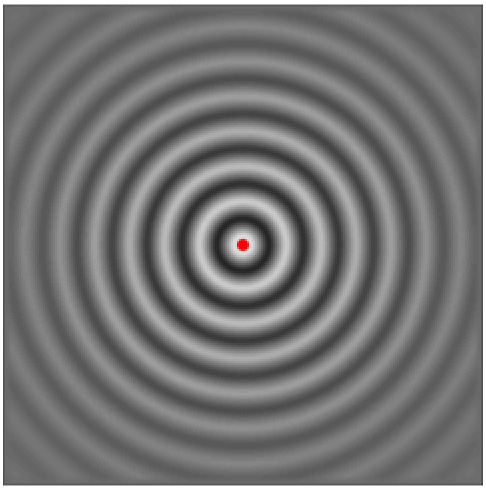


Radio link balance as a function of distance.

Summary

Logarithmic scale and radio link balance are key issues in the design of wireless systems. The calculations show the importance of considering propagation losses and antenna gains in signal quality analysis.

Isotropic antenna and antenna gain



In telecommunications and radio engineering, an understanding of basic antenna concepts is crucial to the successful design of communication systems. One of the basic types of antennas is the isotropic antenna, which provides an ideal reference point for measuring the gain of antennas.

Isotropic antenna

An isotropic antenna is a theoretical type of antenna that emits electromagnetic waves uniformly in all directions in space. This means that an isotropic antenna has identical energy emission in every possible plane and direction.

Mathematically, an isotropic antenna is not physically realisable, but is used as an idealised model to measure and compare other antennas. This model assumes that the antenna's radiated power is distributed symmetrically in all directions, resulting in homogeneous distributions in spherical space.

$$text{G} = 1 quad{(unit gain of isotropic antenna)}$$.

The isotropic antenna provides a reference point when determining the gain of other antennas. It can also be assumed that for an isotropic antenna the power is emitted with equal intensity in all directions.

Antenna Gain

Antenna gain is a measure of the efficiency of an antenna in the direction in which its main beam is located, compared to an isotropic antenna. Antenna gain tells us how strongly an antenna concentrates radiation in a particular direction.

Antenna gain is defined mathematically as the ratio of the power radiated by an antenna to the power radiated by an isotropic antenna at the same input power. The formula for antenna gain (G) in decibels (dB) is as follows:

$$G = \frac{P_{\text{max}}}{P_{\text{iso}}} = 4{frac{A_{{text{eff}}}}{{lambda^2}$$.

where: - G is the antenna gain (dimensionless or in dB), - $P_{{text{max}}$ is the power radiated by the antenna in the direction of maximum gain, - $P_{{text{iso}}$ is the power radiated by the isotropic antenna, - $A_{{text{eff}}$ is the effective area of the antenna, - $lambda$ is the wavelength.

The value G expressed in decibels is a logarithmic scale in which the dB gain of an antenna is expressed by the formula:

$$G_{text{dB}} = 10 \cdot \log_{10}(G)$$.

Antenna gain is a measure of directivity, or the ability of an antenna to direct energy in a particular direction. An antenna with a high gain in a particular direction will be more effective in that direction because it concentrates more energy in that particular plane. Otherwise, an antenna with low gain will radiate energy more evenly in different directions.

Physical Explanation of Antenna Gain

Physically, antenna gain is the effect of concentrating energy in a particular direction. Antennas that have a high gain, such as directional antennas (e.g. Yagi antennas), can direct more energy to a specific point, which increases their efficiency in a given area. An example of this is a parabolic antenna, which, due to its design, can concentrate electromagnetic radiation in a narrow beam, leading to a significant increase in gain in that direction.

Gain in decibels

Antenna gain is also often expressed in units of decibels (dB). The decibel scale is a logarithmic scale used to express ratios between different values and, in the case of antenna gain, allows comparison between antennas with different degrees of directivity. For example, if the gain of an antenna is 2, then its gain in dB is:

$$G_{text{dB}} = 10 \log_{10}(2) \approx 3.01 \text{dB}$$.

