BPM112: Bidirectional Power Meter for R26 Waveguide

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General Description

BPM112 (Fig. 1) is a bidirectional power meter designed for accurate simultaneous measurement of incident and reflected powers up to 30 kW in high-power 2450 MHz industrial applications using an R26 (WR340) rectangular waveguide. Each power meter is calibrated individually.

The BPM integrates a four-port directional coupler with the following components in each of its two channels:

- Zero-bias Schottky diode detector
- Low noise amplifier
- 16-bit A/D converter for sampling detector voltages
- 12-bit D/A converter providing the analog output
- Microcontroller unit (MCU)
- Optional display (common for both channels)

The MCU:

- Controls both A/D and D/A conversions.
- Performs detector nonlinearity and temperature dependence correction.
- Generates the following simultaneous outputs:
  - ✓ Two analog outputs, one (FWD) corresponding to the forward (incident) power; one (RFL) to the reflected power.
  - ✓ One digital output (RS232, RS422, or CAN Bus).

Fig. 1. BPM112 version with LCD display.

The two analog outputs can be

- voltage output 0 – 10 V; or
- current output 4 – 20 mA.

The desired output type can be switched by the user. Both FWD and RFL outputs are of the same type. The output voltages/currents are linear functions of the microwave powers propagating in the forward and reverse directions of the parent waveguide. The digital outputs provide also internal power sensors temperatures. The RS232 and RS422 outputs have the form of easily readable text streams.

Note: The desired *digital* output type must be specified in the purchase order.

The optional LCD display shows the incident (FWD) and reflected (RFL) powers as well as the temperatures of the internal power sensors. The powers are displayed both numerically and by bar indicators (see the inset in Fig. 1).

BPM is accompanied by the simple Windows-based visualization software **BPM_Monitor**. LabVIEW instrument drivers are also available.

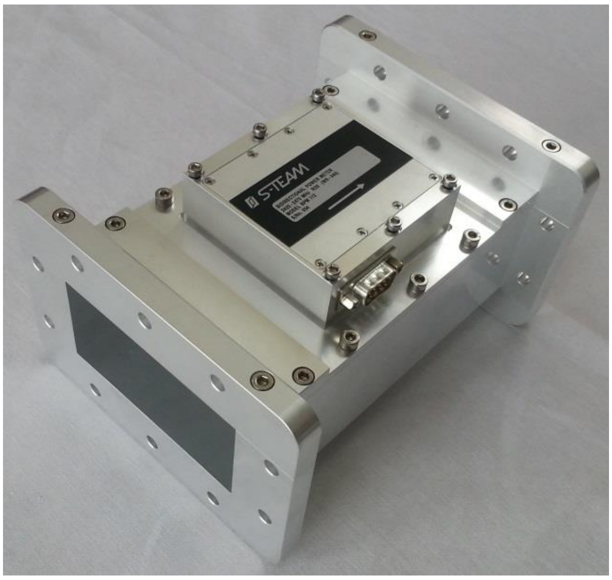

Fig. 2. BPM112 (version without LCD display) installed on a standard-length waveguide.

The BPM module is fastened to a parent waveguide by means of eight M3 or similar-diameter screws after machining of appropriate holes in the waveguide wall. As an option, a calibrated assembly consisting of a BPM fixed to a precisely machined parent waveguide with the standard length 174 mm can be provided (Fig. 2).

Specifications

Waveguide of destination	R26 (WR340)
Waveguide wall thickness	2 mm ± 0.025 mm
Waveguide surface flatness required at BPM interface	0.04 mm
Frequency range	2425 – 2475 MHz
Peak working power	0.5 kW, 1 kW, 3 kW, 6 kW, 10 kW, 30 kW (Note 1)
Directivity	25 dB min
Default measurement rate	5 points/s
Max measurement rate	100 points/s (Note 2)
Max sampling duration	5 s (Note 3)
Output voltage polarity	Positive
Power supply voltage	24 V ± 10% DC
Power consumption	4 W / 6 W (without/with LCD display)
Connector	D-sub 9-pin male (D9m)
Dimensions (L x W x H)	80 x 73 x 29.5 mm
Mass (without/with LCD display)	230 g / 300 g
Operating temperature range	-10 °C to +65 °C
Storage temperature range	-20 °C to +80 °C

Notes:

1. Peak working power must be specified in the purchase order.
2. High measurement rates can be attained using high sampling rates and short sampling durations. For details about sampling, please refer to section Sampling.
3. Sampling duration or *integration time* is the time over which the samples are acquired for obtaining one measurement data point.

Pin Assignment

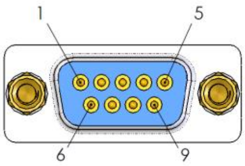

Fig. 3. Pin numbering of D9 connector.

Pin	Signal	Description
1	VRFL	Reverse (reflected) power: analog voltage output
2	RX/B-/H	RS232: RX RS422: B- CAN: L
3	TX/A+/L	RS232: TX RS422: A+ CAN: H
4	IFWD	Forward (incident) power: analog current output
5	GND	Signal ground. Negative DC power supply input (0 V)
6	VFWD	Forward (incident) power: analog voltage output
7	IRFL	Reverse (reflected) power: analog current output
8	SHLD	Shielding, Mass
9	VPOS	Positive DC power supply input (+24 V)

Notes:

- All outputs are referred to GND.
- GND (pin 5) is isolated from SHLD (pin 8).
- The forward wave should propagate in the direction of the arrow on the nameplate.
- Although the pins for the analog voltage output and the analog current output are separate, only one output type at a time can be active.

