EMC – Critical Component Evaluation

Example: Ferrites under BIAS current

MAH2202161416

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1 Outline

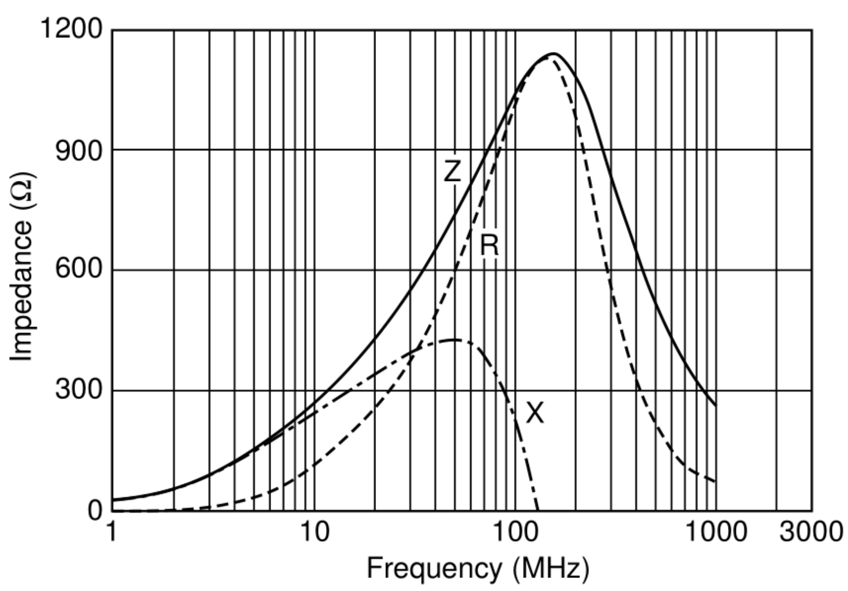
Modern digital electronics may be rather forgiving of suboptimal design. However, there is still a huge difference between some tinker toy that runs under rather specific conditions and a commercial product that adheres to industry standards.
One topic that repeatedly leads to designers' frustration is electromagnetic compatibility (EMC). Any changing electric current will lead to radiated emissions. These emissions are largely dependent on the structure of the electric circuit. To improve EMC, a circuit designer may use filters to corral high frequency currents or guide them into more desirable paths.
In modern EMC design, we have to take a wide frequency range into account. This essay examines filter behavior in the range between 1MHz and 2GHz. An EMC emission test may look at much higher frequencies. Some standards require measurements at up to ten times the highest operating frequency.

A designer will preselect filter components based on manufacturer data sheet information. However, the data sheet might not contain all the required information and, a designer may want to verify how individual components interact in a certain arrangement and under specific conditions. This essay focuses on the behavior of ferrites under bias current conditions.

2 Component Datasheet Specifications

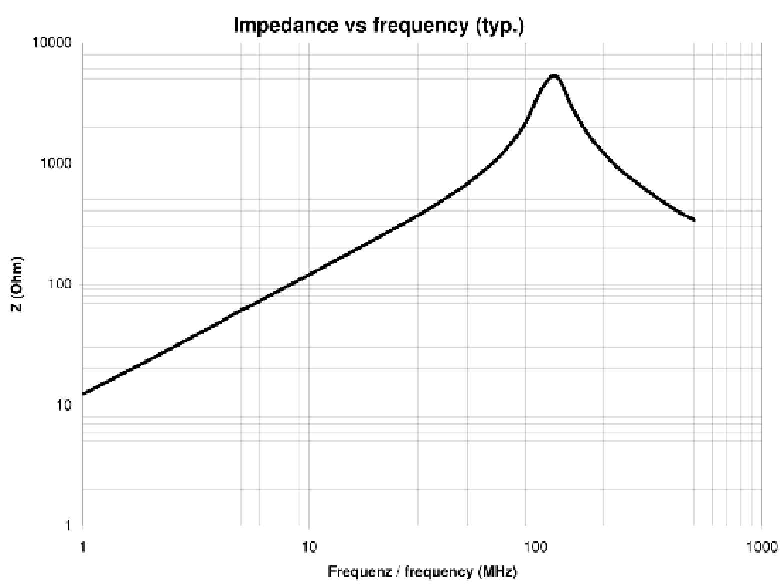
2.1 BLM18AG102SN1 – Ferrite Bead

Data sheet information:	
Manufacturer:	Murata
Part number:	BLM18AG102SN1
Size:	0603 (0.01")
Impedance (at 100MHz/20°C):	1000ohm±25%
Rated Current:	400mA
DC Resistance (max.):	0.50Ω
Self-resonant frequency:	ca.150MHz



2.2 744710203 – Rod Core Inductor WE-SD

Data sheet information:	
Manufacturer:	Würth Elektronik
Part number:	744710203
Size:	ca. 12.5mm x 3mm
Inductivity (at 10kHz/5mA):	2µH
Rated Current:	2500mA
DC Resistance (max.):	0.011Ω
Self-resonant frequency:	110MHz



2.3 100nF Capacitor

Example: Taiyo Yuden HMK107B7104KA-T
100V 0603 X7R 100nF
Size: 0603 (0.01”)

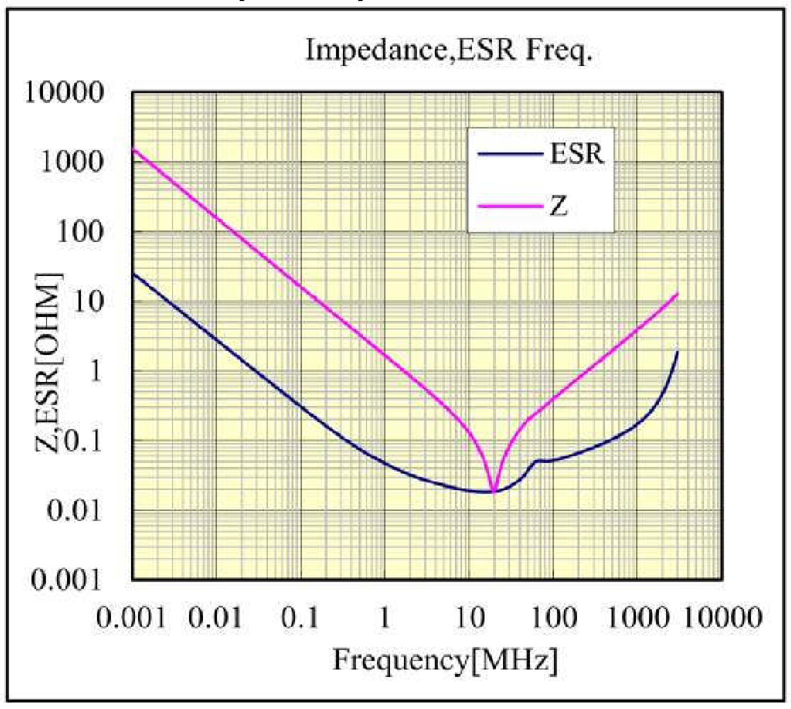


Figure 1 - 100nF Capacitor Resonance

3 Setup

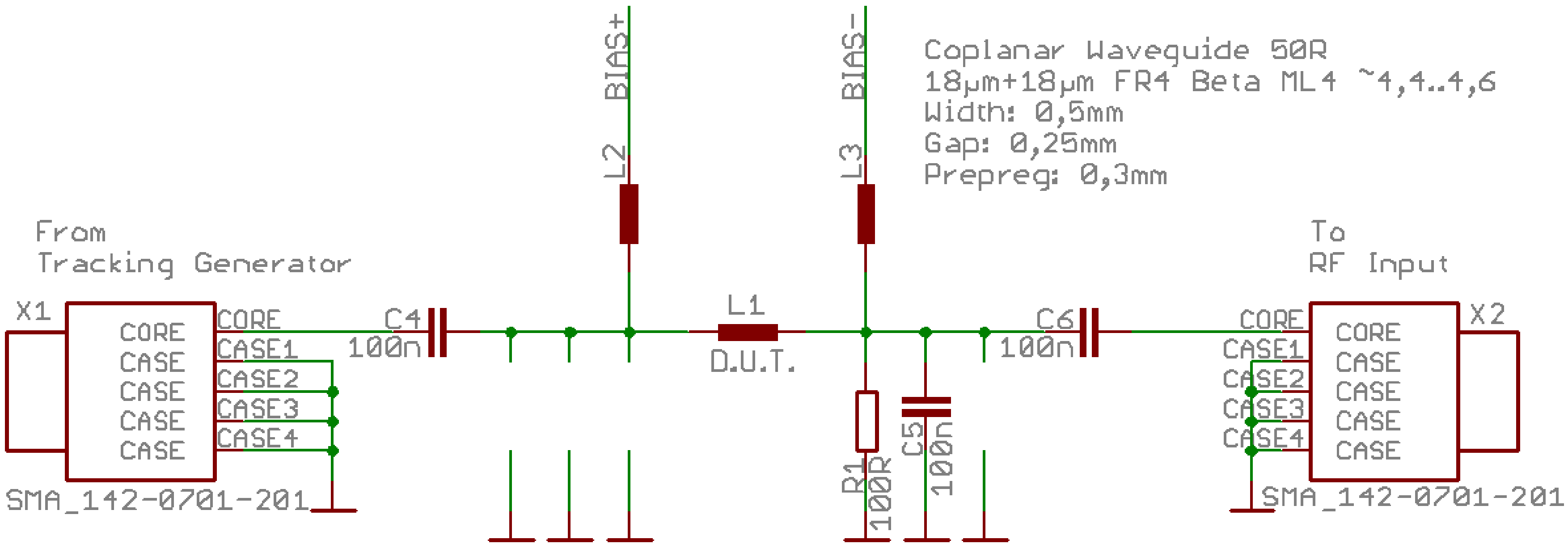


Figure 2 – Test Adapter Schematic

The test setup uses a modified HARERORD HFTP3 filter evaluation board. The layout matches the 50Ω impedance of the tracking generator and the RF input of the spectrum analyzer.

L1 is the primary device under test (DUT). C5 completes the LC-filter. R1 serves as a local load. All capacitors are 100nF 16V X7R 0603.

L2 and L3 serve to HF-insulate the DUT from the DC bias supply. For reasons of availability, each of these inductors are series compounds of two Würth 744710215 2µH 15A and one WE-SD 744710203 2µH 2.5A.

The laboratory power supply EX354RT acts as a DC-floating current source and injects a bias currrent into L1. C4 and C6 decouple the DC-bias current from the spectrum analyzer.

The tracking generator of the SSA3021X spectrum analyzer feeds a high frequency sweep signal into the circuit.