This means that an antenna with a gain of 2 is 3.01 dB more efficient than an isotropic antenna in the same direction.

Summary

An isotropic antenna is an ideal model for comparing different antenna types. Antenna gain, on the other hand, indicates how effectively an antenna concentrates energy in a particular direction compared to an isotropic antenna. This gain can be described both in dimensionless form and in decibels, where a higher gain indicates greater efficiency of the antenna in a particular direction. An understanding of these concepts is essential in the design of modern communication systems, including both telecommunications and radar systems.

The dBi unit and its calculation

Unit **The dBi** is the unit used to express the gain of an antenna relative to an isotropic antenna. It is a logarithmic scale to express the ratio of the gain of an antenna in the main direction to that of an isotropic antenna, which is 1 (i.e. 0 dBi). This unit is commonly used in telecommunications, radio engineering and communication systems to describe antenna efficiency.

Definition of dBi

The unit dBi (decibels relative to an isotropic antenna) describes the gain of an antenna relative to an ideal isotropic antenna that emits power uniformly in all directions. The gain in dBi is expressed in decibels and is calculated based on the ratio of the power radiated by the antenna to the power radiated by the isotropic antenna.

The formula for antenna gain in dBi units is as follows:

$$G_{{dBi}} = 10 \cdot \log_{10}\left(\frac{P_{\text{antenna}}}{P_{\text{iso}}}\right)$$

where: - $G_{{text{dBi}}}$ is the antenna gain in dBi units, - $P_{{text{antenna}}}$ is the power radiated by the antenna in the direction of maximum gain, - $P_{{text{iso}}}$ is the power radiated by the isotropic antenna.

Application of the dBi unit

The dBi unit is commonly used to describe the efficiency of antennas in various radio and telecommunications applications. The gain of an antenna in dBi units allows the efficiency of different antennas to be compared in terms of their directivity and ability to concentrate energy in a particular direction. The higher the gain in dBi, the more effective the antenna is in a particular direction.

The gain of an antenna expressed in dBi tells us how many dB more effective the antenna is in a particular direction compared to an isotropic antenna. For example, an antenna with a gain of 3 dBi is 3 dB more effective than an isotropic antenna, and an antenna with a gain of 10 dBi is 10 dB more effective.

Example of dBi calculation

Suppose we have an antenna that emits a power of $P_{text{antenna}} = 10 {P_{text{W}}$ in the direction of the main gain. The power radiated by an isotropic antenna P_{iso} is $1 \, \text{W}$ (for an isotropic antenna). The gain of the antenna in units of dBi can be calculated using the formula:

$$G_{{text{dBi}} = 10 ¯log_{10}left(¯frac{10}{1}right) = 10 ¯log_{10}(10) = 10 ¯, ¯text{dBi}$$.

This means that this antenna has a gain of 10 dBi, which means that it is 10 times more efficient than an isotropic antenna in the direction of maximum gain.

Summary

The unit dBi is used to express the gain of an antenna compared to an isotropic antenna. It is a measure of antenna efficiency, indicating by how many dB the antenna concentrates energy in a particular direction compared to an ideal isotropic antenna. The gain in dBi units is expressed on a logarithmic scale, allowing easy comparison between different antennas with different degrees of directivity. An increase in the dBi value indicates greater efficiency of the antenna in concentrating energy in a given direction.

Types of radio antennas and their radiation characteristics

Radio antennas are devices used for the emission and reception of electromagnetic waves. Depending on their design and purpose, antennas can vary in their radiation characteristics, resonant frequencies, bands and gains. A selection of antenna types, their operating principles and design formulas are outlined below.

