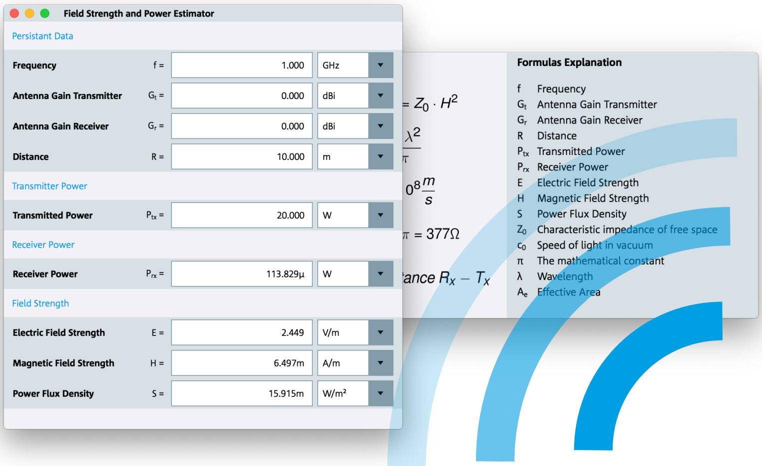
R&S® Field Strength and Power Estimator

Application Note



Determining the field strength from transmitted power is not an easy job. Various, quite complicated formulas have to be evaluated correctly. This application note explains how to calculate electric and magnetic field strength, and power flux density. A program associated with this application note helps with the calculation and converts Watts to mW and dBm, V/m to µV/m and dBµV/m as well as A/m to µA/m and dBµA/m. Additional applications are calculation of propagation loss or antenna factor. Smartphone versions of the application software are also available.

Note:

Please find the most up-to-date document on our homepage http://www.rohde-schwarz.com/appnote/1MA85.

This document is complemented by software. The software may be updated even if the version of the document remains unchanged.

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1 Introduction

Determining the field strength from transmitted power and frequency is not an easy job. This application note explains how to calculate electric and magnetic field strength, and power flux density.

The program Field Strength and Power Estimator available with this application note helps with the calculation and converts mW to dBm, V/m to µV/m and dBµV/m as well as A/m to µA/m and dBµA/m.

- An introduction of the program features and the calculation formulas is presented.
- Information about installing and operating the program are given.
- Some examples show additional applications of the program.

1.1 Trademarks

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2 Software Features and Formulas

The program Field Strength and Power Estimator calculates power flux density, electric and magnetic field strength from the transmitted power, associated frequency and gain of the transmitting antenna.

Additionally the input power into a receiver with 50Ω(Ohm) input impedance is calculated from the gain of the receiving antenna.

The program automatically converts power flux density into electric and magnetic field strength.

Depending on the transmitted frequency, various parameters influence the received power and field strength, such as Non-line-of-sight propagation, changes in polarization, reflections, and multi path propagation affect the true values. Additionally antenna VSWR and cable losses have to be considered.

The program Field strength and Power Estimator does not consider these impairments. It assumes conditions, that are close to the best possible theoretical values. This is why we say the program is an **Estimator**, not a **Calculator**.

2.1 Power Flux Density

The power flux density and the resulting electric and magnetic field strength are calculated from following formulas:

$$S = \frac{P_t}{4 \cdot \pi \cdot R^2}$$

A transmitter of power P_t (measured in Watts W) feeds an isotropical antenna (see Antenna Characteristics below for an explanation of isotropical). This causes a power flux density S (in Watts per square meters W/m^2) in the distance R (in meters m) to the transmitter. The magnitude of the power flux density S is simply calculated by dividing the transmitted power P_t by the surface of a sphere with a radius of R meters.

