Keysight's Test & Measurement Solution for Wireless Power Transfer

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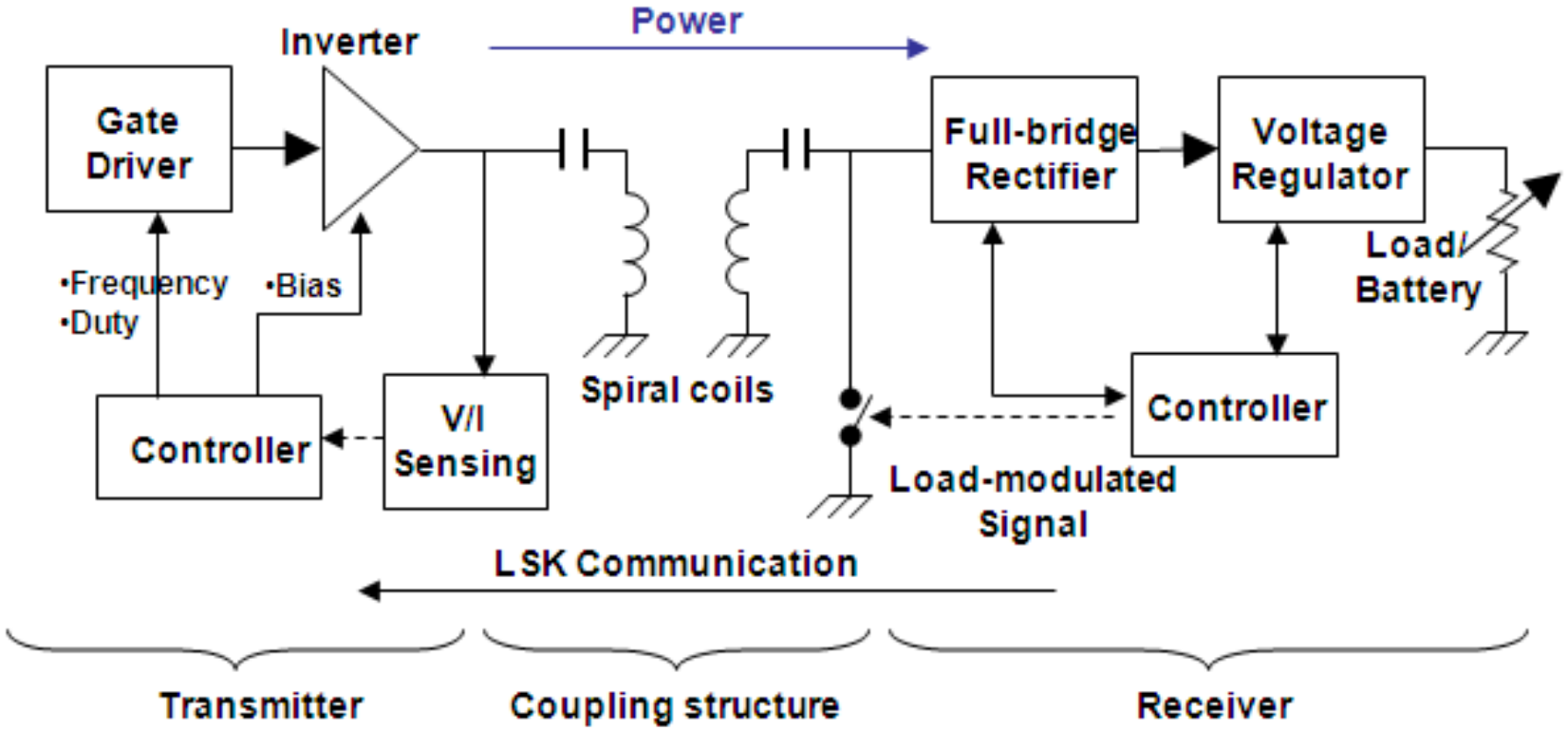
KEYSIGHT TECHNOLOGIES

Agenda

- **Block Diagram of WPT system**
  - ✓ Test Application List
- Example set-up:
  - ✓ DC-DC converter loop-gain measurement with gain-phase test port
  - ✓ PSRR of DC-DC Regulator Measurement set-up
  - ✓ Loop Resonator Test
- HPNA(High Power Network Analyzer)for WPT
- Power Measurement Solution with Oscilloscope –DSOX3PWR
- Wireless Power Transfer Analysis using ENA

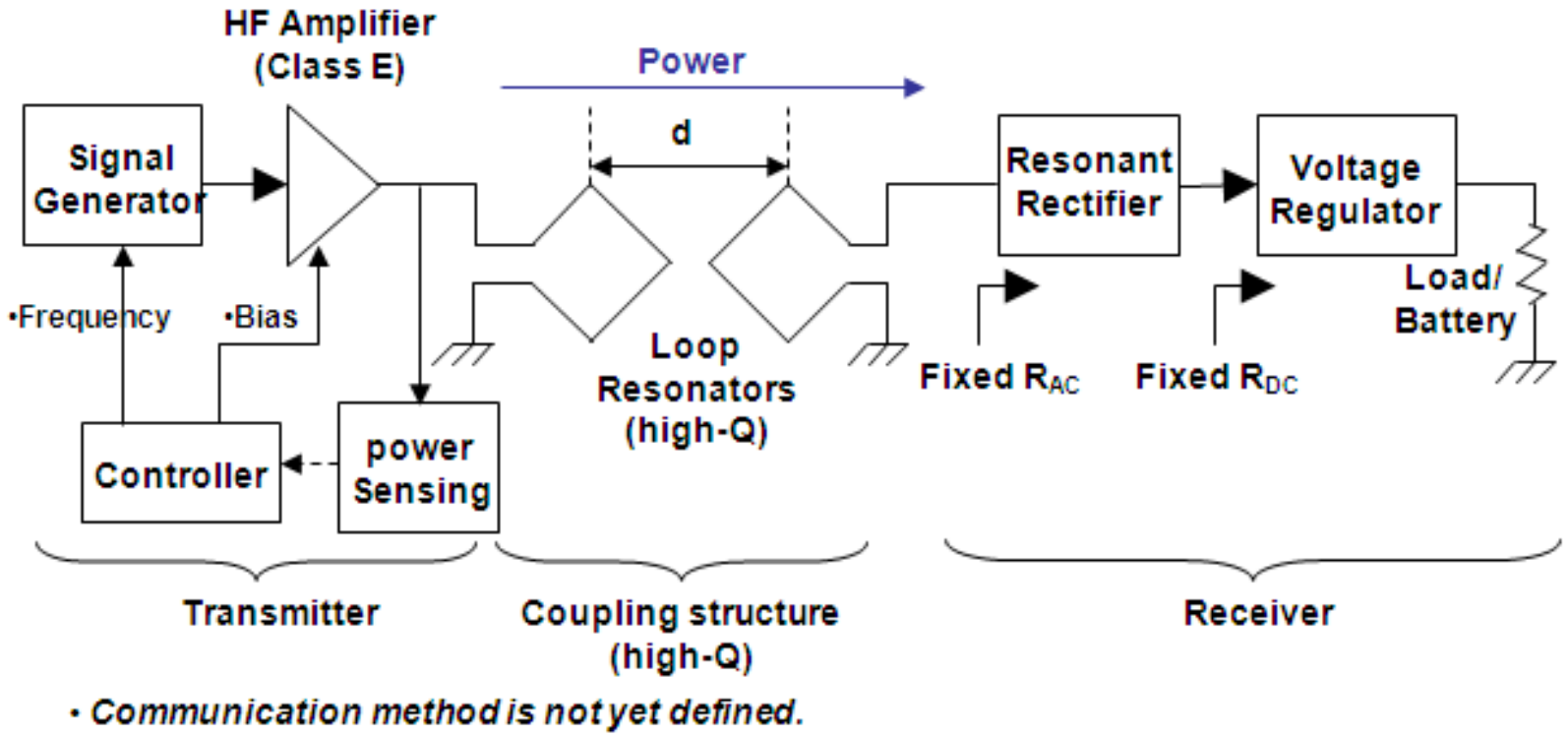
Block Diagram of WPT system

LF-band Inductor Coupling System



Block Diagram of WPT system

HF-band Magnetic Resonance Coupling



• *Communication method is not yet defined.*

Test Applications

Device / Component Test

Test Applications	Instruments	Accessary	Test Parameters
DC-DC Converter (Switching Voltage regulator) Bypass Capacitor, etc..	E5061B-3L5, 005 Power Supply	J2110A(Picotest Signal Injection Transformer), Power Splitter, etc..	Loop gain, milliohm impedance measurement, etc..
PSRR in linear regulator Low Droupout (LDO) regulator	E5061B-3L5 Power Supply Electric load	J2120A(Picotest Line Injector)	PSRR(Power Supply Rejection Ratio)
Resonator(high Q)	4294A, E4990A E5061B-3L5		Resonant Frequency, Q factor Load capactance
Resonator in High Power	HPNA (E5072A or PNA-L)		Resonant Frequency, Q factor Impedance, Reactance
Voltage regulator in High Power	HPNA (E5072A or PNA-L)	High Power AMP, Coupler, Atten, Term, etc…	S-parameters
High Power Amplifier Test	HPNA (E5072A or PNA-L)	High Power AMP, Coupler, Atten, Term, etc…	S-parameters

Test Applications

System Performance Test

Test Applications	Instruments	Accessary	Test Parameters
Resonator SCAN pattern / Coupling	ENA		SCAN Pattern, Min./Max. Coupling
Resonator (Current)	DC power supply Oscilloscope Electronic Load	Current Probe	Current threshold
Tx/Rx Coupling	HPNA Electronic Load		Impedance, Coupling
Coupling Efficiency (%)	ENA/ENA-L	Analysis SW	In/Output Current, Voltage Power efficiency

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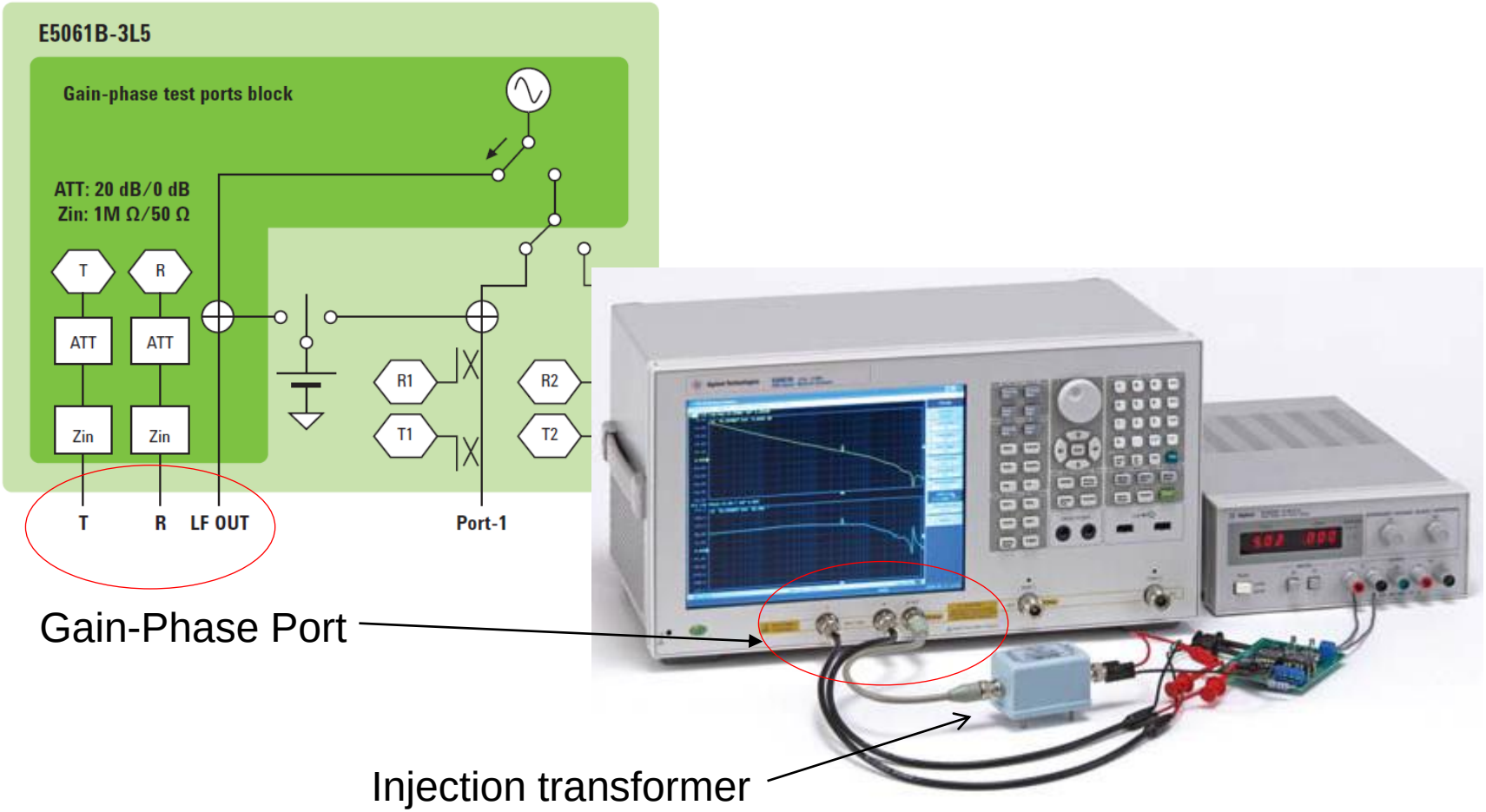
DC-DC Converter Stability Test

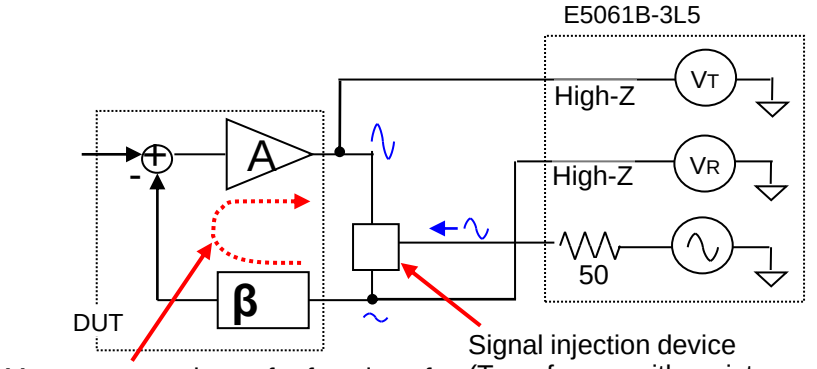
Loop gain/Phase test with Gain/Phase test ports of E5061B

