

Rohde&Schwarz Products: Various Antennas, Receivers, Spectrum Analyzers and Field Strength Measurement Equipment

Field Strength and Power Estimator

Application Note 1MA85

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 $\mu\text{V/m}$ and $\text{dB}\mu\text{V/m}$ as well as A/m to $\mu\text{A/m}$ and $\text{dB}\mu\text{A/m}$. Additional applications are calculation of propagation loss or antenna factor e.g.



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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 Fieldstrength and Power Estimator available with this application note helps with the calculation and converts mW to dBm, V/m to $\mu\text{V/m}$ and $\text{dB}\mu\text{V/m}$ as well as A/m to $\mu\text{A/m}$ and $\text{dB}\mu\text{A/m}$.

- 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.

2 Software Features And Formulas

The program Fieldstrength 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 50 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,

Power Flux Density

changes in polarisation, reflections, and multi path propagation affect the true values. Additionally antenna VSWR and cable losses have to be considered.

The program Fieldstrength 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**.

Power Flux Density

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

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

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/m²) 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 transmited power is concentrated to a part of the sphere's surface. The power flux density is then:

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

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

$$S = E * H$$

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 $\lambda/2\pi$ 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.

$$Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} = 120 * \pi \approx 377 \text{ Ohms}$$

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

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

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

Antenna Characteristics

E is measured in V/m (Volts per meter), $\mu\text{V/m}$ (microvolts per meter) or $\text{dB}\mu\text{V/m}$ (decibels over 1 microvolt per meter).

H is measured in A/m (amperes per meter), $\mu\text{A/m}$ (microamperes per meter) or $\text{dB}\mu\text{A/m}$ (decibels over 1 microampere per meter).

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

$$A_i = \frac{I}{4 * \pi} * \lambda^2 \approx 0.08 * \lambda^2$$

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:

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

The effective area of a commonly used $\lambda/2$ dipole is:

$$A_D = 0.13 * \lambda^2 \text{ so}$$

$$G_D = \frac{A_D}{A_i} = \frac{0.13}{0.08} = 1.625 \equiv 2.1 \text{dB}_i$$

The gain G_D of a $\lambda/2$ 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:

$$P_r = S * A_r$$

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 dBm means the power referred to 1 mW (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):

$$P_r / \text{dBm} = 10 * \log_{10} \frac{P_r / \text{mW}}{1 / \text{mW}}$$

Receiving Signals and Measuring Power Flux Density

Please read this formula as follows:

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

Receiving Signals and Measuring Power Flux Density

In order to measure the power flux density, we need a receiver or a spectrum analyser and an antenna. As explained above, the receiving antenna picks up the power P_r from the electromagnetic field with its 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 $P_r = S * A_r$ we get

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

Remembering that the effective area A_r of an antenna is:

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

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 $0.08 * \lambda^2$, this is $0.08 * 0.332 \text{ m} * 0.332 \text{ m} = 0.0088 \text{ m}^2$. A dipole antenna has a gain of 1.625, so its area is 0.0143 m^2 . With this, the power flux density is 139.6 mW/m^2 or 21.5 dBm/m^2 .

Receiving Signals and Measuring Electric Field Strength

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

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

we get:

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

If our receiver shows the input voltage U_r at an input impedance of Z_i (normally 50 Ohm), 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:

Receiving Signals and Measuring Magnetic Field

$$E = \sqrt{\frac{U_r^2}{Z_i} * \frac{I}{A_r} * Z_0} \text{ or, by rearranging the formula:}$$

$$E = U_r * \sqrt{\frac{I}{A_r} * \frac{Z_0}{Z_i}}$$

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

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

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:

$$E = U_r * K_a$$

Sometimes K_a is expressed in dB:

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

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

Example: 0.0003 V/m = 300 $\mu\text{V/m}$

You can also convert the field strength from $\mu\text{V/m}$ to $\text{dB}\mu\text{V/m}$ using following equation:

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

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 $\text{dB}\mu\text{V}$. 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 $\text{dB}\mu\text{V/m}$.

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 $Z_0 = 377 \Omega$). Then we simply have to divide this value by 377Ω .

Magnetic field strength is measured in A/m or in $\mu\text{A/m}$. In order to convert to $\mu\text{A/m}$, remember that $1 \text{ A} = 1000000 \mu\text{A}$ (1 million micro Amperes).

Example: $0.0003 \text{ A/m} = 300 \mu\text{A/m}$.