If the transmitter antenna has some gain G_t over an isotropical antenna, the transmitted power is concentrated to a part of the sphere´s surface. The power flux density is then:

$$S = \frac{G_t \cdot P_t}{4 \cdot \pi \cdot R^2}$$

The power flux density is the product of electric and magnetic field strength:

$$S = E \cdot H$$

At a sufficiently large distance from the transmitting antenna, electric and magnetic field strength are proportional to each other. "Sufficiently large" means more than 4λ (λ being the wavelength of the transmitted signal in meters). Distances from λ/2π to 4λ give good results, though under certain circumstances the values may not be too precise.

$$\frac{E}{H} = Z_0$$

Similar to the relation voltage divided by current, which is the resistance, electric field strength divided by magnetic field strength is a resistance Z_0. Z_0 is the characteristic impedance of free space.

$$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 120\pi \approx 377\Omega$$

With this E resp. H are derived from S as follows:

$$E = \sqrt{S \cdot Z_0}$$

$$H = \sqrt{\frac{S}{Z_0}}$$

E is measured in V/m (Volts per meter), µV/m (microvolts per meter) or dBµV/m (decibels over 1 microvolt per meter).

H is measured in A/m (amperes per meter), µA/m (microamperes per meter) or dBµA/m (decibels over 1 microampere per meter).

2.2 Antenna Characteristics

An antenna picks up some energy from the power flux density. As real antennas always have some size, we can define the effective electric area of an antenna in terms of an area, which picks up some power from the power flux density.

The effective area of an isotropical antenna is given as

$$A_i = \frac{1}{4\pi} \cdot \lambda^2 \approx 0.08 \cdot \lambda^2$$

A_I is measured in m^2 (square meters).

An isotropical antenna theoretically radiates equally in each direction. In practice, isotropical antennas do not exist. Real existing antennas always concentrate the radiated energy into some preferred directions. The characteristics of transmitting antennas and receiving antennas are the same. Thus the effective area of these antennas always is somewhat greater than the effective area of isotropical antennas (assumed that there are no losses). We say, a real antenna with an effective area A has some gain G over an isotropical antenna:

$$A = G \cdot A_i = G \cdot \frac{\lambda^2}{4\pi}$$

The effective area of a commonly used λ/2 dipole is:

$$A_D = 0.13 \cdot \lambda^2$$

$$G_D = \frac{A_D}{A_i} = \frac{0.13}{0.08} = 1.625 \equiv 2.1 dB_i$$

The gain G_D of a λ/2 dipole is 1.625 or 2.1 dB_I, as 10 · $\log_{10}$(1.625) equals 2.1 dB.

The power P_r which we can get from a certain power flux density S by using an antenna of an effective area A_r is:

$$P_r = S \cdot A_r$$

As S is measured in W/m^2 and A_r in m^2, we get the power P_r in W (Watts).

It is more common however, to express the power in mW (milli Watts, milli means one thousands of a Watt) or in a logarithmical scale, then we get dBm.

Logarithmical scales always represent a ratio of 2 values. So dB***m*** means the power referred to 1 ***m***W (1 milli Watt = 1 thousandth of a Watt) expressed in dB (deciBel). Bel is the logarithm to the base 10, decibel is the tenth of a Bel, we have to multiply Bel values by 10 to get deciBel):

$$P_r/dBm = 10 \cdot log_{10}\left(\frac{P_r/mW}{1/mW}\right)$$

Please read this formula as follows:

P_r in dBm is 10 times the logarithm of P_r in mW divided by 1 mW.

2.3 Receiving Signals and Measuring Power Flux Density

In order to measure the power flux density, we need a receiver or a spectrum analyzer and an antenna. As explained above, the receiving antenna picks up the power P_r from the electromagnetic field with it's effective antenna area A_r. If we feed this power into the input of the receiver or spectrum analyzer, we can measure it. As we certainly know the effective electric area or the gain of our antenna, we can measure the power flux density S of the electromagnetic field as follows:

With $P_r = S \cdot A_r$ we get

$$S = \frac{P_r}{A_r}$$

Remembering that the effective area A_r of an antenna is:

$$A_r = G_r \cdot A_i = G_r \cdot \frac{\lambda^2}{4\pi}$$

where G_r means the gain of the receiving antenna over an isotropic antenna of area A_I or $\lambda^2/4\pi$.

