BPM112: Bidirectional Power Meter for WR-340 Waveguide

General Description

BPM112 (Fig. 1) is a bidirectional power meter serving for accurate simultaneous measurement of incident and reflected powers up to 30 kW in high-power 2450 MHz industrial applications using WR-340 (R-26) 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)

Fig. 1. BPM112 version with LCD display.

The MCU:

- Controls 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 or RS422 or CAN Bus).

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 internal power sensors temperatures. The powers are displayed both numerically and by bar indicators (see the inset in Fig. 1).

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

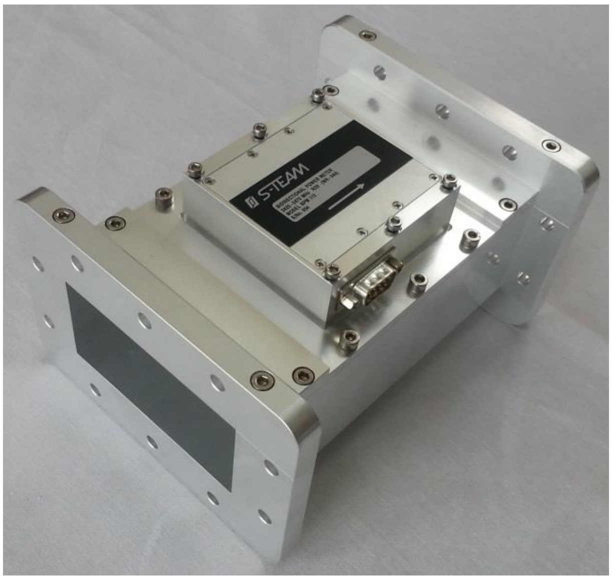

Fig. 2. BPM112 (version without LCD display) installed on the standard-length waveguide.

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 standard or customized length can be provided (Fig. 2). The standard length is 174 mm.

Specifications

Waveguide of destination	WR-340, R-26 (86.36 mm x 43.18 mm)
Waveguide wall thickness	2 mm ± 0.025 mm
Waveguide surface flatness 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
Output voltage polarity	Positive
Power supply voltage	24 V ± 10% DC
Power consumption	4 W / 6 W (without/with LCD display)
Power supply, analog & digital connector	D-sub 9-pin male
Operating temperature range	-10 °C to +60 °C
Default measurement rate	5 points/s
Max measurement rate	100 points/s (Note 2)
Max sampling duration	5 s (Note 3)

Notes:

1. Peak working power must be specified in the purchase order.
2. Max measurement rate can be reached with high sampling rates and short sampling durations. Details about sampling see in section Sampling.
3. Sampling duration or integration time is the sampling time for obtaining one measurement data point.

Pin Assignment

Pin	Signal	Description
1	VRFL	RFL Power – analog voltage output
2	RX/B-/H	RX (RS232); B- (RS422); H (CAN Bus)
3	TX/A+/L	TX (RS232); A+ (RS422); L (CAN Bus)
4	IFWD	FWD Power – analog current output
5	GND	Negative DC power supply input (0 V)
6	VFWD	FWD Power – analog voltage output
7	IRFL	RFL Power – analog current output
8	SHLD	Shielding, Mass
9	VDC	Positive DC power supply input (+24 V)

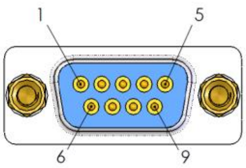

Fig. 3. BPM connector pin numbering.

Notes:

- FWD = incident (forward) power.
- RFL = reflected (reverse) power.
- GND = signal ground.
- GND (pin 5) is isolated from SHLD (pin 8).
- All outputs are referred to GND.
- FWD wave is supposed to 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 can be active at a time.