Nominal Transfer Curves for Analog Outputs

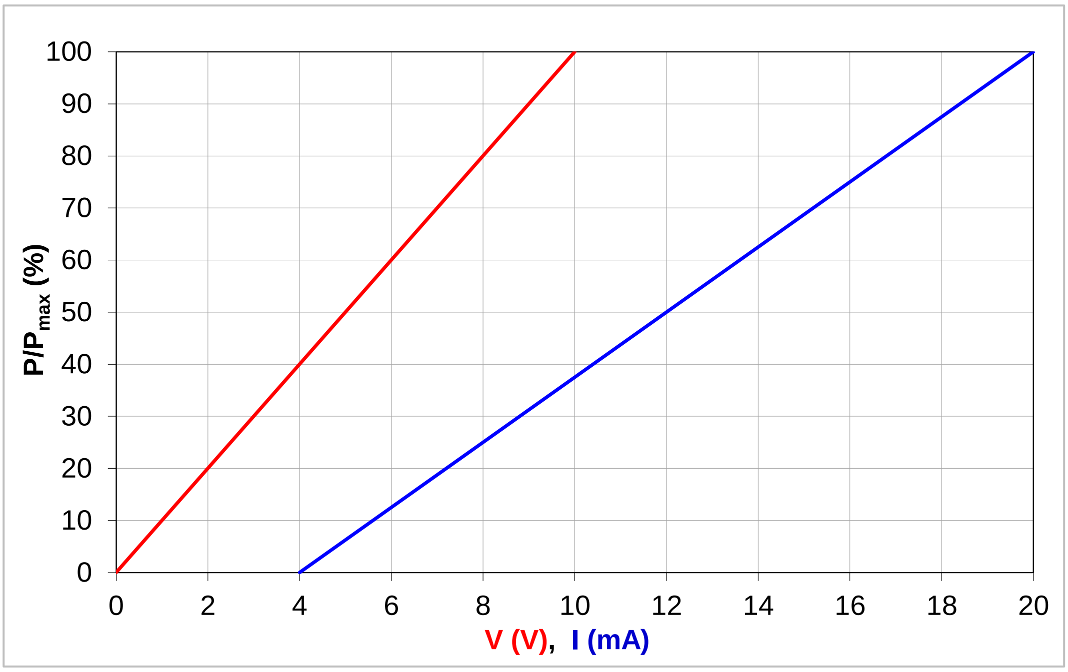

Fig. 4. Nominal BPM transfer curves for analog outputs 0 – 10 V, 4 – 20 mA. P_{max} is the specified maximum working power.

Typical Directivity

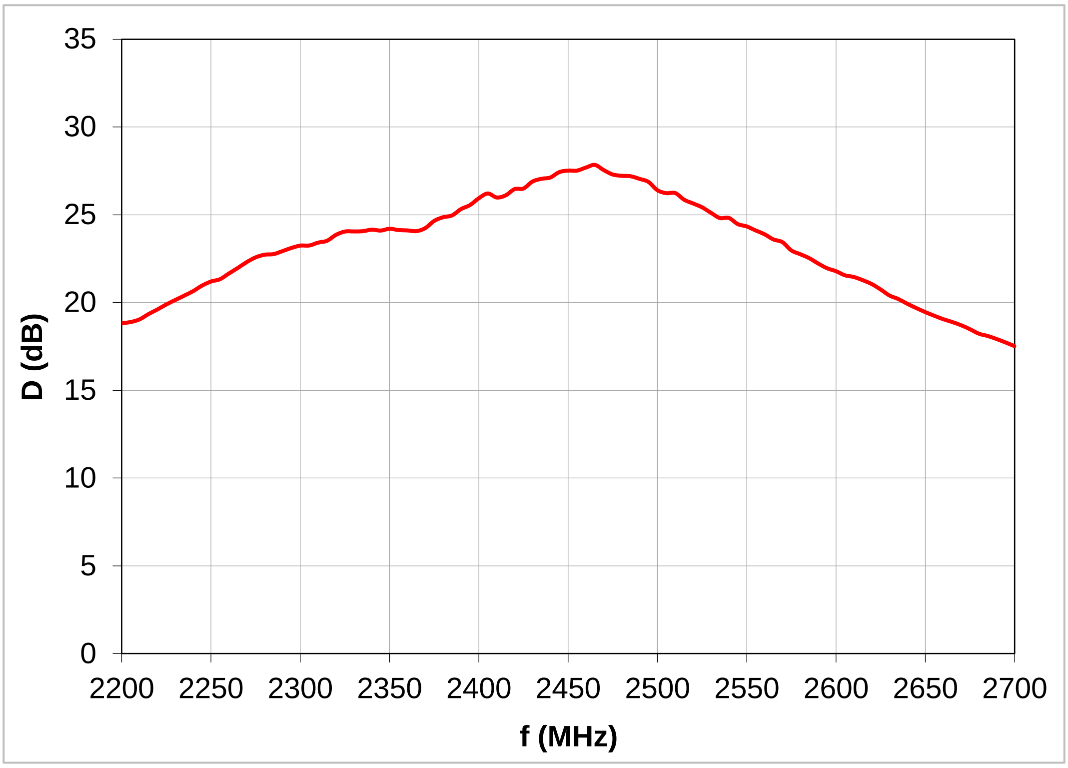

Fig. 5. Typical BPM112 directivity (both directions).

Typical Linearity Error for Analog Outputs

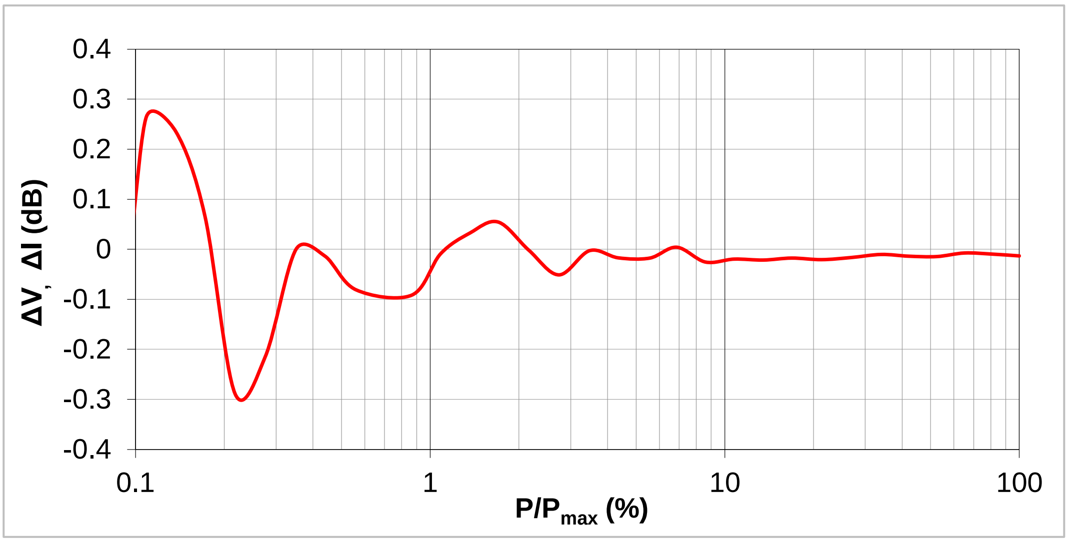

Fig. 6. Typical BPM linearity error for analog outputs 0 – 10 V, 4 – 20 mA. P_{max} is the specified maximum working power.

