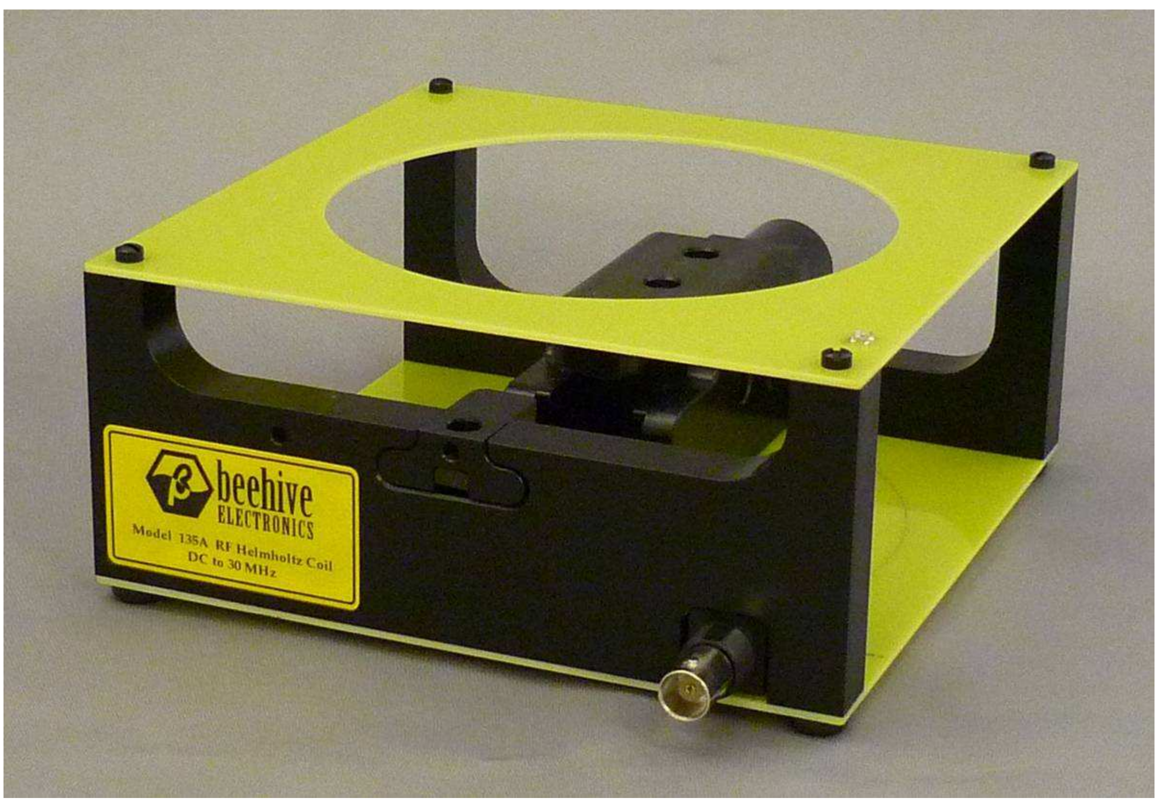
135A RF Helmholtz Coil
Operating Manual



Description

The 135A RF Helmholtz Coil generates a controlled, well-defined magnetic field between its coils. This magnetic field can be used to calibrate magnetic field probes, or to generate a controlled field for testing other devices.

The 135A is optimized for high-frequency performance, and is usable up to 30 MHz.

The 135A includes fixturing to precisely hold the Beehive Electronics 100A, 100B, and 100C EMC probes to that the user may measure the sensitivity of the probes and calculate their calibration factors. Mounting holes are provided to allow the user to fixture other devices inside the Helmholtz coil.

Features

- Wide bandwidth allows operation up to 30 MHz.
- Includes fixtures for use in calibration 100A, 100B, 100C probes.
- Mounting features provided for customer-supplied fixtures.
- Designed for use with standard 50 ohm signal sources.

