Keysight Technologies

# Wireless Power Transfer (WPT) Measurements Using the Keysight ENA Series Network Analyzers

Application Note

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights

# Introduction

With the evolution of cloud computing systems and highly integrated mobile terminals, various types of digital contents and applications can be enjoyed in the palm of your hand today. As a result, power consumption in mobile terminals rapidly increases, raising demands for more convenient and versatile ways of battery charging. Wireless Power Transfer (WPT) technology has drawn much attention recently as one of the realistic solutions and is widely discussed and researched.

The theory of wireless power transfer by inductive coupling between coils/resonators has been well known (Figure 1). Today there are already many commercialized products to wirelessly transfer power using the magnetic induction method. In addition, the demand for wireless power transfer using the magnetic resonance method is growing mainly due to its flexibility in charging range and capability to charge multiple-devices. Compared to power transfer through wirelines, power transfer in air has larger power loss. Therefore, power transfer efficiency in WPT systems is one of the challenges for WPT technology, and it largely relies on quality of components used in these systems. To ensure system performance and interoperability, it is important to specify test requirements and perform tests according to them. In this application note, we will review components used in WPT systems as well as measurement requirements and solutions with Keysight ENA Series network analyzers.

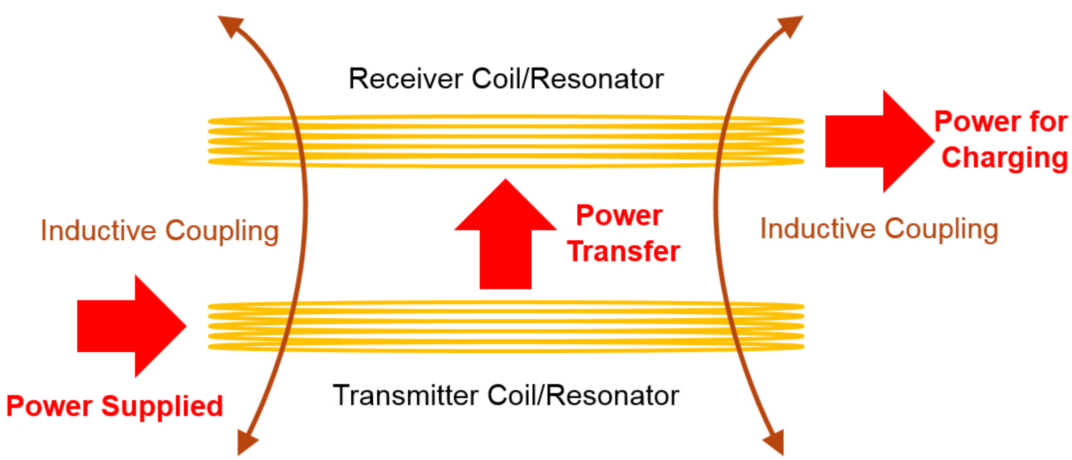



Figure 1. Power transfer by magnetic field using inductive coupling between coils/resonators

# Measurement Requirements for Components in WPT Systems

Figure 2 illustrates components used in WPT systems and measurement requirements for each component. In the power transmitter module, power is amplified by a power amplifier before wirelessly transferred to the receiver module. A matching circuit is inserted between power amplifier and transmitter coil/resonator for impedance matching between them in order to transfer power more efficiently. Power is transferred wirelessly through the magnetic field generated by transmitter coils/resonators that couple to receiver coils/resonators. Power received in receiver coils/resonators will be rectified by a DC-DC converter to power a load or charge a battery.

Power transfer efficiency and impedance matching between transmitter and receiver modules are measured when coils/resonators are coupled. These measurements can be performed at low power states or at actual operating conditions (high power) to evaluate the power transfer performance of the entire system. It is also important to characterize each component used in WPT system in order to ensure power transfer stability. For example, the power amplifiers are evaluated with S-parameter measurements at high power to assure a stable power supply and the generation of a magnetic field. The matching circuit and coils/resonators need to be characterized with impedance, capacitance, inductance, and Q factor for efficient power transfer. Loop-gain performance and output impedance of DC-DC converters need to be well-controlled to ensure power integrity.

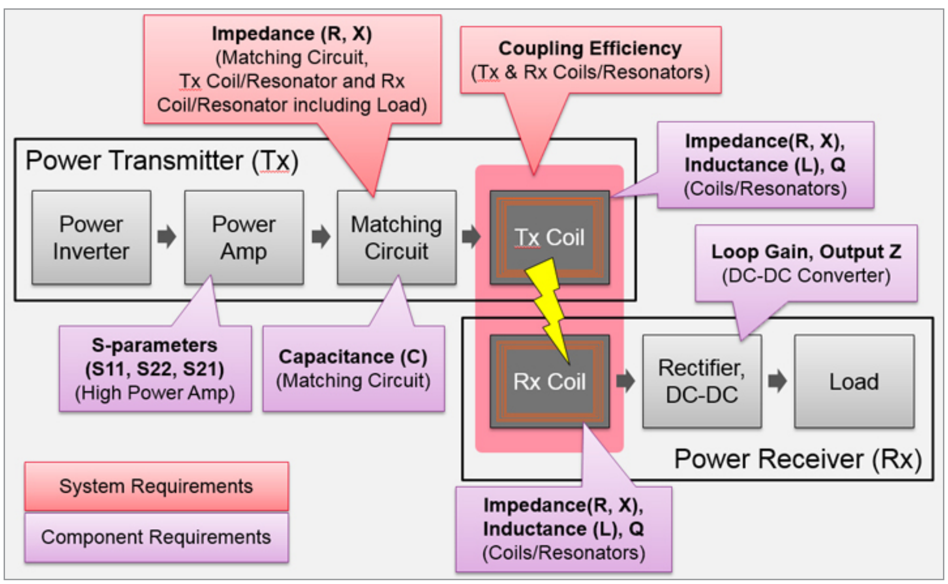



Figure 2. Components used in a wireless power transfer system

# Characterizing WPT Systems and Components with Keysight ENA Series Network Analyzers

Table 1 shows measurement requirements for components used in wireless power transfer systems. Corresponding measurement solutions based on Keysight ENA Series network analyzers are listed together. Each column in the table will be explained in the following sections.