Nominal Transfer Curves for Analog Outputs 0 – 10 V, 4 – 20 mA

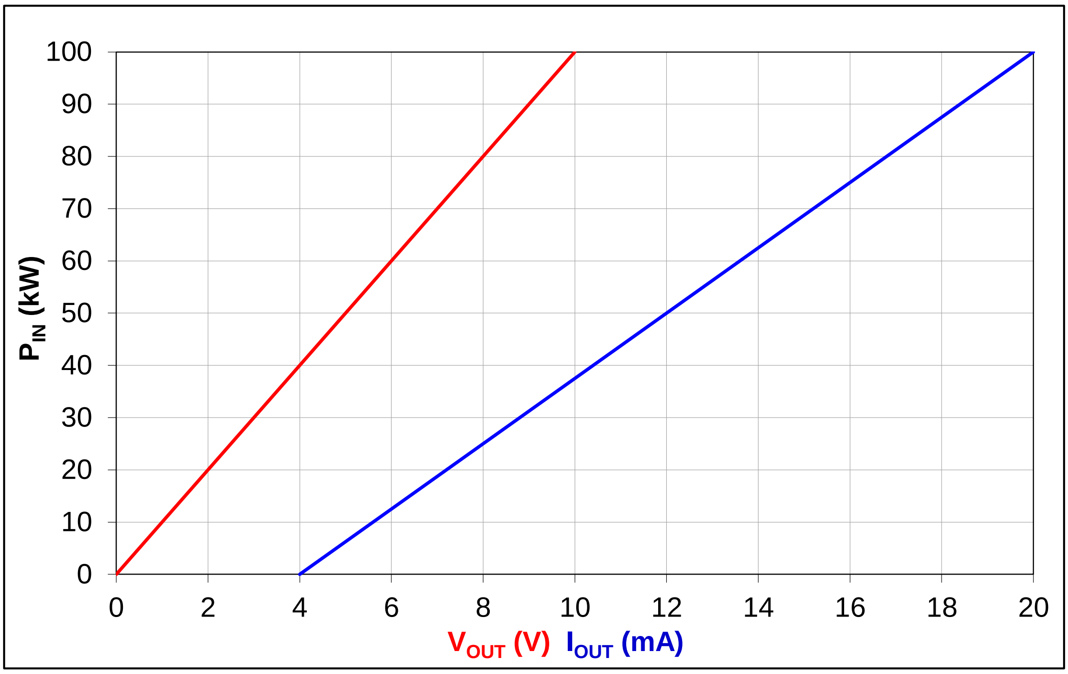

Fig. 4. Nominal BPM transfer curves for analog outputs 0 – 10 V, 4 – 20 mA.

Typical Directivity

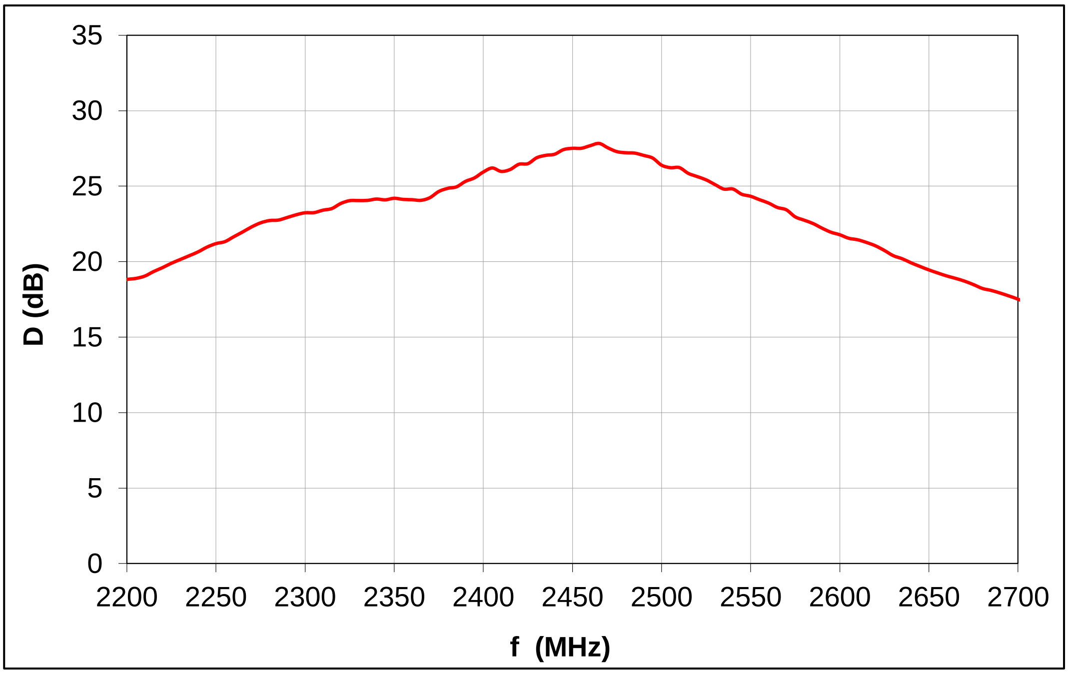

Fig. 5. Typical BPM directivity (both directions).