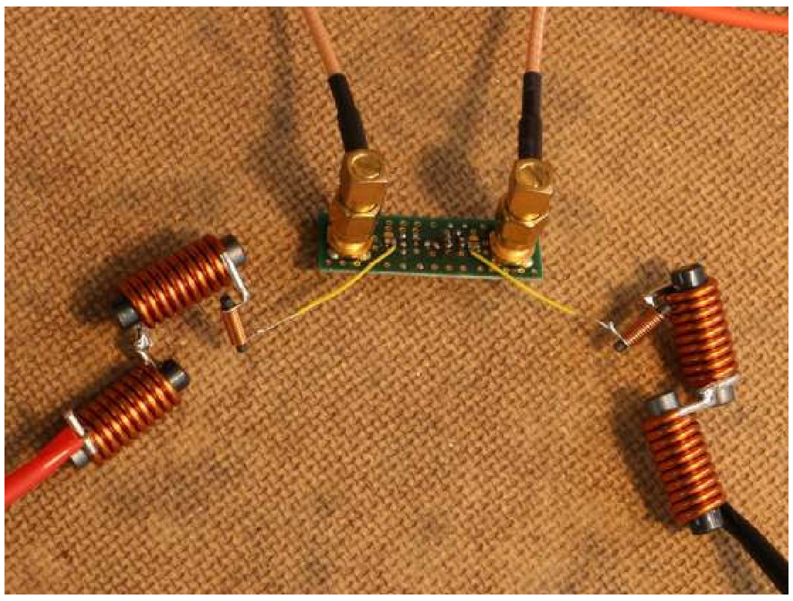


Figure 3 - Setup BLM18

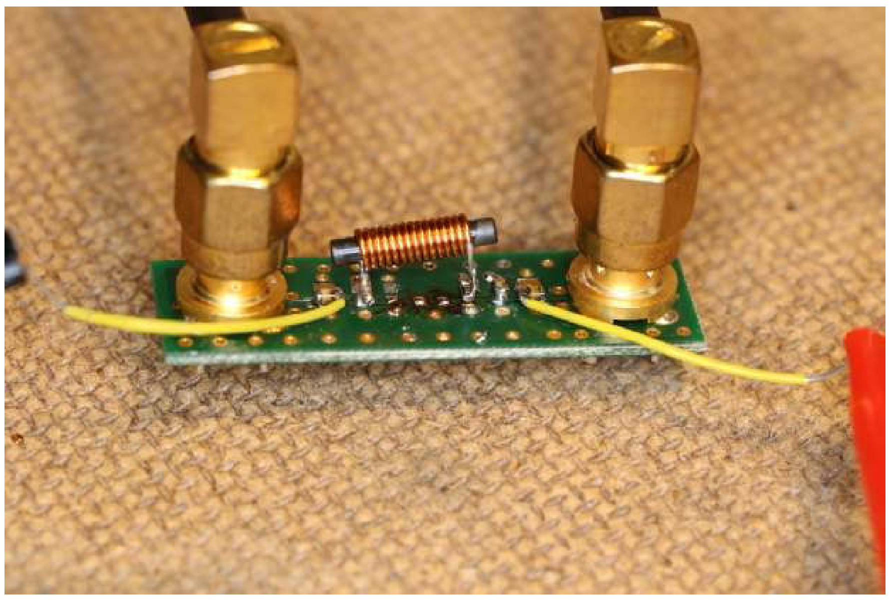


Figure 4 - Setup WE-SD

4 Measurements

4.1 BLM18AG102SN1

4.1.1 Test Setup Baseline – Range 1MHz to 1GHz / TG -20dBm

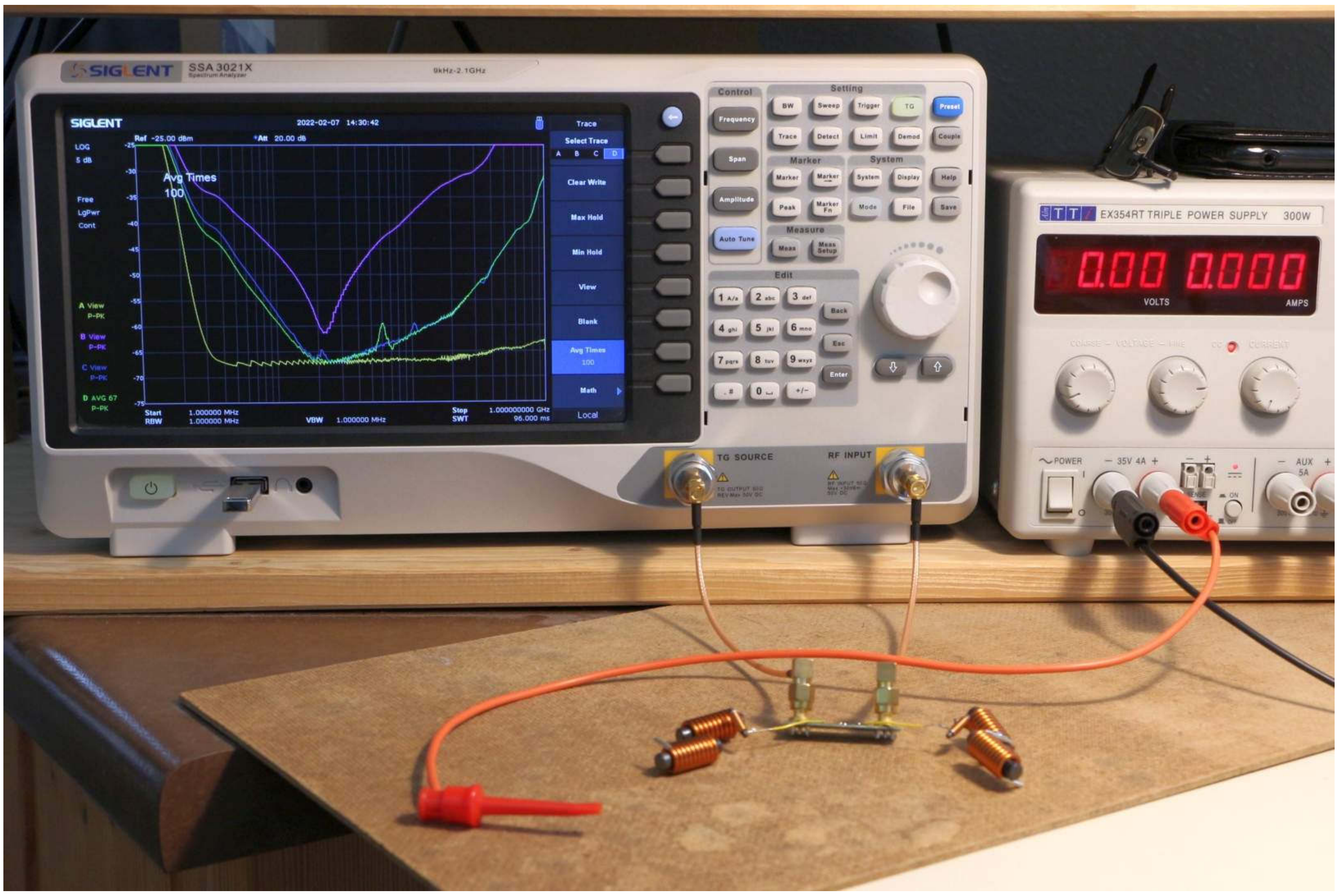


Figure 5 - Baseline Setup

Spectrum Analyzer Settings:

- Tracking Generator (if active): -20dBm (0dBm = 1mW into 50Ω)
- X-Axis: 1MHz to 1GHz, logarithmic
- Y-Axis: -25dBm to -75dBm, logarithmic, 5dBm Grid

To establish a baseline for the measurement, the following tests were run:

- Yellow (A view)
  - Tracking Generator Off. Noise base.
  - Signal shape independent of bias status (determined in multiple configurations)
- Green (D view)
  - Tracking Generator On. Bias disconnected, as seen in fig. 2
  - resonance spikes at 60MHz, secondary/dirt effect
- Blue (C view)
  - Tracking Generator On. Bias connected, current set to 0mA
  - shift of resonance spikes to 20MHz and 100MHz, secondary/dirt effect
- Purple (B View)
  - L1/DUT shorted by solder blob
  - Tracking Generator On. Bias disconnected, as seen in fig. 2
  - Filter effect of C1/R1 alone

4.1.2 Influence of Bias Current – 1MHz to 1GHz

The BLM18AG102SN1 has a rated current of 400mA. The following series of measurements shows the influence of core saturation due to DC bias current within and beyond the permissible current range.

- Green (D view) – the actual filter response due to bias current
  - Tracking Generator On. Bias connected
- Blue (C view) – reference trace, zero bias current
  - Tracking Generator On. Bias connected, current set to 0mA
- Yellow (A view)
  - Tracking Generator Off. Noise base.
- Purple (B View)
  - L1/DUT shorted by solder blob
  - Tracking Generator On. Bias disconnected, as seen in fig. 5
  - Filter effect of C1/R1 alone, resonance low at ca. 21MHz (compare with fig. 1)