Table 1. Test requirements for WPT systems and components

<table>
<tr><th>Test category</th><th>Device under test</th><th>Test requirement</th><th>Recommended instruments (Keysight product number)</th><th>Annotation</th></tr>
<tr><td rowspan="3">WPT systems</td><td rowspan="3">Coupled coils/resonators</td><td>Power transfer efficiency</td><td rowspan="2">Vector network analyzer (E5072A/E5063A/E5061B)</td><td rowspan="2">Low power measurement</td></tr>
<tr><td>Impedance matching</td></tr>
<tr><td>Impedance matching at system operating condition</td><td rowspan="4">High -power network Aanalyzer (E5072A)</td><td rowspan="4">1. High-Power measurement<br>2. External power amplifier and additional accessories may be required depending on operating power level</td></tr>
<tr><td rowspan="8">WPT components</td><td rowspan="3">Power amplifier</td><td>Amplitude</td></tr>
<tr><td>Phase</td></tr>
<tr><td>Gain compression</td></tr>
<tr><td>Matching circuit</td><td>Capacitance</td><td rowspan="4">LF-RF network analyzer with impedance measurement function (E5061B-3L5 with Option 005)</td><td rowspan="2">E4980A LCR meter and E4990A impedance analyzer are capable of measurements as well</td></tr>
<tr><td rowspan="2">Individual coils/resonators</td><td>Inductance</td></tr>
<tr><td>Q factor</td><td>For high Q measurements, E4980A LCR meter/<br>E4990A impedance analyzer are recommended</td></tr>
<tr><td rowspan="2">DC-DC converter</td><td>Output impedance</td><td></td></tr>
<tr><td>Loop-gain</td><td>LF-RF network analyzer (E5061B-3L5)</td><td></td></tr>
</table>

## Power transfer efficiency measurement

Power transfer efficiency is one of the key performance factors of WPT systems. Figure 3 illustrates measurement configuration for power transfer efficiency measurements between transmitter and receiver coils/resonators. The Keysight ENA Series network analyzer offers a software solution to analyze voltage, current, and power transfer efficiency, of WPT systems in real-time from 50 ohm based S-parameter measurements (Figure 4). Users can also define arbitrary load impedance to simulate power transfer efficiency when batteries are connected. Measurement results of resistance (R), reactance (X), and frequency (f) can be visualized in 2D or 3D to help users more easily understand the dependency of load impedance.