Specifications

Gain

Expressed as flux density/current

$1.45 * 10^{-5}$ tesla/ampere

Expressed as magnetic field strength/current

11.54 ((amperes/meter)/amperes) or 11.54 m^{-1}

Frequency Response

3 dB bandwidth: DC to 6.7 MHz, typical when driven from 50 ohm source

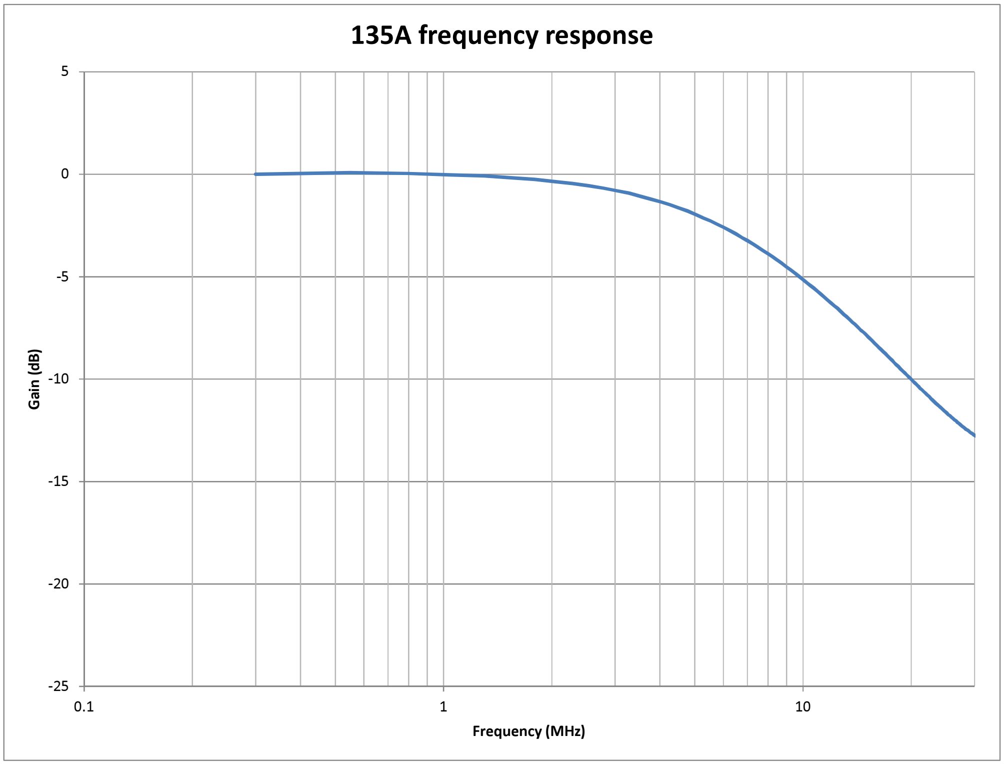


Figure 1

Correcting for the impact of the Helmholtz coil inductance on frequency response, the 3 dB bandwidth is greater than 30 MHz.