You can also convert the field strength from $\mu\text{A/m}$ to $\text{dB}\mu\text{A/m}$ using following equation

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

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 $\text{dB}\mu\text{V}$. Determine the electric field strength first as above. With the gain of the dipole antenna of 1.625, we get $K_a = 23$ or $20 * \log(23) = 27.2 \text{ dB}$. With this, the electric field strength is 7.42 V/m. In order to get the magnetic field strength, we divide this value by 377Ω and get 0.0197 A/m or 85.9 $\text{dB}\mu\text{A/m}$.

3 Installing and Starting Field Strength and Power Estimator

To install the Fieldstrength and Power Estimator program execute the file FieldStrengthEstimator_<version number>.exe with a double click. The installation wizard is activated; the first option is choose the language (English or German) for the installation.

Follow the instructions from the wizard. In the course of the installation select the directory of your choice in which the program is to be installed.

Fieldstrength and Power Estimator requires approximately 1 MB RAM on a hard disk. The wizard also adds an entry for Fieldstrength and Power Estimator in the Start->Programs menu of the computer.

No other parameters are required for installation.

For de-installation, Rohde & Schwarz supplies the program uninstall.exe, which removes the program Fieldstrength and Power Estimator completely from the computer.

Warning: De-install removes the program files and also the directory in which Fieldstrength and Power Estimator is installed. Make sure you have archived any other files or subdirectories present in the directory before de-installation.

Receiving Signals and Measuring Magnetic Field

To start the program, select Fieldstrength and Power Estimator from the Program submenu in the Windows Start menu. When Fieldstrength and Power Estimator starts, the Registration Form appears. Please register the installation; registration is free and does not result in any further commitments for you or your company.

If Fieldstrength and Power Estimator has not yet been registered, you can nevertheless start the program by clicking the *Continue* button.

Registration Form

Welcome to Field Strength and Power Estimator, version 1.1 Rohde&Schwarz GmbH&CoKG

You are using an unregistered version of Field Strength and Power Estimator. This version has full functionality and no expiration date.
As we are continuously improving the program, we depend on your comments and experience with Field Strength and Power Estimator.
Therefore, we kindly ask you to register Field Strength and Power Estimator. Registration is free of charge and does not obligate you or your company.

To register:

1. Fill out the registration form below.
2. Click 'Copy Registration Form to Clipboard'.
3. Open your mail client and paste the clipboard into the email message field with 'Ctrl-V'.
4. Send the registration form to TM-Applications@rsd.rohde-schwarz.com.

You will receive an email from Rohde & Schwarz with your registration key.

Name *

* The registration key is derived from your name. Please fill out Email and country as well.
All other fields may be filled out optionally. Please help us by also providing these few details.

Company Dep.
Street City
Telephone **Country *** ...

EMail *

Comments

Copy Registration Form to Clipboard

Once you received your registration key

1. Enter your User Name and Registration Key.
2. Click 'Continue'.

Field Strength and Power Estimator will start immediately. This registration form will no longer appear at program start.

User Name **Continue**
Key Code

Fig 1 Registration Form

If you complete the Registration form, you will be sent a keycode. Enter the code into the Registration form and click the *Continue* button. The Main Window of Fieldstrength and Power Estimator appears.

Once Fieldstrength and Power Estimator has been registered, the registration form does not appear any more.

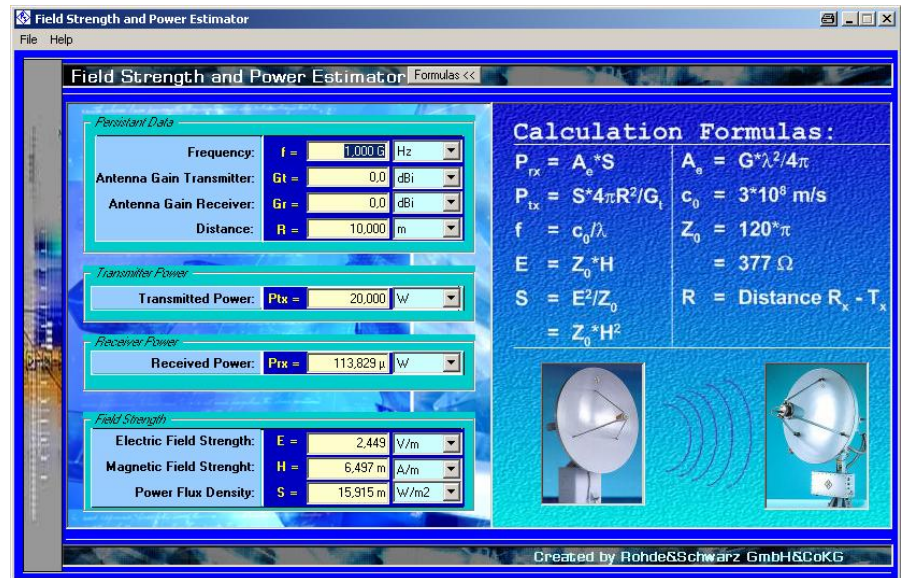


Fig 2 Fieldstrength and Power Estimator Main Window

Click the *Formulas* button to show the calculation formulas.