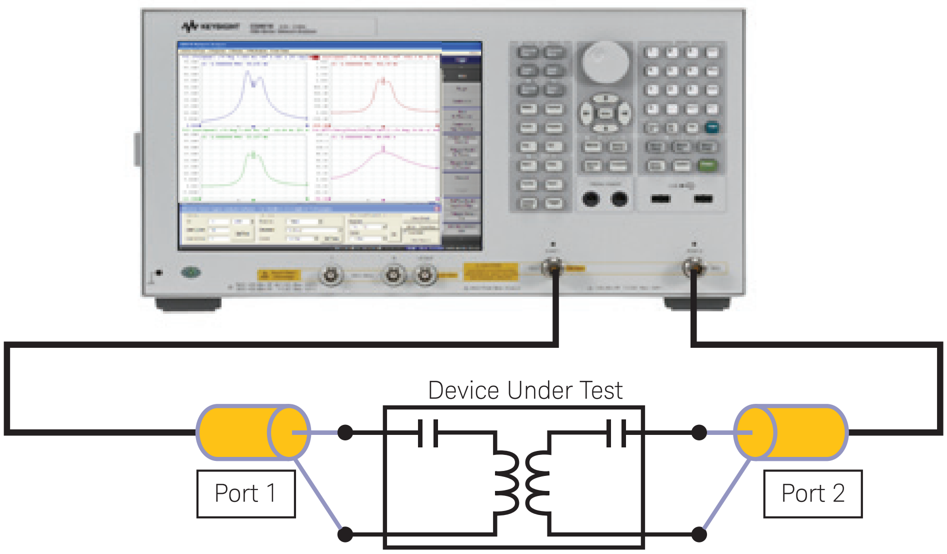



Figure 3. Measurement setup for power transfer efficiency measurements

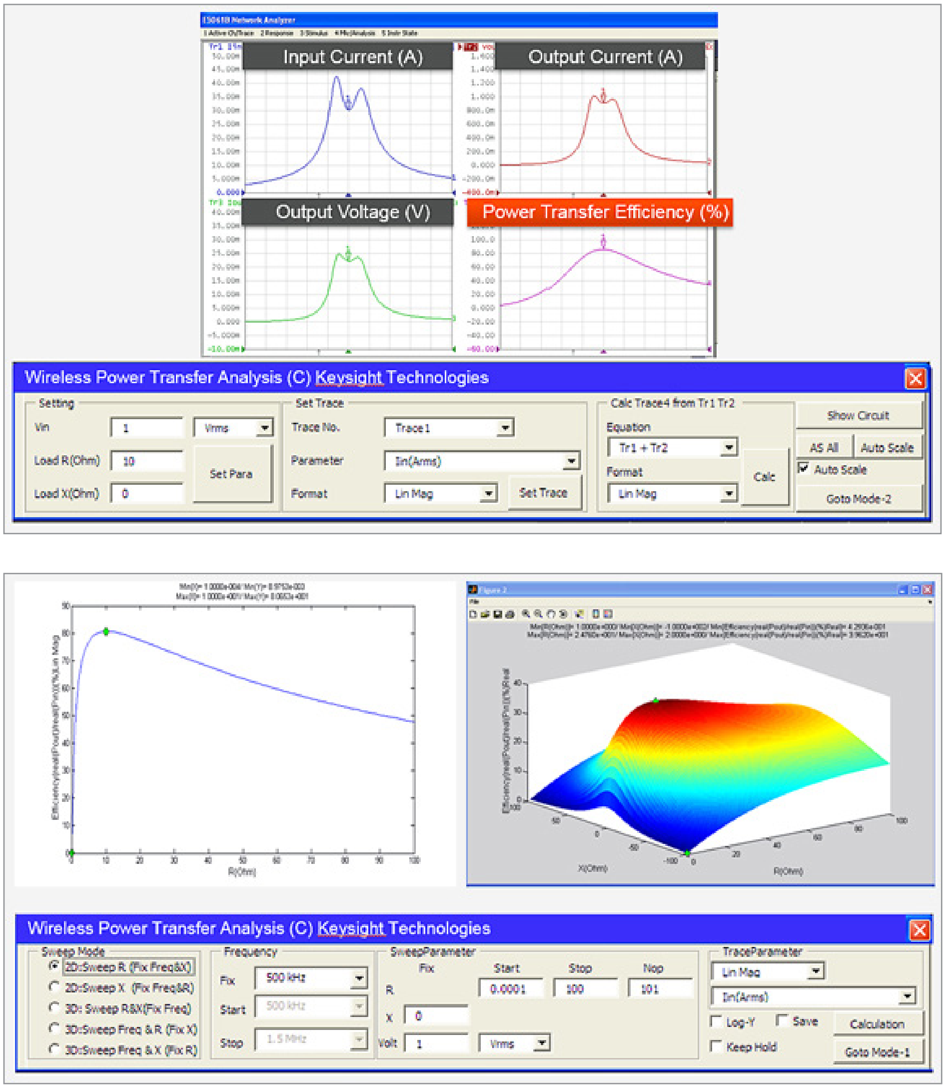



Figure 4. Wireless power transfer software in ENA Series network analyzers

## Impedance matching measurement

To achieve high-power transfer efficiency, it is important to make sure impedance is matched between coils/resonators in the power transmitter and receiver modules when they are placed on or near each other. Power transfer efficiency can be lowered if impedance of these is unmatched. Figure 5 illustrates the measurement configuration for impedance matching measurements of WPT systems. The measurement is performed when a coil/resonator in the power receiver module is coupled to a transmitter coil/resonator. Impedance and capacitance at the power transfer frequency can be displayed in real-time. Users can also display resonance characteristics of the WPT resonator simultaneously in another window.