Typical Linearity Error for Digital Outputs

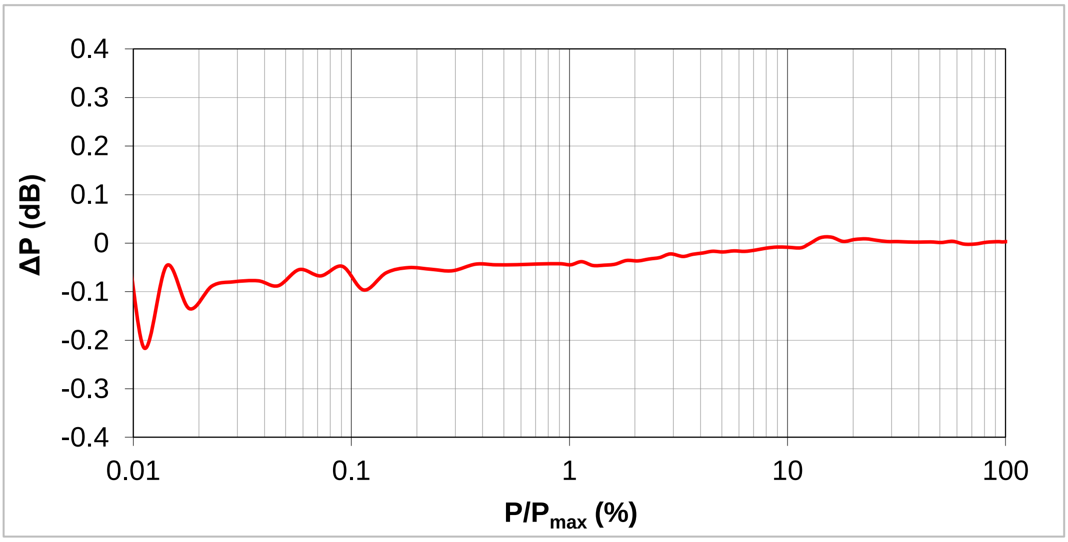

Fig. 7. Typical BPM linearity error for digital outputs. P_{max} is the specified maximum working power.

Sampling

Both analog and digital outputs are obtained as a result of averaging over a number N_s of signal samples taken with a specific *sampling rate* f_s over a specified *sampling time* T_s (sampling duration, integration time). These sampling-governing quantities are constrained by the relation

$$T_s = \frac{1}{f_s}(N_s - 1) = \Delta t_s (N_s - 1)$$

where $\Delta t_s = 1/f_s$ is the *sampling repetition period* (time distance between two consecutive samples). The user controls the sampling by defining Δt_s and N_s; the resulting sampling duration T_s is then computed using the above equation.

The values of Δt_s and N_s can be set by either of these two methods:

- Via any RS232 terminal installed in a PC (see section BPM User Menu)
- Using the **Terminal** window in the auxiliary BPM Monitor application

The sampling repetition period Δt_s can be varied in the range 12 μs to 10 ms with 1 μs step.

The ample count N_s is defined indirectly in terms of the *averaging exponent* E_s where $N_s = 2$^E_s. The exponent can assume the values E_s = 0, 1, 2, … 11. Consequently, N_s = 1, 2, 4, … 2048.

To prevent activation of the built-in watchdog (which occurs after 8 seconds of master MCU inactivity), the maximum allowable integration time T_s is 5 seconds. The user is automatically prevented from entering values of Δt_s and N_s that would result in a higher T_s.

Sampling Rules. If the signal level is not steady but fluctuates (e.g. due to ripples in the magnetron power supply voltage and/or periodically varying load), two rules in choosing Δt_s and N_s should be adhered to for accurate and stable mean power display:

1. If the slowest oscillations (ripples) observed in the signal have period $T_{r\,\max}$, the sampling duratiom T_s should be equal to an integral multiple of $T_{r\,\max}$, i.e.

   $$T_s = n\, T_{r\,\max}, \quad n = 1, 2, \ldots$$

   Alternatively, T_s can be chosen much longer (at least ten times longer) than $T_{r\,\max}$:

   $$T_s \geq 10\, T_{r\,\max}$$

2. The sampling rate f_s should be at least ten times higher than the *highest* ripple frequency observed in the signal. The minimal sampling repetition period is 12 μs (the maximal sampling rate 83 kHz), which enables to cover amplitude- or pulse-modulated signals with modulation frequencies up to about 10 kHz.

If the signal level is nearly constant (CW, low-ripple), any sampling settings will theoretically do. To reduce noise and interference, however, N_s and T_s should not be needlessly low. The default settings below are a good compromise.

Default Settings. The default sampling repetition period is Δt_s = 100 μs. This corresponds to the sampling rate f_s = 1 kHz, which ensures correct sampling of signals with ripple frequencies up to about 100 Hz. The default averaging exponent is E_s = 11, hence N_s = 2048. These default settings result in the integration time T_s = 204.7 ms.

Results Refresh Rate. Due to the data processing overhead, the maximal cadence of the results production is limited to approximately 100 measurements per second, even when sampling with the highest rate f_s and the lowest sample count N_s.

RS232 Digital Output

After switching on the power supply, BPM starts automatically transmitting data in the form of ASCII strings. The COM port settings are:

- 8 data bits
- 1 stop bit
- No parity
- Baud Rate 115000 bits/s

An example of connecting BPM with a PLC is shown later in this document. Please be aware that TX and RX signal leads are crossed.

The transmitted ASCII strings are lines of readable text separated by a Line Feed character <LF> (ASCII #10). Normally, each line has the following form:

`FWD: P= 8.836kW T=38.0 P= 69.46dBm RFL: P= 1.189kW T=38.0 P= 60.75dBm<LF>`

The line contains two sections, one (FWD) for the forward wave, the other (RFL) for the reflected wave. Each section consists of items of the form **P=*Value+Unit*** (for powers in kW and dBm) or **T=*Value*** (for internal temperature in Celsius). The individual items are separated by a space character (ASCII #32). Spaces *within* an item are irrelevant.

In the case of internal ADC overflow, an additional OVERRANGE item occurs, such as (for overflow in FWD channel)

`FWD: P=120.000kW T=38.0 P= 80.79dBm OVERRANGE RFL: P= 1.189kW T=38.0 P= 60.75dBm<LF>`

To obtain numerical values for further processing, the recipient should capture these lines and parse them accordingly.

COM Port Terminal

In order to test and configure BPM112 using a PC, one should run on the PC a RS232 COM Port terminal program. One possibility is using the open-source free terminal emulator **Tera Term**. This program can be downloaded from http://ttssh2.sourceforge.jp/index.html.en (see also http://en.wikipedia.org/wiki/Tera_Term).

For an example of complete BPM – PC connection, see section BPM Monitor below.

An example of RS232 digital outputs is shown in Fig. 8.