Dipole antennas

Example dipole antenna

Dipole antennas are one of the simplest types of antenna. They are constructed from two equal sections of conductor, joined at the centre. Their operation is based on the generation of an electromagnetic field by an alternating current flowing through the antenna elements. A dipole antenna is a resonant antenna, which means that it has a specific resonant frequency at which the radiation efficiency is maximum.

Resonant frequency of a dipole antenna

The resonant frequency of a dipole antenna can be calculated from its length L using the formula: $$f_0 = \frac{c}{2L}$$ where:

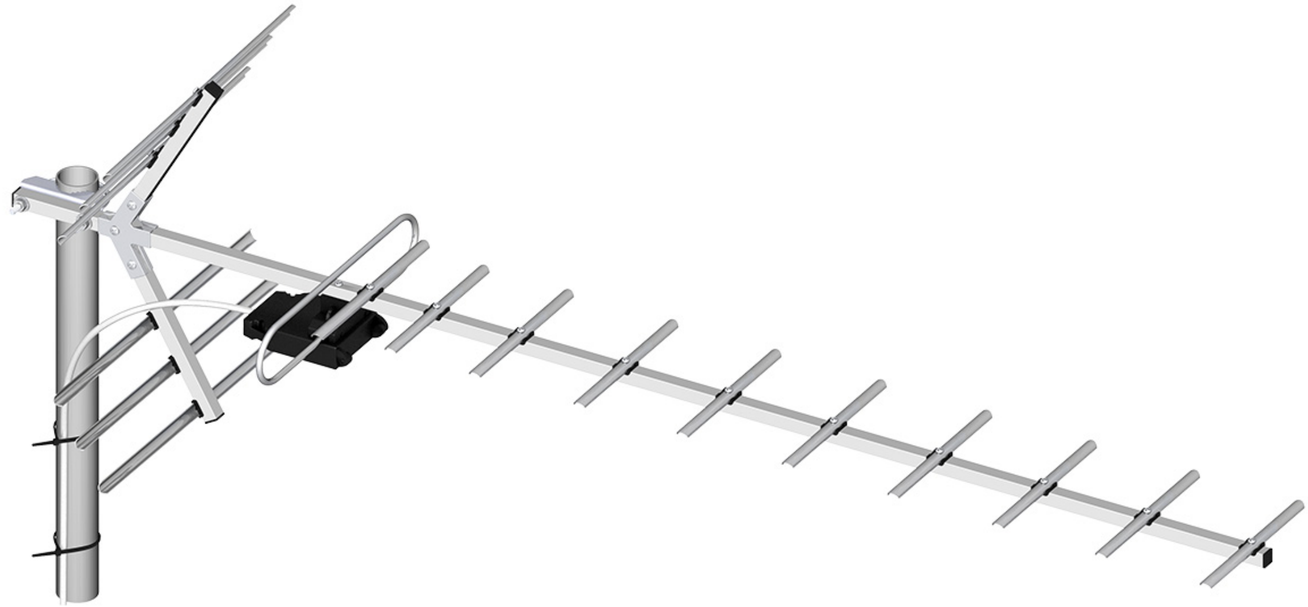
- c - the velocity of light in vacuum, $c \approx 3 \times 10^8 \text{m/s}$$,
- L - the length of the dipole antenna (in the case of a half-wave antenna, $L = \frac{lambda}{2}$$, where $lambda$ is the wavelength).

Bands and gain of a dipole antenna

The bands of a dipole antenna are related to its resonant width, and the antenna gain G is calculated from the radiation pattern. For a dipole antenna of length $L = \frac{lambda}{2}$, the antenna gain is typically about 2.15 dB relative to an isotropic antenna.

$$G_{text{dipol}} = 2.15 {{text{dBi}}$$.

Yagi-Uda antennas



Example of a Yagi-Uda antenna

Yagi-Uda antennas are directional antennas, consisting of a main element (dipole) and several reflector and directional elements. This antenna is mainly used in television and radio communications, as it provides high gain in a specific direction.