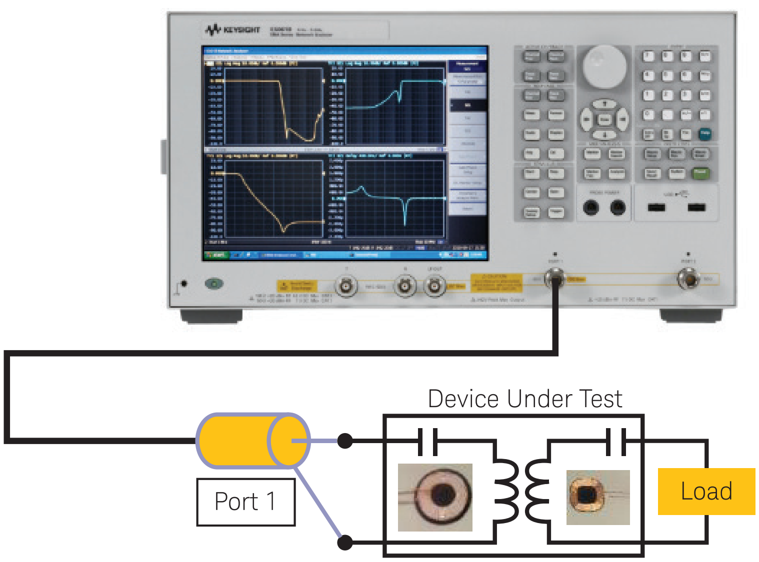



Figure 5. Measurement setup for impedance matching measurements

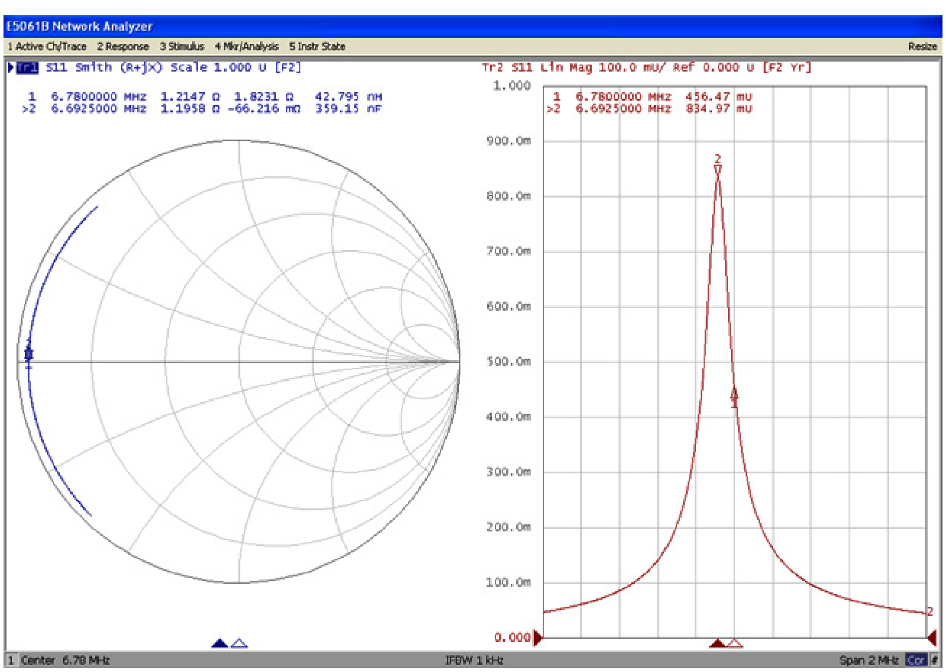



Figure 6. Example of impedance matching and resonance frequency measurements

## Impedance matching measurements at system operating conditions (high-power measurements)

Power transfer efficiency and impedance matching of WPT systems are also measured at system operating conditions to ensure WPT system performance when it is operating. Because the power input required for an operating system usually exceeds the maximum power output level of network analyzers, an additional power amplifier is necessary to boost input power to the DUT. Figure 7 illustrates a measurement configuration for impedance matching measurements at system operating conditions. The E5072A provides direct accessibility to all of the internal sources and receivers that can cancel out the effect of temperature drift from the power amplifier and improve measurement accuracy. High-power attenuators are inserted in the measurement system to prevent the instrument from being damaged by high-power input. Refer to “High-Power Measurements Using the E5072A ENA Series Network Analyzer” application note for more details.

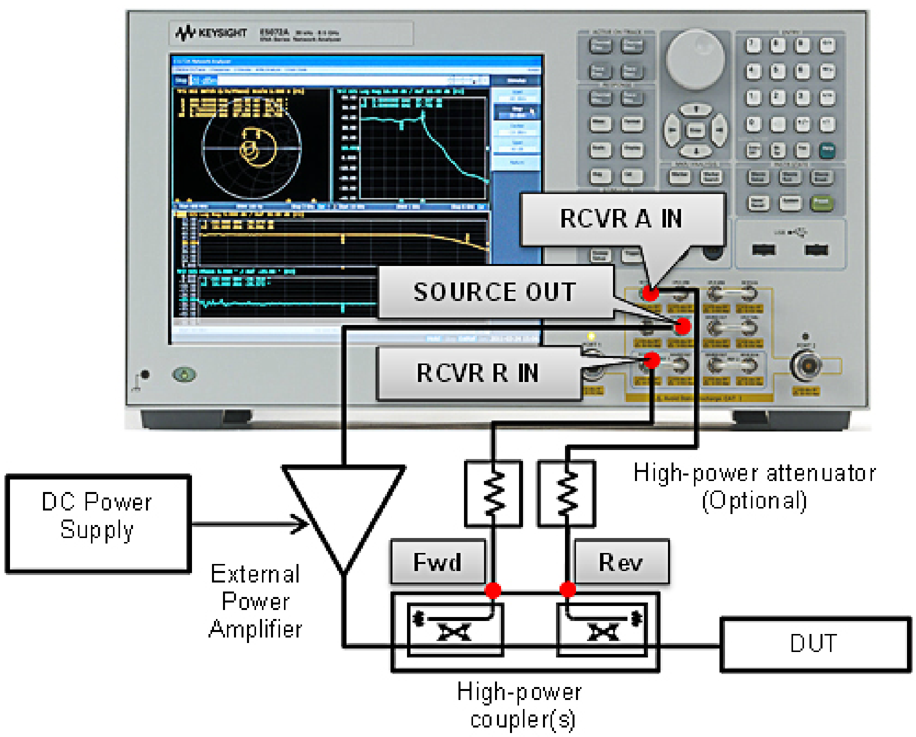



Figure 7. Measurement setup for impedance matching measurement at system operating conditions

## Power amplifier measurements

A power amplifier is one of the key components in a WPT power transmitter. It is characterized with amplitude, phase, and gain compression over frequency for stable operation of the WPT transmitter module. Testing a power amplifier can be a challenge as it often requires output power that exceeds the measurement capability of a standard network analyzer. When testing a power amplifier, temperature drift from the power amplifier can directly affect S-parameter measurement results. In addition, temperature drift of the power amplifier can cause variation of the input power level to the DUT, resulting in unexpected errors.

The E5072A network analyzer provides direct accessibility to all of the internal sources and receivers that can cancel out the effect of temperature drift from a power amplifier and improve measurement accuracy (Figure 8). It can also perform power and receiver calibrations to adjust the source power level across a frequency or power sweep using its receiver measurements. The receiver leveling function in the E5072A provides higher source power level accuracy with faster throughput compared to conventional methods using a power meter and power sensor. Figure 9 shows the Power Amplifier Wizard available in an E5072A to help ease measurements for a power amplifier. For more detail about power amplifier measurements, refer to “High-Power Measurements Using the E5072A ENA Series Network Analyzer” application note.