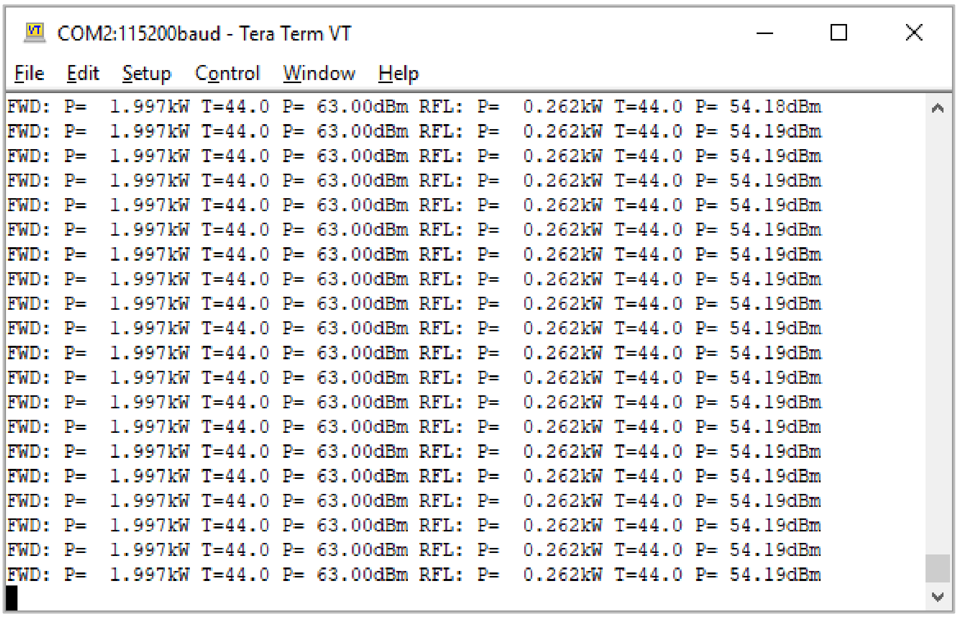

Fig. 8. Example of RS232 digital output.

BPM User Menu

The BPM User Menu enables the following operations:

- Configuration of signal sampling.
- Switching the type of analog output.
- Setting the RS232 baud rate.
- Changing the orientation of the LCD display.
- Scaling of analog outputs.
- Introduction of a power offset to measured data (e.g. to correct for a waveguide wall thickness differing from the nominal).

An RS232 terminal installed in your PC is needed for this. The BPM User Menu is invoked by transmitting either the ASCII character “x” or “X” (ASCII #120 or #88) from the terminal by pressing the **x** or **X** key on the PC keyboard. An example of the BPM User Menu is shown in Fig. 9. For more details, please refer to the application note **AN1601-BPM_UserMenu.pdf**.

An an alternative, one can use the auxiliary BPM Monitor application.

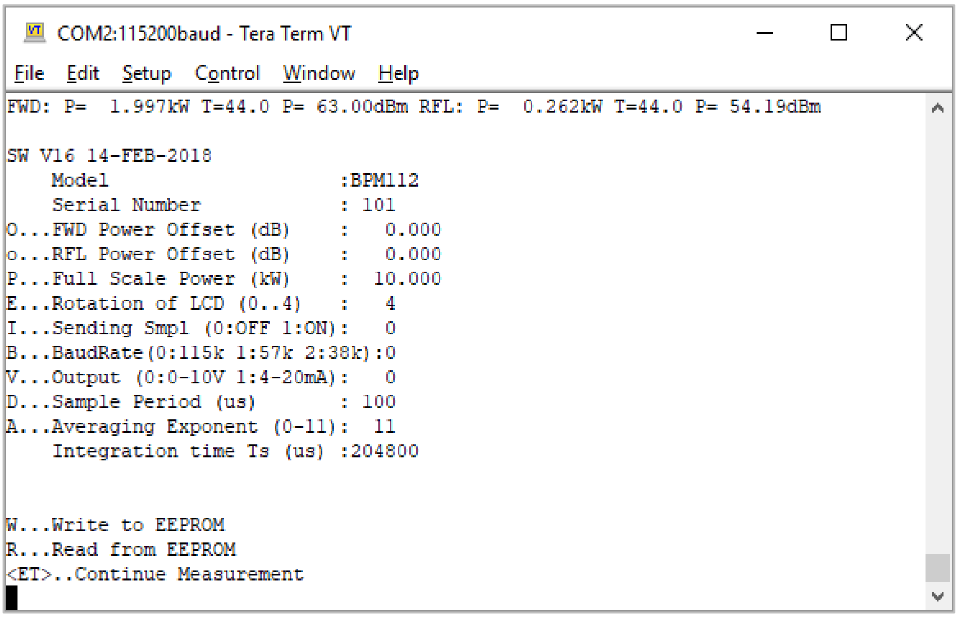

Fig. 9. BPM User Menu.

BPM Monitor

The BPM is accompanied by the simple LabVIEW-based Windows visualization application **BPM_Monitor**. An example program window is shown in Fig. 10.