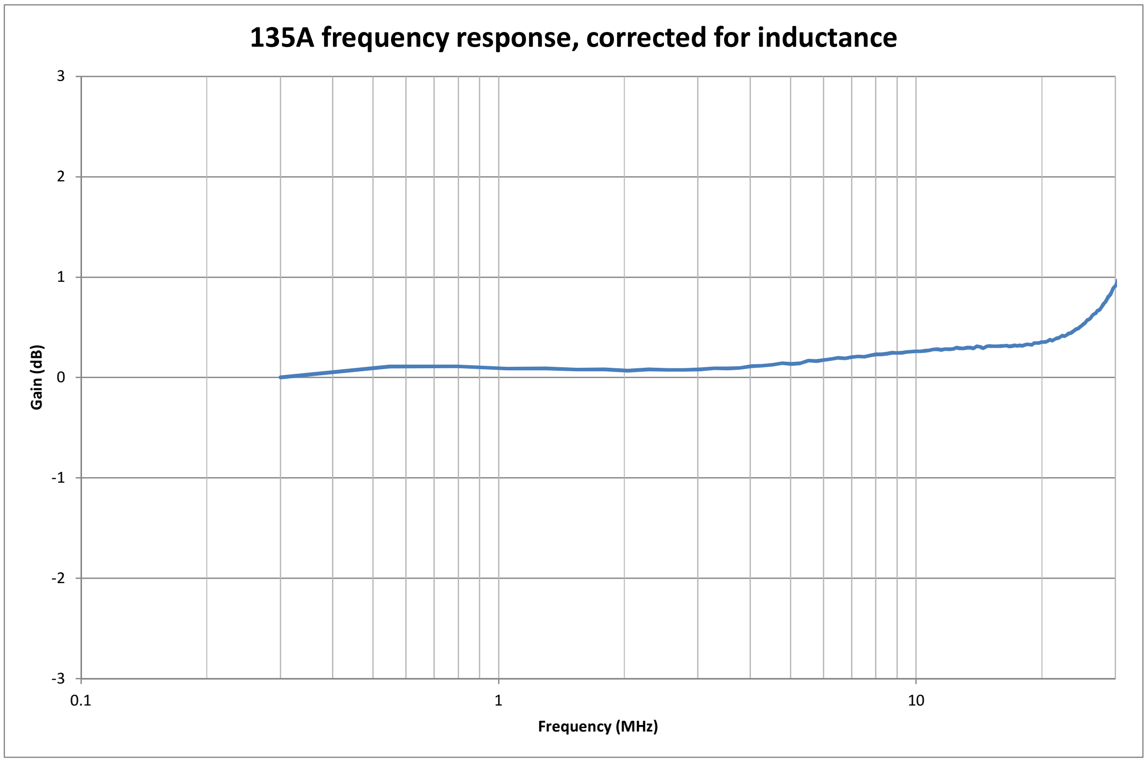


Figure 2

Maximum Input Current

0.5 amperes peak, 0.35 amperes rms

Maximum Input Voltage

240 volts peak, 170 volts rms

Maximum Input Power

+10 dBm, 100 kHz - 2 GHz

Port Characteristics

Impedance

Inductance: 1.25 uH +/- 10%, test frequency 1 MHz

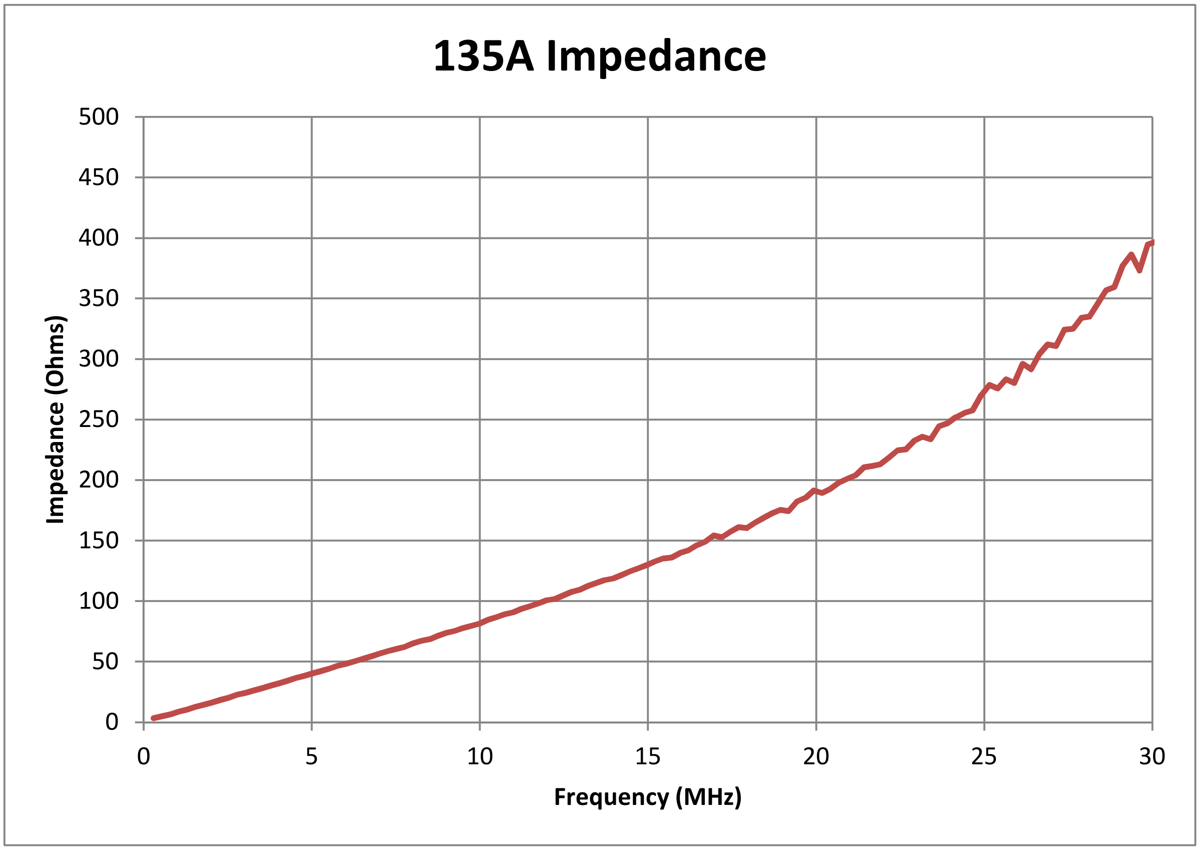


Figure 3

Connector

BNC female

Environmental

Operating temperature: 0C to 55C

Storage temperature: -20C to 70C

Dimensions

Loop dimensions

Loop diameter	4.88” (123.9 mm)
Loop spacing	2.44” (62.0 mm)

Overall dimensions

Height:	2.5” (63 mm)
Width:	6” (152 mm)
Depth:	6” (152 mm)

Warranty

1 year warranty

30 day unconditional return policy

Theory of Operation

A Helmholtz coil consists of two loops of wire (solenoids) aligned on a common axis. The two solenoids are wired in series and connected to a common input. When a signal is applied to the input, the same current flows in both solenoids, contributing to the magnetic field established.

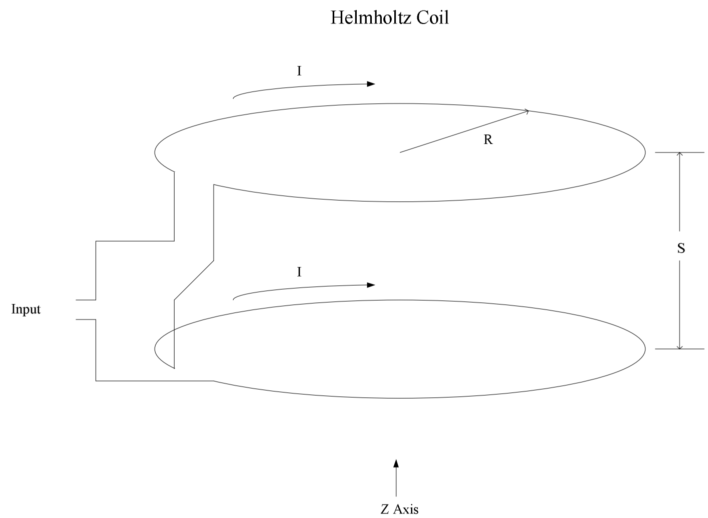


Figure 4

The spacing between the loops affects the shape of the magnetic field. For a Helmholtz coil, the spacing between the coils is set to be equal to the coil radius. When this condition is met, the following conditions are met:

The first derivative of the on-axis magnetic field is zero in the center of the coil:

$$dB/dz = 0$$

The second derivative of the on-axis magnetic field is zero at the center of the coil:

$$d^2B/dz^2 = 0$$

As a result, a relatively uniform magnetic field is created in the center of the coil. The flux density is:

$$B = \left(\frac{4}{5}\right)^{\frac{3}{2}} \frac{\mu_0 nI}{R}$$

Where I is the current in the coil, n is the number of turns in each solenoid, and R is the coil radius. For the 135A, these values are:

n=1

R=2.44” (0.0620 m)

Most Helmholtz coils use a large number of turns in each solenoid to create the largest flux density possible. This works fine at DC, but it results in a large solenoid inductance. This makes the impedance of the Helmholtz coil increase rapidly with frequency, restricting their use to very low frequencies.