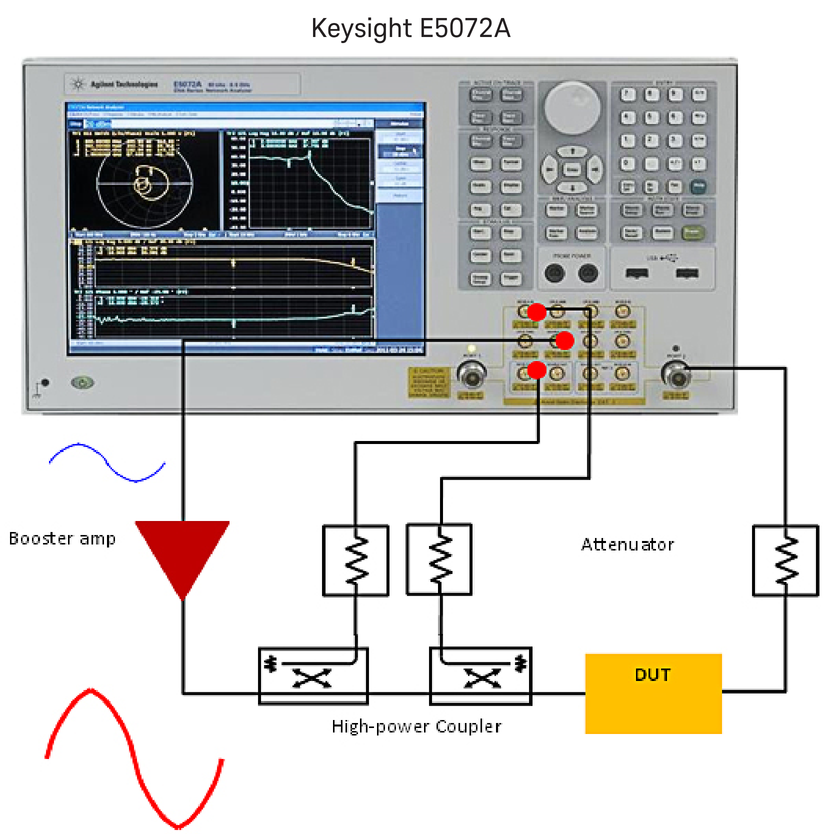



Figure 8. Measurement setup for power amplifier measurements with the Keysight E5072A network analyzer

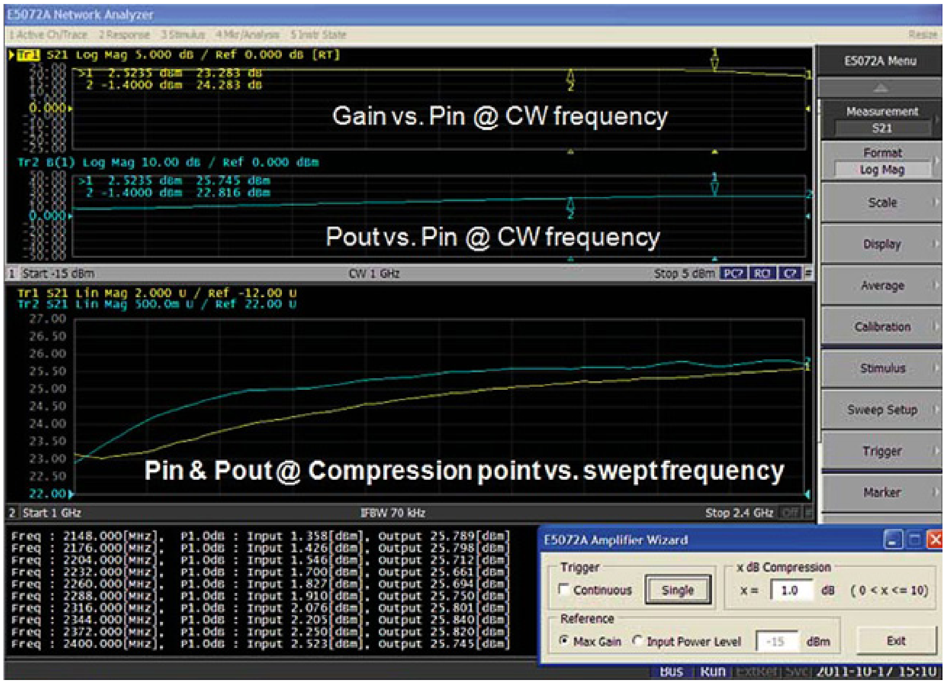



Figure 9. Measurement example of swept gain compression measurement with Amplifier Measurement Wizard in the Keysight E5072A network analyzer

## Coil/resonator/ matching circuit measurements

Coils or LC resonant circuits in resonators are used for power transfer and receiver antennas in WPT systems. These components can directly affect power transfer efficiency, thus need to be characterized carefully with impedance, inductance and capacitance as well as Q factor[1]. Impedance characterization of matching circuits in WPT system is also important in order to assure maximum power transfer.

E5061B-3L5 LF-RF network analyzer provides Option 005 for impedance analysis. This unique option enables the analyzer to measure impedance parameters of electronic components such as capacitors, inductors, and resonators. Option 005 supports reflection, series-thru, and shunt-thru methods using the S-parameter or gain-phase test port. With each method having different impedance range with good accuracy, Option 005 can cover a wide impedance range for WPT component test measurements.