Example:

We want to measure the power flux density of a GSM base station transmitter at 900 MHz with a spectrum analyzer and a dipole antenna. 900 MHz corresponds to a wavelength of 0.332 m. The spectrum analyzer shows a power of 2 mW or 3 dBm. An isotropic antenna has an area of 0.08 · λ^2, this is 0.08 · 0.332 m · 0.332 m =0.0088 m^2. A dipole antenna has a gain of 1.625, so it´s area is 0.0143m^2. With this, the power flux density is 139.6 mW/m^2 or 21.5 dBm/m^2.

2.4 Receiving Signals and Measuring Electric Field Strength

We can also determine the electric field strength in a similar way. With:

$$E = \sqrt{S \cdot Z_0}$$

we get:

$$E = \sqrt{\frac{P_r}{A_r} \cdot Z_0}$$

If our receiver shows the input voltage U_r at an input impedance of Z_I (normally 50 Ω), then we have to use the following relationship between input power P_r and input voltage U_r.

$$P_r = \frac{U_r^2}{Z_i}$$

Using this we get:

$$E = \sqrt{\frac{U_r^2}{Zi} \cdot \frac{1}{A_r} \cdot Z_0}$$

or, by rearranging the formula:

$$E = U_r \cdot \sqrt{\frac{1}{A_r} \cdot \frac{Z_0}{Z_i}}$$

The square root expression is also known as antenna factor K_a:

$$K_a = \sqrt{\frac{1}{A_r} \cdot \frac{Z_0}{Z_i}} = \sqrt{\frac{4\pi}{G_r \cdot \lambda^2} \cdot \frac{Z_0}{Z_i}}$$

G_r is the receiver antenna gain over an isotropic antenna, λ is the wavelength of the received signal, Z_0 is the propagation impedance of free space (377 Ω) and Z_I the receiver input impedance (normally 50 Ω), so:

$$E = U_r \cdot K_a$$

Sometimes K_a is expressed in dB:

$$K_a/dB = 20 \cdot log_{10}(K_a)$$

Electric field strength is measured in V/m or in µV/m. In order to convert to µV/m, remember that 1V = 1000000 µV (1million micro Volts).

Example:

0.0003 V/m = 300 µV/m

You can also convert the field strength from µV/m to dBµV/m using following equation:

$$E/dB\mu V/m = 20 \cdot log_{10}\left(\frac{E/\mu V/m}{1/\mu V/m}\right)$$

Example:

We want to measure the electric field strength of a GSM base station transmitter at 900 MHz with a receiver and a dipole antenna. 900 MHz corresponds to a wavelength of 0.332 m. The receiver shows an input voltage power of 0.315 V or 110 dBµV. With the gain of the dipole antenna of 1.625, we get K_a = 23 or 20 · log(23) = 27.2 dB. With this, the electric field strength is 7.42 V/m or 137.2 dBµV/m.

2.5 Receiving Signals and Measuring Magnetic Field Strength

To determine the magnetic field strength we have to start with the equation

$$H = \sqrt{\frac{S}{Z_0}}$$

and perform similar mathematics.

We can however, and this is much simpler, use the equation:

$$H = \frac{E}{Z_0}$$

and determine the electric Field strength first (remember Z_0 = 377 Ω. Then we simply have to divide this value by 377 Ω.

Magnetic field strength is measured in A/m or in µA/m. In order to convert to µA/m, remember that 1 A = 1000000 µA (1 million micro Amperes).

Example:

0.0003 A/m = 300 µA/m.

You can also convert the field strength from µA/m to dBµA/m using following equation

$$H/dB\mu A/m = 20 \cdot log_{10}\left(\frac{H/\mu A/m}{1/\mu A/m}\right)$$

Example:

We want to measure the magnetic field strength of a GSM base station transmitter at 900 MHz with a receiver and a dipole antenna. 900 MHz corresponds to a wavelength of 0.332 m. The receiver shows an input voltage power of 0.315 V or 110 dBµV. Determine the electric field strength first as above. With the gain of the dipole antenna of 1.625, we get K_a = 23 or 20 · log(23) = 27.2 dB. With this, the electric field strength is 7.42 V/m. In order to get the magnetic field strength, we divide this value by 377 Ω and get 0.0197 A/m or 85.9 dBµA/m.