Since the 135A uses a single turn in each solenoid, its inductance is much lower, allowing operation as high as 50 MHz. The tradeoff for this wide bandwidth is that it results in a low flux density. In typical applications, such as when calibrating a magnetic field probe, the output signal from the probe will be relatively low. We recommend the user connect their probe to a spectrum analyzer or network analyzer, since these have good sensitivity.

Operating Instructions

General measurement recommendations

When making magnetic field measurements, it is important to be aware of items in the environment that might affect the magnetic fields. When testing with a DC magnetic field, this is easiest. Only high-permeability materials, such as iron, steel, ferrite, and nickel, will distort field patterns. Plastics and wood will not affect the magnetic field, nor will low-permeability metals like aluminum or copper.

However, when testing at high frequency, the rules change slightly. Non-conductors such as plastic and wood are still safe – they will not affect the magnetic fields. But any conductor, regardless of its permeability, will change the magnetic fields around it. So, when you're trying to measure AC magnetic fields, it's important to clear the measurement area of conductors as well.

This is because AC magnetic fields will generate AC currents in nearby metal objects. Those currents generate their own magnetic fields, disturbing the overall field pattern.

When using the Helmholtz coil, you should clear the area around it of metal objects. In particular, the Helmholtz coil should not be set on a metal surface. We recommend that you set it on a wood or plastic surface. If these are not available, you can place the Helmholtz coil on an empty cardboard box.

As a general recommendation, we suggest that you keep all metal objects at least 12" (0.3m) away from the Helmholtz coil when in use.

When routing cables to the Helmholtz coil or the probe under test, be sure to route the cables directly away from the Helmholtz coil and the probe. Do not let the cables loop through the measurement area.

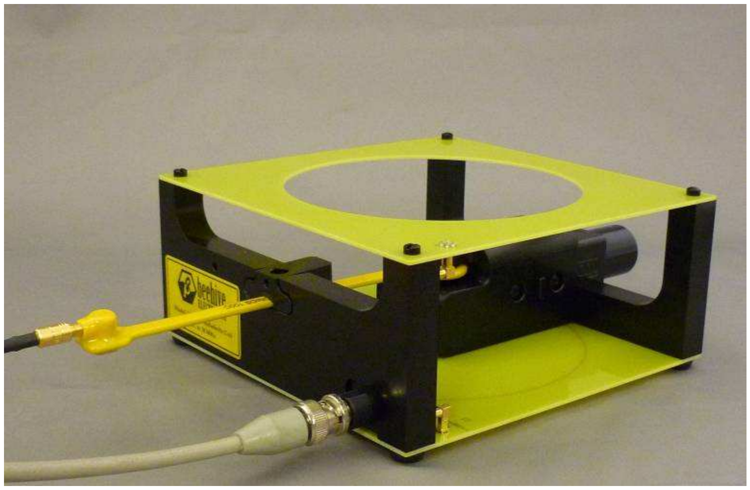


Figure 5
Good cable routing

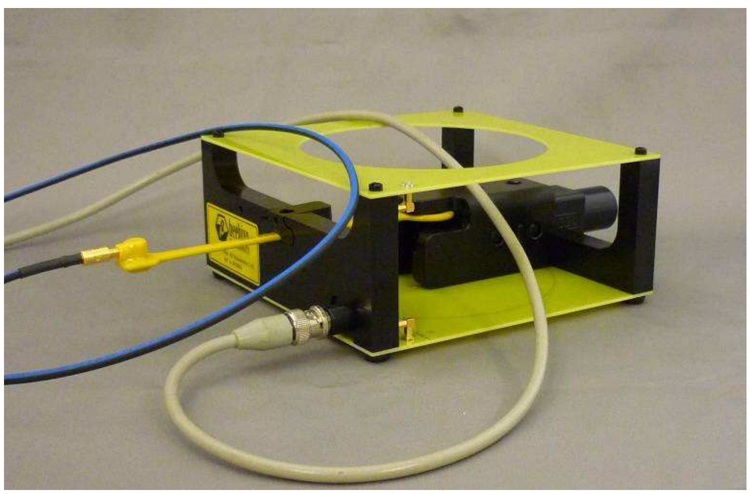
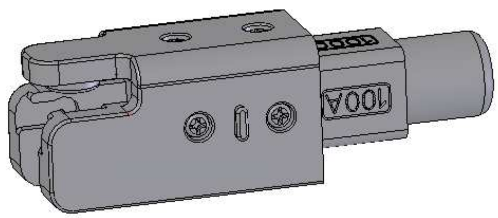


Figure 6
Bad cable routing

Testing of Beehive Electronics 100A/B/C probes

Aligning the probe fixture

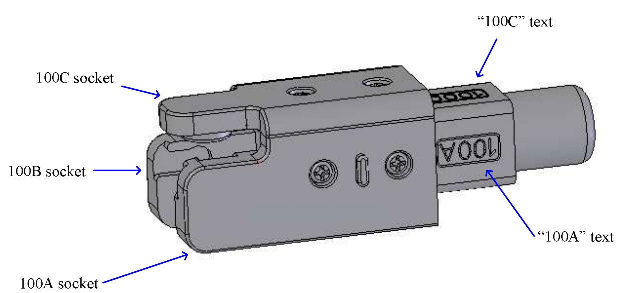
If you are testing a Beehive Electronics 100A, 100B, or 100C probe, you can use the included probe fixture to properly place the probe's sensor in the center of the Helmholtz coil. If you're testing another type of device, skip this step.