The combination of NA and ZA capabilities further enhances the analyzer's versatility as a general R&D tool for WPT component characterization. Basic ZA functionalities including fixture compensation and equivalent circuit analysis are supported by the firmware. A DC-biased impedance measurement is also possible with the built-in DC bias source provided by the E5061B-3L5. Various kinds of 7 mm and 4 terminal-pair fixtures are available.

For more details regarding impedance measurements with E5061B, refer to "E5061B-3L5 LF-RF Network Analyzer with Option 005 Impedance Analysis Function Data Sheet".

1. For high Q measurements, the E4980A LCR meter is recommended for frequencies below 2 MHz and the E4990A impedance analyzer for frequencies above 2 MHz.

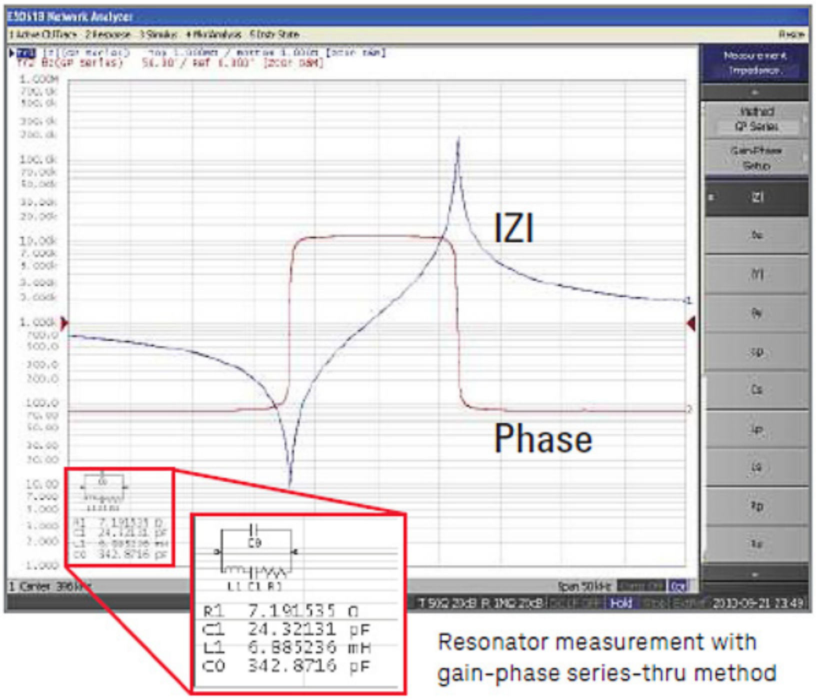



Figure 10. Example of resonant measurement with gain-phase series-thru method supported by the E5061B-3L5 Option 005

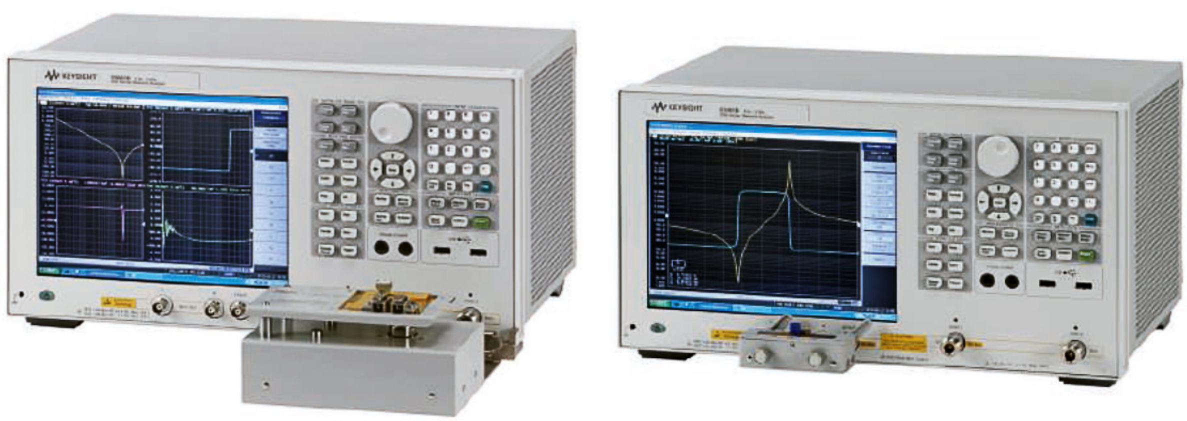


Figure 11. 7 mm and 4 terminal-pair fixtures connected to the E5061B-3L5 with Option 005

## DC-DC converter measurements

Power transferred from a transmitter to a receiver coil/resonator will be rectified at the DC-DC converter. It is important to characterize feedback loop, phase margin, and gain margin of DC-DC converters in order to deliver stable power to loads or batteries in WPT systems. Also output impedance of DC-DC converters need to be designed in milliohm impedance, especially in low frequency ranges in order to achieve successful regulation of output voltage and to avoid power integrity problems in the power distribution network (PDN).

Figure 12 illustrates a configuration example for measuring loop gain by using the gain-phase test port of the E5061B-3L5 LF-RF network analyzer. An example of loop gain measurement result is shown in figure 13. Measurement configuration for the DC-DC converter output impedance by E5061B-3L5 LF-RF network analyzer with Option 005 is illustrated in figure 14 and measurement results in figure 15.

For more detail regarding DC-DC converter characterization with E5061B-3L5 LF-RF network analyzer, refer to “Evaluating DC-DC Converters and PDN with the E5061B LF-RF Network Analyzer” application note.