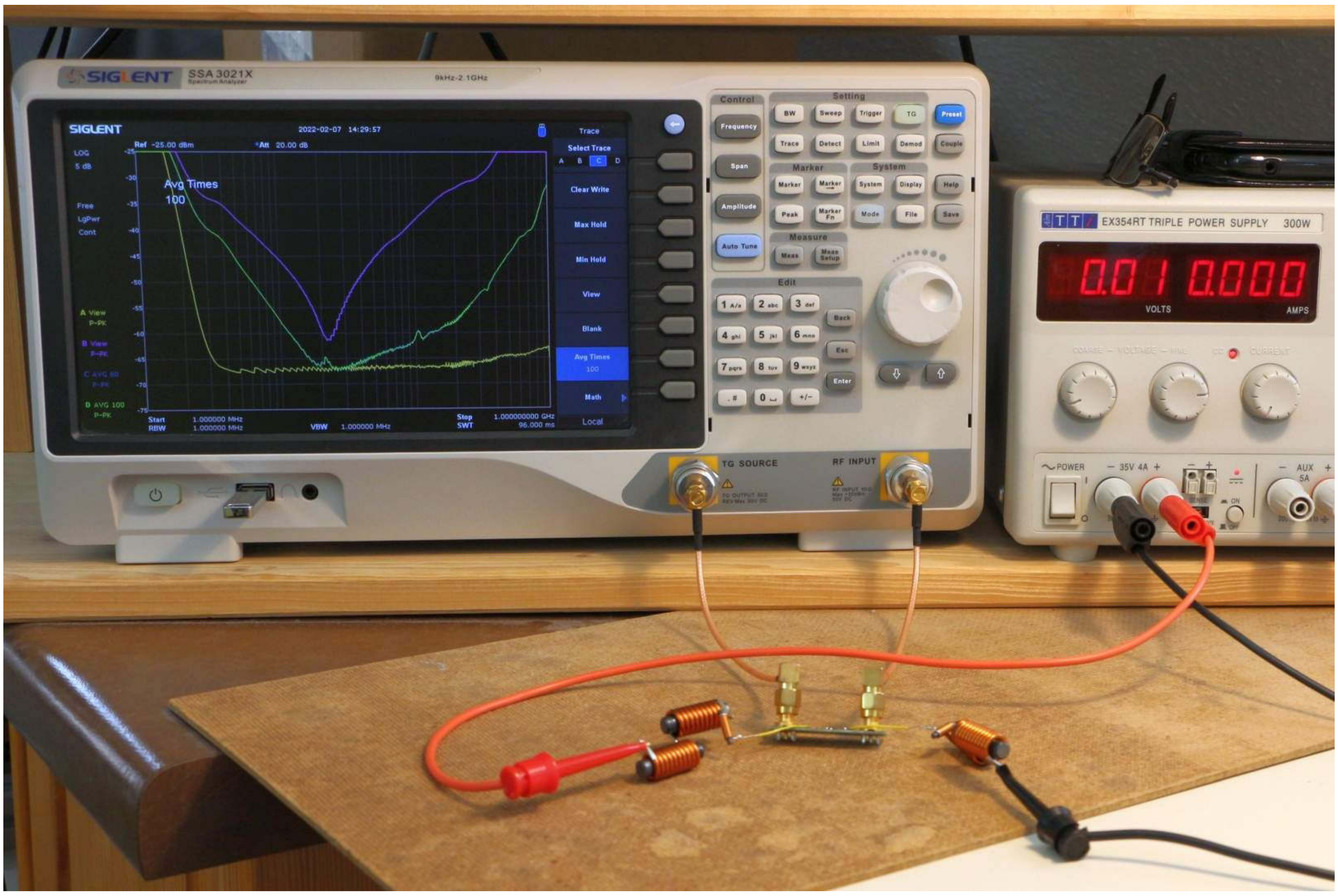


Figure 6 - 0mA

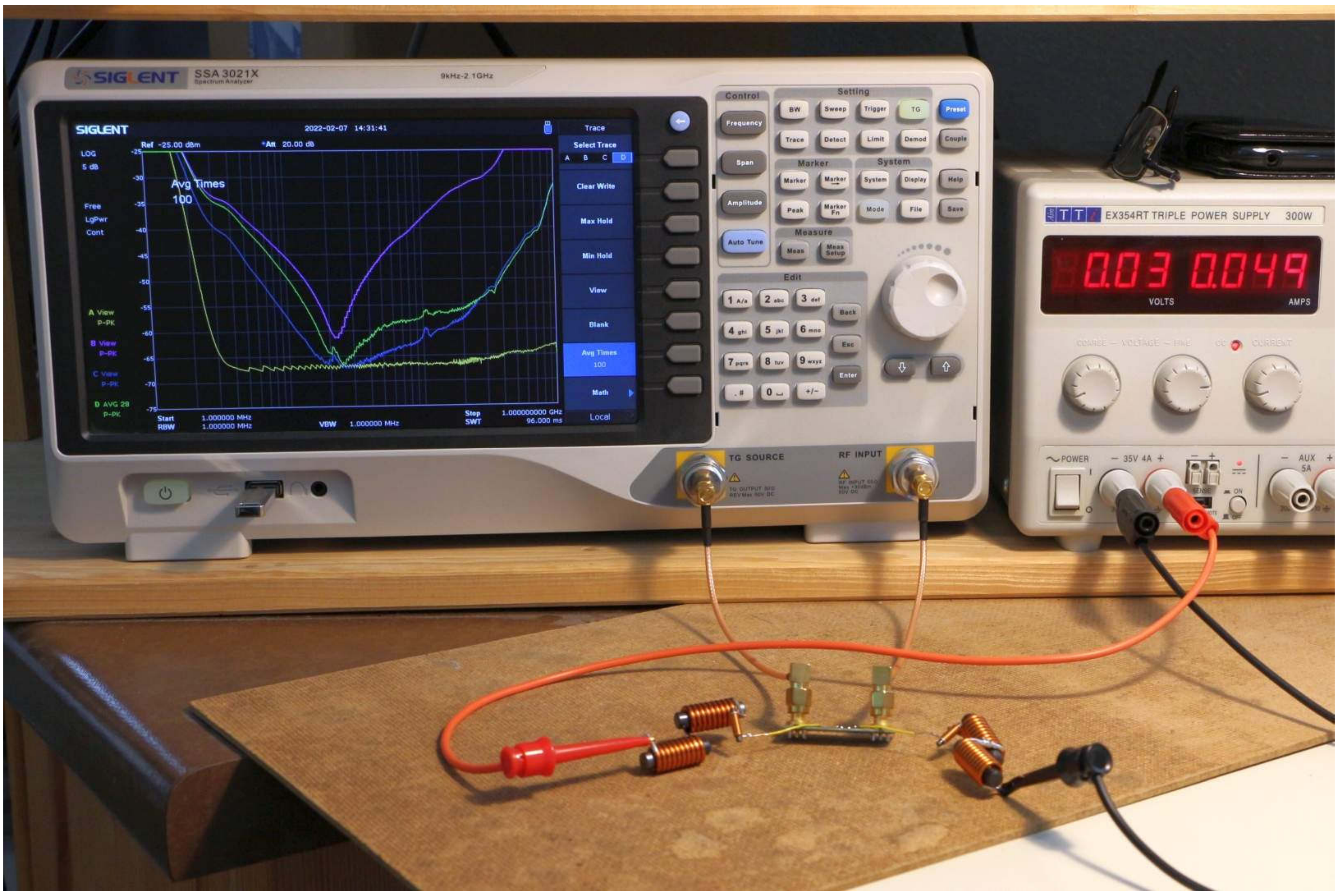


Figure 7 - 49mA

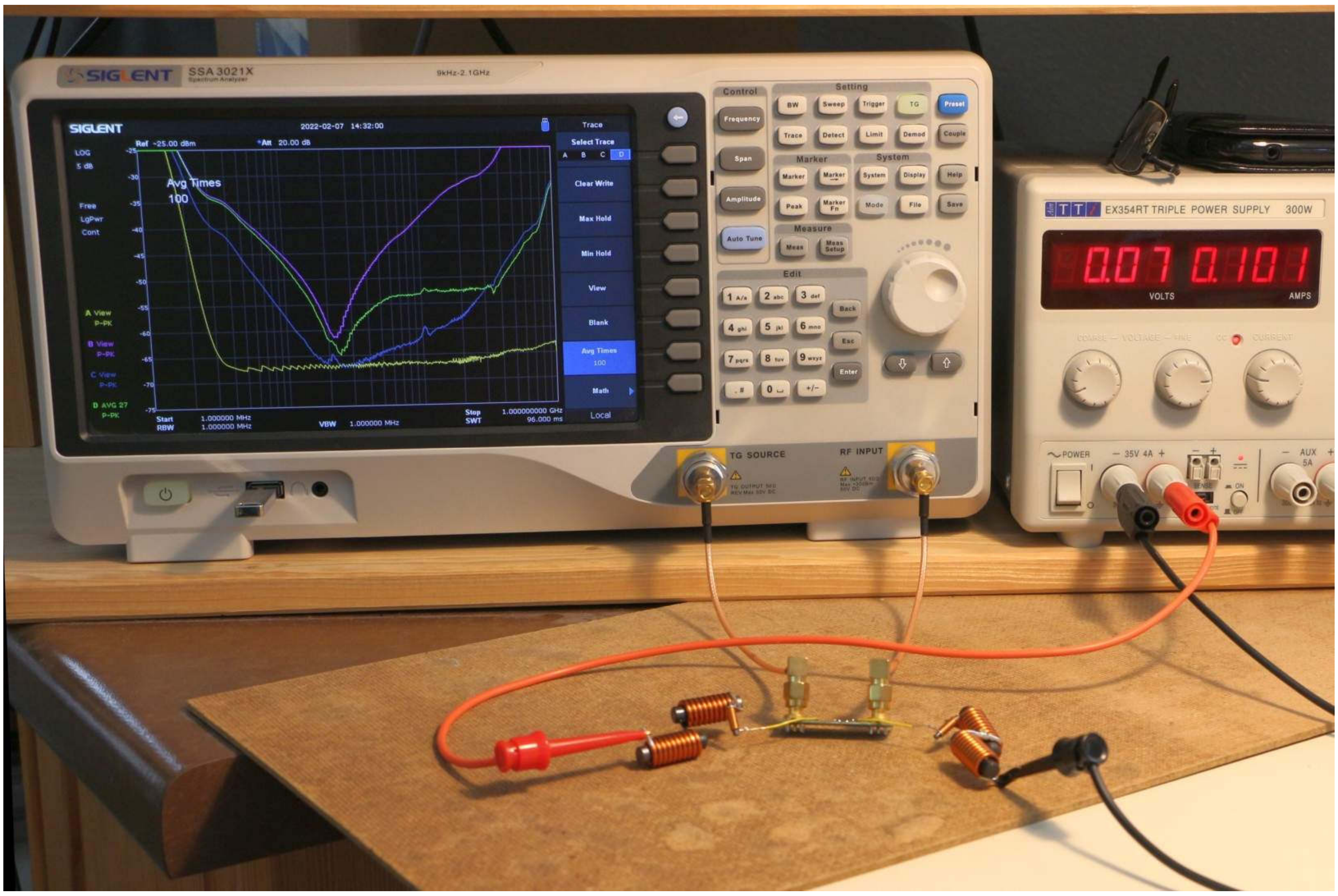


Figure 8 - 101mA

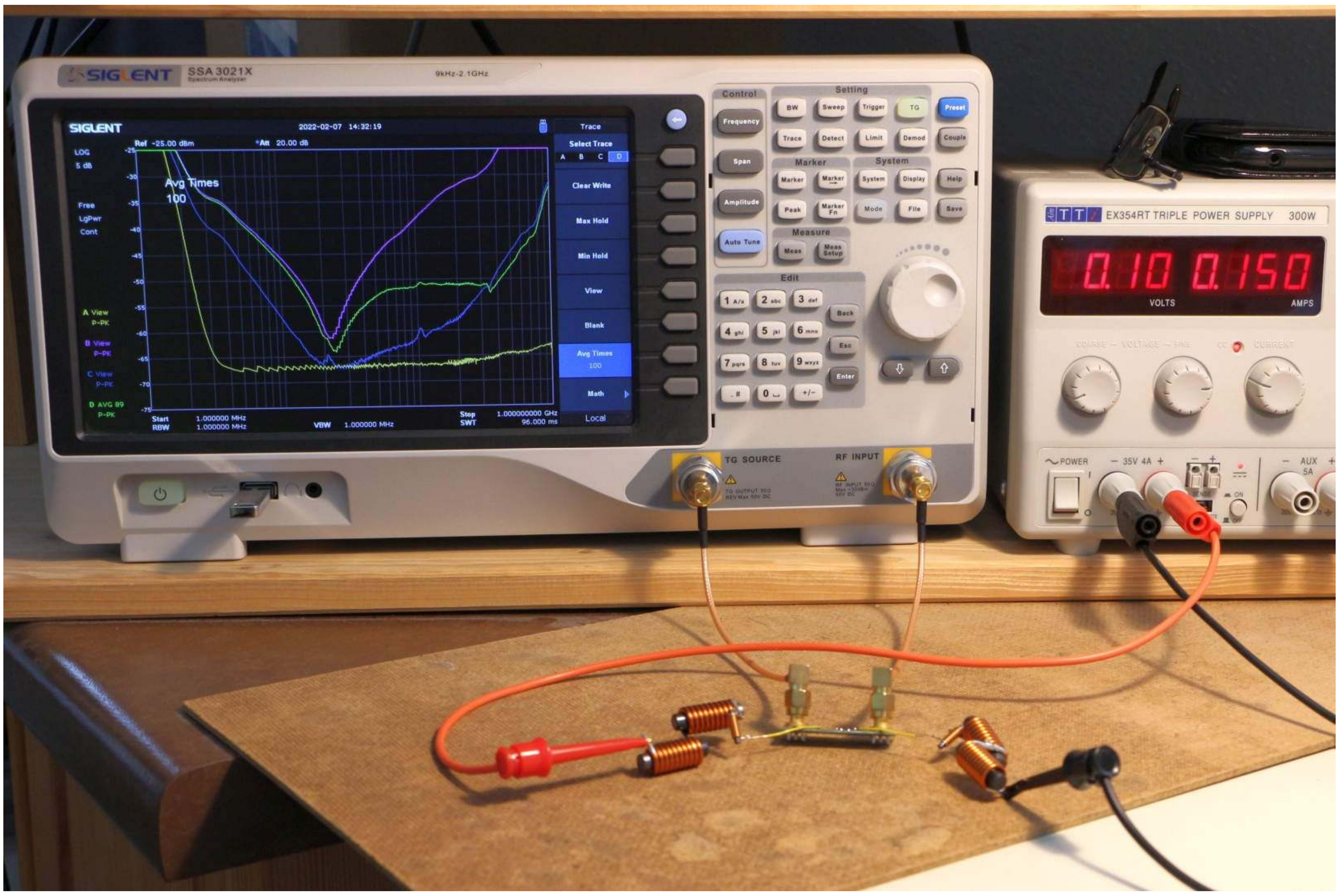


Figure 9 - 150mA

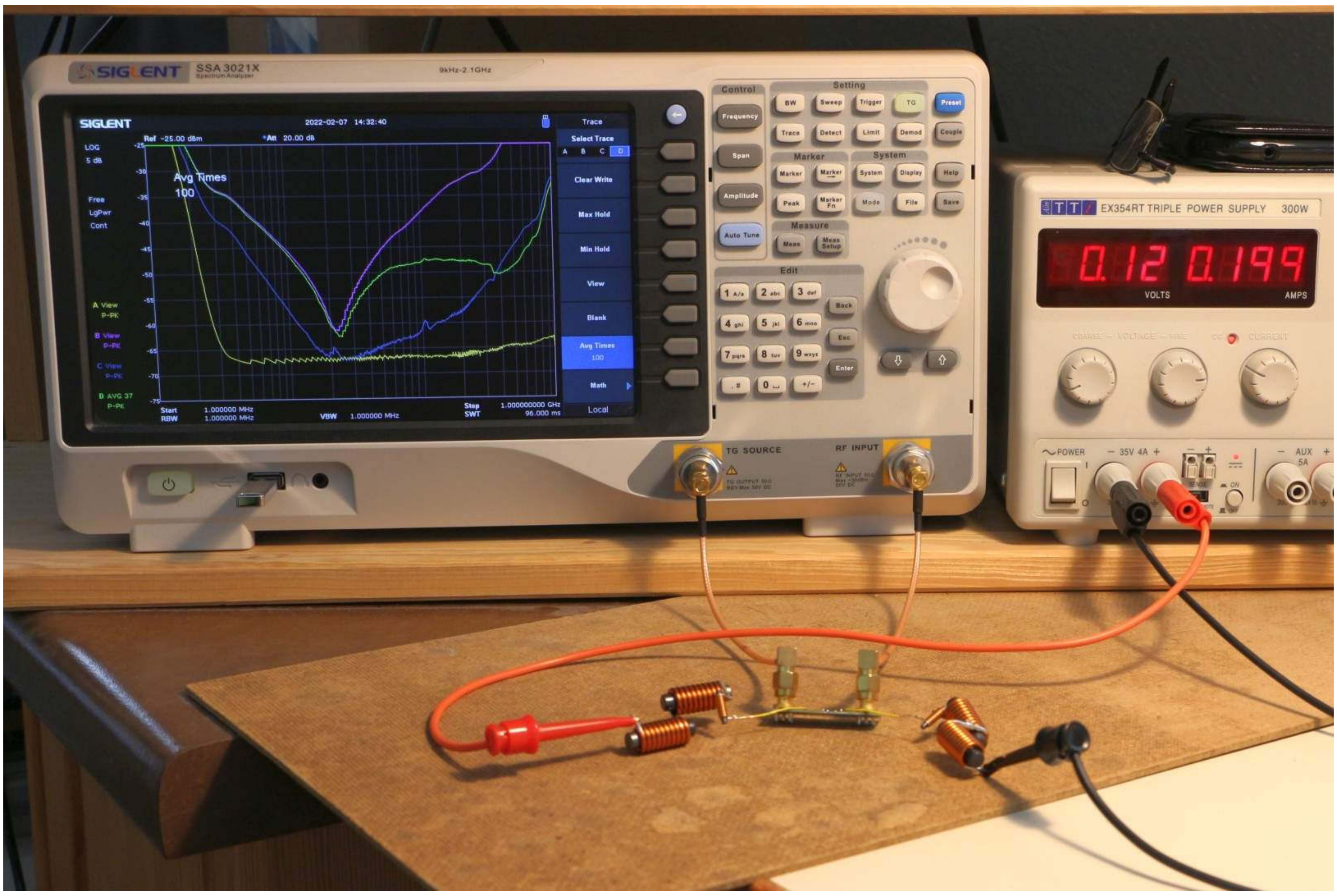


Figure 10 - 199mA

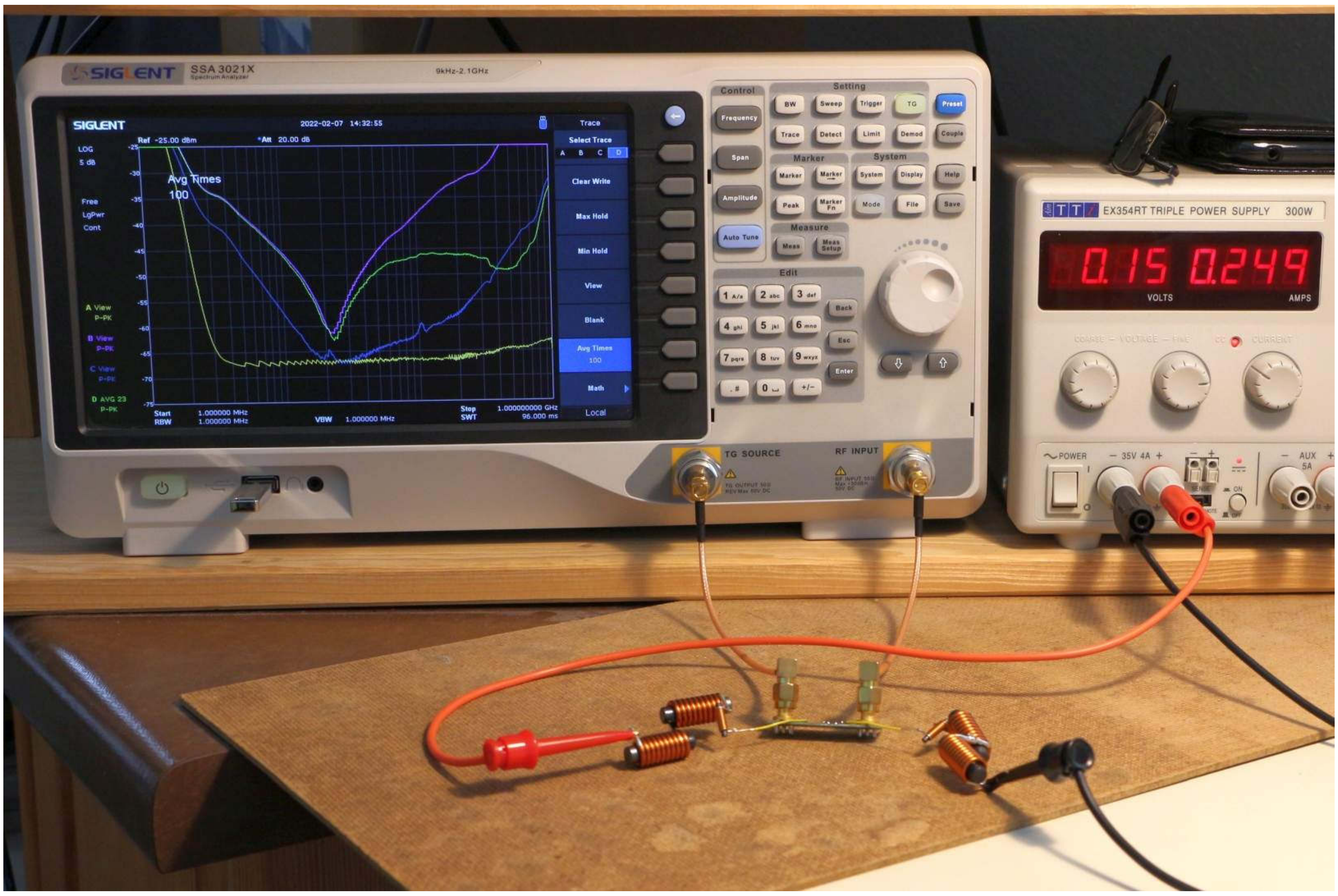


Figure 11 - 249mA

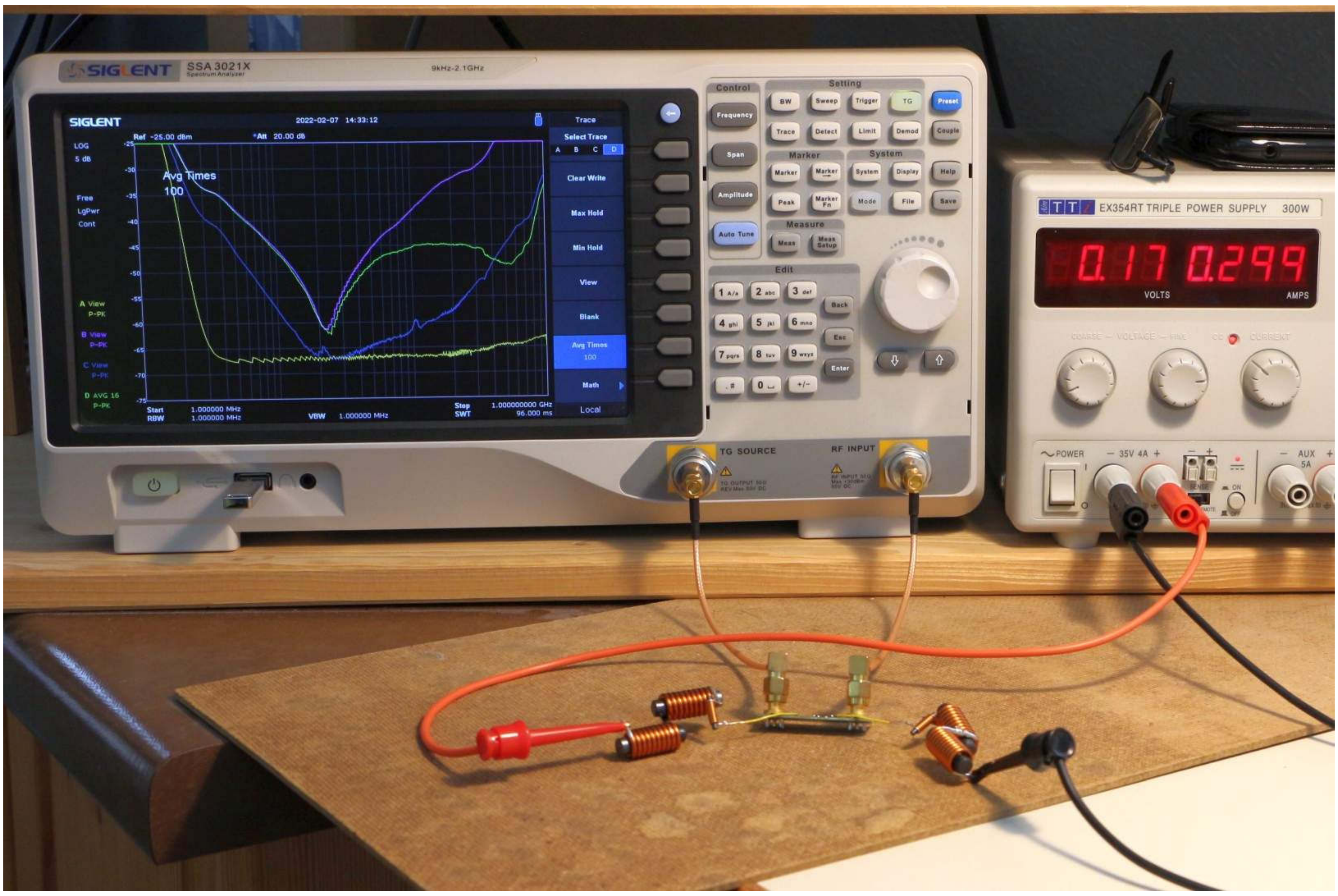


Figure 12 - 299mA

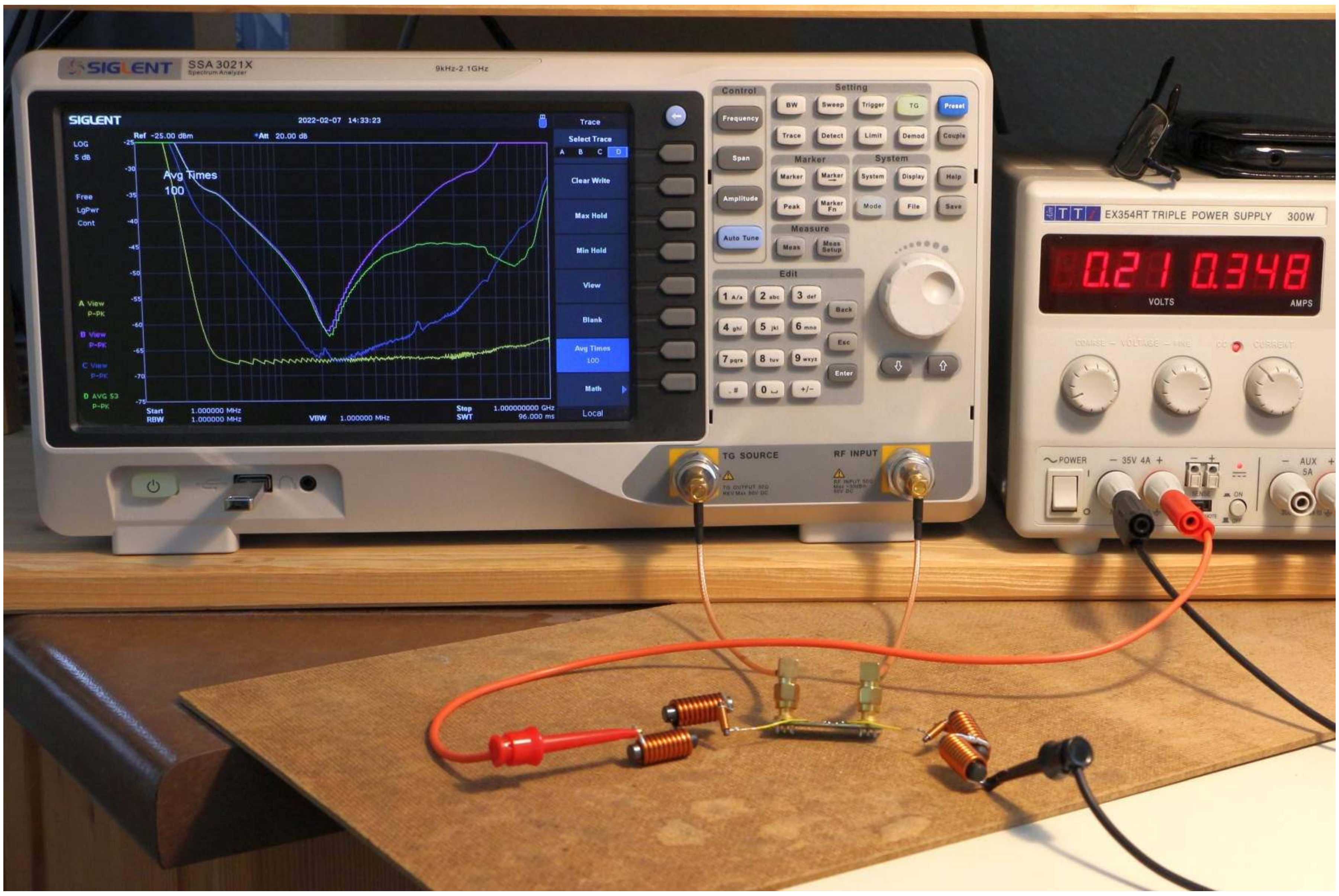


Figure 13 - 348mA

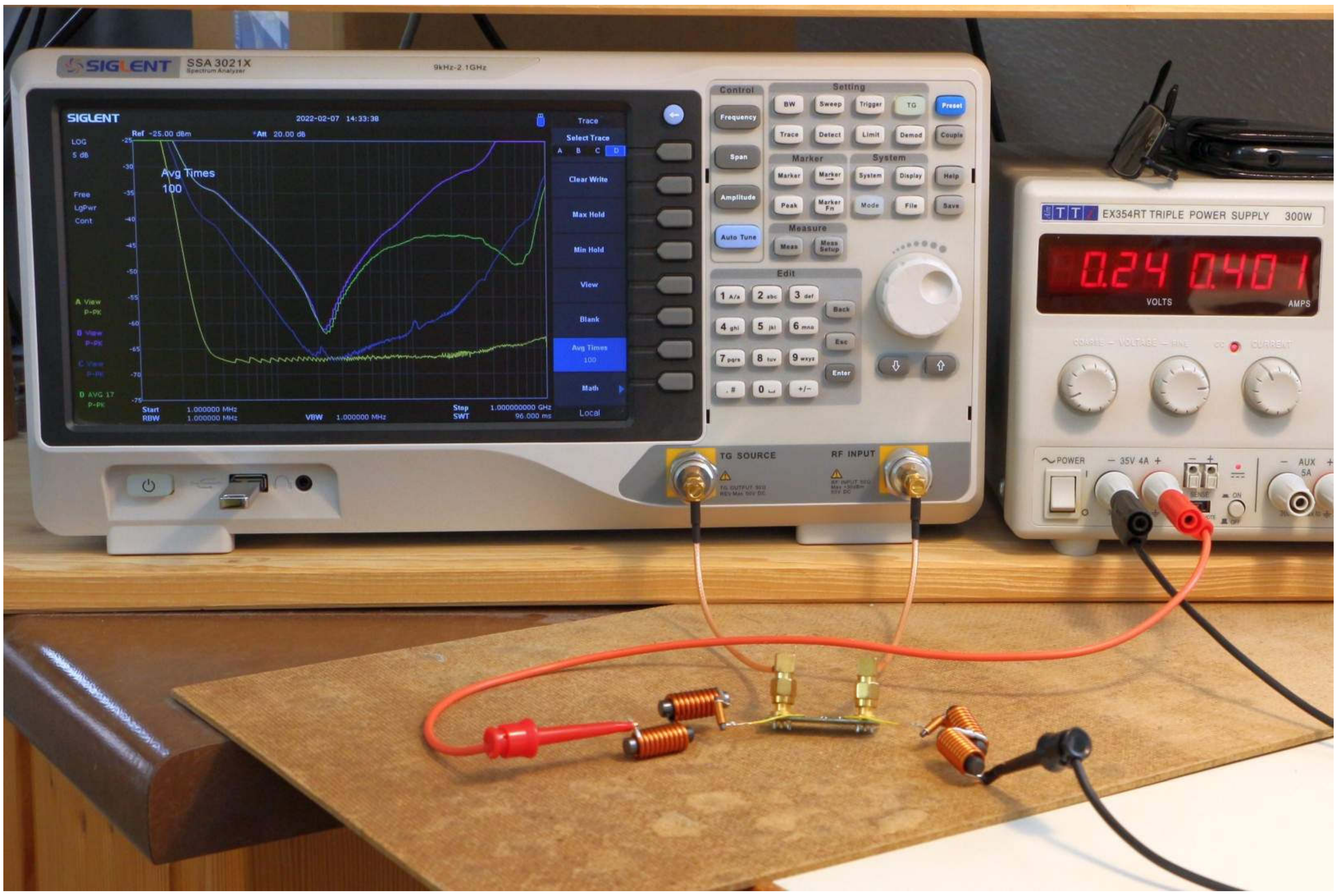