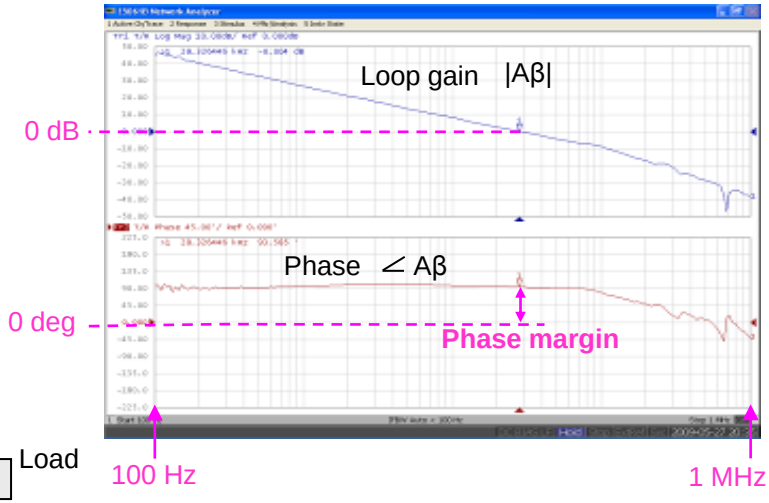


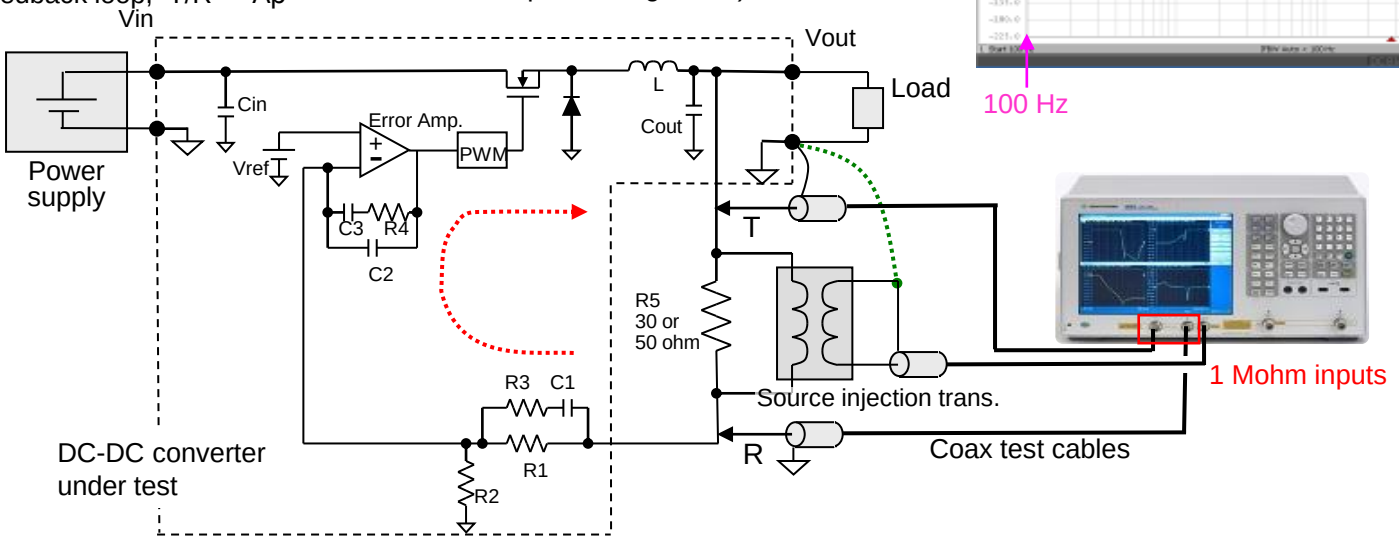
DC-DC Converter Stability Test

Loop gain/Phase test with Gain/Phase test ports of E5061B

Easy in-circuit gain-phase measurement with 1 Mohm inputs



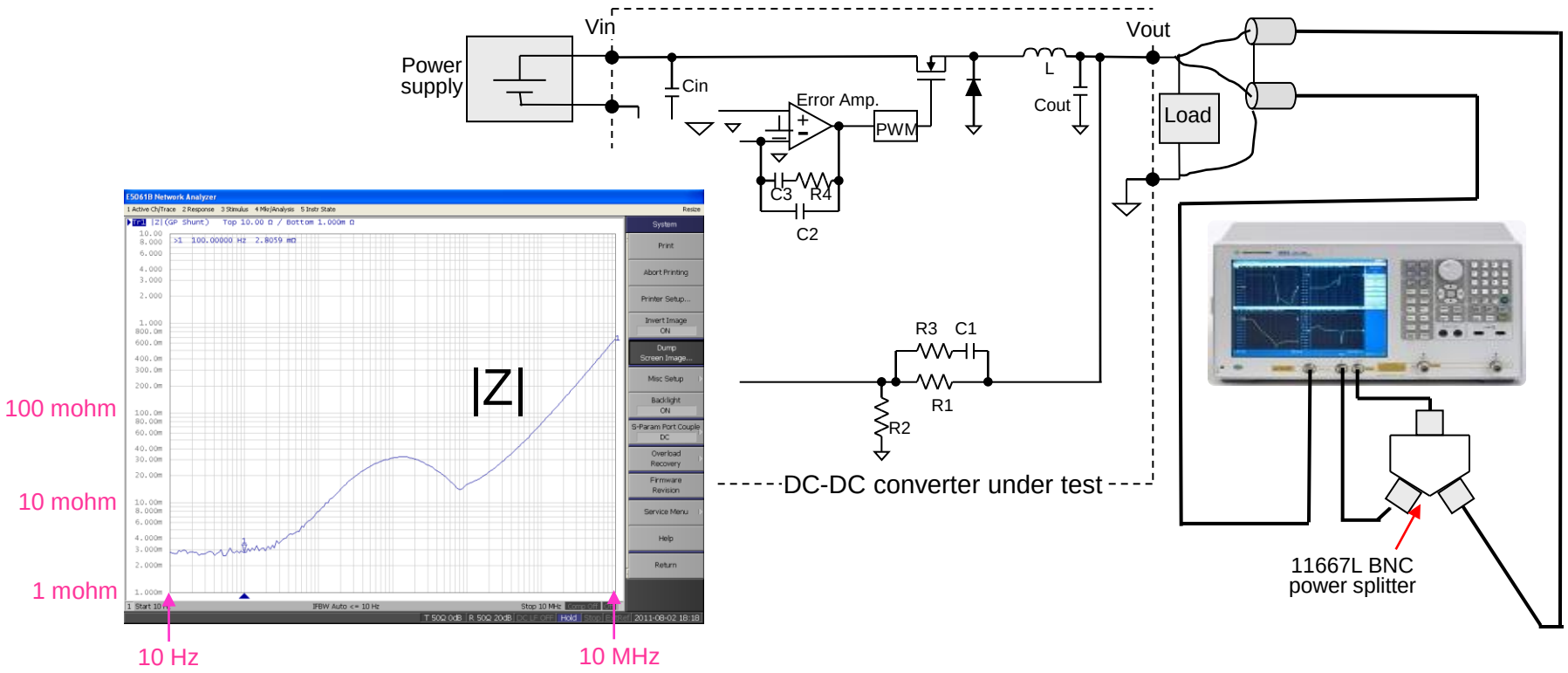




DC-DC Converter Output Z Measurement

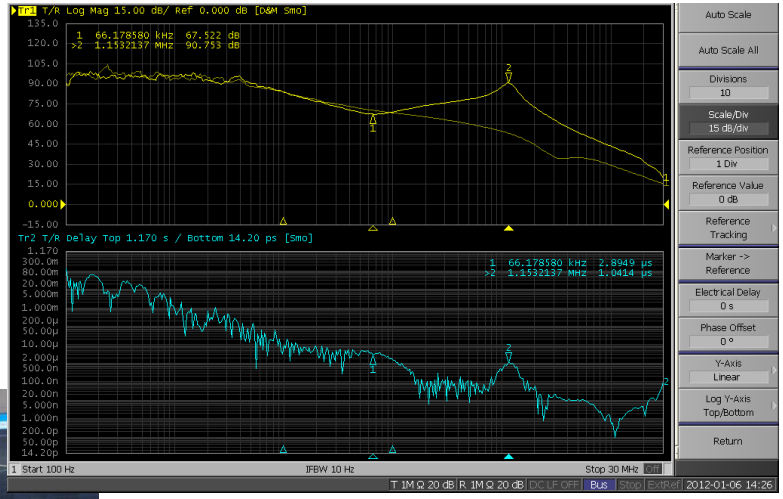
With Gain/Phase test ports of E5061B

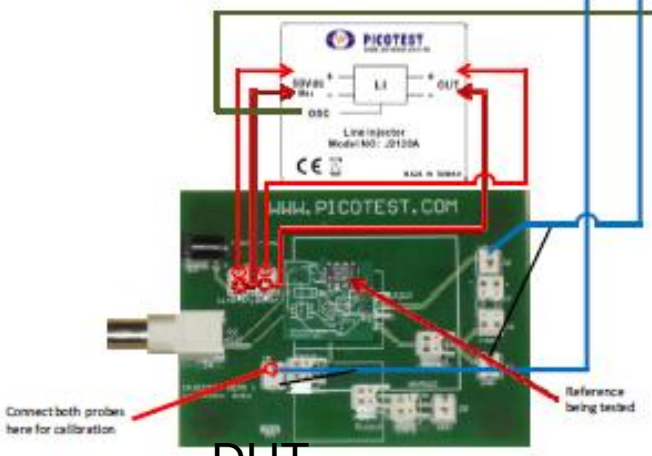
Accurate milliohm |Z| measurement in the low frequency range



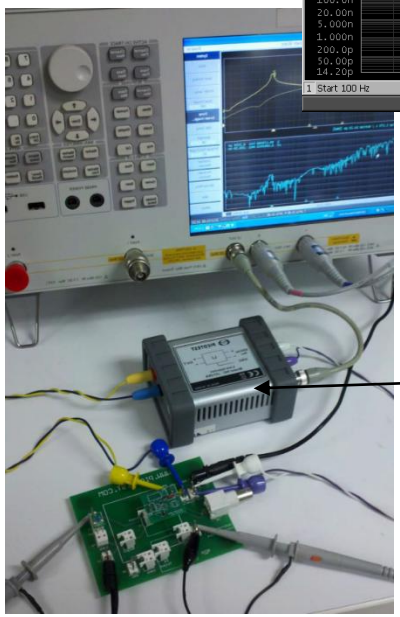
PSRR of DC-DC Regulator Test set-up

With Gain-Phase port of E5061B





DUT

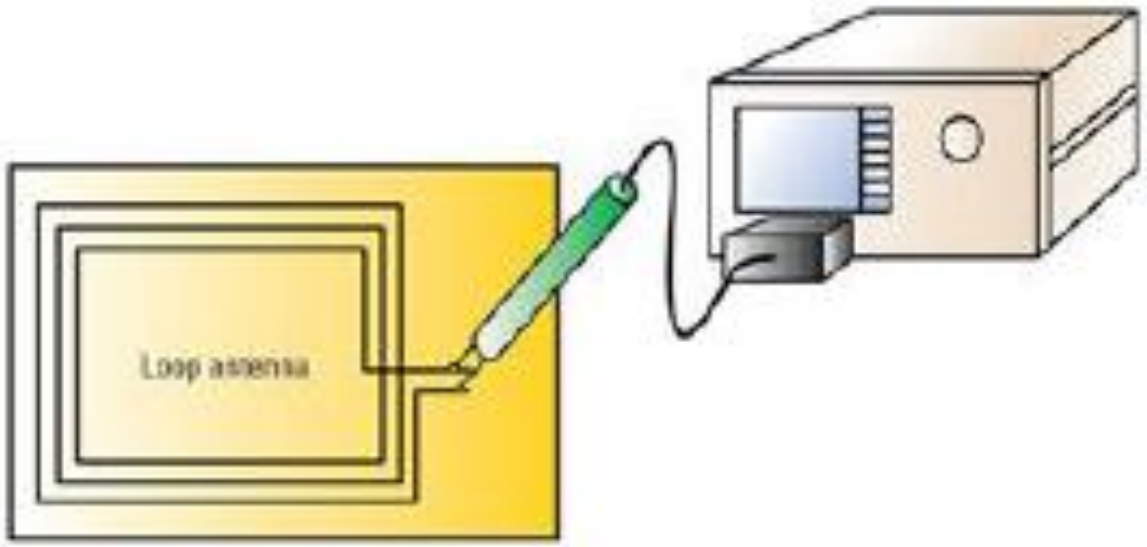


J2120A
(Picotest Line Injector)
10Hz~10MHz,
up to 50VDC/5A

Loop Resonator Test

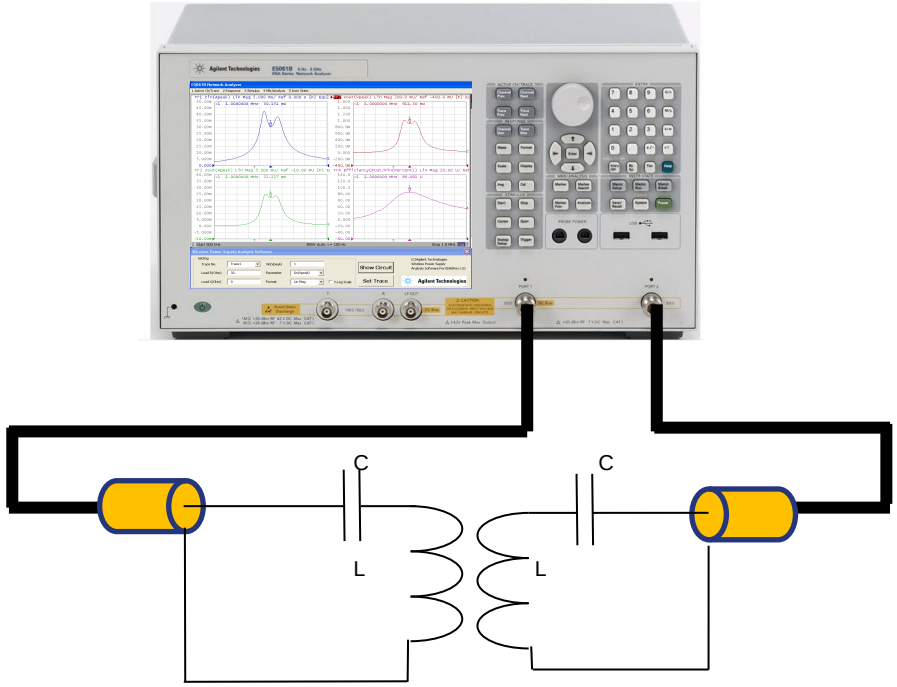
4294A impedance analyzer or E5061B-3L5 LF-RF network analyzer with option 005 impedance analysis function:

- the characteristics of L and C component parts (loop antenna)
- the resonance characteristics of the completed tag in its entirety, and measure the resistance values on a part by part basis.