Typical Linearity Error for Analog Outputs 0 – 10 V, 4 – 20 mA

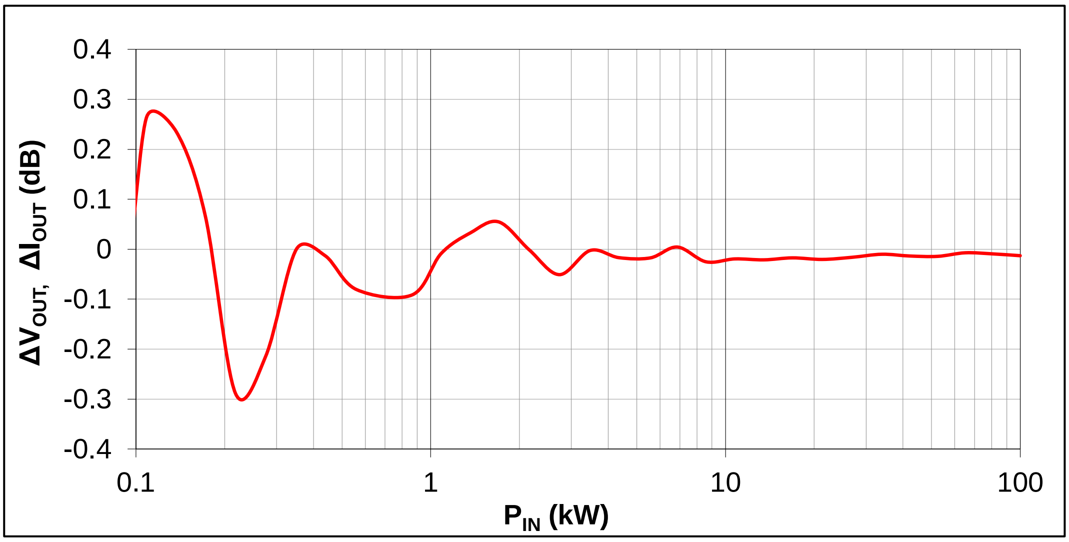

Fig. 6. Typical BPM linearity error for analog outputs 0 – 10 V, 4 – 20 mA.

Typical Linearity Error for Digital Outputs

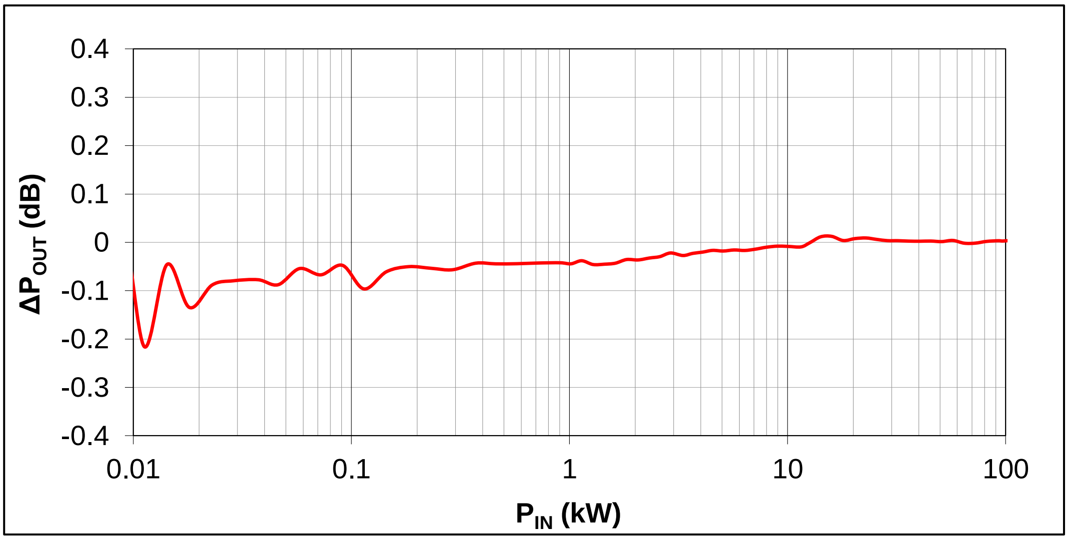

Fig. 7. Typical BPM linearity error for digital outputs.