Probe fixture

Figure 7

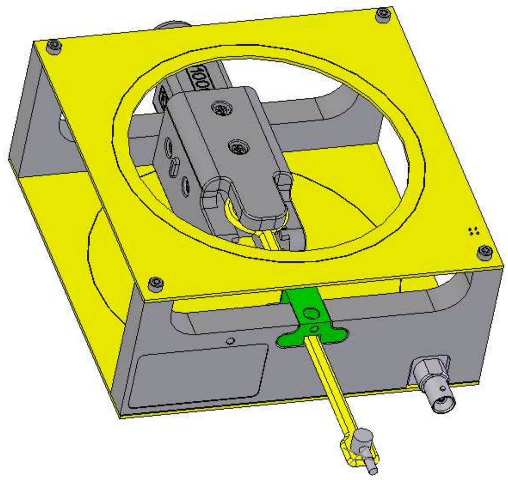
The probe fixture has three sockets machined into its body, designed to accept the probe tip of the 100A, 100B, and 100C. When the probe is rotated so that, for example, the text "100A" is on top, the socket for the 100A will be on top as well.



Probe fixture socket locations

Figure 8

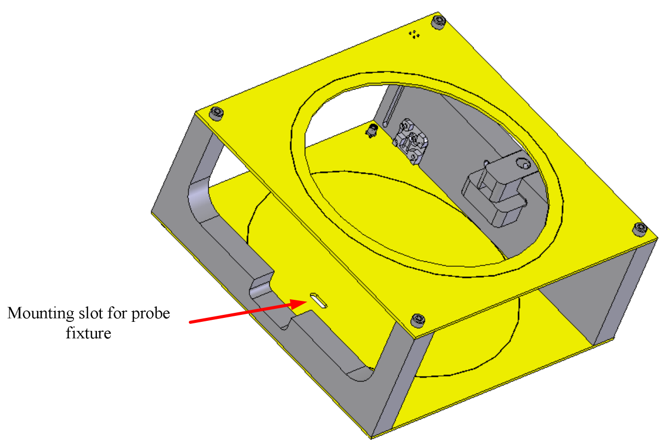
Place the probe fixture into the Helmholtz coil with the correct text facing up. For example, if you're testing a 100C probe, the "100C" text should be on top.



Clamp installed in Helmholtz coil

Figure 9

Note that underneath the probe fixture, in the Helmholtz coil baseplate, there is a slot designed to mate with the probe fixture:



Mouting slot in Helmholtz coil baseplate or probe fixture

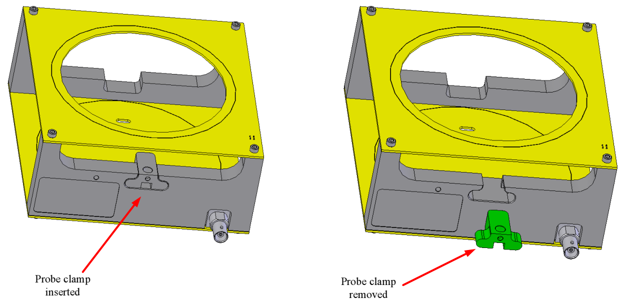
Figure 10

There is a corresponding protrusion on the bottom of the probe fixture that fits in this slot. The probe fixture should be mounted with its protrusion in the baseplate slot.

Mounting the probe in the probe fixture

This step can also be skipped if your device under test is something other than a Beehive Electronics 100A, 100B, or 100C probe.

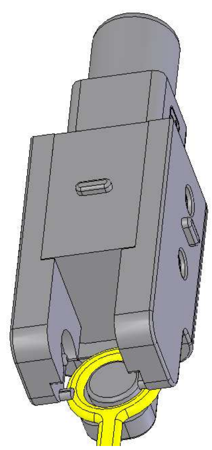
Slide the probe clamp out of the Helmholtz coil front panel.



Probe clamp insertion and removal

Figure 11

Insert the tip of your probe into the appropriate socket. The sockets are designed to be a relatively snug it with the probe tip to aid in centering the probe in the Helmholtz coil accurately.



100C probe in probe fixture,
Bottom view

Figure 12

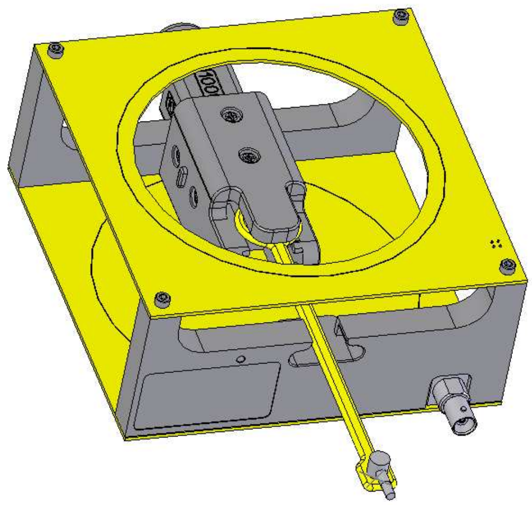
Important note regarding probe fit

The 100 A/B/C probes are coated with a yellow vinyl coating that covers the antenna inside. This coating can vary in thickness from probe to probe. As a result, if you have a probe with a thicker coating than normal, you may find that the probe won't fit in the socket.