Resonant frequency of the Yagi-Uda antenna

The resonant frequency of a Yagi-Uda antenna can be calculated on a similar basis to that of a dipole antenna, except that the length of the dipole in a Yagi-Uda antenna is slightly shorter than that of a half-wave dipole antenna. We determine the resonant frequency from the formula: $$f_0 = \frac{c}{L}$$ where L is the length of the main dipole of the Yagi-Uda antenna.

Yagi-Uda antenna bands and gain

The gain of a Yagi-Uda antenna in the main direction is typically between 7 and 10 dBi, depending on the number of elements. The more elements, the higher the gain. This antenna also has a narrow bandwidth but excellent directional properties, making it ideal for applications where it is important to direct the signal to a specific point.

Parabolic antennas

Example of a parabolic antenna

Parabolic antennas, also known as satellite dishes, use a parabolic reflector to focus electromagnetic waves to a single point that is received by the receiver. They are very high-gain antennas, particularly used in satellite and radio communications.

Resonant frequency of a parabolic antenna

The resonant frequency of a parabolic antenna can be determined from the formula: $$f_0 = \frac{c}{d}$$ where:

- d - diameter of the antenna reflector.

Bands and gain of a parabolic antenna

The gain of a parabolic antenna increases as the diameter of the reflector increases and is described by the formula: $$G = ¯left(¯frac{4 ¯ d^2}{ ¯lambda^2} ¯right) ¯dot ¯eta$$ where $$eta$ is the antenna efficiency factor, which is typically around 0.55-0.75. The gain of a parabolic antenna can range from 30 dBi to 50 dBi depending on its diameter and the frequency used.

Horn antennas

Example of a horn antenna

Horn antennas are directional antennas that use an expanding channel to direct an electromagnetic wave in a specific direction. They are mainly used in radar applications and microwave communications.

Resonant frequency of a horn antenna

The resonant frequency of a horn antenna can be calculated using a formula that depends on the wavelength and input dimensions: $$f_0 = \frac{c}{\sqrt{A}}$$ where A is the cross-sectional area of the horn (usually rectangular or cylindrical in shape).

Horn antenna bands and gain

The gain of a horn antenna depends on the scattering angle and the dimensions of the horn. The gain of a horn antenna can range from 10 dBi to 30 dBi, depending on its design and operating frequency.

Summary

Different types of radio antennas differ in their radiation characteristics, frequency bands and gains. Appropriate antenna selection depending on the application allows optimum performance in radio systems. For dipole and Yagi-Uda antennas, resonant frequencies and bandwidth are important, while for parabolic and horn antennas, gain and directivity play a key role.

Applications and bandwidths for different antenna types

Dipole antenna

A dipole antenna is one of the simplest antennas, consisting of two conductors, usually of length $frac{lambda}{2}$, where $lambda$ is the wavelength. It is a multiband antenna, mainly used in the radio and television bands, as well as in various medium and high power communication systems.

Applications:

- Radio communications at medium and high frequencies (HF, VHF, UHF).
- Television systems.
- Meteorological radars.

Bands:

- HF band (3-30 MHz).
- VHF band (30-300 MHz)
- UHF band (300 MHz - 3 GHz)

Yagi-Uda antenna

The Yagi-Uda antenna is a directional antenna consisting of several elements: one main dipole, several reflectors and directors. Thanks to its design, it provides high gain in the main direction and a relatively narrow radiation angle.

Applications:

- Terrestrial television (VHF, UHF).
- Amateur communications (particularly in the VHF, UHF bands).
- Radar and detection systems.

Bands:

- VHF band (30-300 MHz).
- UHF band (300 MHz - 3 GHz)

Parabolic antenna

The parabolic antenna is a high-gain antenna whose main element is a parabolic dish that reflects radio waves. Thanks to its design, it provides a very low radiation angle, resulting in a long range and precision.

Applications:

- Satellite communications (GSM, satellite internet).
- Radar.
- Satellite television (often used for signal reception).
- Monitoring and detection systems.