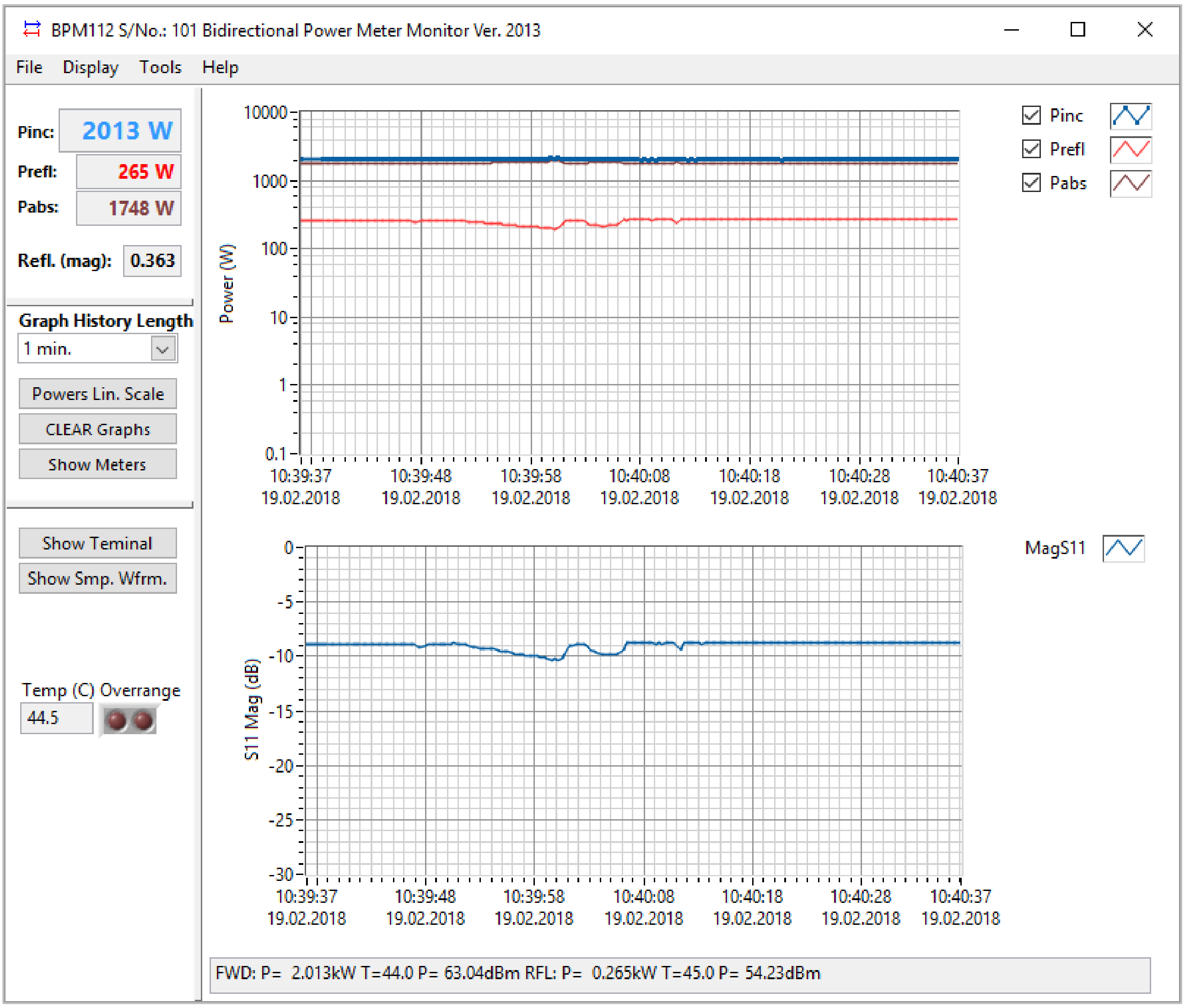

Fig. 10. BPM Monitor screen example.

BPM Monitor is a program for monitoring and controlling BPM devices. It displays graphs of the incident, reflected and absorbed powers as functions of time. The reflection coefficient magnitude is also displayed in a separate graph. The history of the graphs can be extended to up to 24 hours. All data on graphs can be easily exported to Excel for analysis.

The BPM Monitor also contains a simple RS232 **Terminal** dialog (Fig. 11) for setting the internal BPM parameters in a more user-friendly way than by using the BPM User Menu.

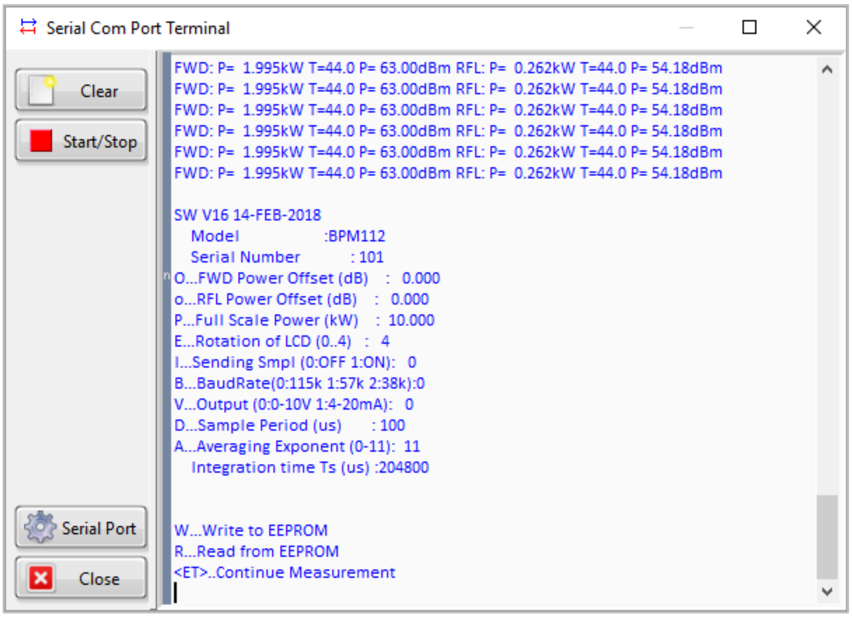

Fig. 11. Serial COM Port Terminal window of the BPM Monitor. The example displays BPM User Menu.

One can perform a more detailed analysis of the generator output waveform with the help of Samples Waveform and FFT Dialog windows, that show the output power as a function of time and its power spectrum, respectively (Fig. 12).