If this is the case, you will need to trim the yellow vinyl coating back with an Exacto knife or something similar.

This sounds risky, but there is no risk to the probe in doing this. Trimming the yellow vinyl back will not damage the probe, affect its performance, or void your warranty.

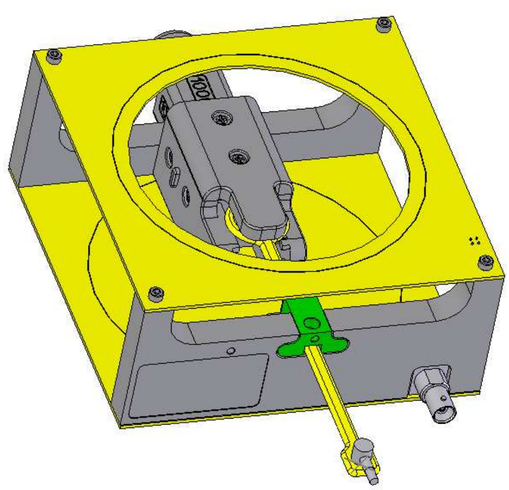
The connector end of the probe should be sticking out the front of the Helmholtz coil:



Probe installed in Helmholtz coil

Figure 13

Re-install the probe clamp. Note that the probe clamp has a foam shim inside it so that it can firmly hold the probe in place. You will need to press down on the clamp as you insert it to compress the foam.



Clamp installed in Helmholtz coil

Figure 14

Measurement

When using the Helmholtz coil, two pieces of test equipment are required:

1. A signal source, such as a signal generator or function generator. A 50 ohm source is recommended, but not required. This will supply the signal to the Helmholtz coil
2. A receiver to measure the output of the probe under test.

A network analyzer has both a source and receiver, and can be used for this measurement. Alternatively, a signal generator can be used as a source, and a spectrum analyzer as the receiver.

Note on the use of oscilloscopes with the measurement

In principle, an oscilloscope can be connected to the probe under test and used as a receiver, in place of the network analyzer or spectrum analyzer. However, the sensitivity of oscilloscopes in general is not nearly as good as these other instruments. In most cases, the oscilloscope will have insufficient sensitivity for the measurement.

However, there is a way to improve the sensitivity of the oscilloscope. Many newer oscilloscopes have an FFT (fast Fourier transform) mode that display the Fourier transform of the input signal. In this frequency-domain display, the noise floor will be significantly lower than in the time domain display. For this reason we recommend using FFT mode if you're trying to use an oscilloscope.

Connections when using a network analyzer

Most network analyzers have two ports:

Port 1, usually on the left side, which is the source

Port 2, usually on the right side, which is the receiver

Connect the Helmholtz coil to port 1 and the probe output to port 2, as shown below

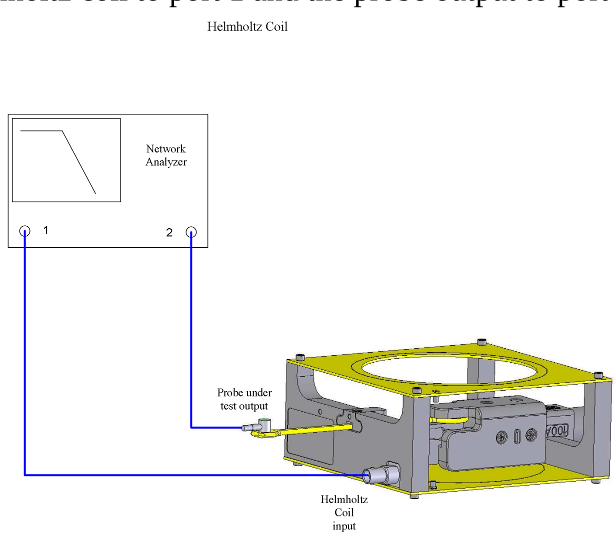


Figure 15

Measure gain/S21 of the test setup.

Tips on network analyzer setup:

For best sensitivity reduce the resolution bandwidth to the lowest practical value.

For best sensitivity set the source output power to the maximum level.

Connections when using a signal generator and spectrum analyzer

Connect the signal generator to the Helmholtz coil input and connect the spectrum analyzer to the output of the probe under test, as shown below:

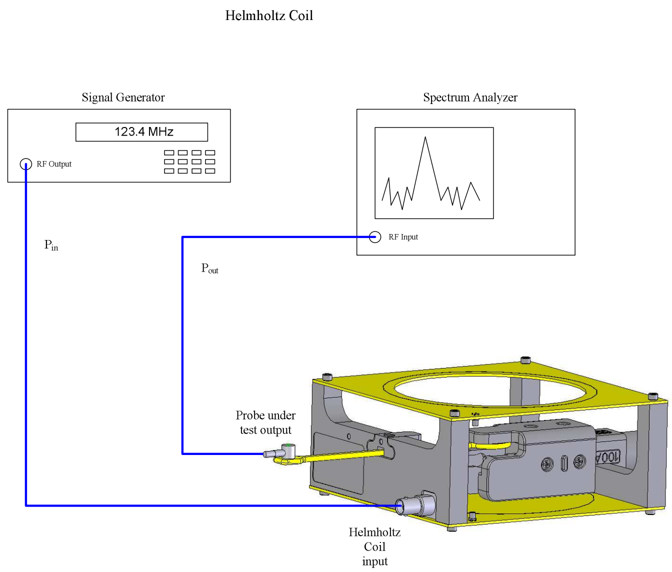


Figure 16

Setup tips

For best sensitivity reduce the resolution bandwidth of the spectrum analyzer to the lowest practical value. Note that as the resolution bandwidth is decreased, the sweep time increases. Depending on the resolution bandwidth and the frequency span settings, this could result in unacceptably slow sweep time.