Bands:

- C-band (4-8 GHz)
- Ku-band (12-18 GHz)
- Ka-band (26.5-40 GHz)

Horn antenna

The horn antenna is a wide-angle antenna often used for broadband applications. It features good impedance and a wide frequency range.

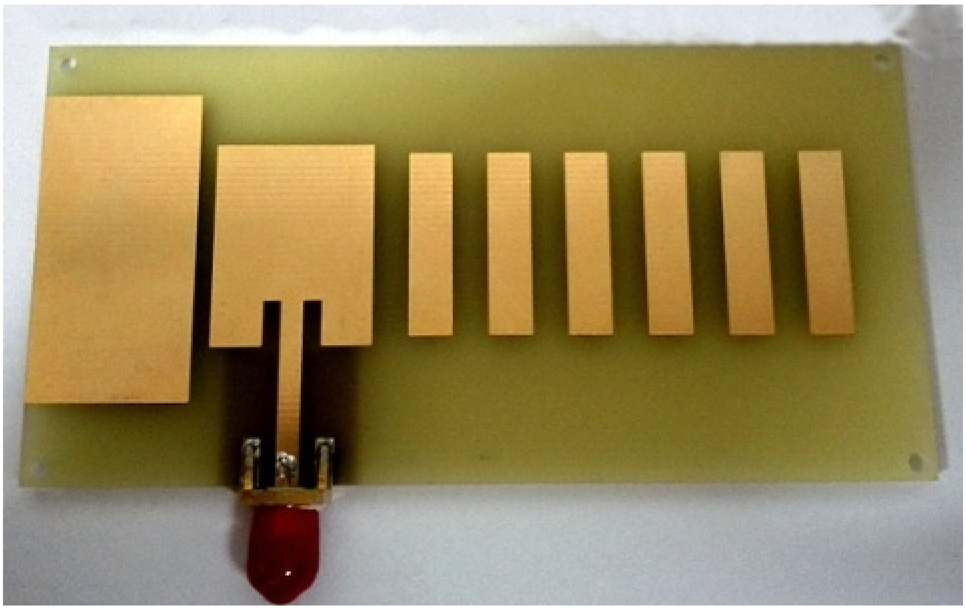
Applications:

- Antenna testing (often used in laboratories to calibrate other antennas).
- Broadband communications.
- Radar.
- Satellite television (in conjunction with parabolic systems).

Bands:

- UHF band (300 MHz - 3 GHz).
- SHF band (3-30 GHz)
- EHF band (30-300 GHz)

Principle of operation of microstrip antennas


Example of microstrip antenna

A microstrip antenna is a type of antenna that consists of a thin layer of conductive material (e.g. copper) placed on a dielectric substrate. It works on the principle of electromagnetic resonance, in which electrical energy is transformed into an electromagnetic field. The principle of microstrip antennas is based on the fact that part of the conductive material is shaped into a flat structure, which is connected to a suitable power source.

Physical phenomena associated with a microstrip antenna

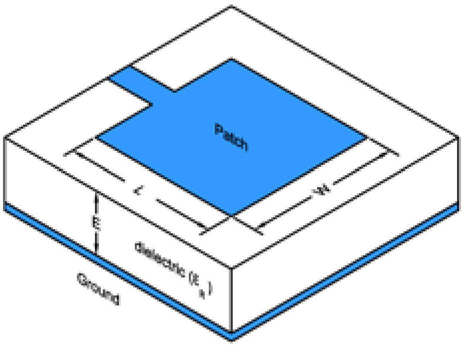
- **Electromagnetic resonance:** Resonance occurs in microstrip antennas when the electromagnetic wavelength matches the dimensions of the antenna elements. The resonant frequency depends on the length and shape of the antenna.
- **Impedance:** Microstrip antennas have a specific impedance, which depends on the design and dimensions of the antenna elements. The impedance is typically 50 $Omega$ or 75 $Omega$, which is the standard for transmission systems.
- **Electromagnetic wave:** During the operation of a microstrip antenna, an electromagnetic field is generated which emits electromagnetic waves into space.