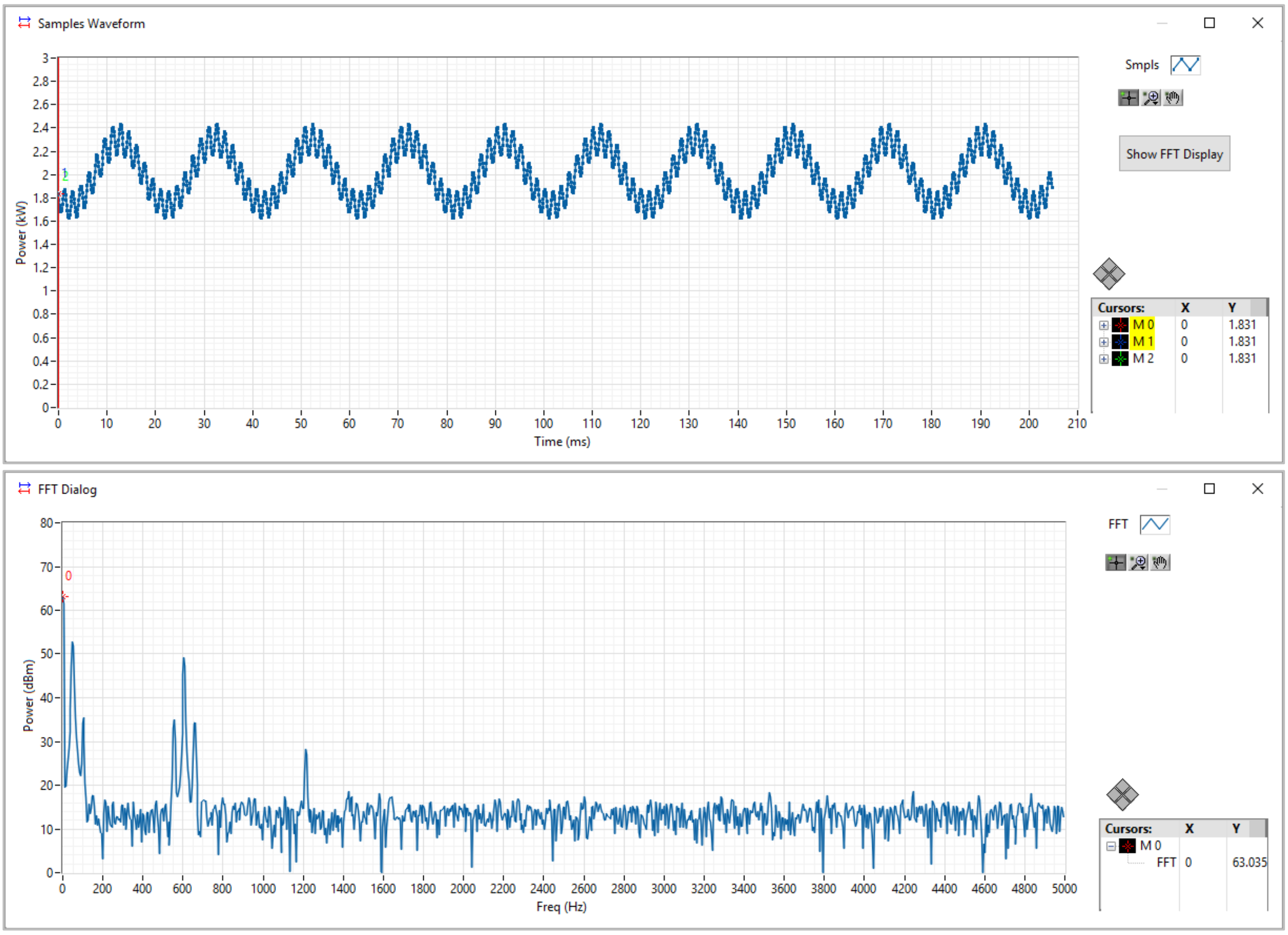

Fig. 12. The BPM Samples Waveform and FFT Dialog windows for a twelve-pulse bridge rectifier.

For LabVIEW programmers wishing to develop their own applications, there is a BPM library of virtual instruments available. The library is a part of the BPM Monitor installation package.

If you wish to use the Monitor, please proceed as follows:

- Locate the installation on the CD accompanying the product. Alternatively, download the latest installation from https://s-team.sk/software#bpm (zipped in a file such as **BPM_MonitorV2031.ZIP**).
- In the case of a zipped installation file, first unpack the zip file.
- Run the installation program (**setup.exe**).
- After installing, connect the BPM to your PC. You will need the following:
  - 24V DC power supply.
  - Extension cable, branching the DC power supply inputs VDC and GND to the power supply and TX, RX, GND pins to standard D9 RS232 connector. You have to make this extension yourself.
  - Standard RS232 cable (a null modem, i.e. a type with crossed RX/TX leads).
  - RS232-to-USB adapter. In case of problems, we recommend the Brainboxes US-101 (supplied worldwide e.g. by Farnell).

  An example of the BPM connection with a PC is shown in Fig. 17. The same connection applies to the COM Port Terminal emulator.
- On the PC, run **BPM_Monitor.exe** (shortcut found on the PC desktop). In the program, you will be asked to choose an appropriate COM Port. Then the measurement should start.

Dimensional Drawing

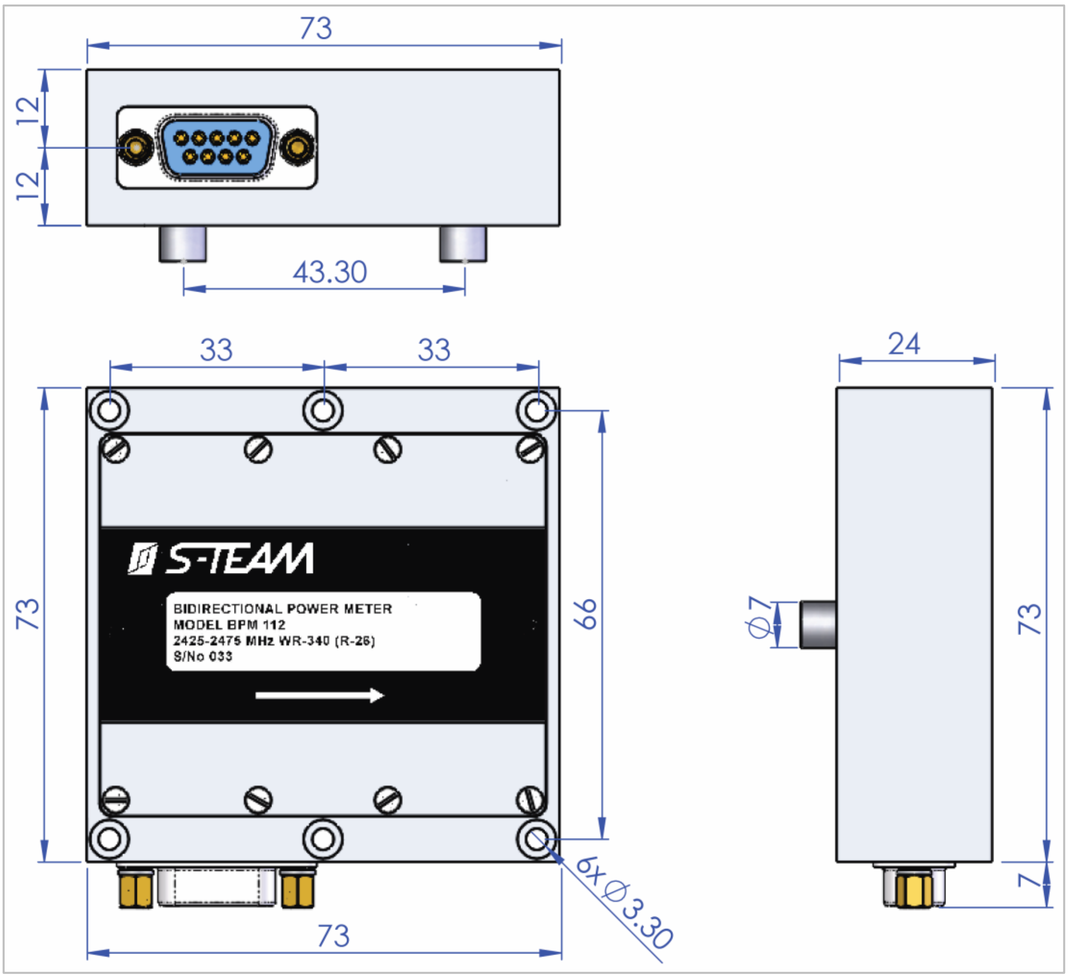

Fig. 13. Basic BPM112 dimensions (in millimeters). The probe protrusion is 5.5 mm.