For best sensitivity set the spectrum analyzer input attenuator to 0 dB.

Set the signal generator output power to its maximum value.

Testing other devices in the Helmholtz coil

The Helmholtz coil can be used to test other devices than the 100 series probes. Any device that can fit between the coils can be placed inside.

The device under test (DUT) should be place in the center of the Helmholtz coil, both horizontally and vertically. Mounting holes are provided in the Helmholtz coil base plate so that a user-provided fixture can be mounted to the Helmholtz coil. The hole pattern is shown below:

Mounting hole locations

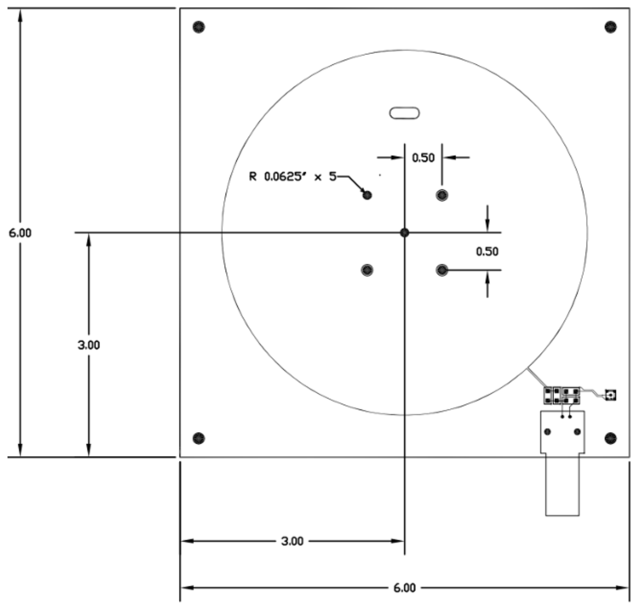


Figure 17

Calculating the sensitivity of the device under test

Calculating sensitivity with network analyzer measurements

When measuring a device under test (DUT) in the Helmholtz coil using a network analyzer (figure 15), we measure the combined gain of the Helmholtz coil and the device under test. Gain is measured as the S-parameter S21, typically expressed in decibels. For the calculations below, G_{meas}, the measured gain of the Helmholtz coil / DUT combination is equal to S21.

Calculating sensitivity with signal generator/spectrum analyzer measurements

When measuring a device under test (DUT) in the Helmholtz coil using a signal generator and spectrum analyzer (figure 16), we measure the combined gain of the Helmholtz coil and the device under test. This gain is calculated by subtracting the power into the Helmholtz coil (Pout) from the signal power into the spectrum analyzer (P_{load}). Both are typically in units of dBm.

G_{meas}, the measured gain of the Helmholtz coil / DUT combination is equal to:

$$G_{meas} \quad = \quad P_{out} - P_{in}$$

When all are expressed in decibels.

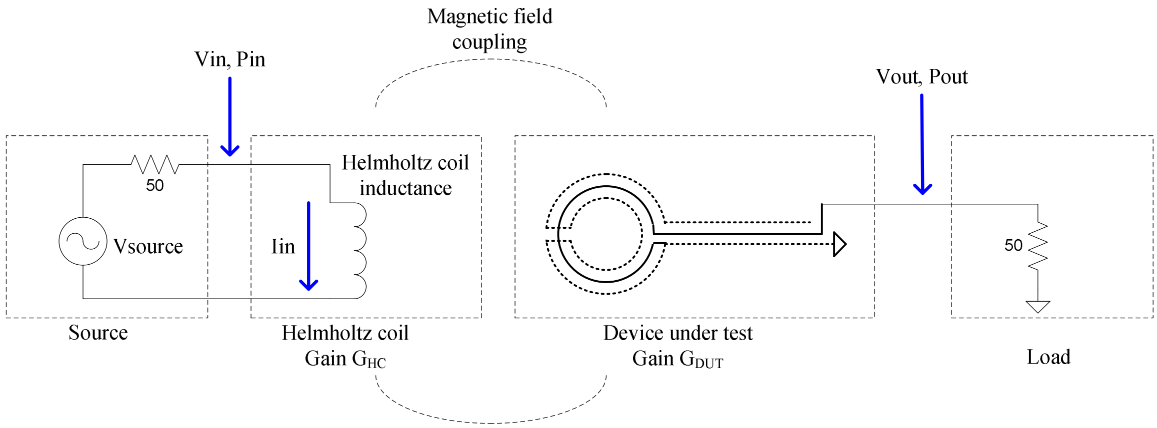
Calculating the gain of the device under test

In order to calculate the gain of the device under test, we need to consider these things:

- The measured gain of the Helmholtz coil and the device under test
- The voltage the source would deliver into an open circuit
- Inductance of the Helmholtz coil
- Gain of the Helmholtz coil
- Gain of the device under test

As an example, we'll assume that we measured a total gain (G_{meas}) of -70 dB on the network analyzer at a frequency of 1 MHz.