Calculations related to the microstrip antenna

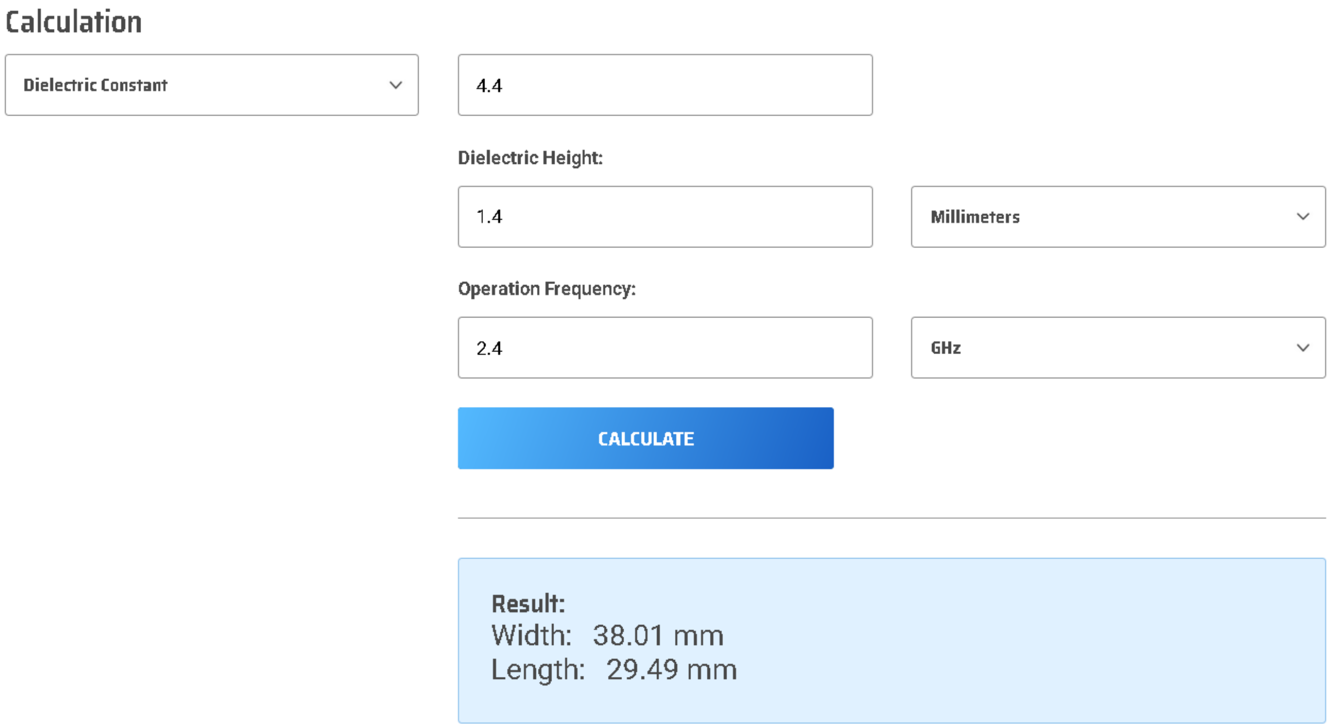
$$Width = \frac{c}{2f_o\sqrt{\frac{\varepsilon_R+1}{2}}}; \quad \varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right]$$

$$Length = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right)$$

List of formulae for calculating the dimensions of a microstrip antenna



Visualisation of microstrip antenna dimensions



Calculation

Dielectric Constant: 4.4

Dielectric Height: 1.4 Millimeters

Operation Frequency: 2.4 GHz

Result:
Width: 38.01 mm
Length: 29.49 mm

Example of using the online calculator to calculate the dimensions of a 2.4GHz antenna

Assumed parameters for calculations in the online calculator

- Dielectric constant = 4.4 (the same as in the PCB laminate)
- Dielectric height = 1.4 (similar to that of the PCB laminate)

- Operating frequency = 2.4 GHz (same as in WiFi networks)

Antenna shortening with coil

In radio engineering, one often encounters the term *to shorten the antenna with a coil*. This means using an inductance (coil) in an antenna circuit to electrically lengthen an antenna that is physically shorter than the resonant length for a given frequency.