Waveguide Machining Template

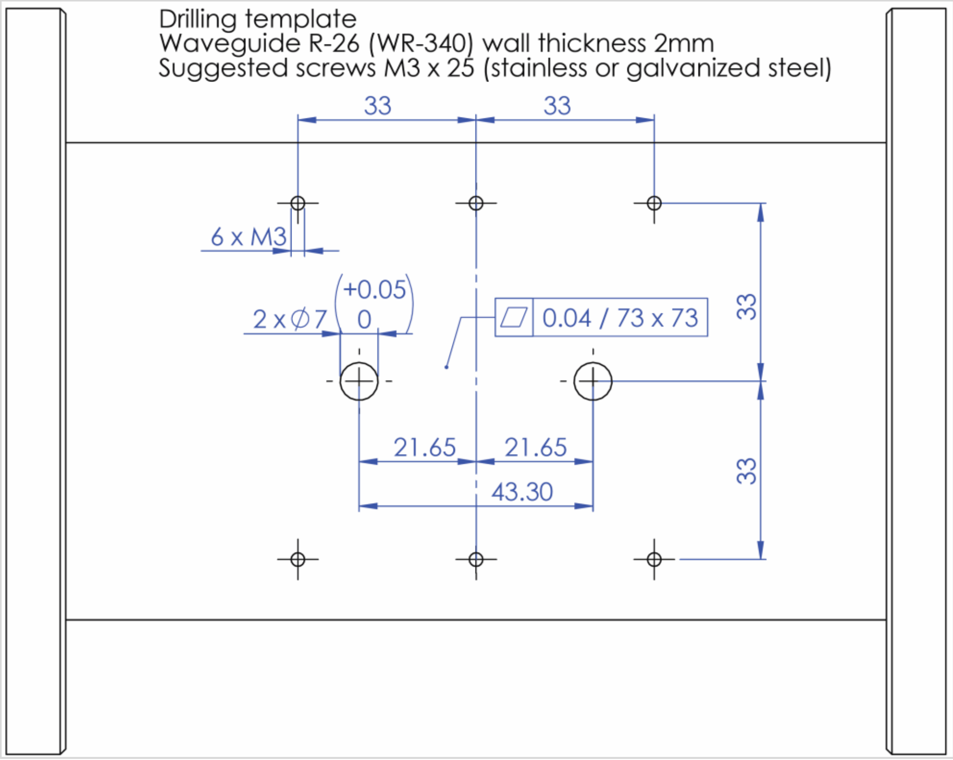

Fig. 14. Waveguide machining template. All dimensions are in millimeters. The pattern is centered about the waveguide axis. The waveguide wall thickness must be 2 mm.

Important Note

Complying with the specified waveguide wall thickness and flatness of its surface interfacing with the BPM is essential in order to achieve the specified measurement accuracy. The slope of the coupling factor as a function of the wall thickness is about -6 dB/mm (i.e., increasing the wall thickness decreases the output power readings).

If the wall thickness differs from the specified figure but is known, one can apply a user-defined correction based on the above slope. Nevertheless, the wall thickness should not deviate from the specification by more than ±0.3 mm, otherwise BPM directivity will deteriorate.

To avoid problems with manufacturing precision waveguide components, one can order a calibrated assembly consisting of a BPM module fixed to a parent waveguide. The standard waveguide length is 174 mm.

Analog Voltage Outputs Wiring

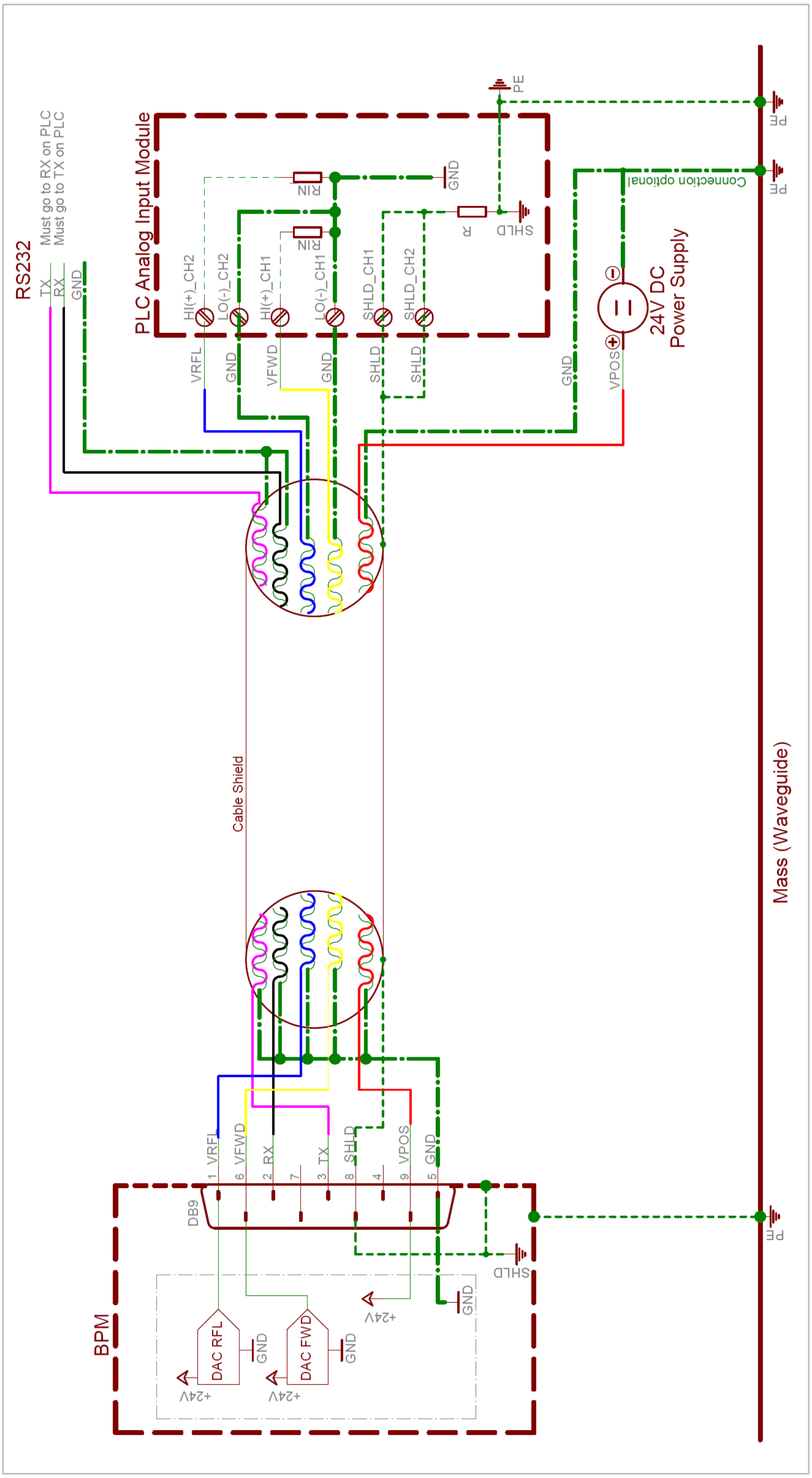

Fig. 15. Example of BPM – PLC wiring for analog voltage outputs.