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  selection function with your mouse.

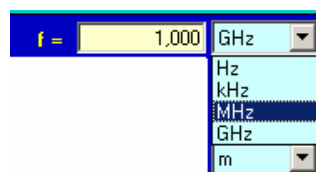


Fig 3 Selecting Units

Entering numerical values:

Depending on the language settings of your computer's operation system, a colon or a dot is used as a decimal separator.

Entering numerical values:

The following inputs all result in the same value:

- 123.45E-7
- 12.345 μ , 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	SI	SI
	words	prefix	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

Fig 4 Exponential abbreviations

Starting Calculation

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 ($< \lambda/2 \pi$), the distance entry field becomes yellow as a warning for leaving the far-field condition.

Frequency:	f =	30,000 M	Hz
Antenna Gain Transmitter:	Gt =	0,0	dBi
Antenna Gain Receiver:	Gr =	2,1	dBi
Distance:	R =	1,580	m

Fig 5 Near-Field Warning

Save and Recall Settings

On exiting the program, all numerical values and units are saved to a file *settings.ini* in the program 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.

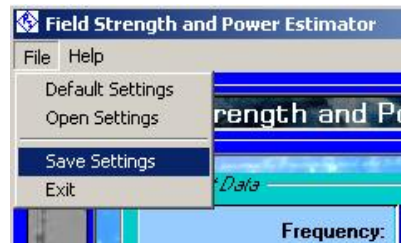


Fig 6 Save and Recall Settings

Help and About Menu

Help and About Menu

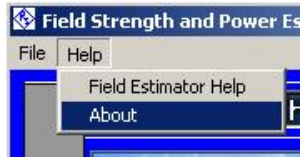


Fig 7 Help Menu

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

On selecting About, the following menu will show up:

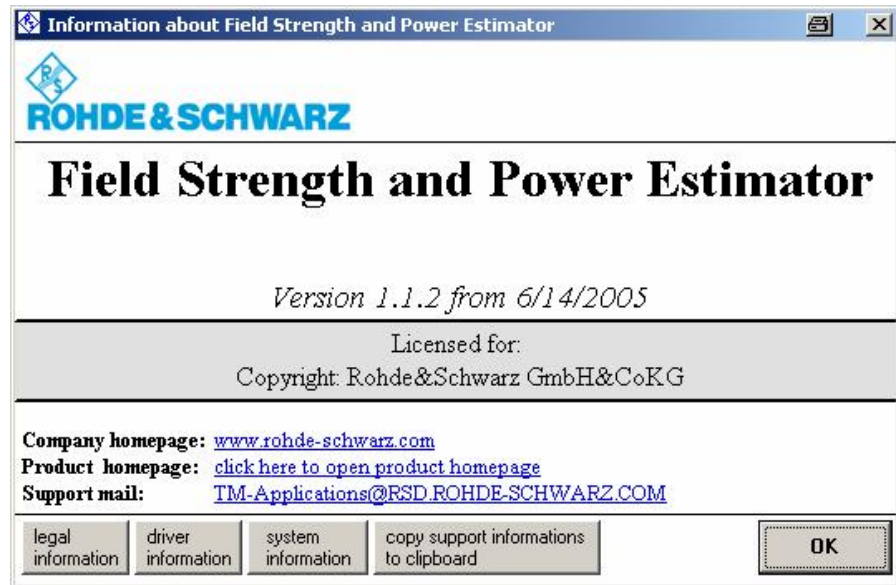


Fig 8 About Menu

The button *legal information* shows the conditions for using this program.

The buttons *driver information* 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@rsd.rohde-schwarz.com.

5 Some Examples

The following examples show some of the additional capabilities of the program Field Strength and Power Estimator. Please note, that there are corresponding setting files available in your installation directory. You can load them in the File/Open Settings menu.

Determining the Propagation Attenuation between 2 Antennas

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

Enter the frequency, set the antenna gains of transmit and receive antennas to 0 dBi 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 satellites 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.