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 time T_s (sampling duration, integration time). The quantities governing the sampling are constrained by the relation

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

where $\Delta t_s = 1/f_s$ is *sampling period* (time distance between two consecutive samples). The user controls 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 period Δt_s can be varied in the range 12 μs to 10 ms with 1 μs step.

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

To prevent the built-in watchdog activation (occurring 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 higher T_s.

Sampling Rules. If the signal level is not stable but fluctuates (e.g. due to ripples in 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 $T_{r\,\max}$, sampling time 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 (at least ten times) higher than $T_{r\,\max}$:

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

2. Sampling rate f_s should be at least ten times higher than the *highest* ripple frequency observed in the signal. The minimal sampling 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 stable (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 period is $\Delta t_s = 100$ μs. This corresponds to sampling rate $f_s = 1$ kHz, ensuring 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 integration time $T_s = 204.8$ ms.

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

RS232 Digital Output

After switching on the power supply, BPM starts automatically transmitting data in 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 Line Feed character <LF> (ASCII #10). Each line has normally the form of the following example:

`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 space character (ASCII #32). Spaces *within* an item are irrelevant.

In 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

For testing and configuring purposes using a PC, an RS232 COM Port terminal program should run in the PC. One possibility is using **Tera Term**, which is an open-source free terminal emulator. The 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.

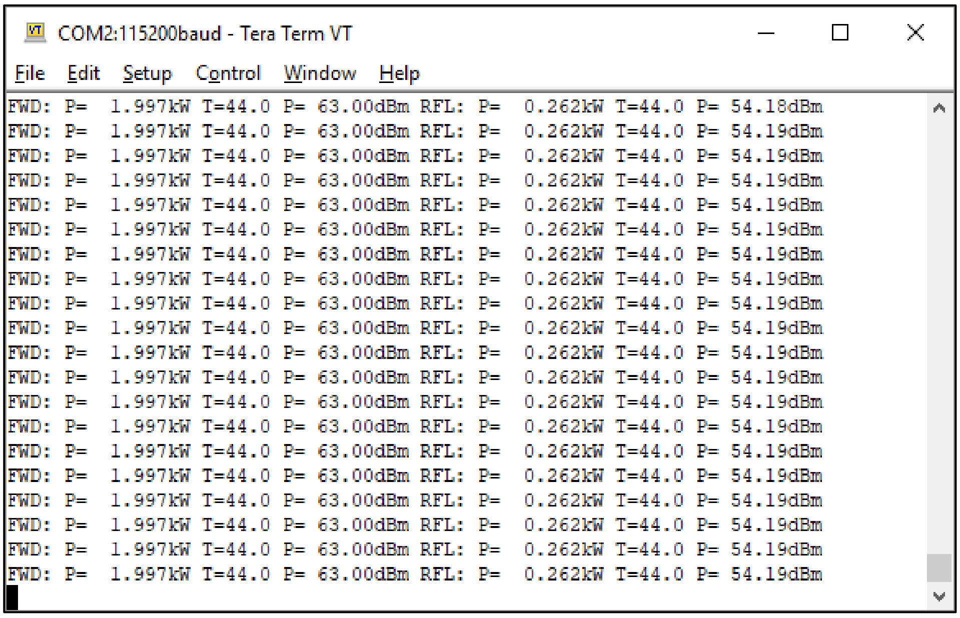

Fig. 8. Example of RS232 digital output.

BPM User Menu

The BPM User Menu serves for:

- Configuring the signal sampling.
- Switching the type of analog output.
- Setting of RS232 baud rate.
- Changing orientation of the LCD display.
- Scaling the analog outputs.
- Introducing 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 ASCII character x (ASCII #32) from the terminal (pressing the lower-case **x** key on the PC keyboard). Example of BPM User Menu is shown in Fig. 9. For details, see the application note **AN1601-BPM_UserMenu.pdf**.