Loop Resonator Test

- E5072A network analyzer : non-contact measurements
  - E5072A can output as high as +20 dBm!(300KHz to 1GHz)
- HPNA(High Power Network Analyzer) : External high power configuration with



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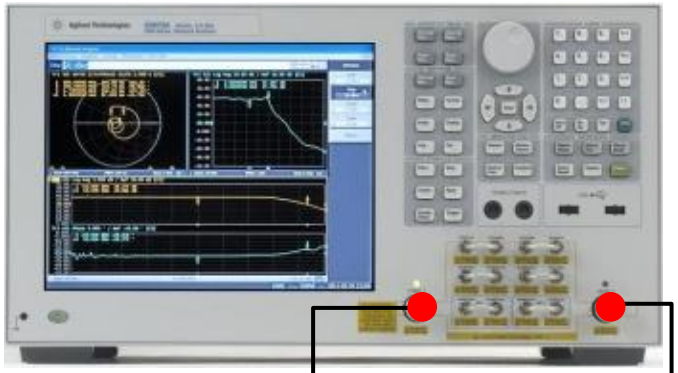
High Power Network Analysis

- Output power level of a network analyzer is not sufficient for measurements.
- Input power level to receivers of a network analyzer exceeds the maximum allowable level.



Not Enough Power for DUT!

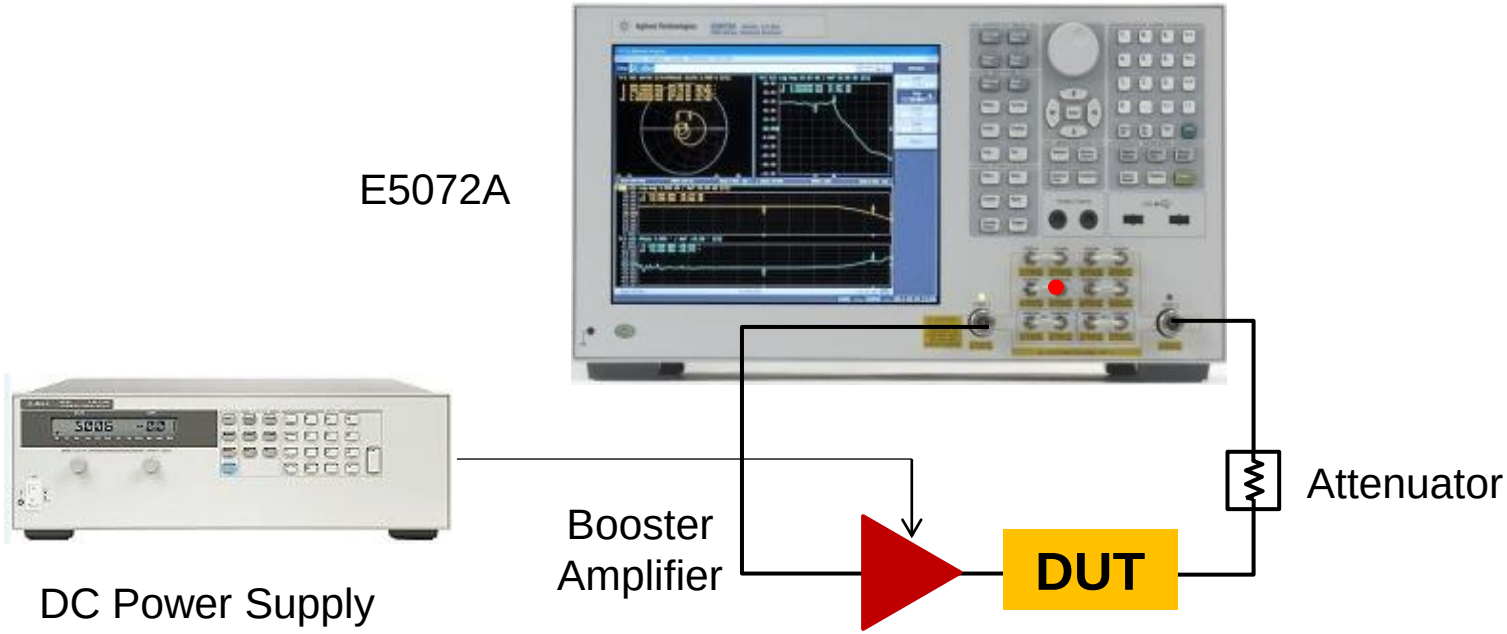
+46dBm???

DUT

Need protection from damage of high-power!

High Power Measurement

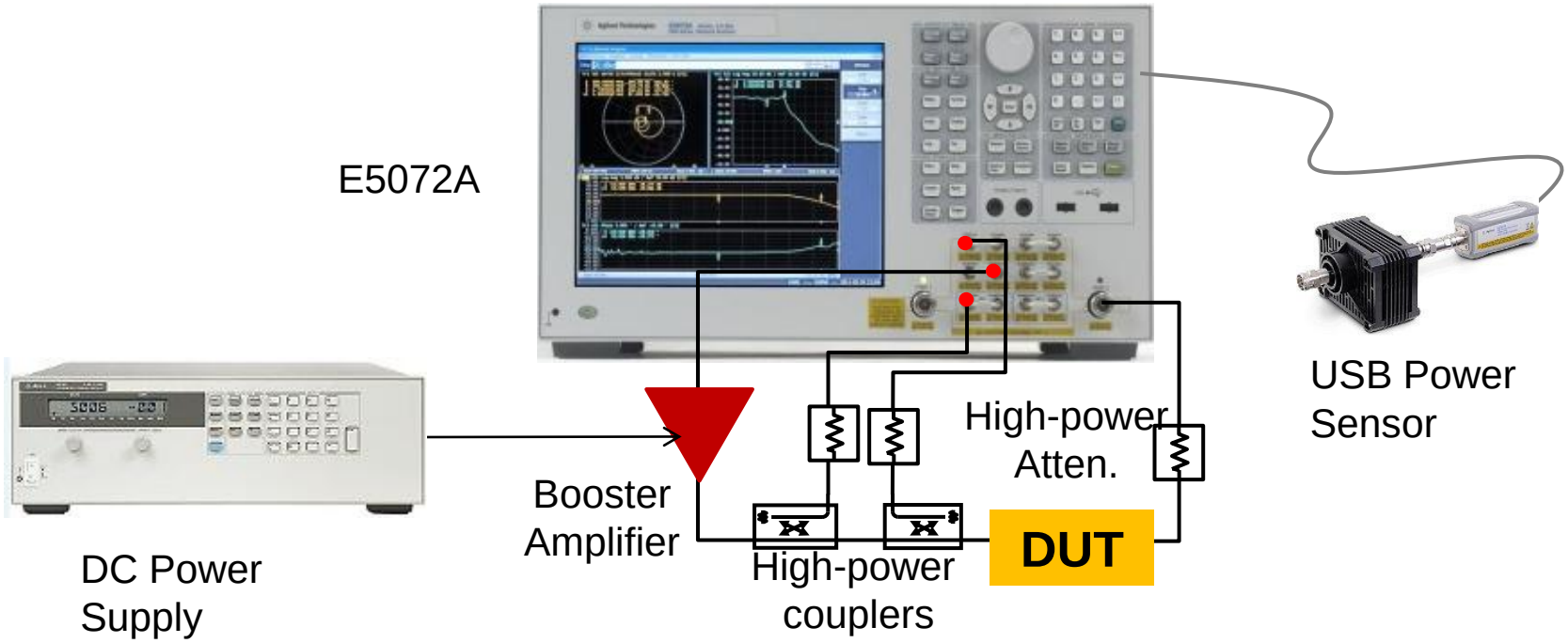
Measurement using a booster Amplifier



- No S11 measurement – forward transmission measurement only
- No match correction – Response cal only
- “Ripple” in measurement due to mismatch between DUT and booster amp
- Drift due to booster amplifier results in error
- Poor S22 measurement due to attenuator

HPNA System with E5072A

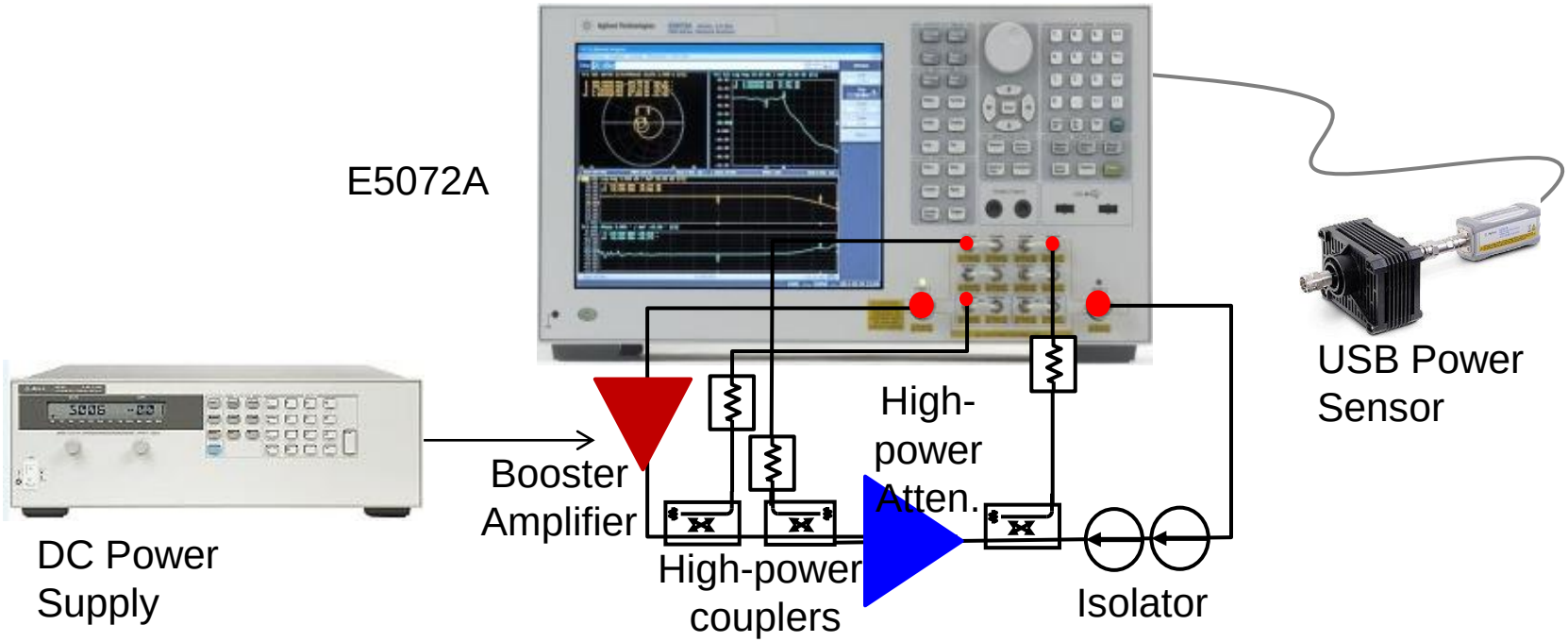
General configuration for High-power DUT



- Accurate S11 & S21 measurement for high input & output power DUT.
- Eliminates the temperature drift of a booster amp.

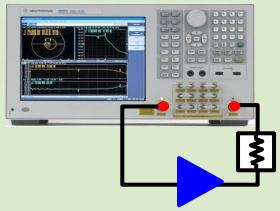
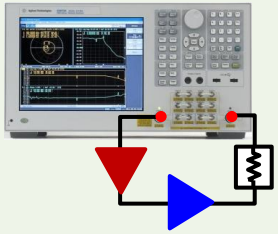
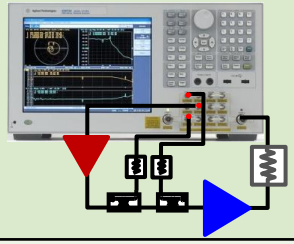
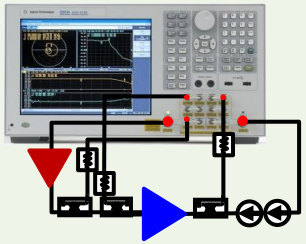
HPNA System with E5072A

Full 2-port Correction for High-power DUT



- The most accurate measurements for high input & output power DUT.
- All S-parameters (S11 to S22) of 2-port DUT can be obtained.
- Narrow band solution due to isolators on output port.

Comparison of HPNA Configurations

Configuration	Connection	Benefits	Issues
Standard 2-port Configuration		• Simple setup • No additional cost (Booster amp etc.)	• Only within power level of network analyzers.
Measurement using a booster amplifier		• High power level beyond network analyzer's capability • Can place the amp physically closer to DUT for higher power.	• Temperature drift effect can not be removed. • Not accurate measurements because of high reverse isolation of a booster amplifier
Direct Receiver Access with a booster amplifier		• Accurate **S11 & S21** measurement for high input & output power DUT. • Eliminates the temperature drift of a booster amp.	• Complicated setup • Configurable test set option needed for VNA. • External attenuators are required for protection of receivers.
Full 2-port Correction for High-power DUT		• The most accurate measurements for high input & output power DUT. • **All S-parameters (S11 to S22)** of 2-port DUT can be obtained.	• Complicated setup • Configurable test set option needed for VNA. • Narrow band solution due to isolators on output port.