Figure 14 – 401mA

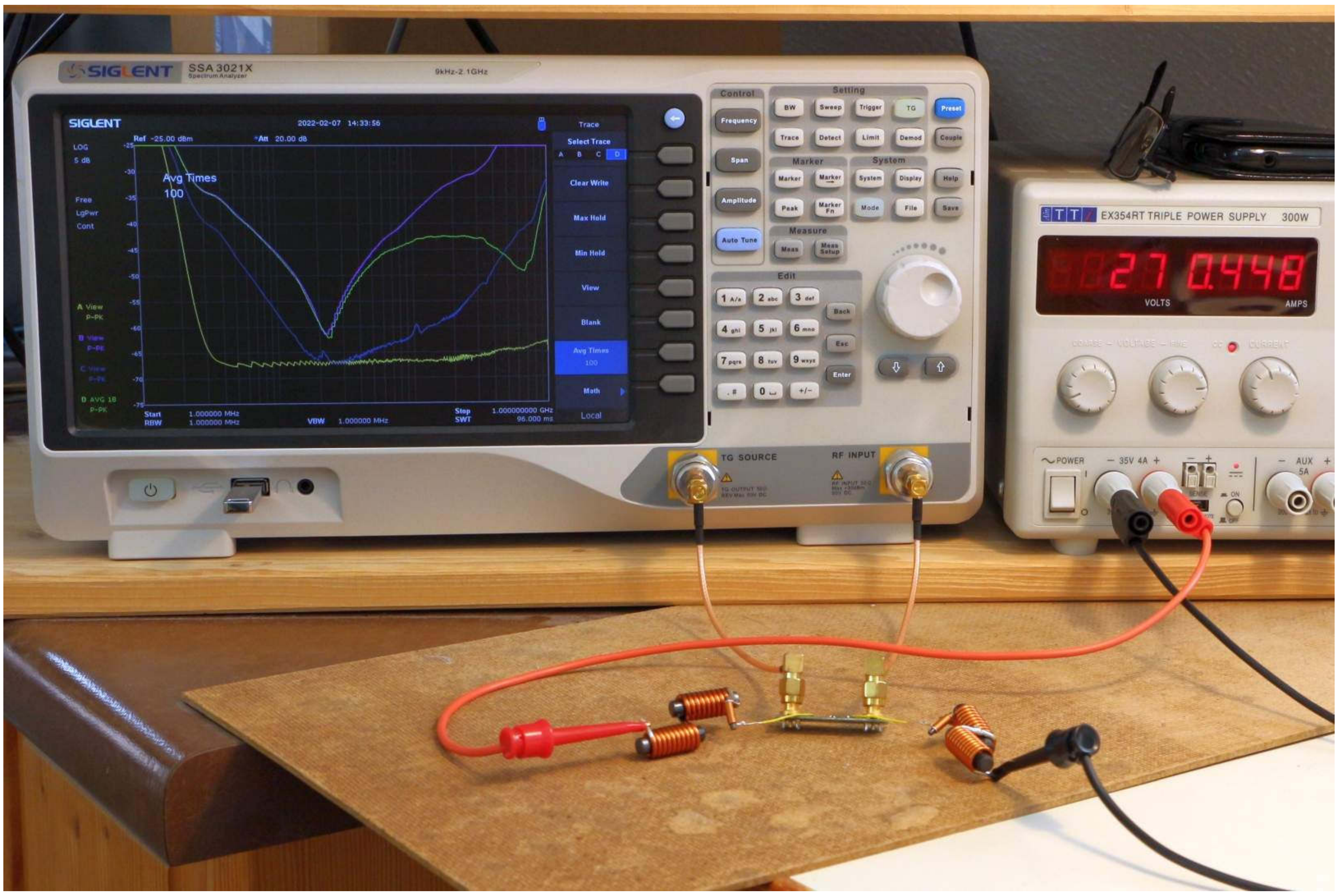


Figure 15 - 448mA

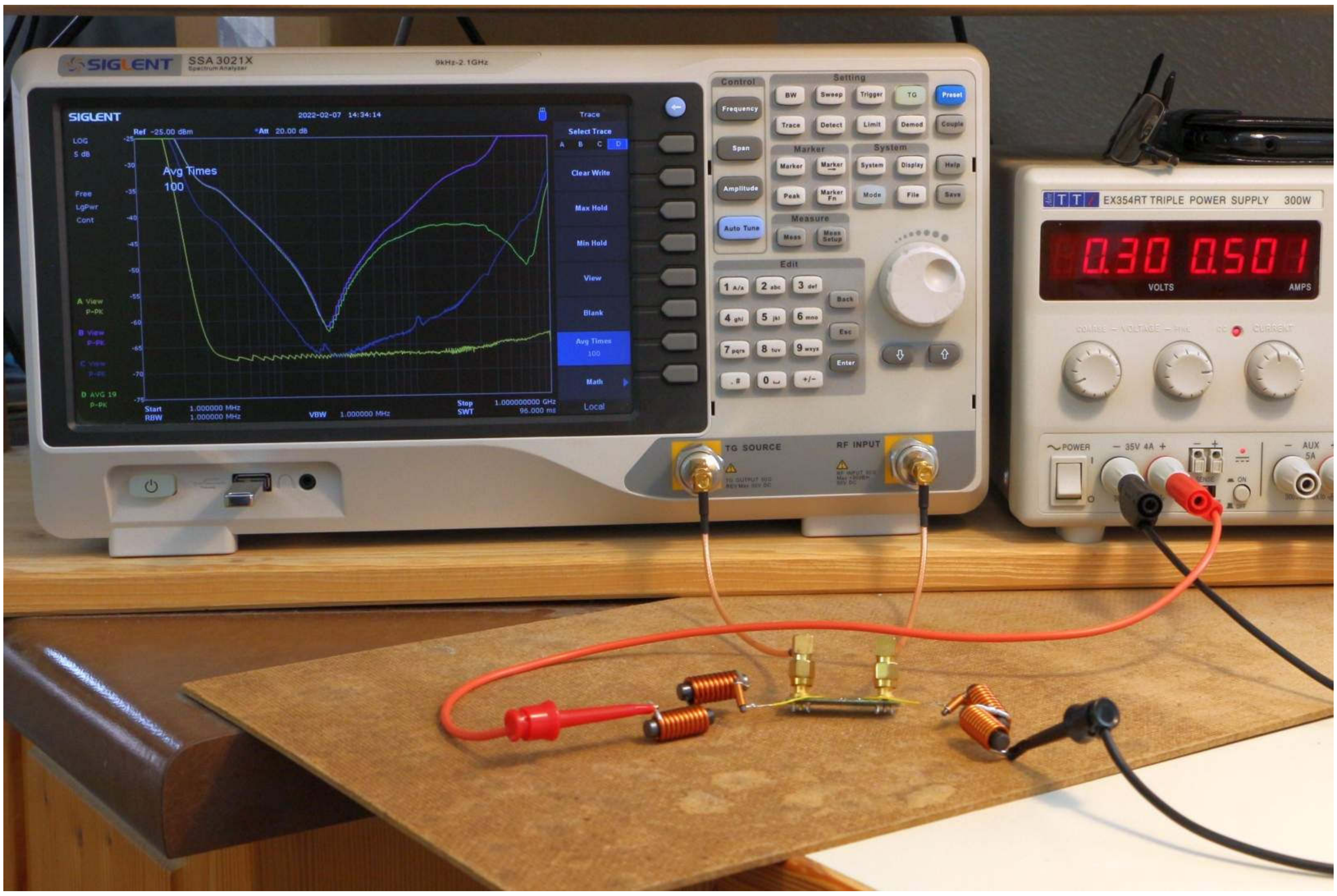


Figure 16 - 501mA

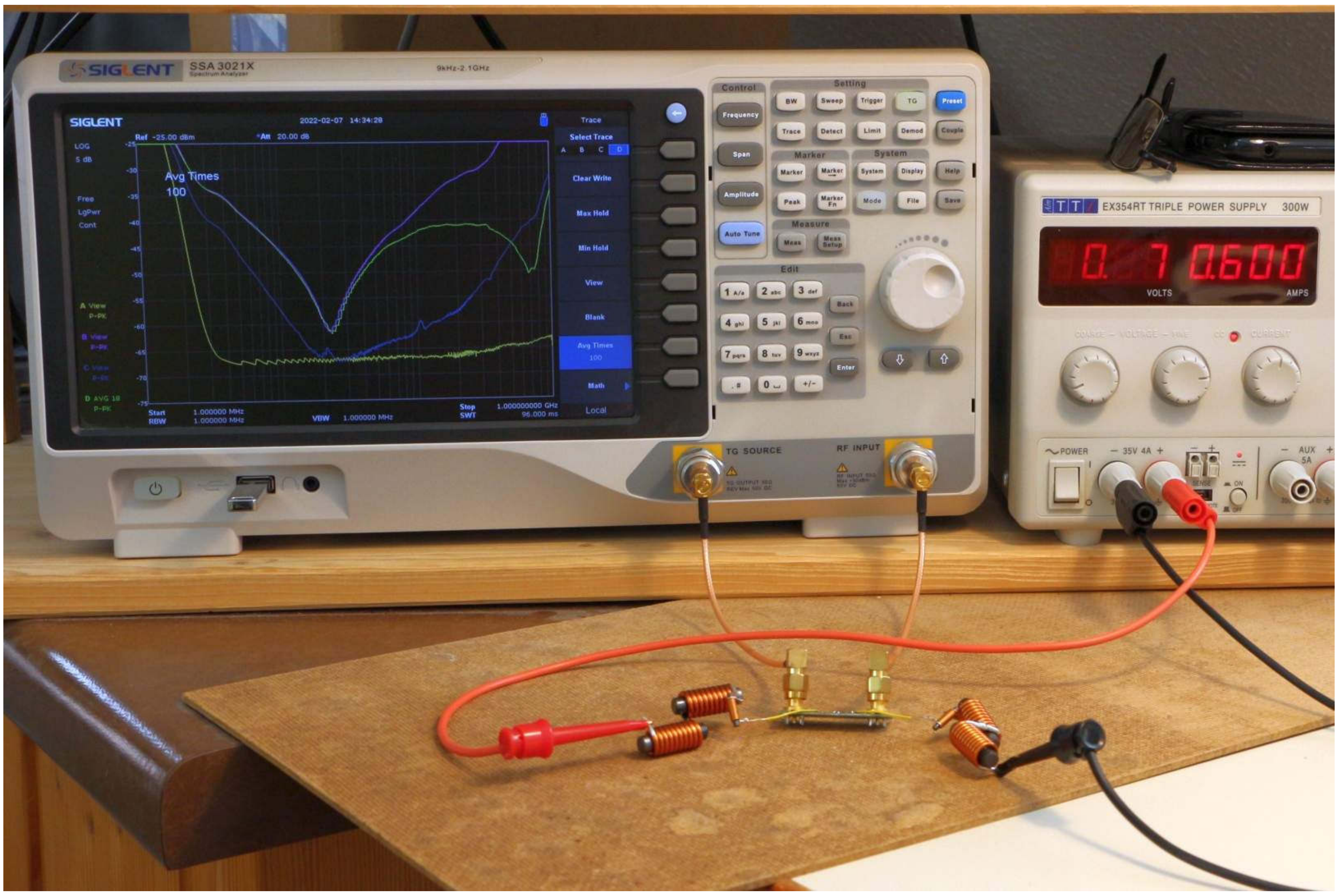


Figure 17 - 600mA

4.1.3 Test Setup Baseline – Range 1MHz to 2.1GHz / TG 0dBm

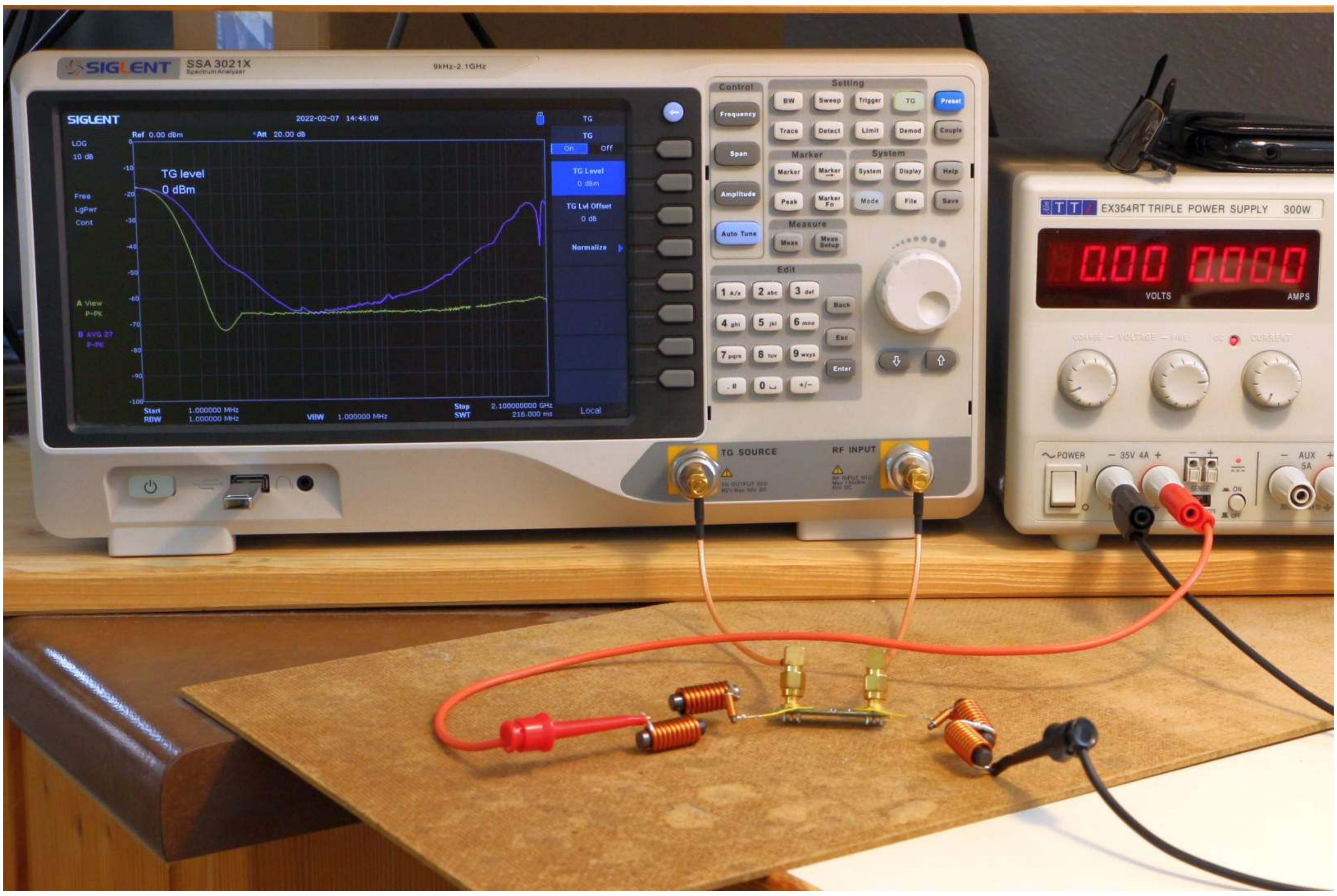


Figure 18 - Baseline Setup

Spectrum Analyzer Settings:
- Tracking Generator (if active): 0dBm (1mW into 50Ω)
- X-Axis: 1MHz to 2.1GHz, logarithmic
- Y-Axis: 0dBm to -100dBm, logarithmic, 10dBm Grid

To establish a baseline for the measurement, following tests are run:
- Yellow (A view)
  - Tracking Generator Off. Noise base.
  - Signal shape independent of bias status (determined in multiple configurations)
- Purple (B View)
  - Tracking Generator On. Bias connected, current set to 0mA

4.1.4 Influence of Bias Current – 1MHz to 2.1GHz

The BLM18AG102SN1 has a rated current of 400mA. The following measurement series shows the influence of core saturation due to DC bias current within and beyond the permissible current range.