Analog Current Outputs Wiring

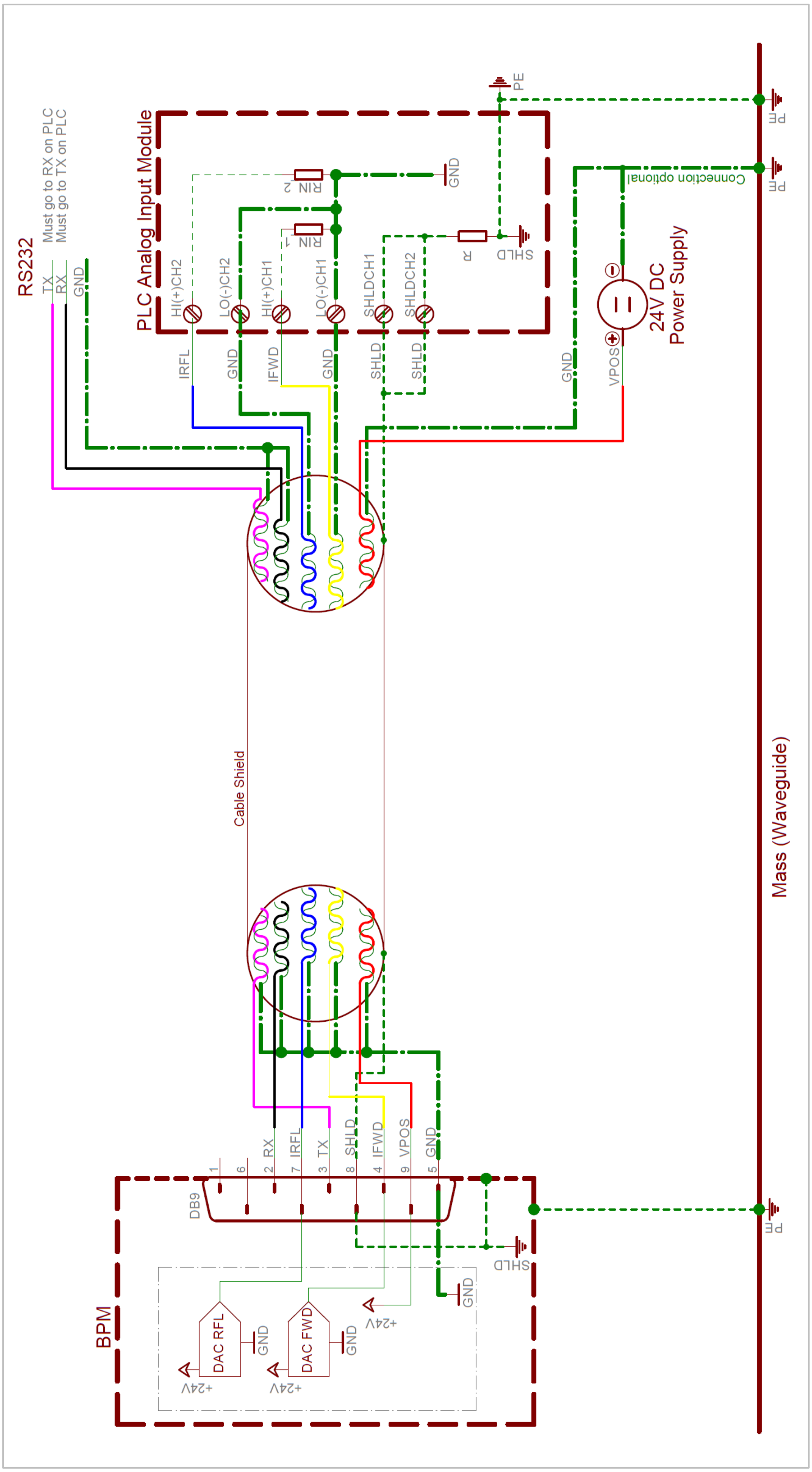

Fig. 16. Example of BPM – PLC wiring for analog current outputs.

Example of BPM Connection

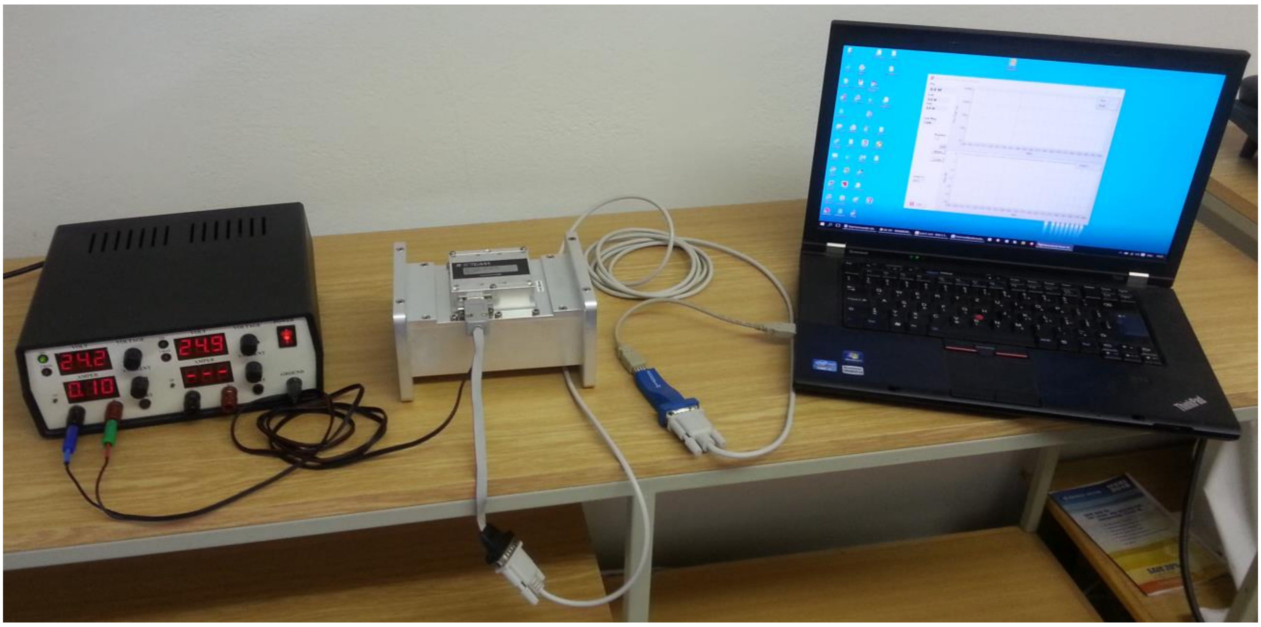

Fig. 17. Illustration of BPM – PC connection.