Principle of operation

The wavelength of an electromagnetic wave is related to the length of the antenna, and lengths equal to half or a quarter of the wavelength are often used for effective antenna operation. If the antenna is too short relative to the required length, it has too much capacitive reactance. Adding an inductor helps to compensate for this reactance, bringing the antenna into resonance.

Advantages of

- Allows the use of shorter antennas, which is advantageous in portable devices or vehicles.
- Allows the impedance of the antenna to be matched to the transceiver system.
- Can improve antenna efficiency in confined spaces.

Disadvantages

- Causes an increase in energy loss in the coil, which reduces the efficiency of the antenna.
- Reduces the operating bandwidth of the antenna, which limits the frequency range over which it can operate effectively.
- Can cause an increase in impedance loss and increased effects of ambient elements on antenna characteristics.

Calculation of coil winding number and inductance

To select a suitable coil to shorten an antenna, its inductance and number of turns must be calculated.

Calculation of the required inductance

The inductance of a coil L can be calculated from the formula: $$L = \frac{X_L}{2 \pi f}$$ Where:

- X_L - inductive reactance, equal to $X_L = | Z_A - Z_0|$, where Z_A is the impedance of the antenna to be shorted and Z_0 is the target impedance,
- f - the operating frequency of the antenna.

Calculation of the number of turns

For an air coil, the number of turns N is given by the formula: $$L = \frac{N^2 \mu_0 \mu_r A}{l}$$ Where:

- $$mu_0 = 4 \times 10^{-7} \$text{ H/m}$ - the magnetic permeability of the vacuum,
- $$mu_r$ - relative magnetic permeability of the core material (for air $$mu_r = 1$),
- A - cross-sectional area of the coil ($A = \pi r^2$ for a cylindrical coil of radius r),
- l - length of the coil.

By solving the above equation for N, the number of coils can be determined: $$N = \sqrt{\frac{L l}}$$.

Calculation of the coil for a dipole antenna for a given radio band

In order to select a suitable coil for shortening a dipole antenna at a given frequency, it is necessary to calculate the required coil parameters, such as inductance and number of turns. The calculation of these values is shown below.

Calculation of the required inductance

The inductance of a coil L in an antenna system can be calculated from the formula for the inductive reactance X_L and frequency f:

$$L = \frac{X_L}{2 \pi f}$$.

where:

- X_L - the inductive reactance, equal to $X_L = | Z_A - Z_0|$, where Z_A is the antenna impedance and Z_0 is the wave impedance (usually $Z_0 = 50 \nmega$),
- f - the operating frequency of the antenna for which we want to select the coil.

Example: Suppose we want to calculate the inductance for a dipole antenna operating at a frequency $f = 100 \nmega$, and the antenna impedance $Z_A = 75 \nmega$. The wave impedance is $Z_0 = 50 \nmega$.

$$X_L = | Z_A - Z_0| = | 75 - 50| = 25 \nmega$$.

By substituting into the formula for inductance:

$$L = \frac{25}{2 \frac 100 \frac 10^6} = 4 \frac 10^{-8} \Ù, Ùtext{H} = 40 Ù, Ùtext{H}$$.

We obtain the required inductance of $L = 40 \n, \ntext{H}$$.