An alternative approach is using the auxiliary BPM Monitor application.

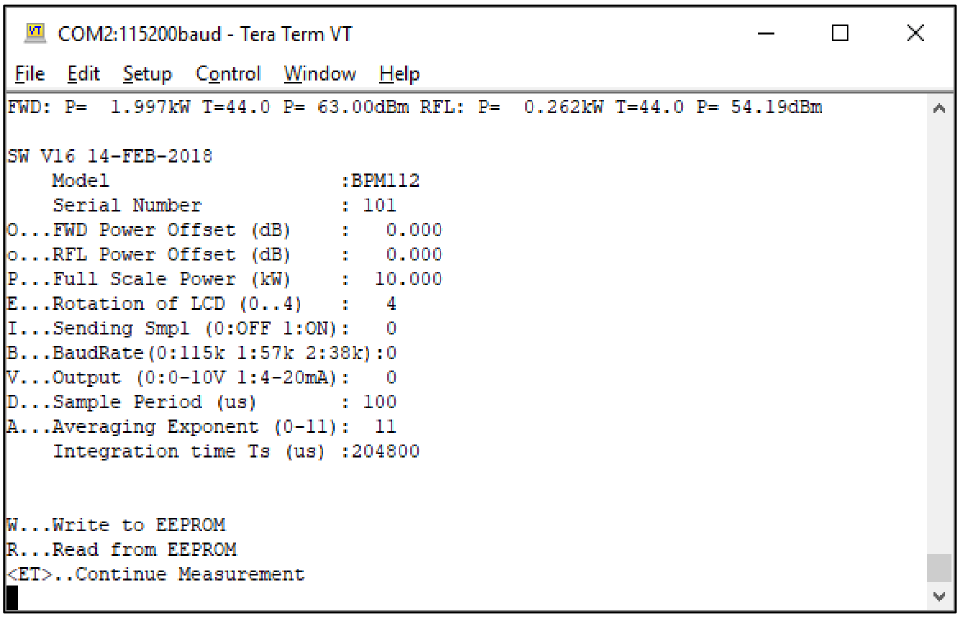

Fig. 9. BPM User Menu.