3 Installing and Starting Field Strength and Power Estimator

The desktop version of Field Strength and Power Estimator is available for Mac OSX and Windows. Please read Chapter 3.1, "macOS", on page 10 or Chapter 3.2, "Windows", on page 11 depending on your system.

Smartphone versions are also available. For more information please read Chapter 6, "Smartphone App Versions", on page 20.

3.1 macOS

To install the R&S Field Strength and Power Estimator software on your Mac, open the App Store and search for "Field Strength Estimator" or go to the following link: https://itunes.apple.com/app/id1445729070

For uninstallation, move *Estimator.app* from your Applications directory to the Trash.

To start the program, double click on the *Estimator.app* or open Estimator in Launchpad.

Figure 3-1: Field Strength and Power Estimator Main Window on Mac OSX

3.2 Windows

To install the R&S Field Strength and Power Estimator software on your Windows PC, start the installer *Estimator_<version number>.exe* supplied with this application note. The installer will guide you through the installation process.

For uninstallation, Rohde & Schwarz supplies the program *uninstall.exe*, which removes the program Field strength and Power Estimator completely from the computer.

To start the program, select Field Strength and Power Estimator from the Program submenu in the Windows Start menu.

Figure 3-2: Field Strength and Power Estimator Main Window on Windows

4 Operating the Program

To enter values for your calculation, select the appropriate field either with a left click of your mouse, by using the TAB key (forward order) or pressing Shift and TAB key simultaneously (reverse order).

Since some values depend on previously entered values, you should use the following order:

1. Frequency
2. Gain of transmitting antenna
3. Gain of receiving antenna
4. Distance of transmitter to receiver
5. Transmitted power

Enter a value and confirm your entry by pressing the ENTER key. If you just want to change only one digit of an existing entry, select this digit with your mouse or with the <> cursor keys.

If you want to use a different unit for your entry, select the new unit first. You can use the TAB /ShiftTAB keys to select the unit field. Use UP and DOWN keys to select the new unit or use the combobox selection function with your mouse.

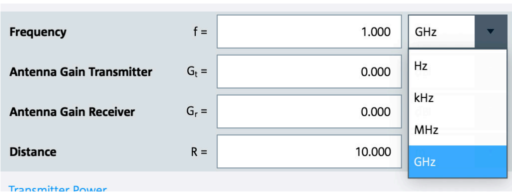


Figure 4-1: Selecting Units

4.1 Entering numerical values

The following inputs all result in the same value:

- 123.45E-7
- 12.345µ, you can use also u for µ = micro
- 0.000012345

Note, that entries are made using the selected units. For example: 0.001 with unit mW results in a value of 1 Microwatt.

If basic units like Hz, m, W, V/m or A/m are selected, you can use the SI symbolic abbreviations for the exponent of your number. Example: 123M (M for Mega) together with Hz gives 123000000 Hz. Values of 0 and negative values are only allowed if the unit is in dB, otherwise an error message will occur.

Factor	in words	SI prefix	SI symbol
1.0E+21	sextillion	zetta	Z
1.0E+18	quintillion	exa	E
1.0E+15	quadrillion	peta	P
1.0E+12	trillion	tera	T
1.0E+9	billion	giga	G
1.0E+6	million	mega	M
1.0E+3	thousand	kilo	k
1.0E+2	hundred	hecto	h
1.0E+1	ten	deka	da
1.0E 0	*initial value*	*one*	
1.0E-1	tenth	deci	d
1.0E-2	hundredth	centi	c
1.0E-3	thousandth	milli	m
1.0E-6	millionth	micro	µ
1.0E-9	billionth	nano	n
1.0E-12	trillionth	pico	p
1.0E-15	quadrillionth	femto	f
1.0E-18	quintillionth	atto	a
1.0E-21	sextillionth	zepto	z
1.0E-24	septillionth	yocto	y

4.2 Starting Calculation

To start calculation, press the ENTER key. The value is calculated to 15 significant figures, the results however are displayed with a 3 decimal places only.