Key Components of HPNA System

Instrument	Recommended Agilent Model	Key Spec.	Others
VNA	E5072A	30kHz ~ 4.5/8.5GHz	PNA-L (300kHz~)
Power Supply	6674A	60V, 35A	Used for supply DC Power for HPA(24VDC, 24A)
USB Power Sensor	U2001B	10MHz~6GHz,-30~+44dBm	N8482B with Power Meter :1MHz to 6GHz
Booster AMP	-	Gain:~50dB, Pout:47dBm (50W)	50Watt (47dBm) High Power Amplifier
High Power Coupler	-	Coupling factor: 40dB Power:>50W	100Watt High Power Couplers from Werlatone
High Power Attenuator	-	50W	50Watt (47dBm) Attenuators from TRILITHIC
Medium/Low Power Atten.	8498A 849XA/B/C	25W, DC to 18GHz, N(f0 to N(m) 2W,	
High Power Terminator	-	50W	50Watt (47dBm) Terminator from Aeroflex

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Power Measurements Solution with Oscilloscope

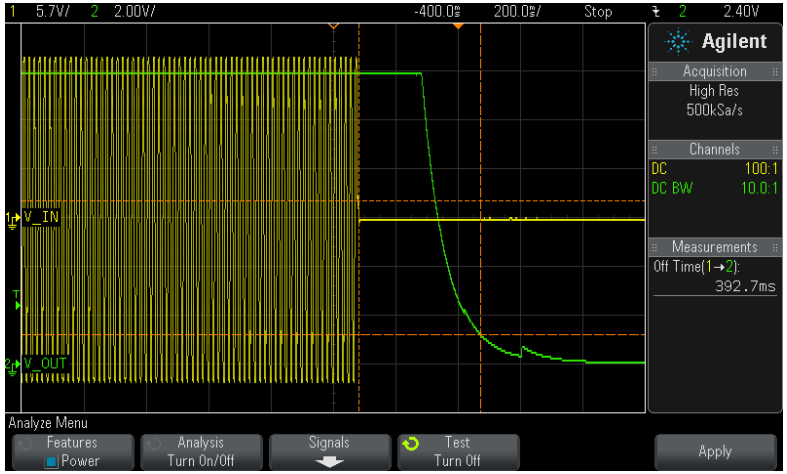
DSOX3PWR- Power Measurement and Analysis

To make fast, automatic and reliable characterization that goes beyond basic current monitoring and simple math functions, including:

Input Measurements
- ✓ Power Quality
- ✓ Current Harmonics
- ✓ InRush current

Switching Measurements
- ✓ Switching Loss
- ✓ Slew Rate
- ✓ Modulation

Output Measurements
- ✓ Output Ripple
- ✓ Turn on/Turn Off
- ✓ Transient Response
- ✓ PSRR
- ✓ Efficiency



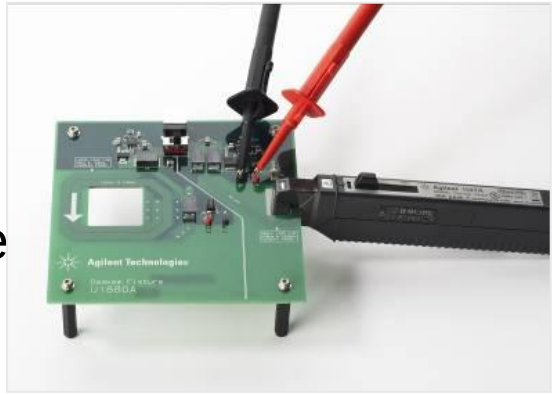
RUNS INSIDE THE SCOPE!

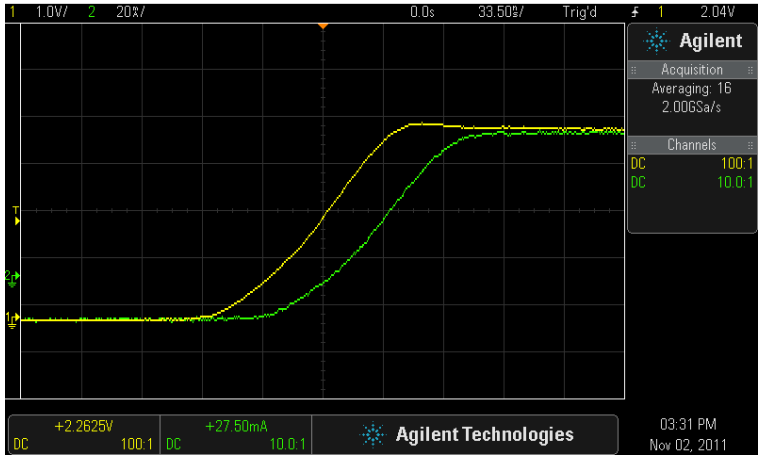
- ❖ **Available on 3000 X-Series only with DSOX3PWR option installed**
- ❖ **Includes a license for the U1881A PC based application**

Power Measurements Solution with Oscilloscope

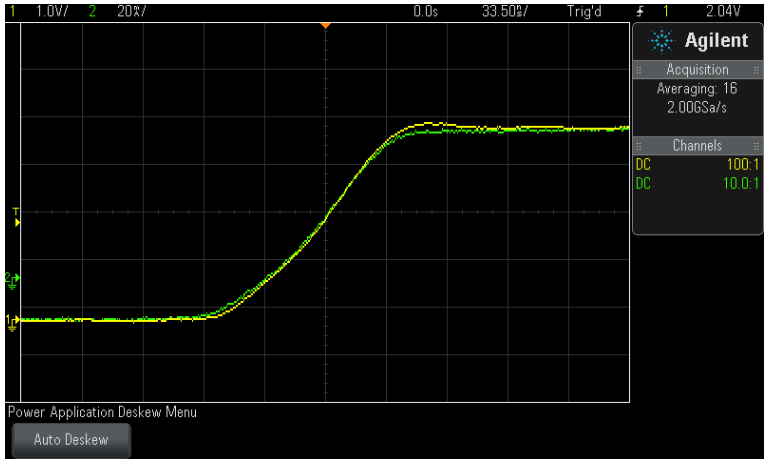
De-skew Fixture (U1880A)

- De-skewing is critical to ensure accurate power (V x I) measurements!
- The de-skew fixture calibrates the time delay between current and voltage probes to ensure accurate power loss measurements
- Fixture is powered by USB device port on scope and comes with the DSOX3PWR





Voltage and current signals skewed by 35nsec



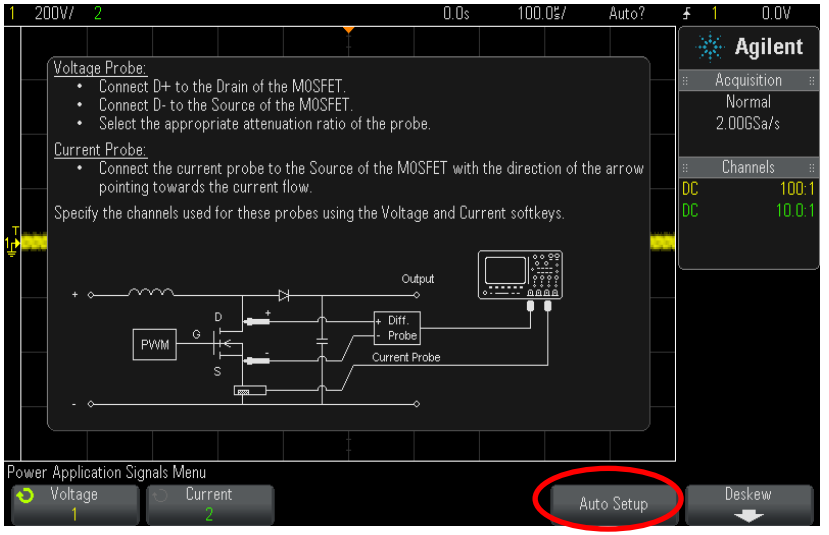
De-skewed!

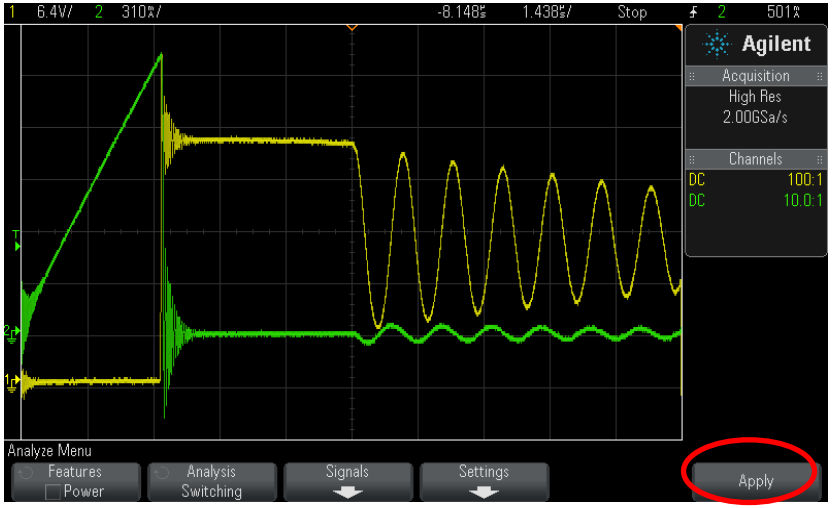
Power Device Analysis

Switching Power Dissipation Measurement Example

Ensuring Proper Set Up:

- First make sure the probe connections are correct by pressing the “signals” softkey and the connection diagram will appear on screen
- Next, use the “Auto setup” to configure the scopes vertical and horizontal scaling
- Next, use the “Apply” softkey to activate the measurements





Power Device Analysis

Switching Power Dissipation Measurement Example

- Power is the absolute value of the power equation:

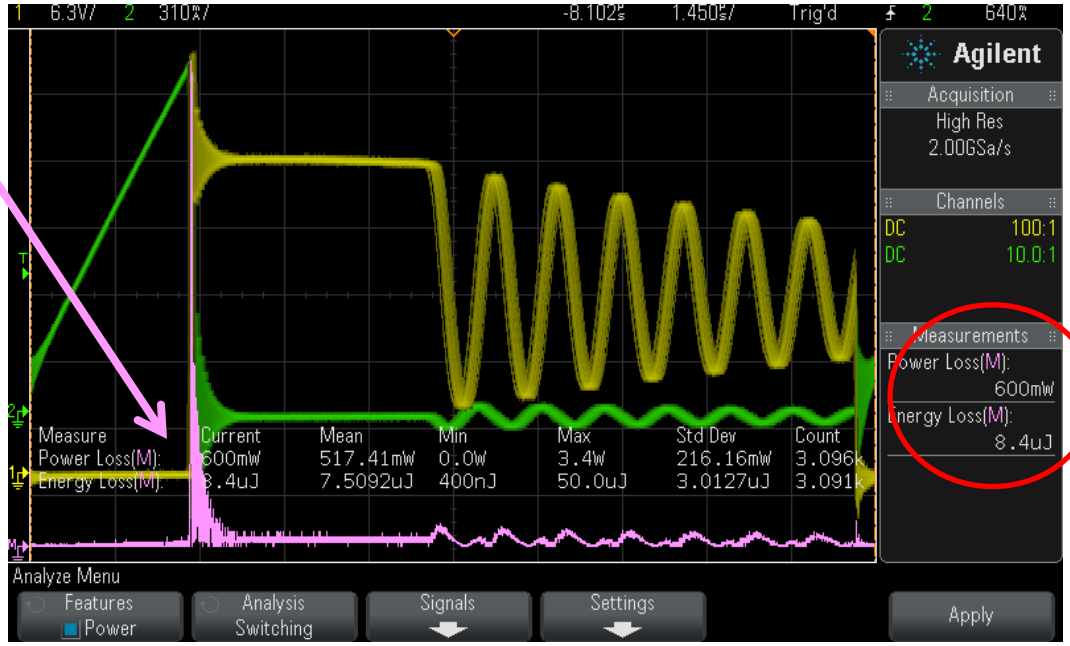
$$P_n = V_n I_n$$

- Power loss is the average power across the acquisition window and the measurement is calculated using the power loss equation:

$$P_{Loss} = \frac{1}{T_S} \cdot \int_0^{T_S} V_{switch}(t) \cdot I_{switch}(t) \cdot dt$$

- Energy loss is the energy lost during the transition of the switch and is calculated using the equation:

$$E_{on} = \int_{t_0}^{t_f} v_a(t) \cdot i_a(t) \cdot dt$$



Actual measurement for power and energy loss over one switching period (Cycle)

Power Measurements Solution with Oscilloscope

Power Measurement Probes and Accessories

- **U1880A De-skew fixture for voltage and current probe de-skewing**
- AC/DC current probes
  - **1147A 50MHz, 15A current probe with AutoProbe interface**
  - **N2893A 100MHz, 15A current probe with AutoProbe interface**
  - N2780B 2MHz, 500A current probe (requires N2779A power supply)
  - N2781B 2MHz, 150A current probe (requires N2779A power supply)
  - N2782B 2MHz, 30A current probe (requires N2779A power supply)
  - N2783B 2MHz, 30A current probe (requires N2779A power supply)
- Differential probes
  - **N2790A 100MHz, 1.4kV differential probe with AutoProbe interface**
  - **N2791A 25MHz, 700V differential probe**
  - N2792A 200MHz, 20V differential probe
  - N2793A 800MHz, 15V differential probe
  - N2891A 70MHz, 7kV differential probe
- Passive probes (for measuring output noise and PSRR)
  - N2870A 1:1 35MHz passive probe (with N2768A vertical mini probe socket adapter)
  - 10070D 1:1 20MHz passive probe

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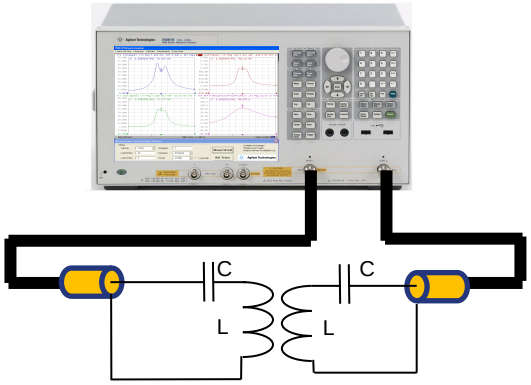
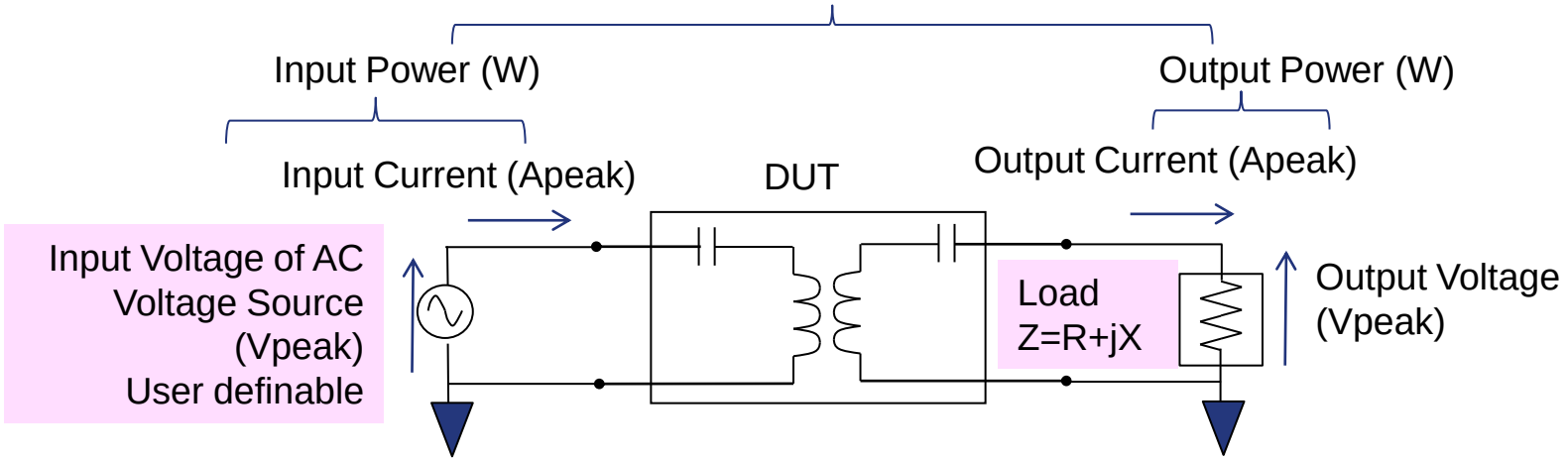
Wireless Power Transfer Analysis