- Blue (C view) – the actual filter response due to bias current
  - Tracking Generator On. Bias connected
- Purple (B View)
  - Tracking Generator On. Bias connected, current set to 0mA
- Yellow (A view)
  - Tracking Generator Off. Noise base.
  - Signal shape independent of bias status (determined in multiple configurations)

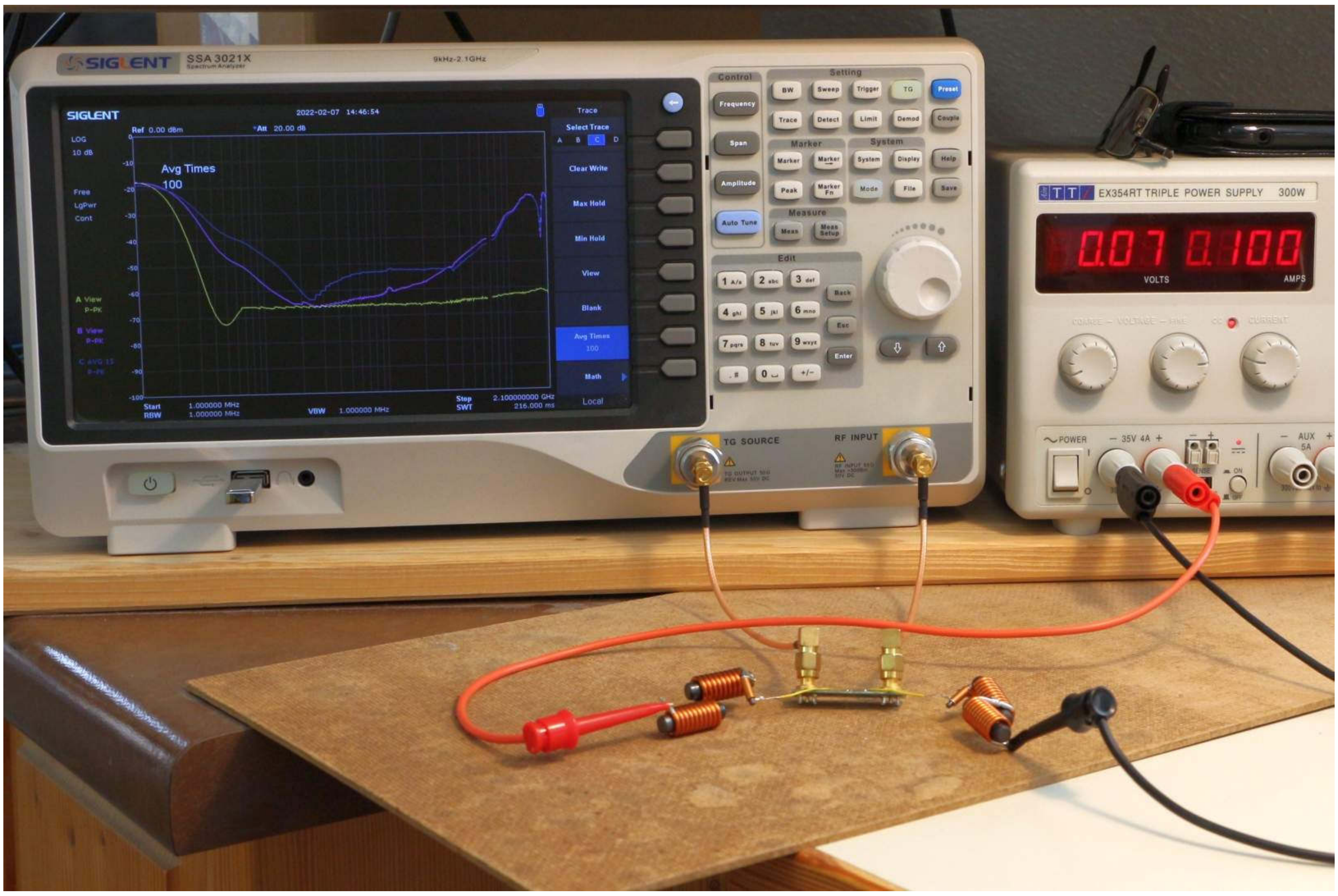


Figure 19 - 100mA

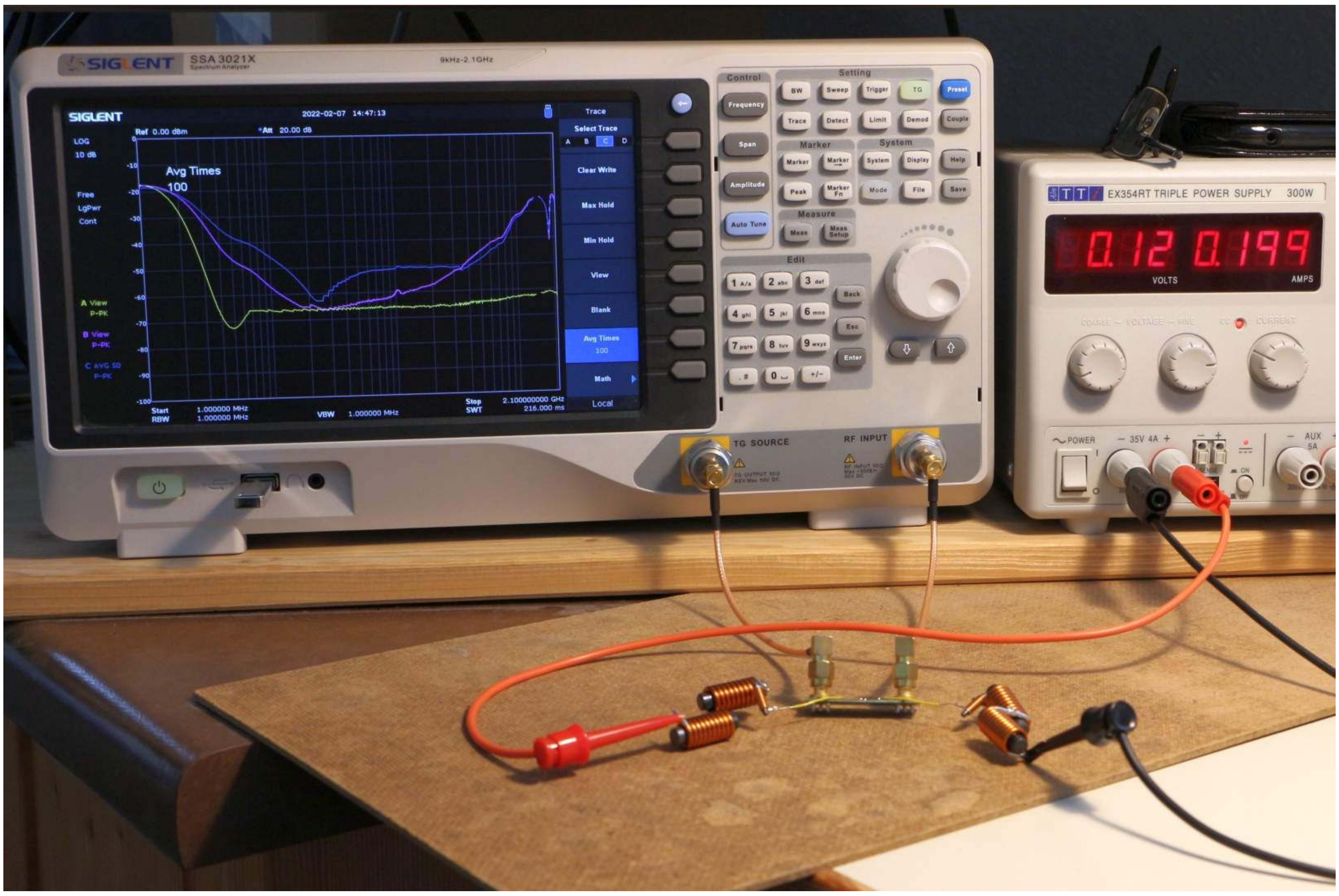


Figure 20 - 199mA

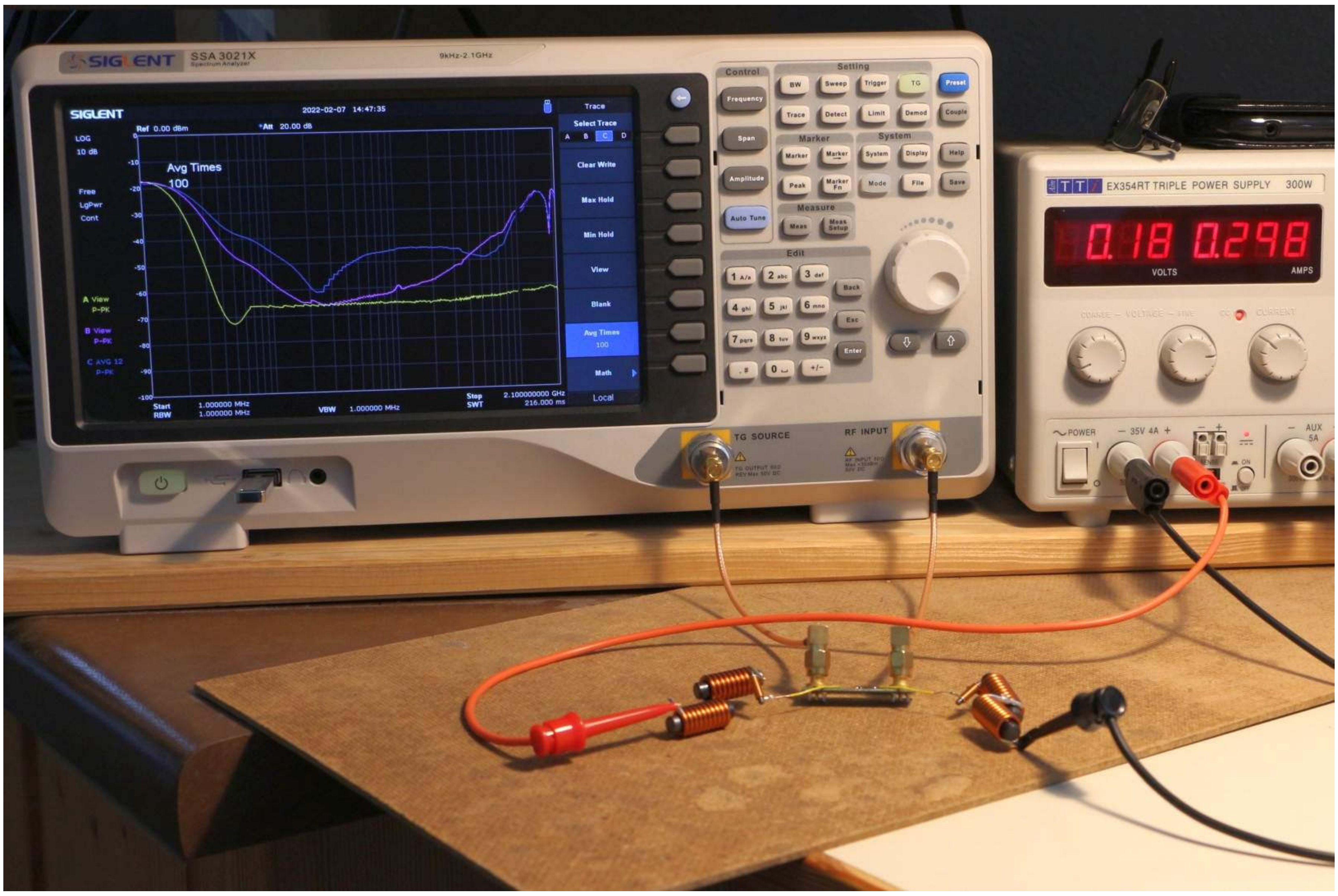


Figure 21 - 298mA

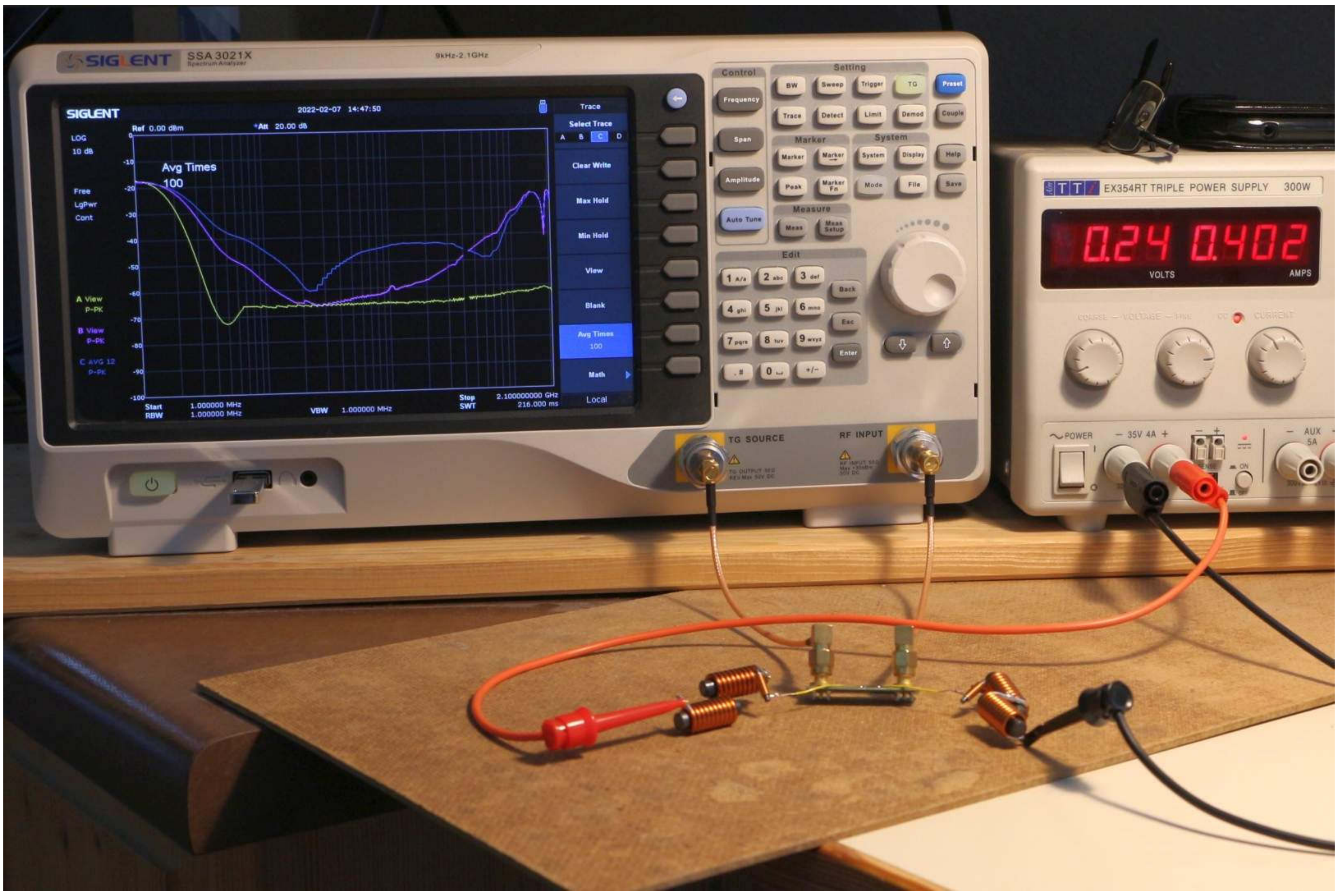


Figure 22 - 402mA

Figure 23 - 500mA Self-Heating

4.1.5 Evaluation

As expected, saturation effects strongly influence the ferrite's frequency response - even within the rated current range. While the ferrite material saturates, the residual "air coil inductivity" remains. There is a significant decrease in inductivity in the lower frequency range and an upwards shift of the self-resonant frequency.