Calculation of the number of turns of the coil

For an air coil, the number of windings N depends on its inductance, magnetic permeability, the cross-sectional area of the coil and its length. The formula for the number of windings is as follows:

$$L = \frac{N^2 \mu_0 \mu_r A}{l}$$.

where:

- * $$mu_0 = 4 \times 10^{-7} \${H/m}$ - the magnetic permeability of the vacuum,
- * $\mu_r = 1$ - relative magnetic permeability of the core material (for air),
- $A = r^2$ - cross-sectional area of the coil (for a cylindrical coil of radius r),
- l - length of the coil.

By solving the equation for N, we can calculate the number of coils:

$$N = \sqrt{{L l}}$$.

Example: Suppose we have a coil with a length $l = 0.1 \nm}$ and a radius $r = 0.01 \nm}$, and the required inductance gain is $L = 40 \nm}$.

By substituting the values:

$$A = \nTimes (0.01)^2 = 3.14 \nTimes 10^{-4} \{text{m}^2$$.

$$N = {sqrt{40 \times 10^{-6} \approx 0.1}{(4 \times 10^{-7}) \times 1 \times 3.14 \times 10^{-4}} \{approx 60 }$$.

We obtain that the number of coils $N = 60$.

Summary

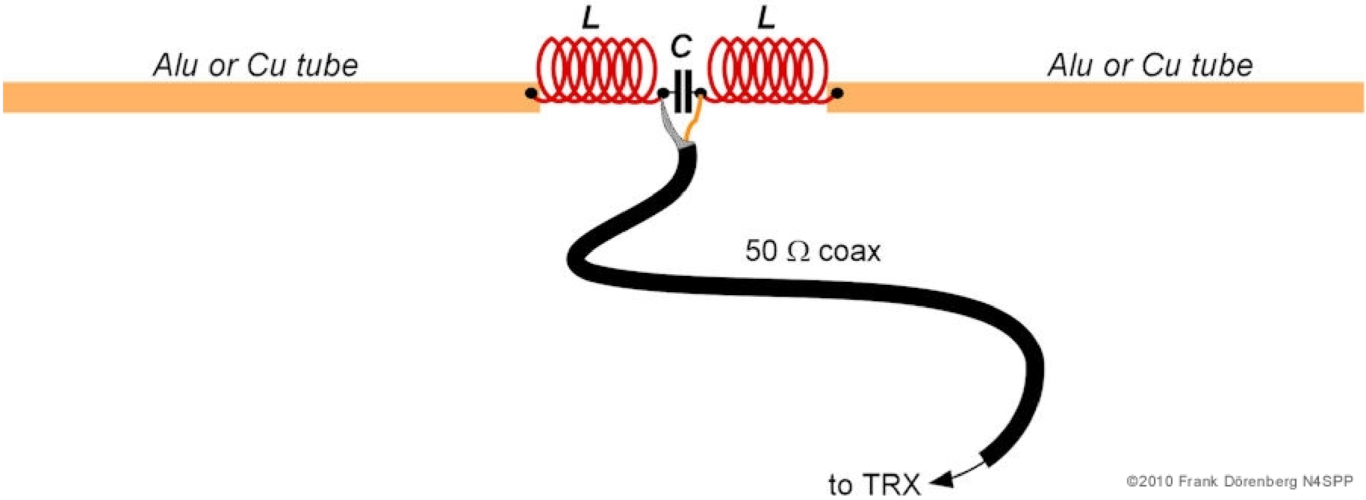
To select a suitable coil for a dipole antenna at a specific frequency, you need:

- Calculate the inductance of the coil based on the antenna impedance and operating frequency,
- Calculate the number of turns of the coil, taking into account the dimensions of the coil and its inductance.

As an example, we have calculated the inductance $L = 40$ and the number of turns $N = 60$ for an air coil. With these calculations, a suitable coil can be selected to shorten the dipole antenna depending on the required frequency parameters.

Appendix: Illustrations of shortening coils


Loading coil example



Example diagram of coil connection in dipole antenna