E5061B Network Analyzer
+ WPT software

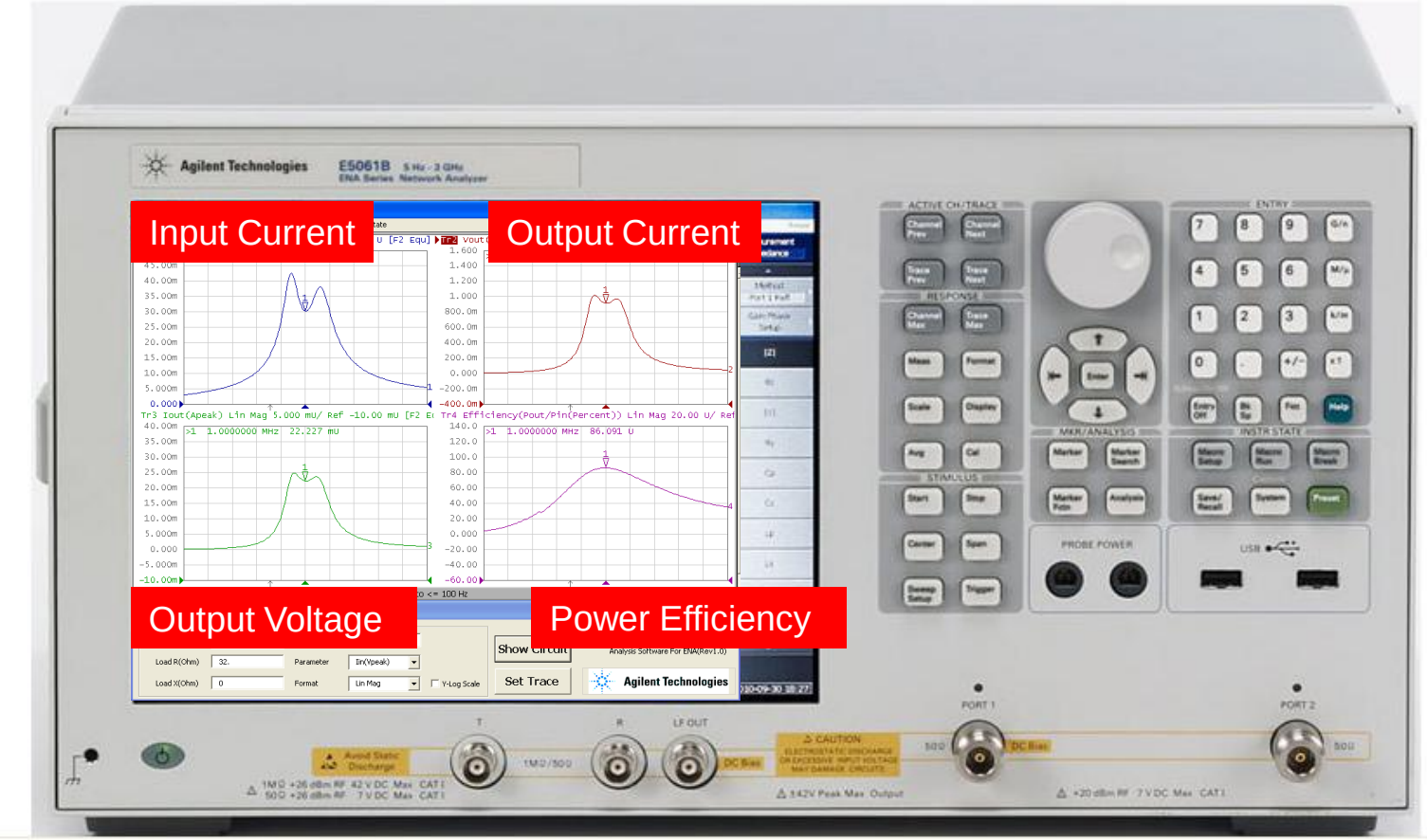


-- Wireless Power Transfer Analysis Software --
50ohm based S-parameters measurements are converted to Voltage, Current, Power and Efficiency of the voltage driving circuit with arbitrary load impedance.
These key parameters for WPT circuit design are displayed on the E5061B display in real-time.