Comparing the overall result with the response from a shorted inductor and a sole filter capacitor, we see that even under maximum rated current, the L1 ferrite will still significantly improve EMI, especially in the region beyond the C1 resonance (21MHz).

Practical example:
MCU STM32F407 operating at a core clock frequency of 168MHz
The self-resonant frequency of the inductor (150MHz) is lower than the core clock of the MCU (168MHz). However, comparison of the L1C1-filter response to the C1-filter response shows at least an additional 20dB attenuation at the third harmonic (504MHz) at 200mA.

Self-heating:
A DC-resistance of 0.5Ω would result in a power dissipation of 100mW at 400mA and 125mW at 500mA. In the shown setup, this results in a self-heating of 6K over ambient temperature.

4.1.6 Manufacturer Data

Seeing the effort in specifying a single EMC-relevant component, we finally approached Murata directly. They kindly provided frequency response data under bias current through their support channel.
This data confirms that saturation effects strongly influence the ferrite's frequency response, even within the rated current range. However, while the ferrite material saturates, the residual "air coil inductivity" remains. The overall effect is a significant decrease in inductivity in the lower frequency range and a upward-shift of the self-resonant frequency.
Caveat: the Z(ohms)-axis is linear, not logarithmic.

-

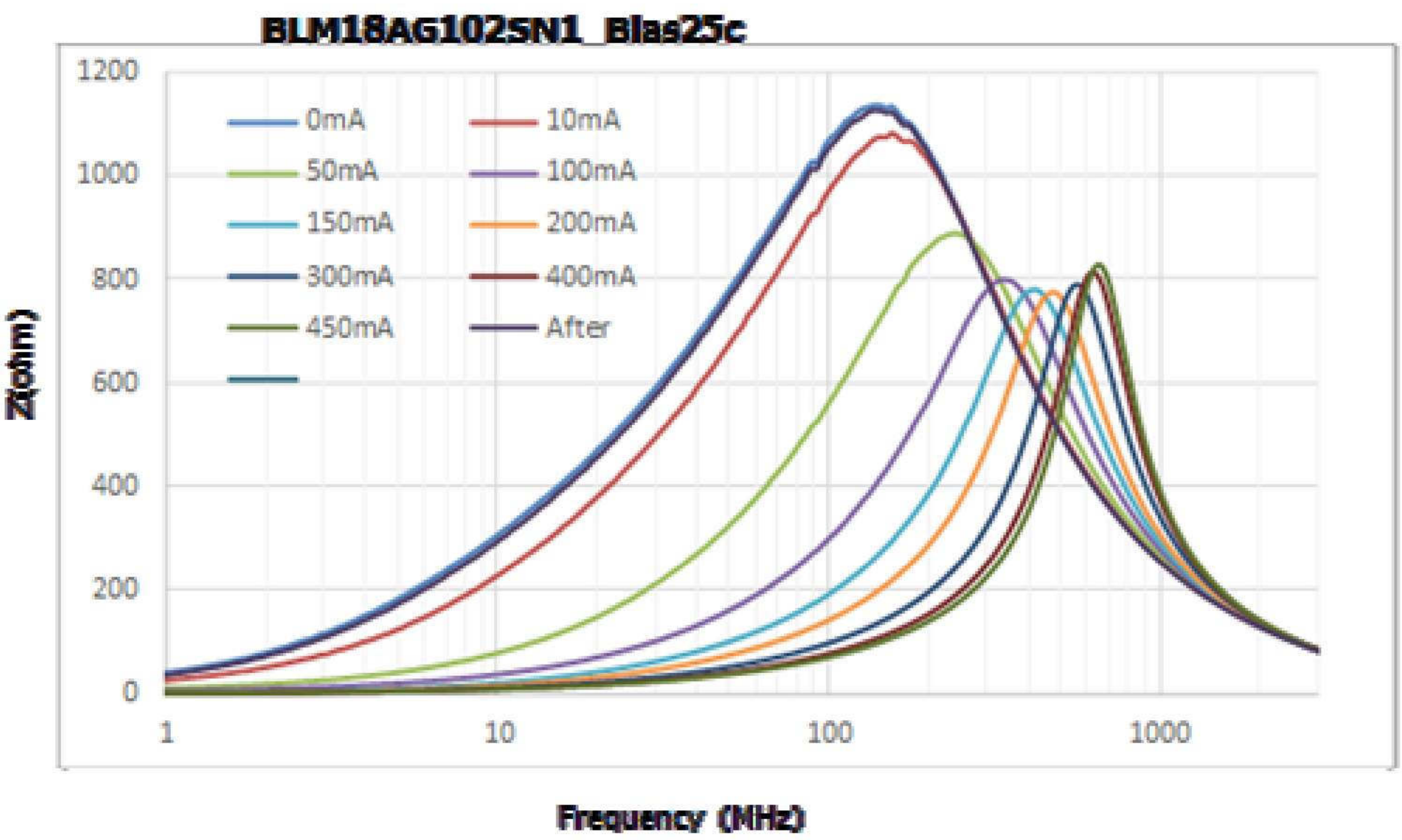


Figure 24 - Manufacturer Data - Impedance and Saturation

4.2 WE-SD - 744710203

4.2.1 Test Setup Baseline – Range 1MHz to 2.1GHz / TG 0dBm

The WE-SD rod core inductors are a staple in HAREROD supply filters. Their large size provides good separation between the filter's ends. There are specific test boards for rod core inductors (e.g. HAREROD HFPF1). However, to be able to compare the performances of the BLM18AG102SN1 and the 744710203, this demonstration uses the modified HAREROD HFTP3.

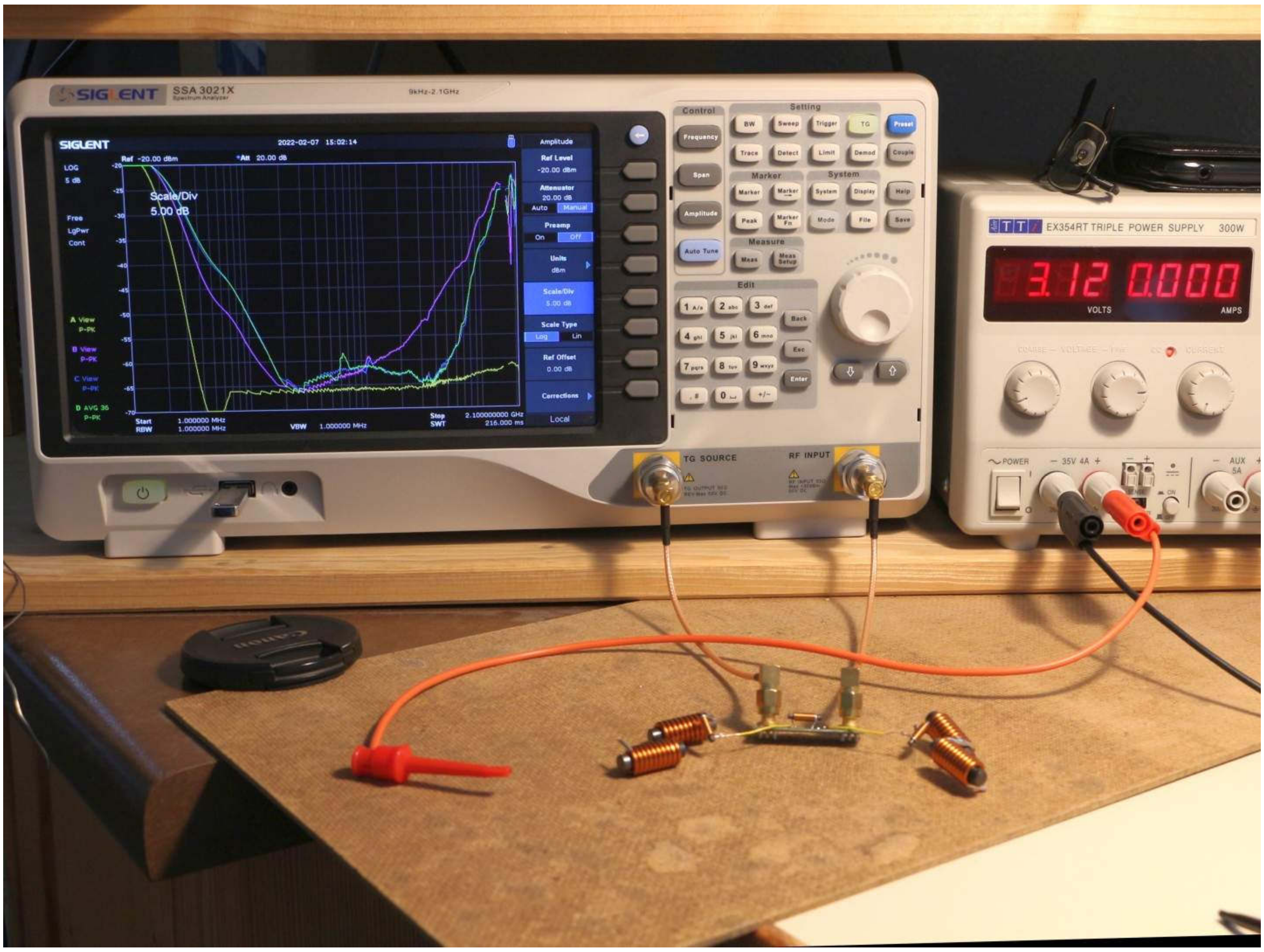


Figure 25 - Baseline Setup

Spectrum Analyzer Settings:
- Tracking Generator (if active): 0dBm (0dBm = 1mW into 50Ω)
- X-Axis: 1MHz to 2.1GHz, logarithmic
- Y-Axis: -20dBm to -70dBm, logarithmic, 5dBm Grid

To establish a baseline for the measurement, the following tests were run:
- Yellow (A view)
  - Tracking Generator Off. Noise base.
  - Signal shape independent of bias status (determined in multiple configurations)
- Green (D view) – WE-SD - 744710203
  - Tracking Generator On. Bias disconnected, as seen in fig. 24
  - resonance spikes at 60MHz, secondary/dirt effect
- Blue (C view) – WE-SD - 744710203

- Tracking Generator On. Bias connected, current set to 0mA
- shift of resonance spikes to 20MHz and 100MHz, secondary/dirt effect

- Purple (B View)
  - L1/BLM18AG102 as reference
  - Tracking Generator On. Bias connected, 0mA

4.2.2 Influence of Bias Current – 1MHz to 2.1GHz

The WE-SD 744710203 has a rated current of 2500mA. The following measurement series shows the influence of core saturation due to DC bias current within and beyond the permissible current range.

Spectrum Analyzer Settings:

- Tracking Generator (if active): 0dBm (0dBm = 1mW into 50Ω)
- X-Axis: 1MHz to 2.1GHz, logarithmic
- Y-Axis: -20dBm to -70dBm, logarithmic, 5dBm Grid

To establish a baseline for the measurement, following tests are run:

- Yellow (A view)
    - Tracking Generator Off. Noise base.
    - Signal shape independent of bias status (determined in multiple configurations)
- Green (D view) – WE-SD – 744710203 – the actual filter response due to bias current
    - Tracking Generator On. Bias connected
- Blue (C view) – WE-SD - 744710203
    - Tracking Generator On. Bias connected, current set to 0mA
- Purple (B View)
    - L1/BLM18AG102 as reference
    - Tracking Generator On. Bias connected, 0mA