If you change a units field, the corresponding numerical values are converted. For example: 1 mW gives 0 dBm if the unit is changed from mW to dBm. Be careful not to change a zero linear value to dB.

The calculation is also done when you leave an entry field with the TAB key. In this case, the program will use the displayed values. Going forth and back through the entry fields with the TAB / Shift TAB keys will result in a small change of all values due to the 3 decimal places only shown on the display.

When changing the values for Frequency, Antenna Gain Transmitter, Antenna Gain Receiver or Distance, all other values are recalculated using the set Transmitted Power.

When changing one of the other values however, Frequency, Antenna Gain Transmitter, Antenna Gain Receiver and Distance will keep their values.

If you enter a Distance value, which is smaller than 0.159 times the wavelength (<λ/2π), the distance entry field becomes yellow as a warning for leaving the farfield condition.

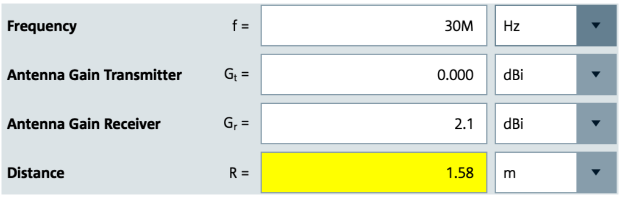


Figure 4-2: Near-Field Warning

4.3 Main / About Menu

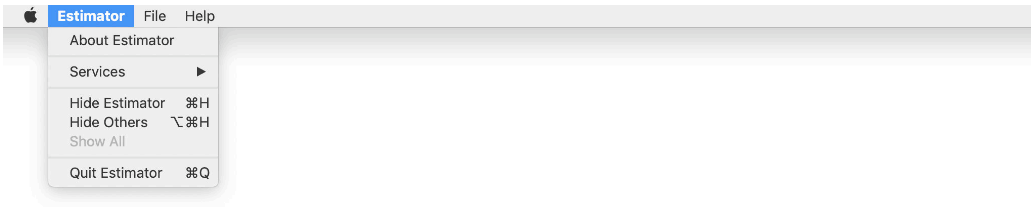


Figure 4-3: Main Menu

On selecting Estimator > About Estimator (on Windows: Help > About), the following menu will show up:

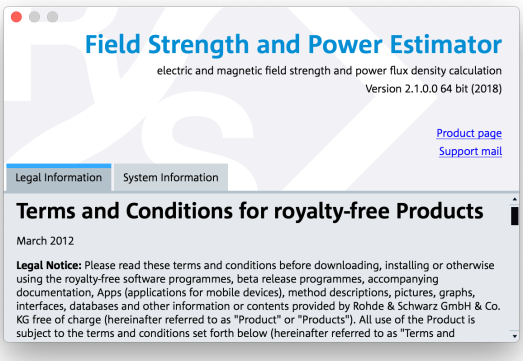


Figure 4-4: About Menu

The tab "Legal Information" shows the conditions for using this program.

The tabs "Driver Information"(only Windows) and "System Information" will display information on some installed drivers and your operating system. You can use the button "copy support information to clipboard" for debugging computer problems. Paste your clipboard contents to your mail system and send it to TM-Applications@rohde-schwarz.com.

4.4 Save and Recall Settings

On exiting the program, all numerical values and units are saved to a file *Estimator.ini* in the AppData directory. Upon restart, these values are automatically restored. For convenience of operation, you can Save and Open Settings dialog. Use Default Settings to get a well defined program state.

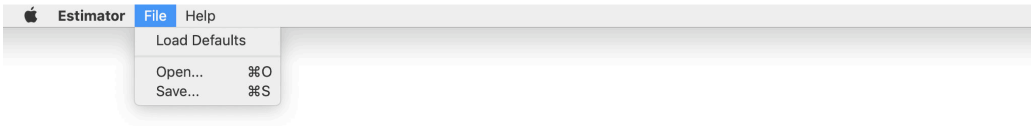


Figure 4-5: File Menu

4.5 Help

Figure 4-6: Help Menu

On selecting "Show Formulas", the following window opens:

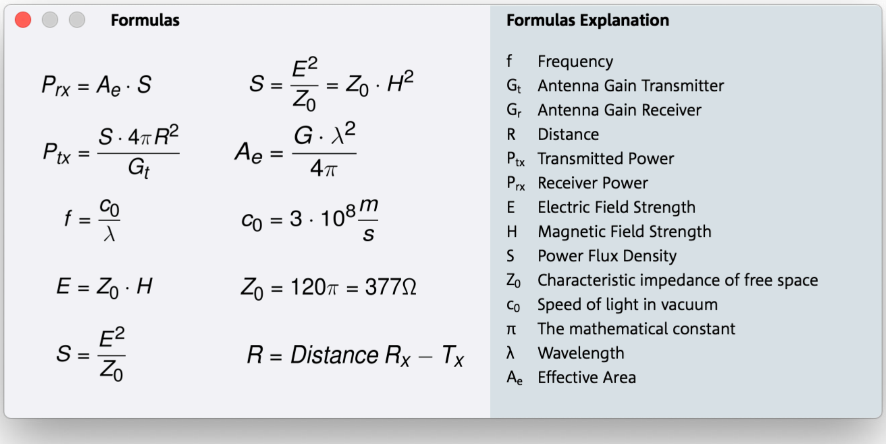


Figure 4-7: Formulas Window

For convenient use of the program and recalling the explanation of the calculation formulas, selecting Help will show you this documentation.

5 Some Examples

The following examples show some of the additional capabilties of the program Field Strength and Power Estimator.

5.1 Determining the Propagation Attenuation between 2 Antennas

You can determine the attenuation of an undistorted wave progagation as follows:

Enter the frequency, set the antenna gains of transmit and receive antennas to 0 dB_i and enter the distance. If you enter 0 dBm for transmitted power, the field Received Power in dBm will show the value of the attenuation in dB.

Example:

Satellites of the ASTRA TV system for Europe are geostationary satellites positioned at 19.3° East. They transmit at frequencies around 12 GHz. Geostationary satelites orbit at a height of 35785 km above the equator. The distance from satellite to the city of Munich (the home city of Rohde & Schwarz) is around 38190 km. The program calculates a propagation attenuation of 205.67 dB.

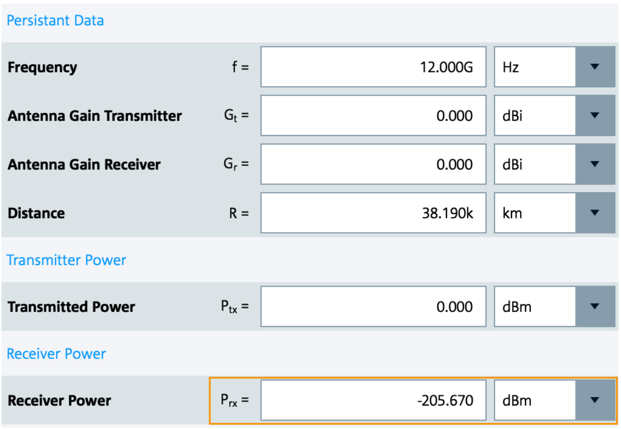


Figure 5-1: Propagation Attenuation at 12 GHz

5.2 Determining the Transmit Power for a GPS Simulation

GPS receivers often have integrated antennas. To test such GPS receivers in your laboratory with a test tranmitter, you have to provide a signal with a field strength similar to real GPS signals transmitted at 1575 MHz. The GPS system makes sure, that a ground receiver gets a power of -165 dBW (= -135 dBm) out of an isotropic antenna. You want to use a dipole antenna 1 m above your GPS receiver. What transmitted power do you have to set at your test transmitter, in order to get the same field strength as from the GPS system?

Set Frequency to 1.575 GHz, transmit antenna gain to 2.1 dBi and distance to 1 m. Now enter a received power of -135 dBm. Pressing the ENTER key will calculate the necessary transmit power as -107.707 dBm. By the way, propagation loss for GPS signals is about -182 dB, since the satellites orbit at a height of 20000 km above earth.