Power efficiency (%) = (Output Power / Input Power) x100

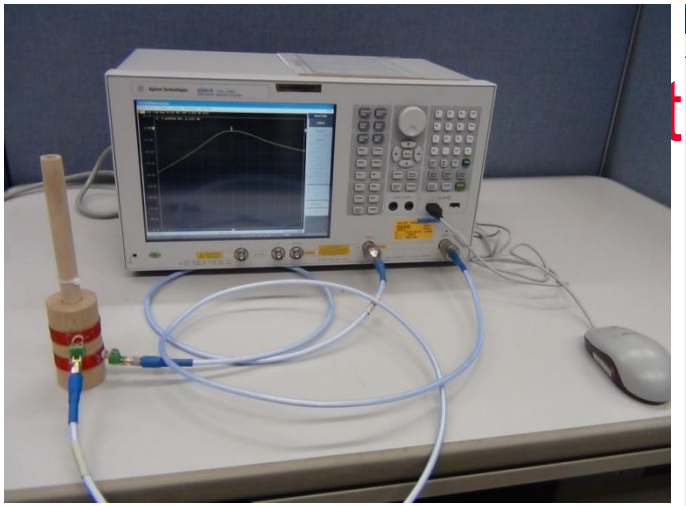


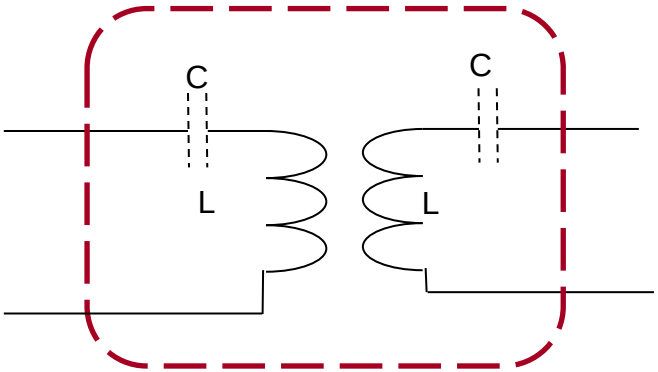
Wireless Power Transfer Analysis SW

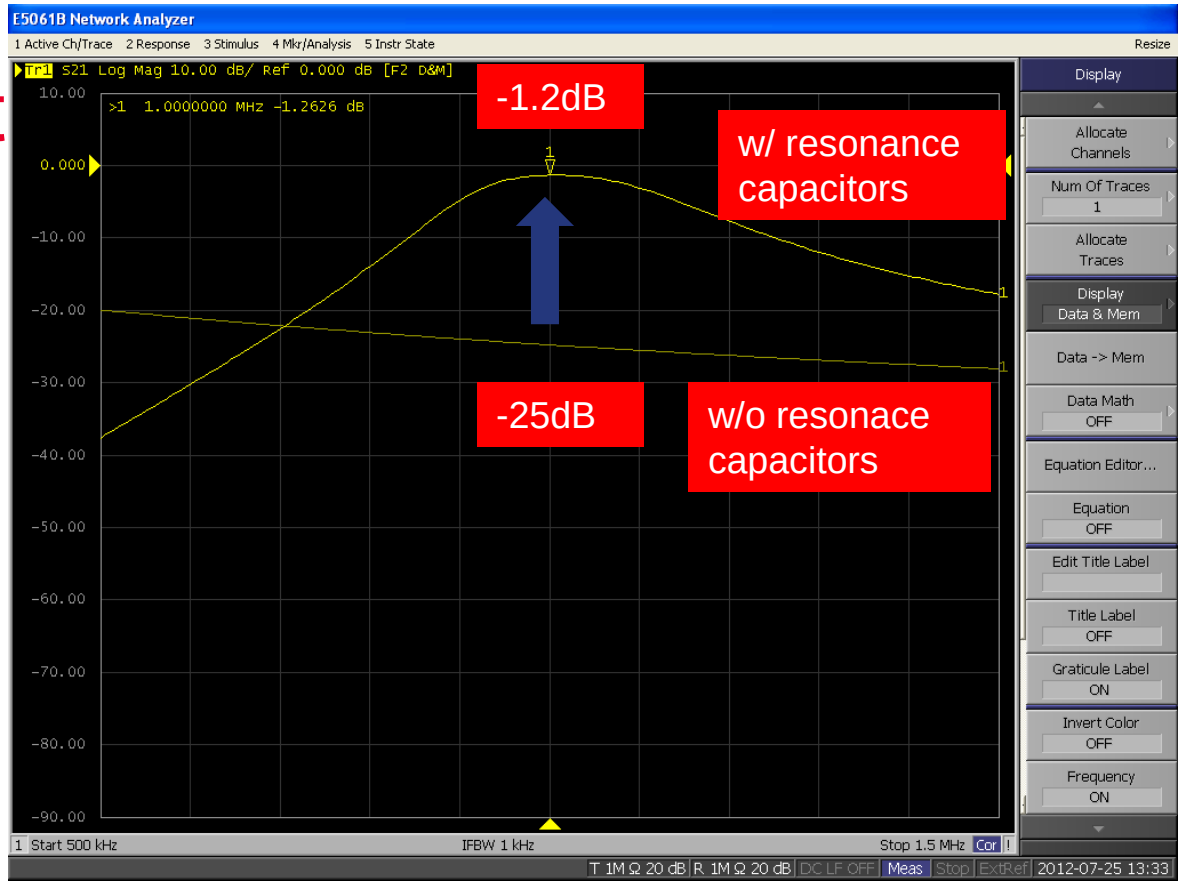


E5061B Network Analyzer

Wireless Power Transfer Analysis SW



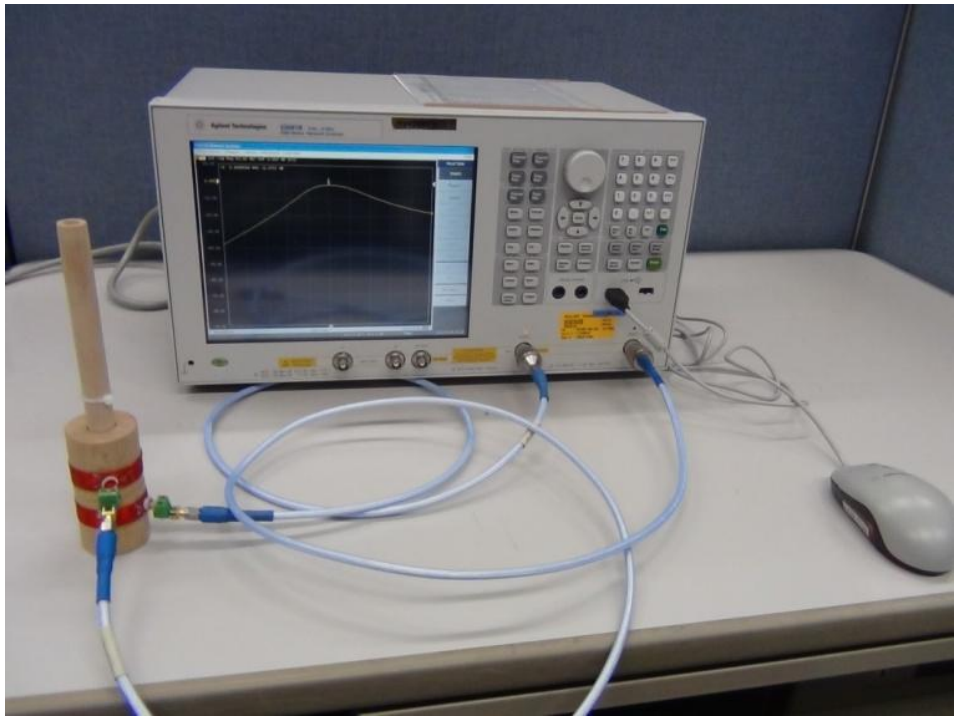


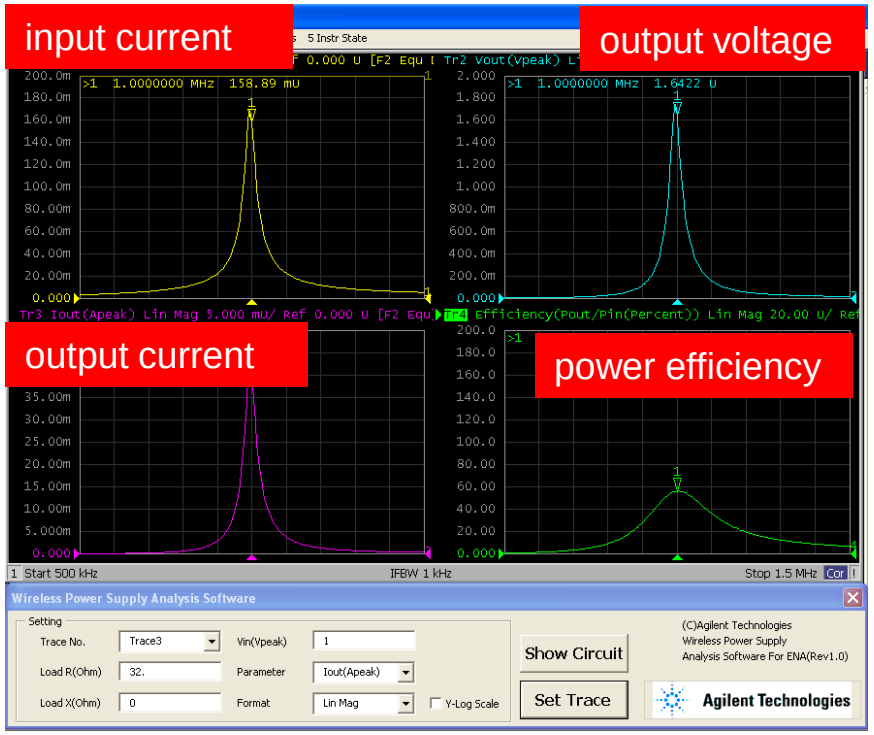


Center=1MHz

Wireless Power Transfer Analysis SW

Conversion from S-parameters to WPT parameters

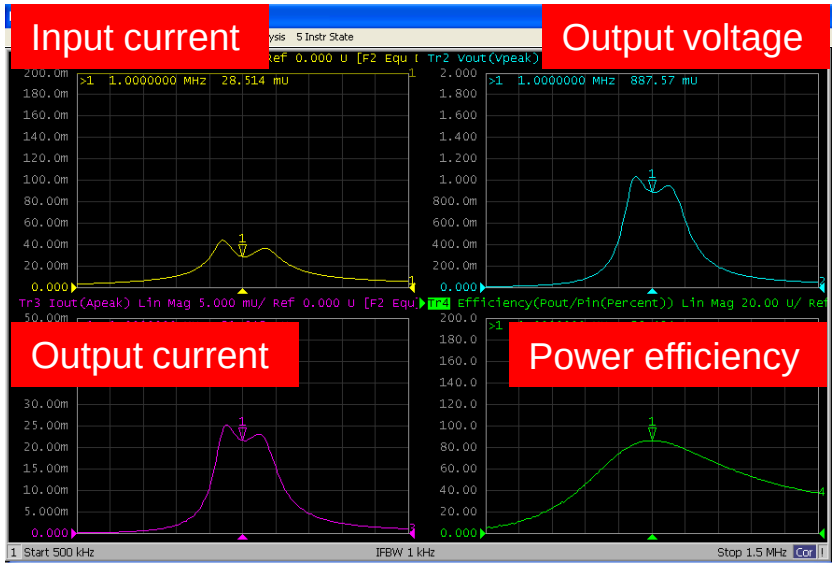


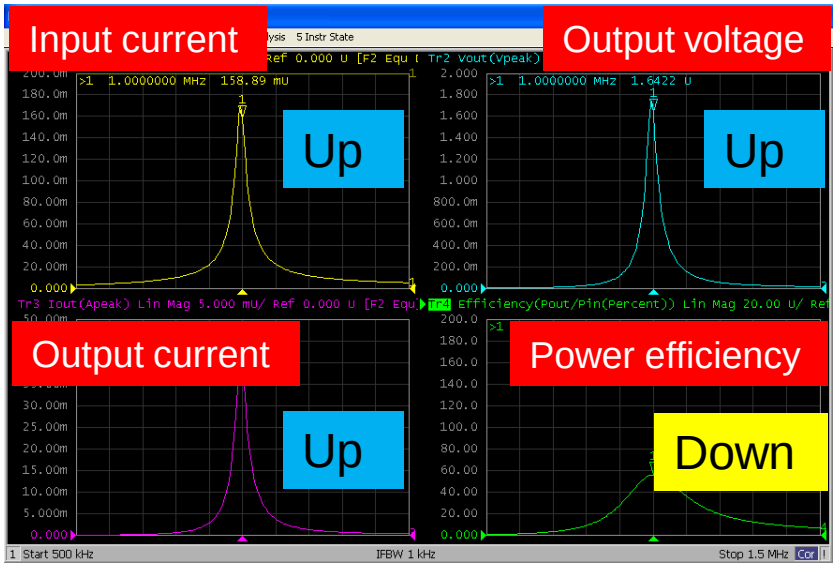


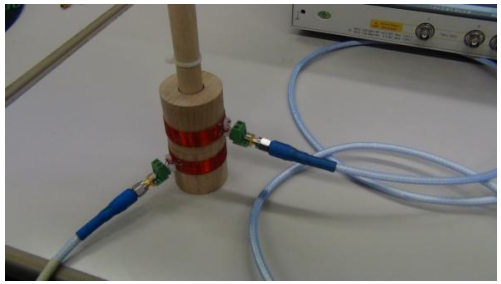
Vac = 1V
Zload = 32 ohms

Parameters dependency on the distance between the coils

Output voltage becomes higher as the coils get farther coils but power efficiency becomes poorer.

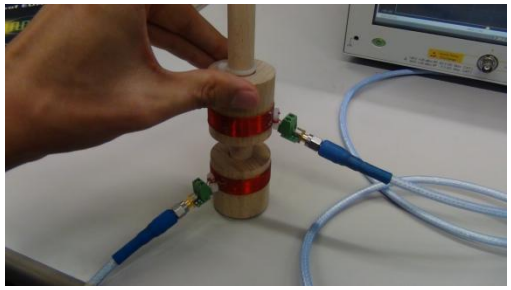






Shorter distance

-- can be seen in real-time



Longer distance

KEYSIGHT TECHNOLOGIES

Appendix:

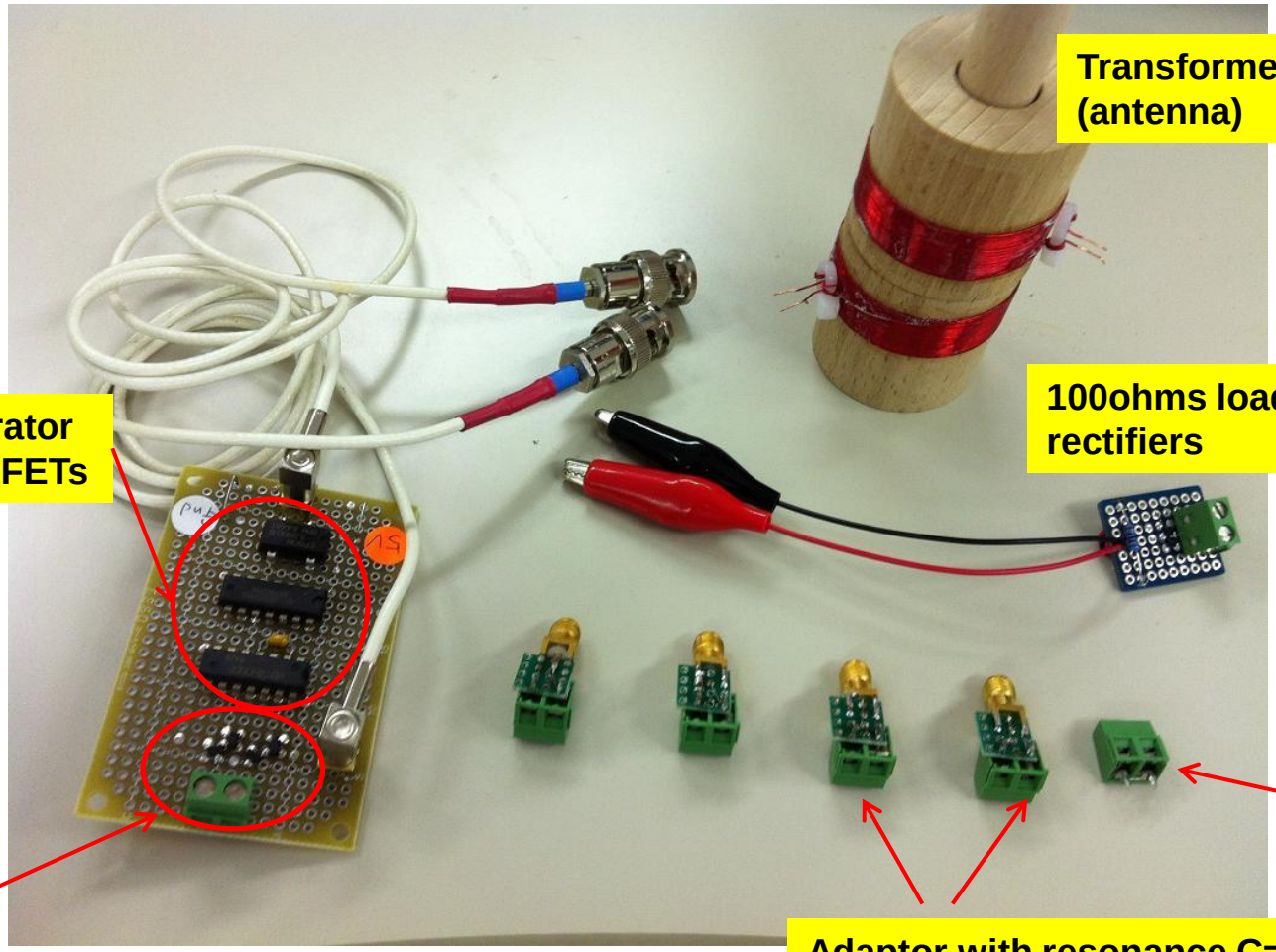
Measurement and Simulation demo for Wireless Power Transfer

Who says S-parameters can't be used for a voltage driving circuit?

Aug. 2013
Yoshiyuki Yanagimoto

KEYSIGHT TECHNOLOGIES

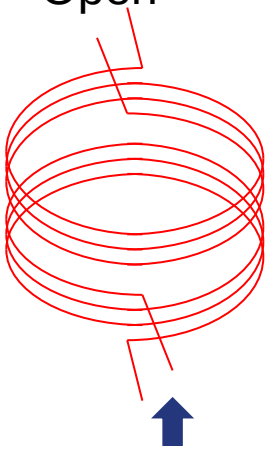
Demo kit


Transformer (antenna)
100ohms load with rectifiers
1MHz pulse generator driving the driver FETs
Short
Driver FETs
Adaptor with resonance C=682pF

Modeling a transformer (a pair of antennas) by measuring its impedances

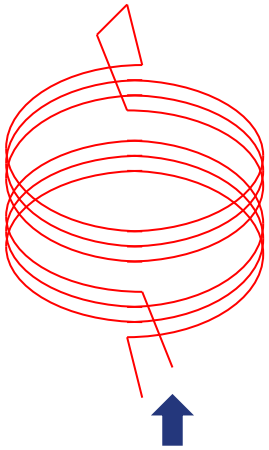
Measurements

Open



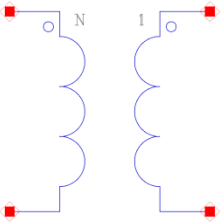
L = 36.51uH
R = 2.51Ω

Short



L' = 35.78uH

Coupling coefficient k = 0.141
***** L' = L x (1 – k^2)**



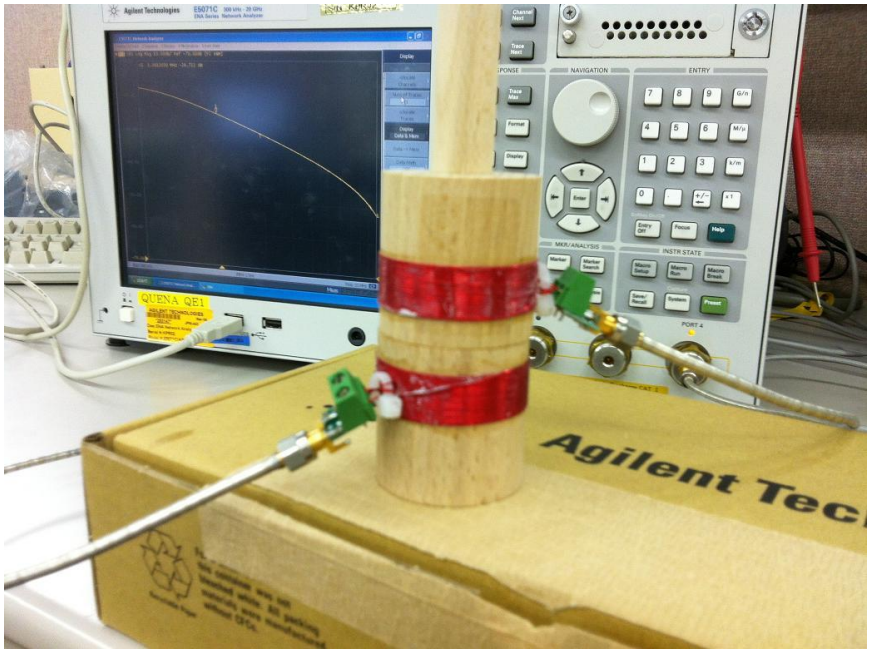
XFERP
XFer3
N=1
Lp=Ls*Kc
K=Kc
R1=Rs
R2=Rs