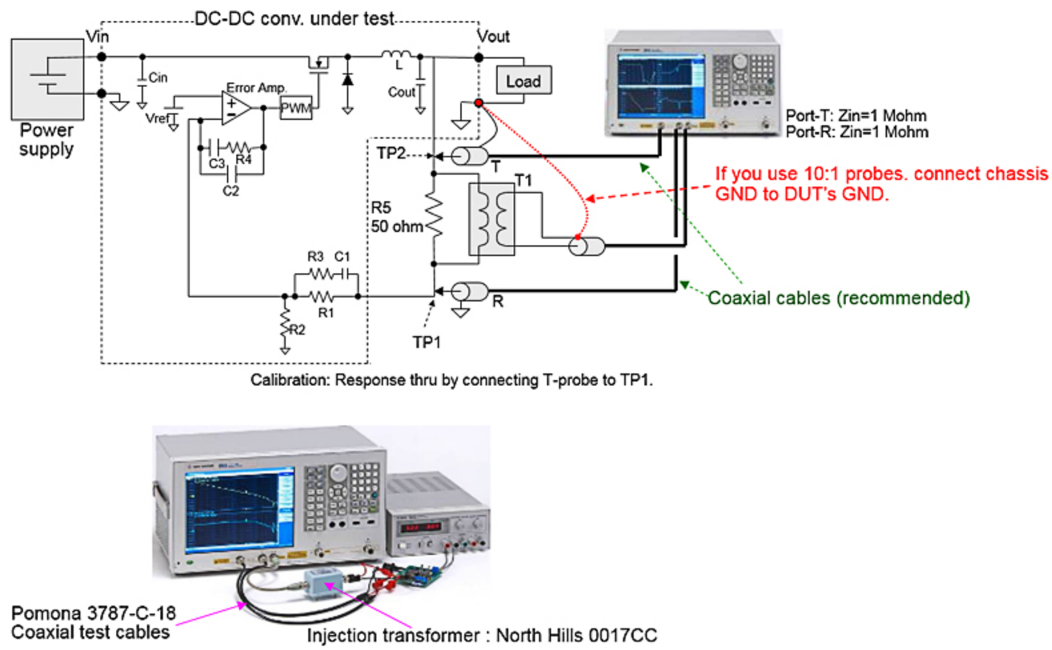



Figure 12. Example of measurement configuration for a DC-DC converter loop gain measurement with the Keysight E5061B-3L5 LR-RF network analyzer