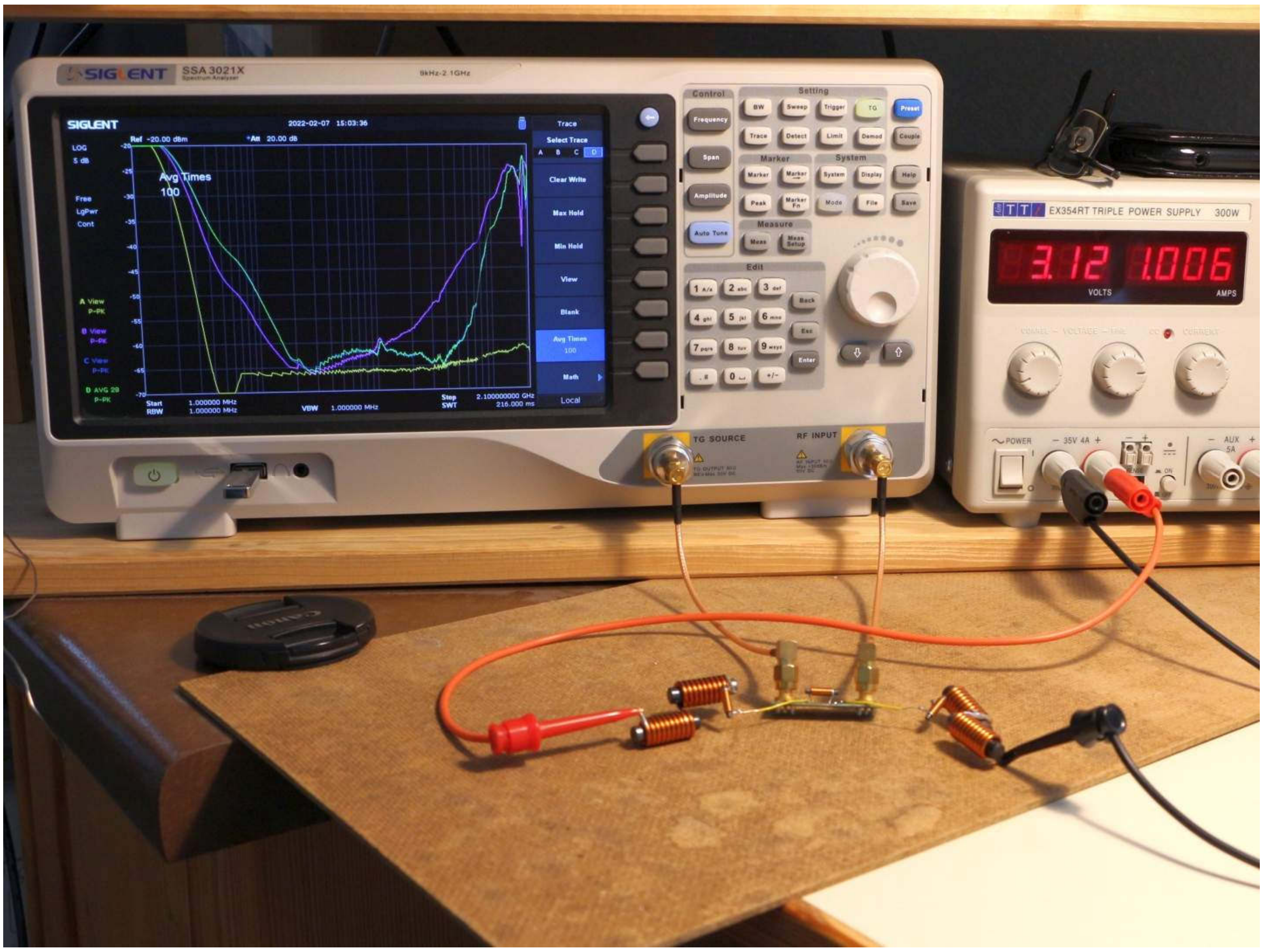


Figure 26 - 1006mA

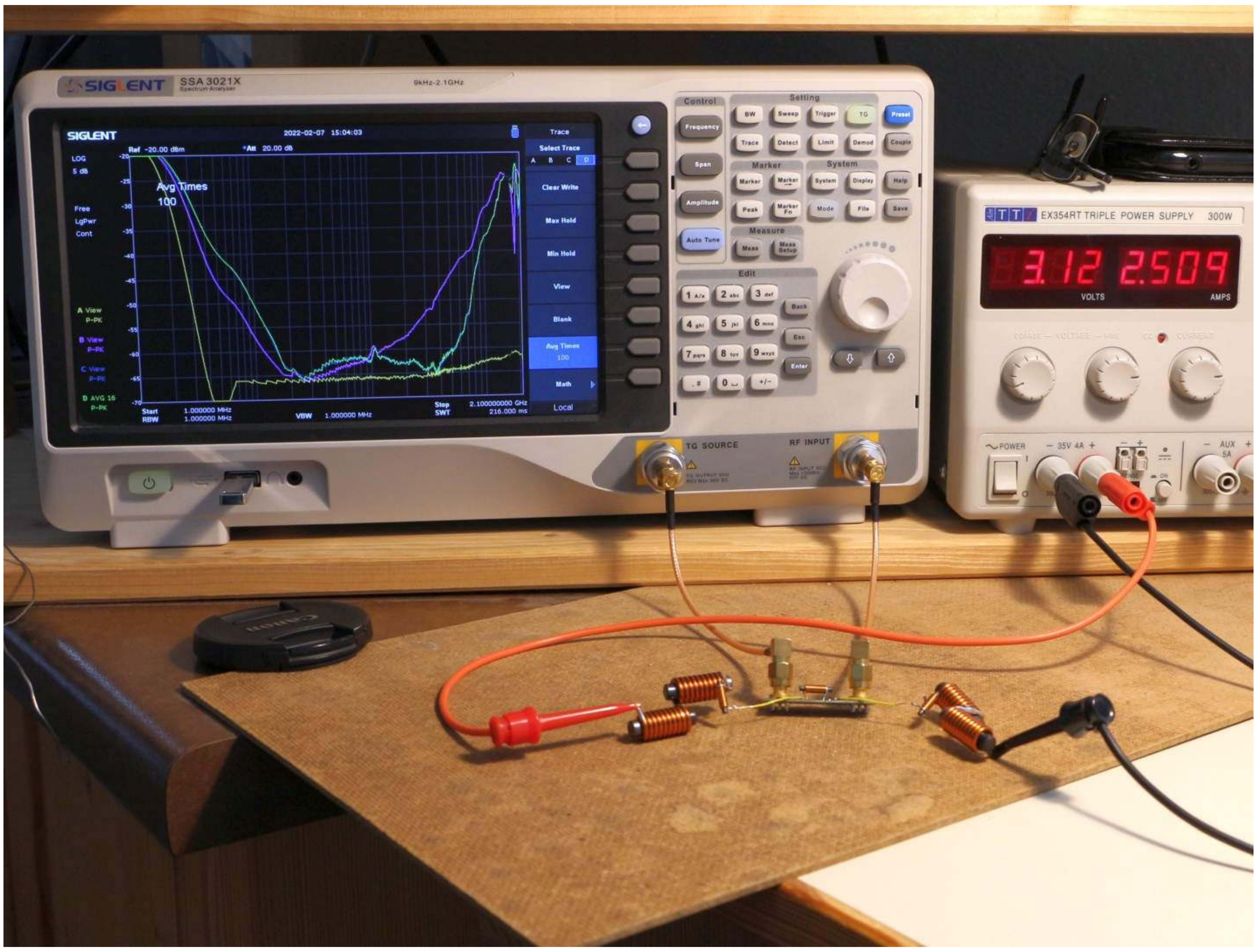


Figure 27 - 2509mA

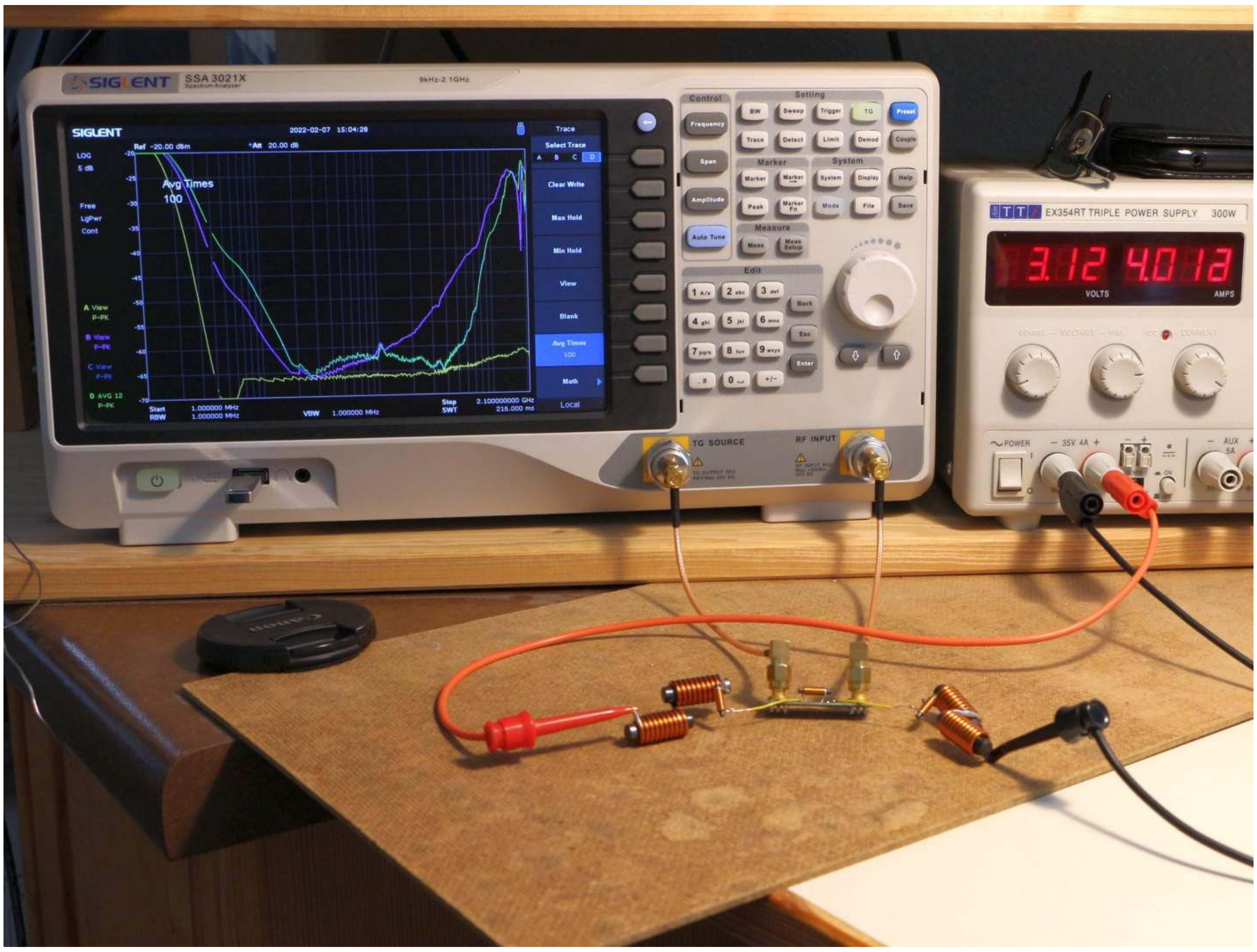


Figure 28 - 4012mA

4.2.3 Evaluation

These measurements demonstrate the excellent response of the LC-filter (L1/C5).

The inductor seems to be largely unaffected by the bias current. Even at the higher currents (4000mA), a difference between the blue measurement curve and the purple reference curve cannot be made out.

5 Outlook

This short essay illustrates a basic approach for evaluating critical EMC filter components. Filter components may suffer from different operating conditions. For example, much like the preceding tests show that ferrites are susceptible to core saturation, most ceramic capacitors rapidly lose capacity with increasing bias voltage.
HAREROD has a whole line of test boards, adaptable for varied tasks. Figure 29 shows milling the pads for C4/C6 with a 0.6mm cutter from larger existing pads on HFTP3.

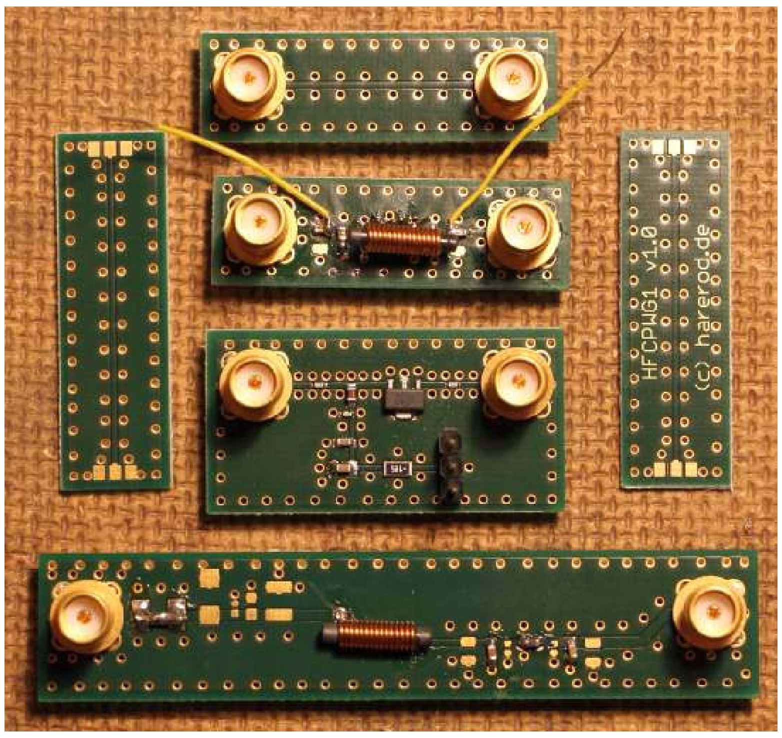


Figure 29 - Selection of Test Boards

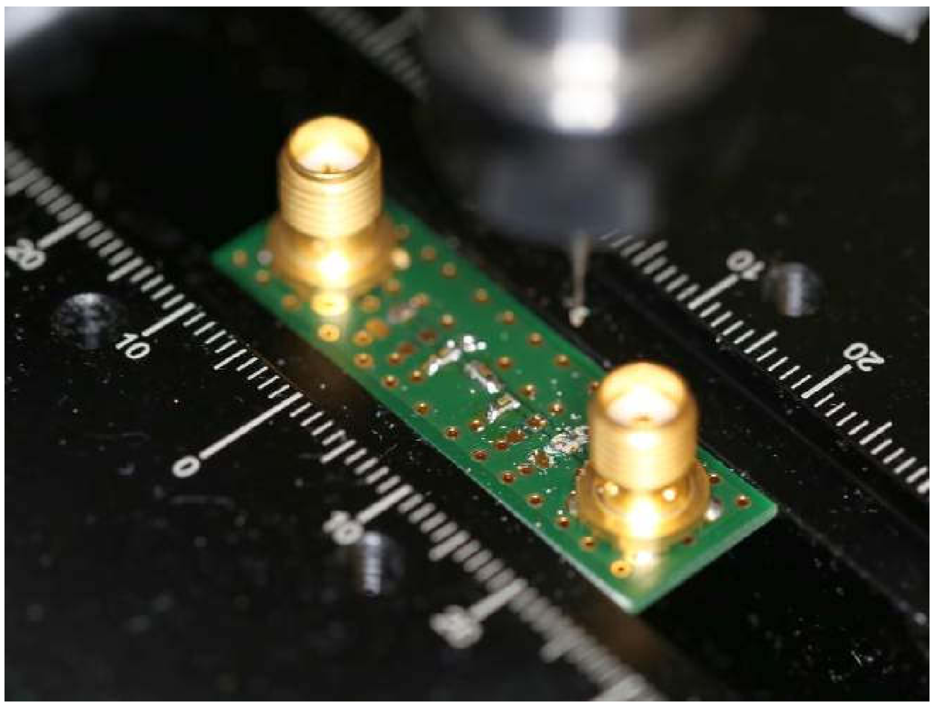


Figure 30 - Adapting SMD Pads on Mill Router