Circuit Model

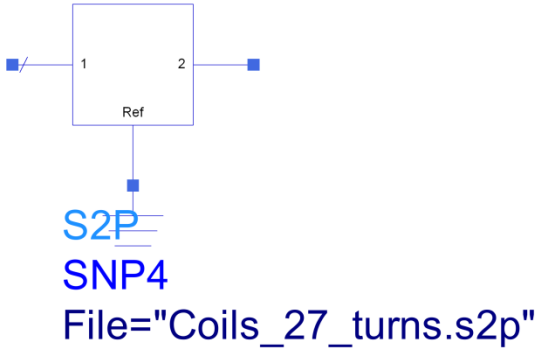
VAR
VAR4
Kc=0.14
Rs=2.5 Ohm
Ls=36.5 uH

Modeling a transformer using S-parameters

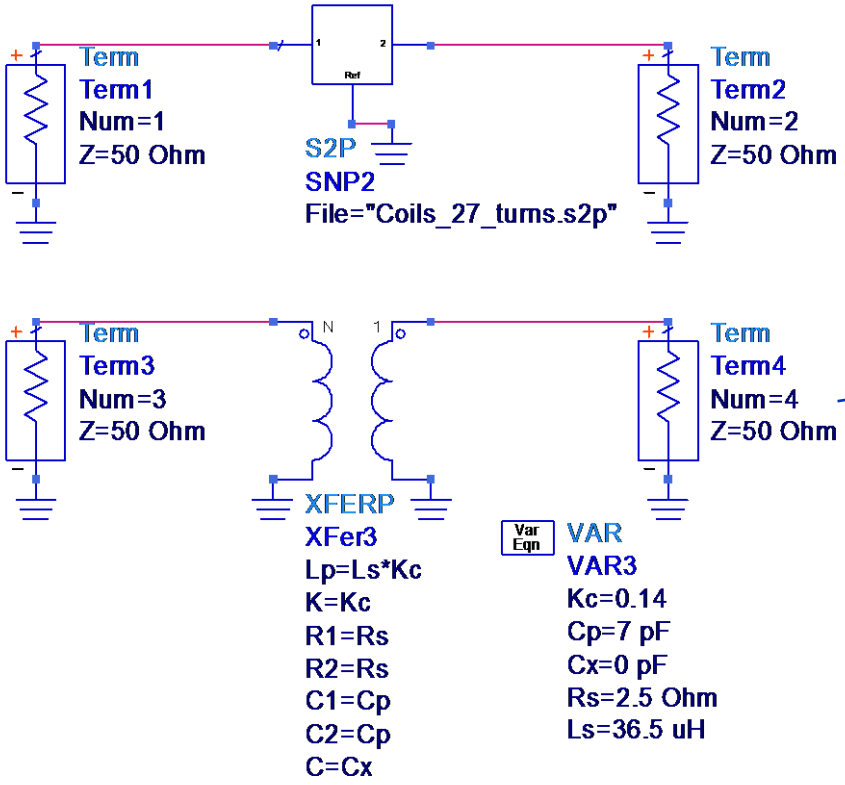
Measurements



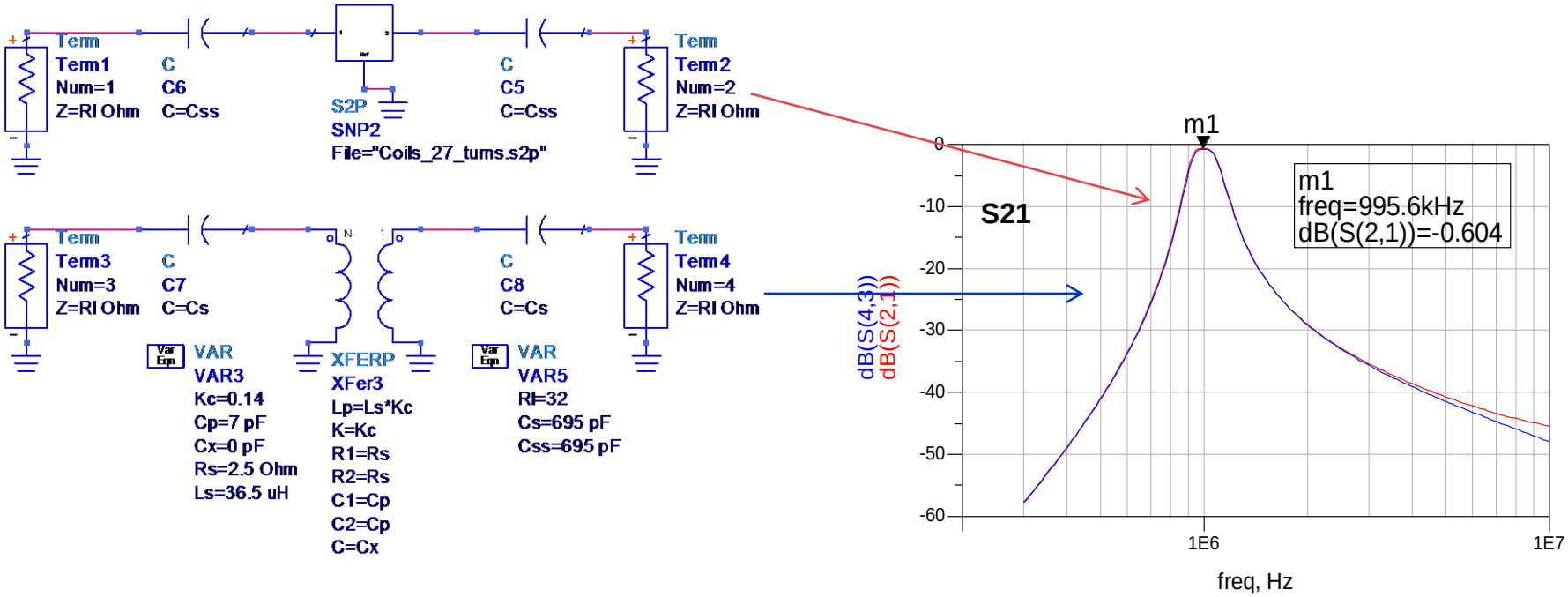
S-parameters Model



Comparing Circuit model and S-parameters model

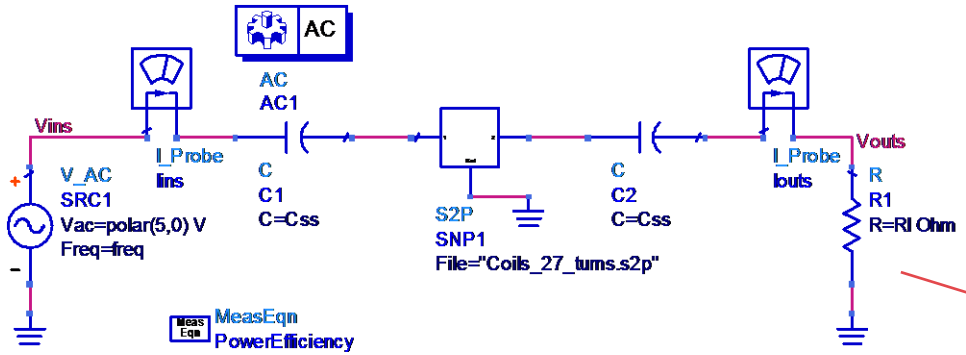


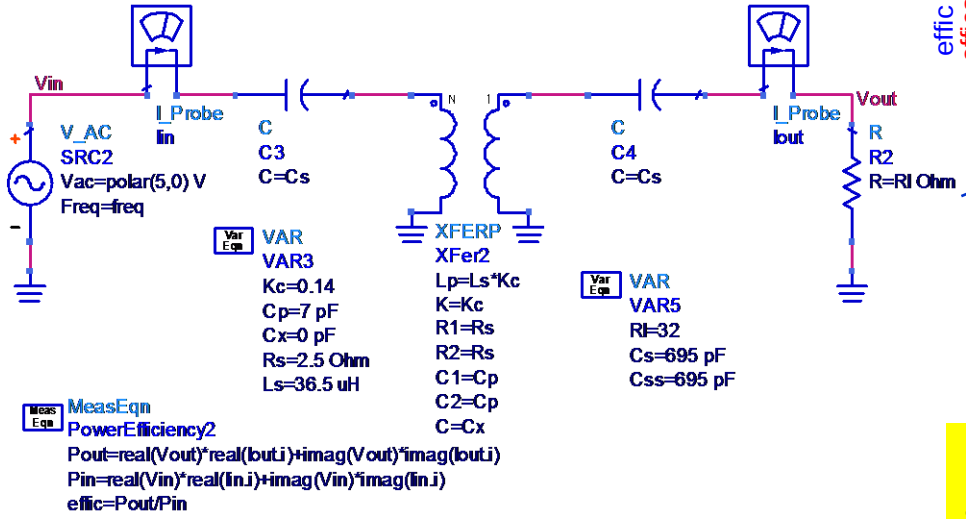
Adding a resonance capacitor to increase the transfer efficiency

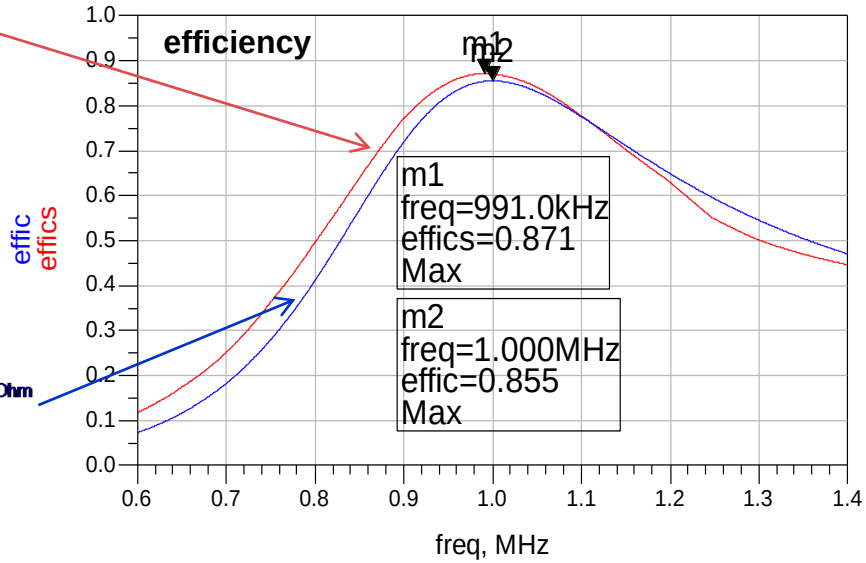


-25dB loss without capacitors became almost 0dB loss with capacitors

RF power transfer efficiency simulation

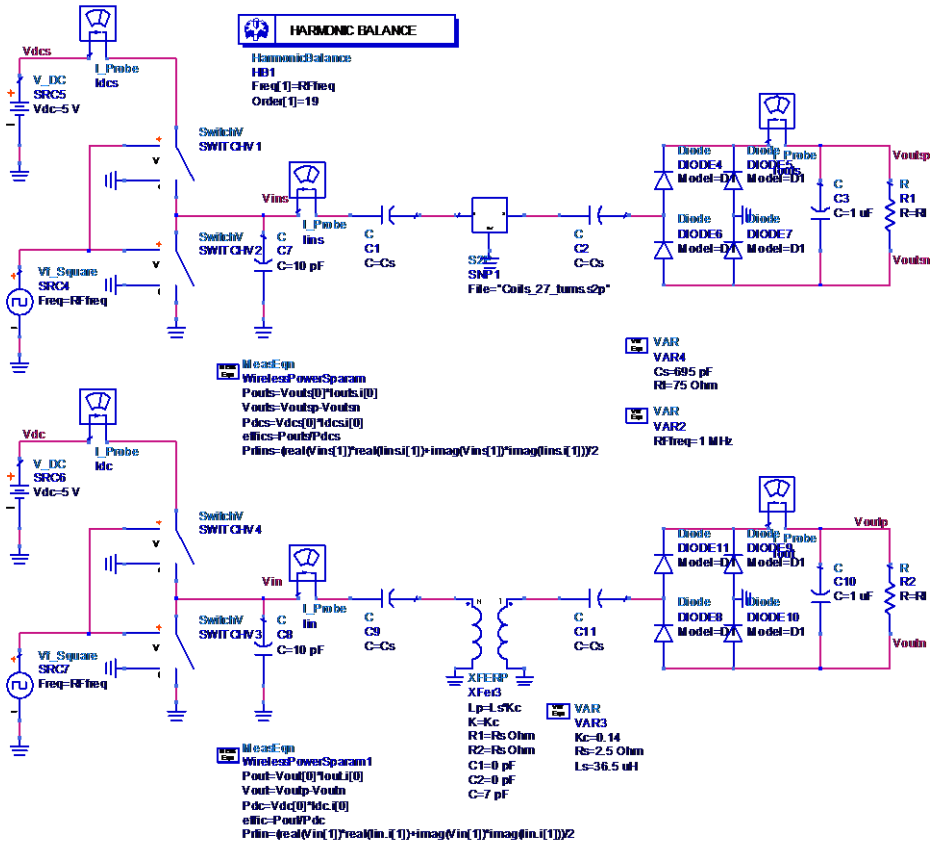


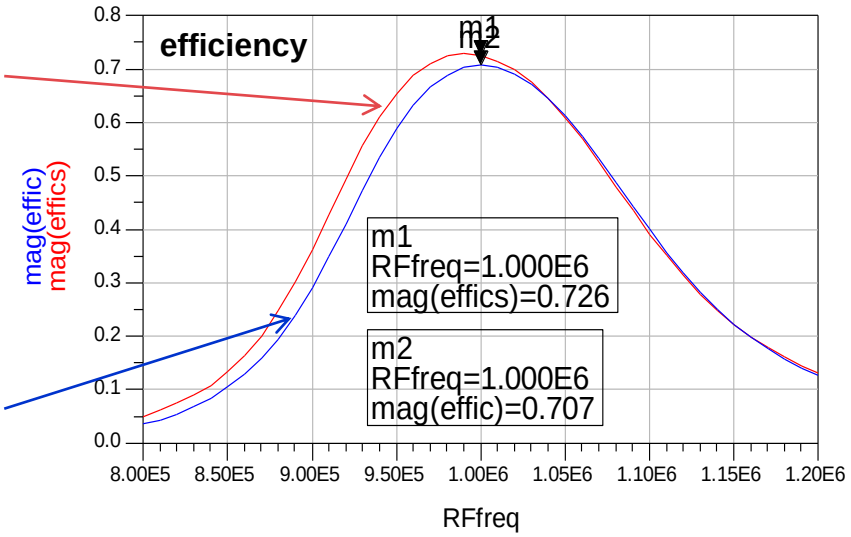




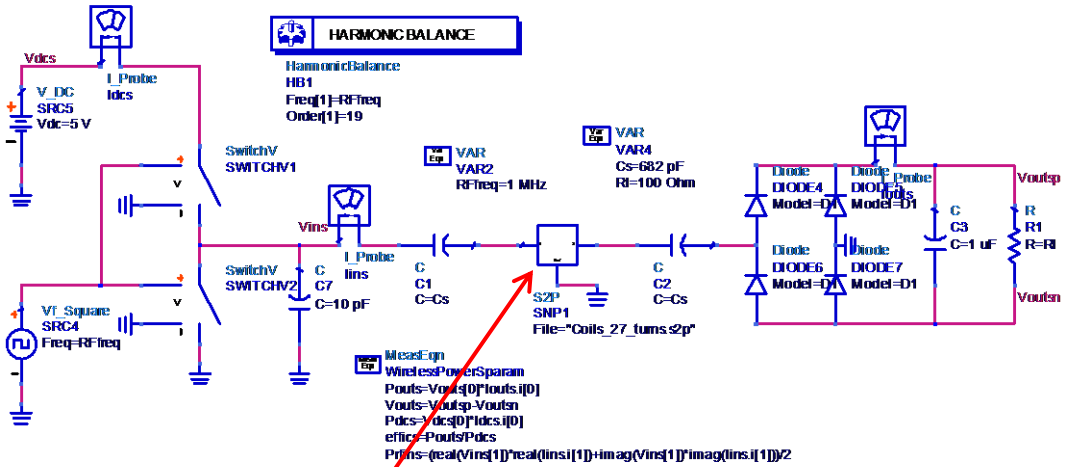
S-parameters just works fine with a voltage source