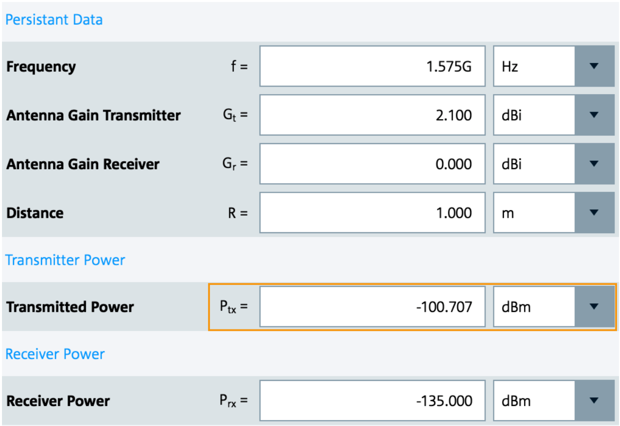


Figure 5-2: GPS Simulation

5.3 Using EIRP

Sometimes transmitter power and transmitter antenna gain are not specified separately but as EIRP (Effective Isotropic Radiated Power). EIRP is the product of transmitted power and transmitter antenna gain when using linear values or the sum of both values in dB or dBm. If EIRP is given, use 0 dB_i for Antenna Gain Transmitter and enter the EIRP in dBm, mW or W in the field for Transmitter Power.

5.4 Calculating Antenna Factor from Antenna Gain

For many antennas only antenna gain is specified. However, same spectrum analysers allowing direct display of the field strength, need the antenna factor to be entered. Determining the antenna from gain is easy:

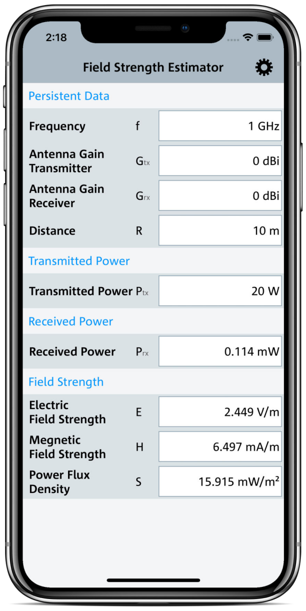
Set frequency to 1GHz and enter the gain in the field Antenna Gain Receiver. Select the units for Received Power and Electric Field Strenght to dBµV/50Ω and dBµV/m resp.

Enter 0 for the Received Power. The numeric field of Electric Field Strenght will show the antenna factor 24.219 dB.

Figure 5-3: Determine Antenna Factor

Calculating the antenna gain from a given antenna factor is not so easy, but you can try to enter a first estimation for the gain in the field Antenna Gain Receiver and proceed by entering 0 for the Received Power as above. Compare the value for the antenna factor from the field Electric Field Strength. Note the difference to the antenna factor of your antenna. Now change the value for the receiver antenna gain by this amount. Enter 0 for the Received Power again and check the antenna factor. Loop through this process until the result meets your expectation.

6 Smartphone App Versions



Download on the App Store

GET IT ON Google Play

Get it from Microsoft

Figure 6-1: Smartphone Versions

The app can be downloaded free of charge from different app-stores, depending on your mobile operating system. To find the app easily, please use search terms "Rohde & Schwarz" or "Field Strength Estimator" or click on the following links to access the app landing page directly:

- **iOS:**
  https://itunes.apple.com/app/id364229792
- **Android:**
  https://play.google.com/store/apps/details?id=com.rohdeschwarz.android.estimator
- **Windows Phone:**
  https://www.microsoft.com/store/apps/9nblggh0fwb1

7 Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, monitoring and network testing. Founded more than 80 years ago, the independent company has an extensive sales and service network with locations in more than 70 countries.

The electronics group ranks among the world market leaders in its established business fields. The company is headquartered in Munich, Germany. It also has regional headquarters in Singapore and Columbia, Maryland, USA, to manage its operations in these regions.

Sustainable product design

- Environmental compatibility and eco-footprint
- Energy efficiency and low emissions
- Longevity and optimized total cost of ownership

Certified Quality Management
ISO 9001

Certified Environmental Management
ISO 14001

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