An equivalent circuit of the measurement setup is shown below:



Equivalent Circuit of Helmholtz Coil Measurement Setup

Figure 18

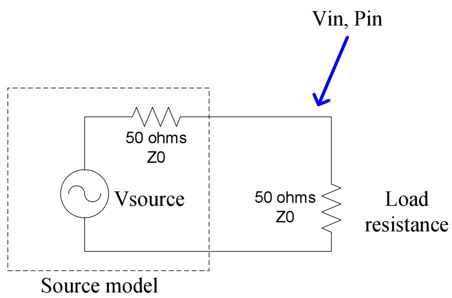
Step 1: Calculate V_{out}/V_{in}

The ratio V_{out}/V_{in} is the measured gain of the system expressed as a ratio of voltages. The measured gain G_{meas} is typically expressed in dB; we'll convert it to a linear voltage gain:

$$G_{meas,v} = \frac{V_{out}}{V_{in}} = 10^{G_{meas,dB}/20}$$

Step 2: Calculate V_{source}

In both the spectrum analyzer and network analyzer scenarios, the signal source will typically have an output impedance of 50 ohms, which we'll call Z_0. If we consider this source connected to a 50 ohm load,



Equivalent Circuit of 50 Ohm
Source and Load

Figure 19

we see that the equivalent ideal voltage source, V_{source}, is:

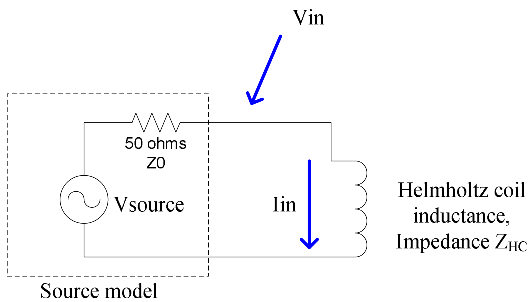
$$V_{source} \quad = \quad 2 * V_{in}$$

V_{source} is the voltage that would be delivered into an open circuit.

Step 3: Calculate the current into the Helmholtz coil

The input impedance of the Helmholtz coil is essentially zero ohms at low frequencies – it's just a few loops of wire, after all. At higher frequencies, the input impedance increases due to the inductance of the Helmholtz coil. Thus, at higher frequencies, the Helmholtz coil impedance affects the total system gain. At frequencies above 1 MHz, we should correct for this effect.

When the source is connected to the Helmholtz coil, the equivalent circuit looks like this:



Equivalent Circuit of Helmholtz Coil
Connected to 50 ohm Source

Figure 20

The impedance of the coil is:

$$Z_{HC} \quad = \quad 2 * \pi * L_{HC} * F$$

Where is the frequency.

The magnitude of the output current is

$$I_{in} \quad = \quad \frac{V_{source}}{\sqrt{{Z_0}^2 + {Z_{HC}}^2}} \quad = \quad \frac{2 * V_{in}}{\sqrt{{Z_0}^2 + {Z_{HC}}^2}}$$

Step 4: Calculate the Helmholtz coil flux density

Since the gain G_{HC} of the Helmholtz coil is $1.45*10^{-5}$ tesla/ampere, the flux density is:

$$B = I_{in} * G_{HC}$$

Note that the units of G_{HC} are tesla/ampere.

Step 5: Calculate the voltage out of the device under test

G_{DUT}, the gain of the device under test, is in units of volts/tesla. The voltage out of the DUT is therefore

$$V_{out} = B * G_{DUT} = I_{in} * G_{HC} * G_{DUT}$$

$$V_{out} = \frac{2 * V_{in} * G_{HC} * G_{DUT}}{\sqrt{Z_0^2 + Z_{HC}^2}}$$

Step 6: Calculate the gain of the device under test from the measured gain

$$G_{meas,v} = \frac{V_{out}}{V_{in}} = \frac{2 * G_{HC} * G_{DUT}}{\sqrt{Z_0^2 + Z_{HC}^2}}$$

$$G_{meas,v} = \frac{2 * G_{HC} * G_{DUT}}{\sqrt{Z_0^2 + (2 * \pi * F * L_{HC})^2}}$$

$$G_{DUT} = \frac{G_{meas,v} * \sqrt{Z_0^2 + (2 * \pi * F * L_{HC})^2}}{2 * G_{HC}}$$

Note that we used V_{in}, not V_{source}, for this calculation.

Example

As an example, we'll assume that we measured a total gain (G_{meas}) of -70 dB on the network analyzer at a frequency of 1 MHz.

The Helmholtz coil parameters are:

$$G_{HC} = 1.45 * 10^{-5}\ tesla / ampere$$

$$L_{HC} = 1.25 * 10^{-6}\ henries$$

The measured gain of the system in decibels, $G_{meas,dB}$ is converted to linear voltage gain:

$$G_{meas,V} = 10^{-70/20} = 3.16 * 10^{-4}$$

Using the equation from step 6, we can calculate the gain of the device under test:

$$G_{DUT} = \frac{(3.16 * 10^{-4}) * \sqrt{50^2 + (2 * 3.14 * 10^6 * (1.25 * 10^{-6}))^2}}{2 * (1.45 * 10^{-5})}$$

$$G_{DUT} = 552\ volts / tesla$$

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