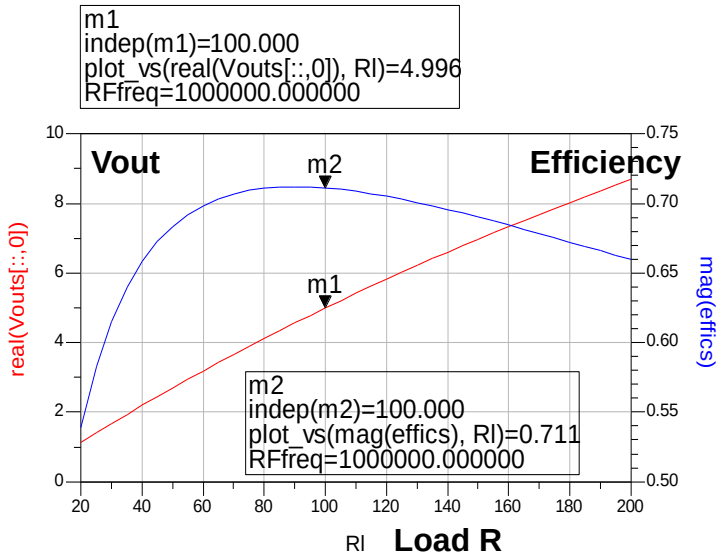
DC to DC efficiency simulation



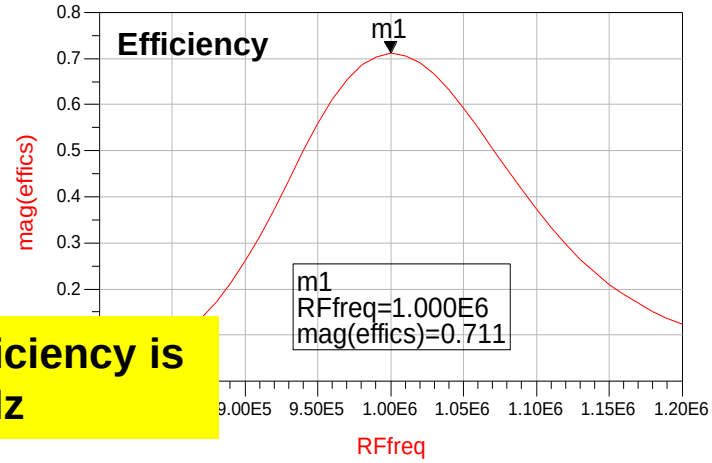


Final circuit and its expected performance



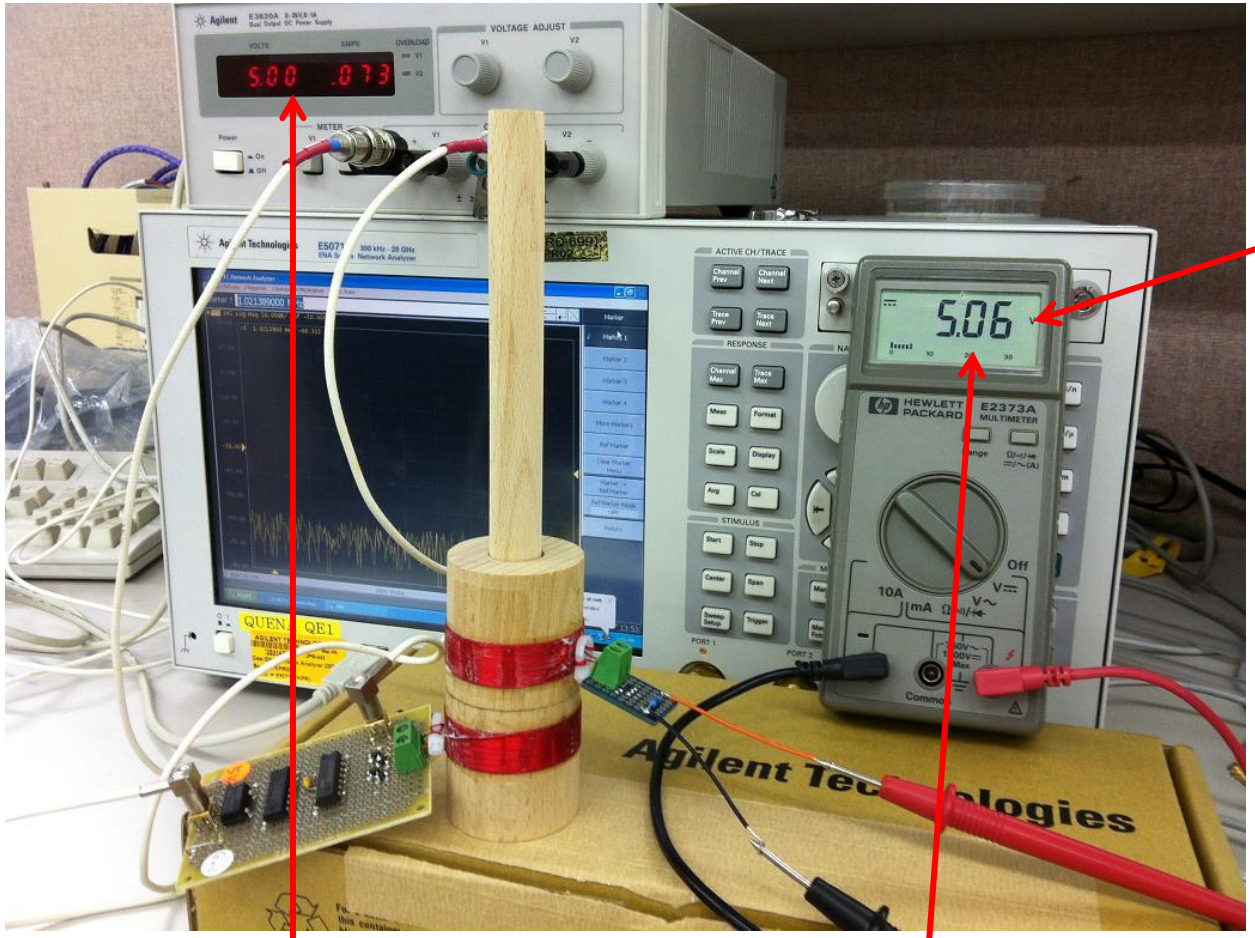


Remark:
Using an S-parameters model taken in 50 ohms environment and simulating with a voltage driving circuit



Expected efficiency is 71.1% @1MHz

Actual Circuit



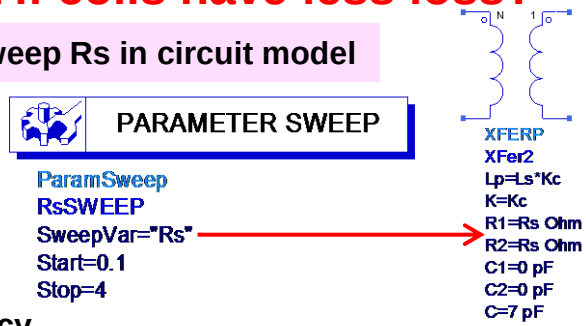
V_{Actual} = 5.06V
V_{Sim} = 5.00V

P_{source} = 5.0V x 73mA = 365mW $P_{receiver}$ = 5.06V^2 / 100Ω = 256mW
Efficiency = 256 / 365 = 70.1% ← 71.1% was simulated

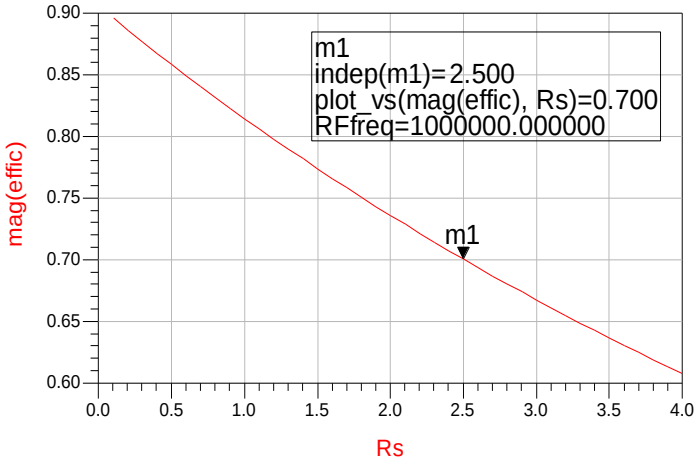
“What if?” simulation

What if coils have less loss?

Sweep Rs in circuit model



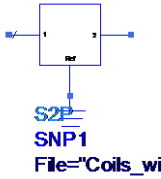
efficiency

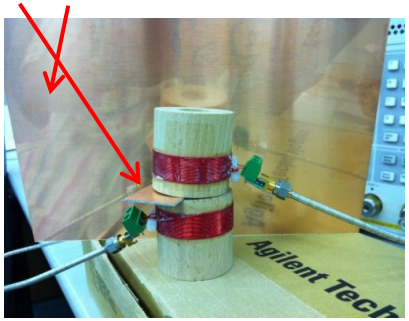


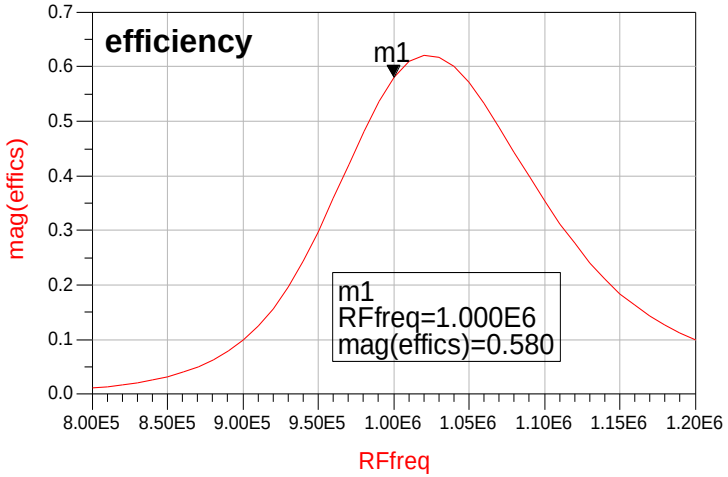
Rs has large impact to efficiency
Better use fatter wire to reduce Rs

What if Metal comes close?

Measured S-param can be used

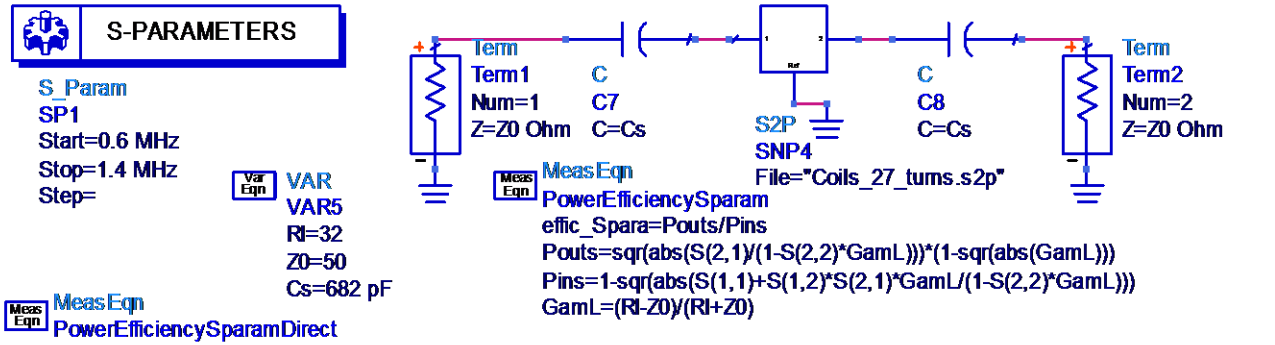


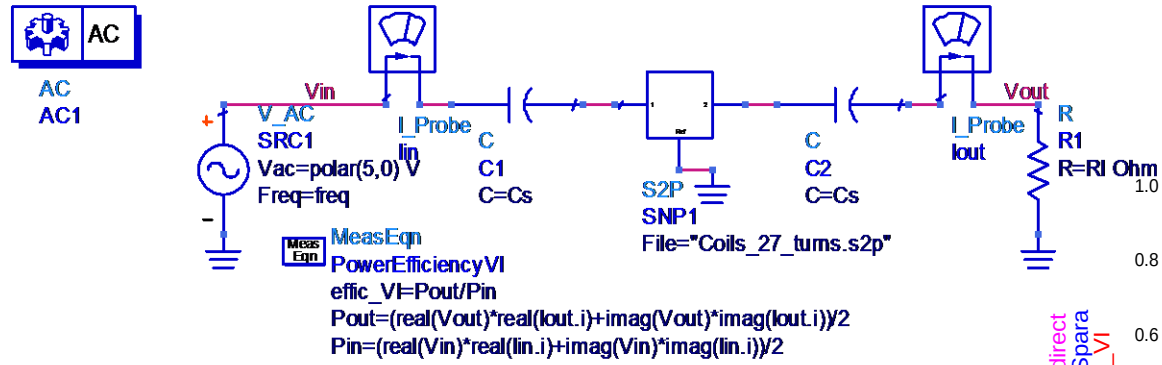


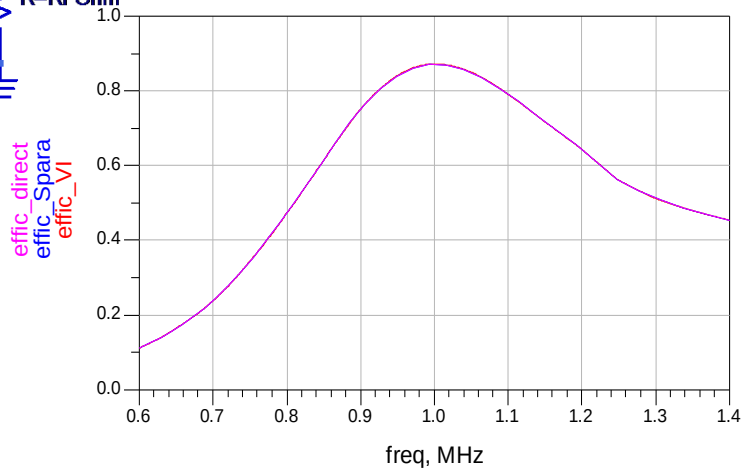


Resonance is off and efficiency gets worse

Verification using ADS







Thank you