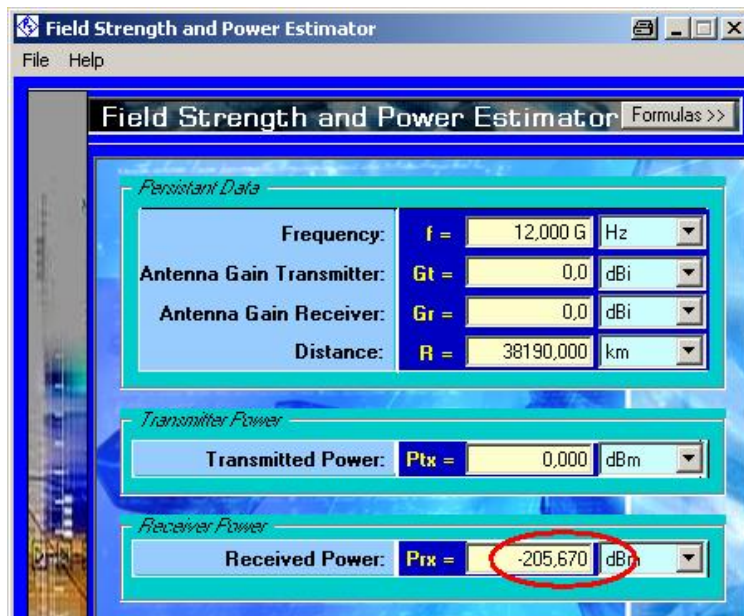


Fig 9 Propagation Attenuation at 12 GHz

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 transmitter, 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 -107.706 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.

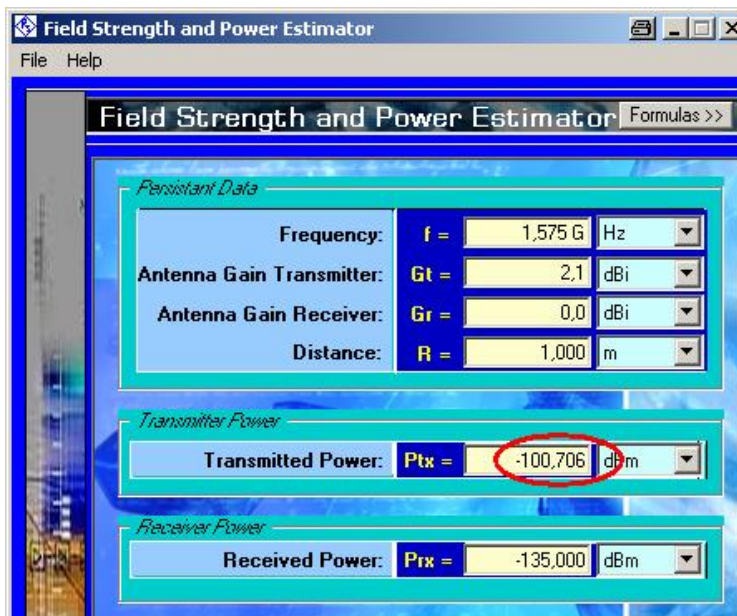


Fig 10 GPS Simulation

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 dBi for Antenna Gain Transmitter and enter the EIRP in dBm, mW or W in the field for Transmitter Power.

Calculating Antenna Factor from Antenna Gain

For many antennas only antenna gain is specified. However, some 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 Strength to $\text{dB}\mu\text{V}/50\Omega$ and $\text{dB}\mu\text{V}/\text{m}$ resp.

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

Persistent Data	
Frequency:	f = 1,000 GHz
Antenna Gain Transmitter:	Gt = 0,0 dBi
Antenna Gain Receiver:	Gr = 6,0 dBi
Distance:	R = 10,000 km

Transmitter Power	
Transmitted Power:	Ptx = -0,552 dBm

Receiver Power	
Received Power:	Prx = 0,000 dBuV/50

Field Strength	
Electric Field Strength:	E = 24,219 dBuV/m
Magnetic Field Strength:	H = 43,114 nA/m
Power Flux Density:	S = -91,544 dBm/m ²

Fig 11 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 Hardware and Software Requirements

Hardware Requirements

CPU: Pentium 300 MHz or better

Hard Disk: 1 MByte free

Monitor: SVGA color monitor, resolution 800x600 or better

Software Requirements

The program was tested with Microsoft 32-bit operating systems (Windows 95/98/NT/2000/ME/XP)

7 Additional Information

This application note and the associated program Fieldstrength and Power Estimator are updated from time to time. Please visit the website [1MA85](#) in order to download new versions. After installation, the latest program information can be found in the file *history.rtf* in the installation directory. You can access this file also from link *Programs / Field Strength Estimator / History* from your *Start Programs* folder.

Please send any comments or suggestions about this application note to TM-Applications@rsd.rohde-schwarz.com.

8 Ordering Information

Please note, that complete solutions for field strength and power measurements for various applications are available from Rohde & Schwarz.

For additional information about antennas, receivers, spectrum analysers and fieldstrength measurement equipment, see the Rohde & Schwarz website www.rohde-schwarz.com.



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