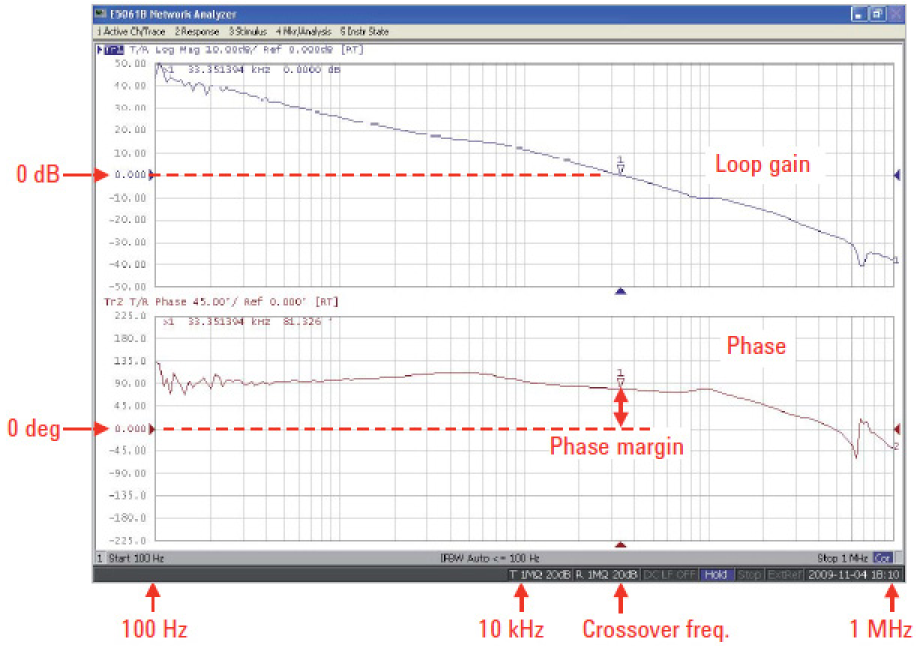



Figure 13. Loop gain measurement example of a DC-DC converter

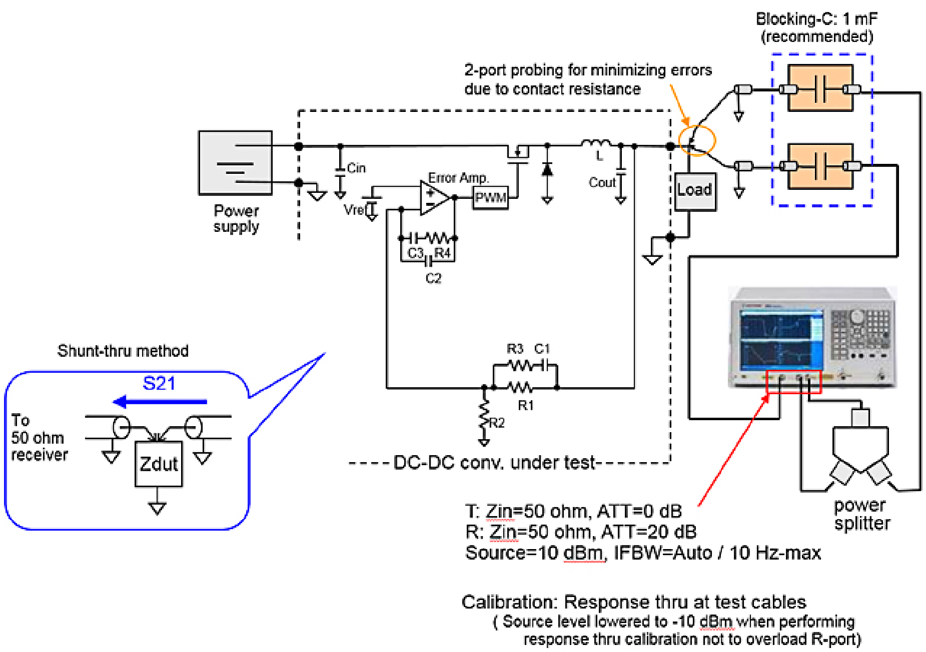
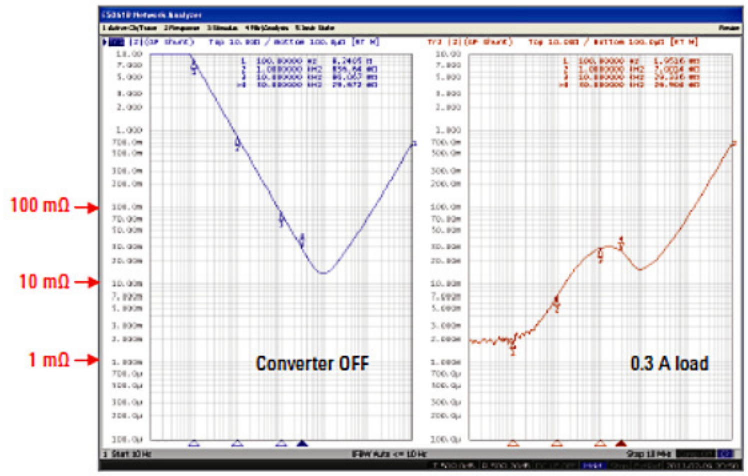
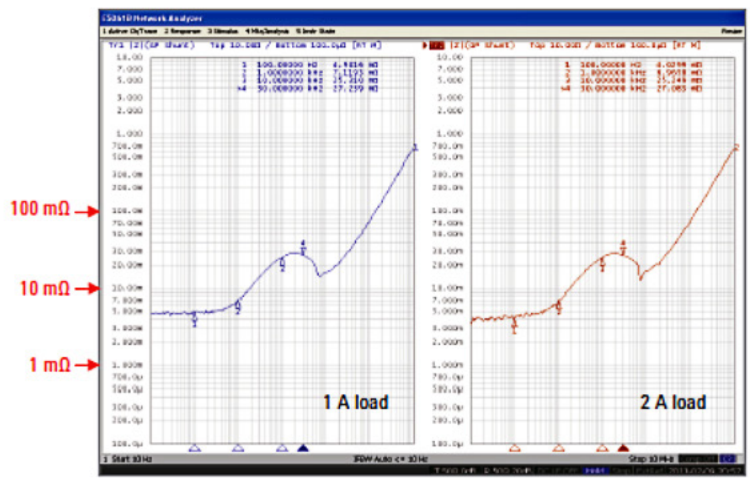



Figure 14. Example of measurement configuration for a DC-DC converter output impedance measurement with a Keysight E5061B-3L5 LR-RF network analyzer with Option 005




**Off-state and 0.3 A load conditions,**
**Start = 10 Hz, Stop = 10 MHz**
**Source = 10 dBm (-5 dBm at thru cal)**
**Port-T: ATT = 0 dB, Zin = 50 Ω, Port-R: ATT = 20 dB, Zin = 50 Ω**




**1 A and 2 A load conditions,**
**Start = 10 Hz, Stop = 10 MHz**
**Source = 10 dBm (-5 dBm at thru cal)**
**Port-T: ATT = 0 dB, Zin = 50 Ω, Port-R: ATT = 20 dB, Zin = 50 Ω**

Figure 15. DC-DC converter output impedance measurement example

# Summary

More and more products are expected to support wireless power transfer technology while power transfer efficiency problems remain for actual use cases. The evaluation of WPT systems and components to achieve higher power transfer efficiency is in progress. This application note describes measurement requirements and solutions to evaluate power transfer efficiency of WPT systems as well as components used in the systems. With unique features and versatility, the Keysight ENA series network analyzers provide solutions to help engineers from design and verification, interoperability, and manufacturing of wireless power transfer systems and components.

# References

*High-Power Measurements Using the E5072A ENA Series Network Analyzer,*
Application Note, literature number 5990-8005EN

*5061B-3L5 LF-RF Network Analyzer with Option 005 Impedance Analysis Function,*
Data Sheet, literature number 5990-7033EN

*Evaluating DC-DC Converters and PDN with the E5061B LF-RF Network Analyzer,*
Application Note, literature number 5990-5902EN

*Network Analyzer Selection Guide,* literature number 5989-7603EN

*LCR Meters, Impedance Analyzers and Test Fixtures Selection Guide,*
literature number 5952-1430E

## Web resources

www.keysight.com/find/e5072a
www.keysight.com/find/e5061b
www.keysight.com/find/e5063a
www.keysight.com/find/impedance

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