BPM Monitor

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

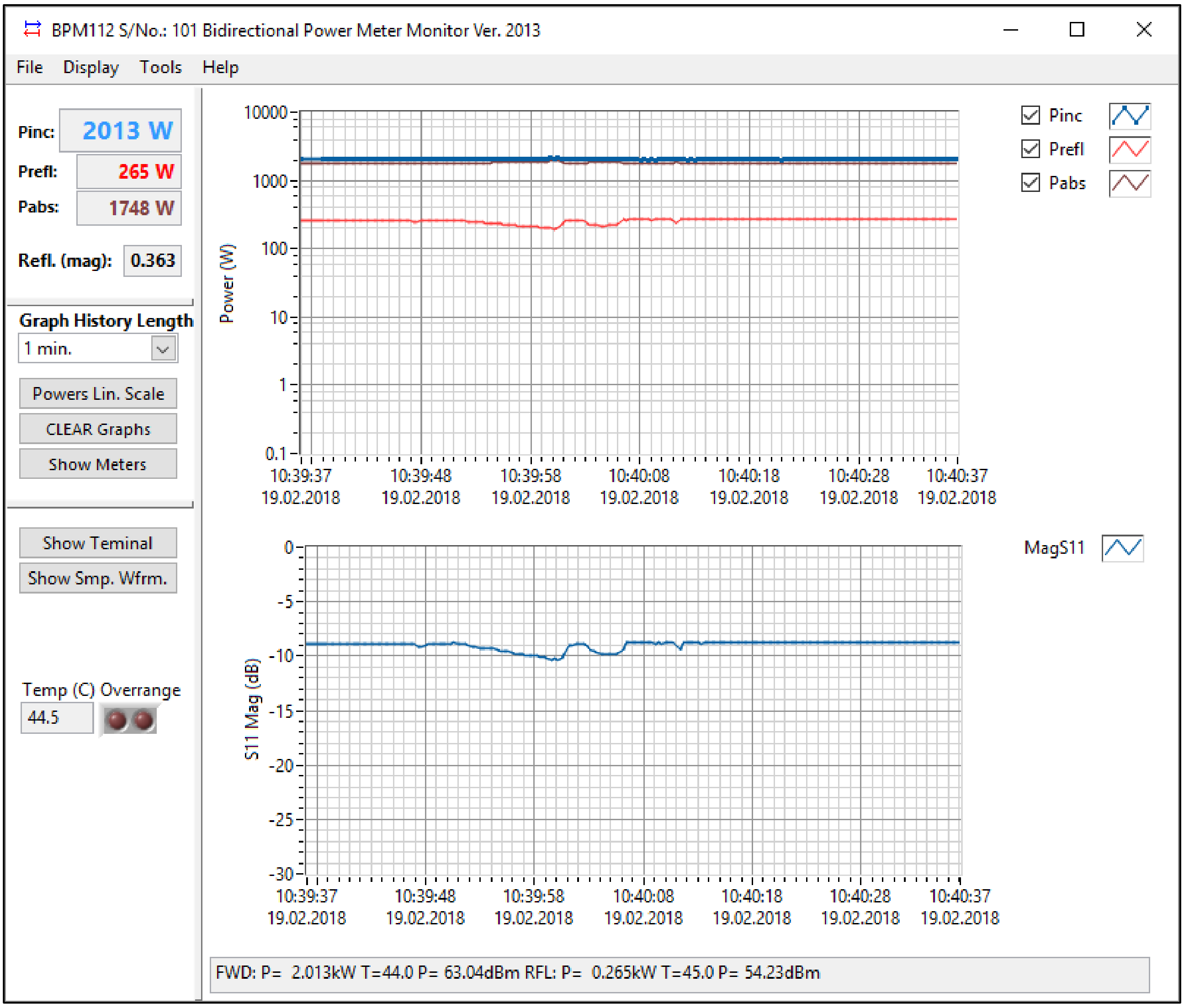

Fig. 10. BPM Monitor screen example.

The **BPM Monitor** is a program for monitoring and controlling BPM devices. It displays the incident, reflected and absorbed powers as time dependence graphs. 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 compared to the BPM User Menu.

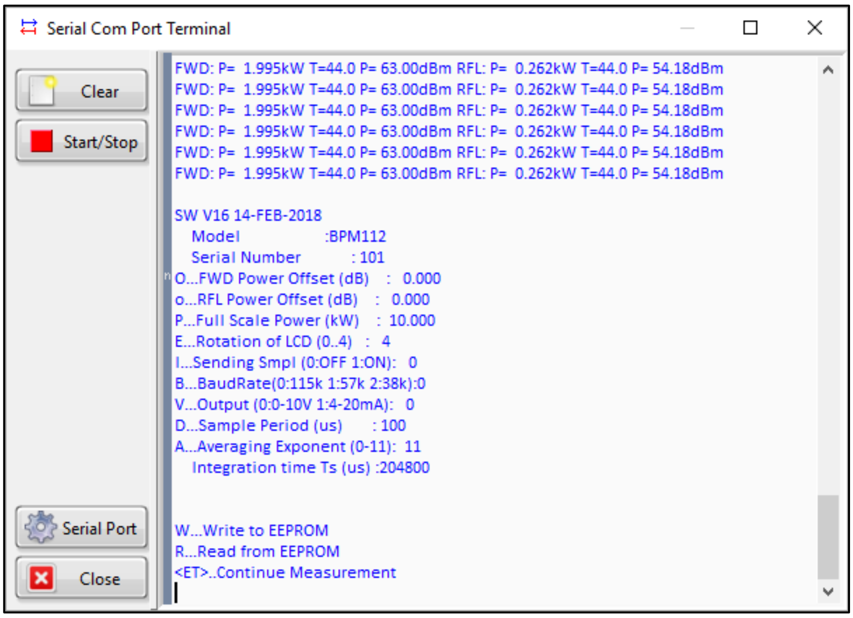

Fig. 11. Serial COM Port Terminal window of the BPM Monitor. The example displays BPM User Menu.

A more detailed analysis of the generator output waveform can be performed with help of Samples Waveform and FFT Dialog windows, showing, in turn, the output power time dependence and its power spectrum (Fig. 12).

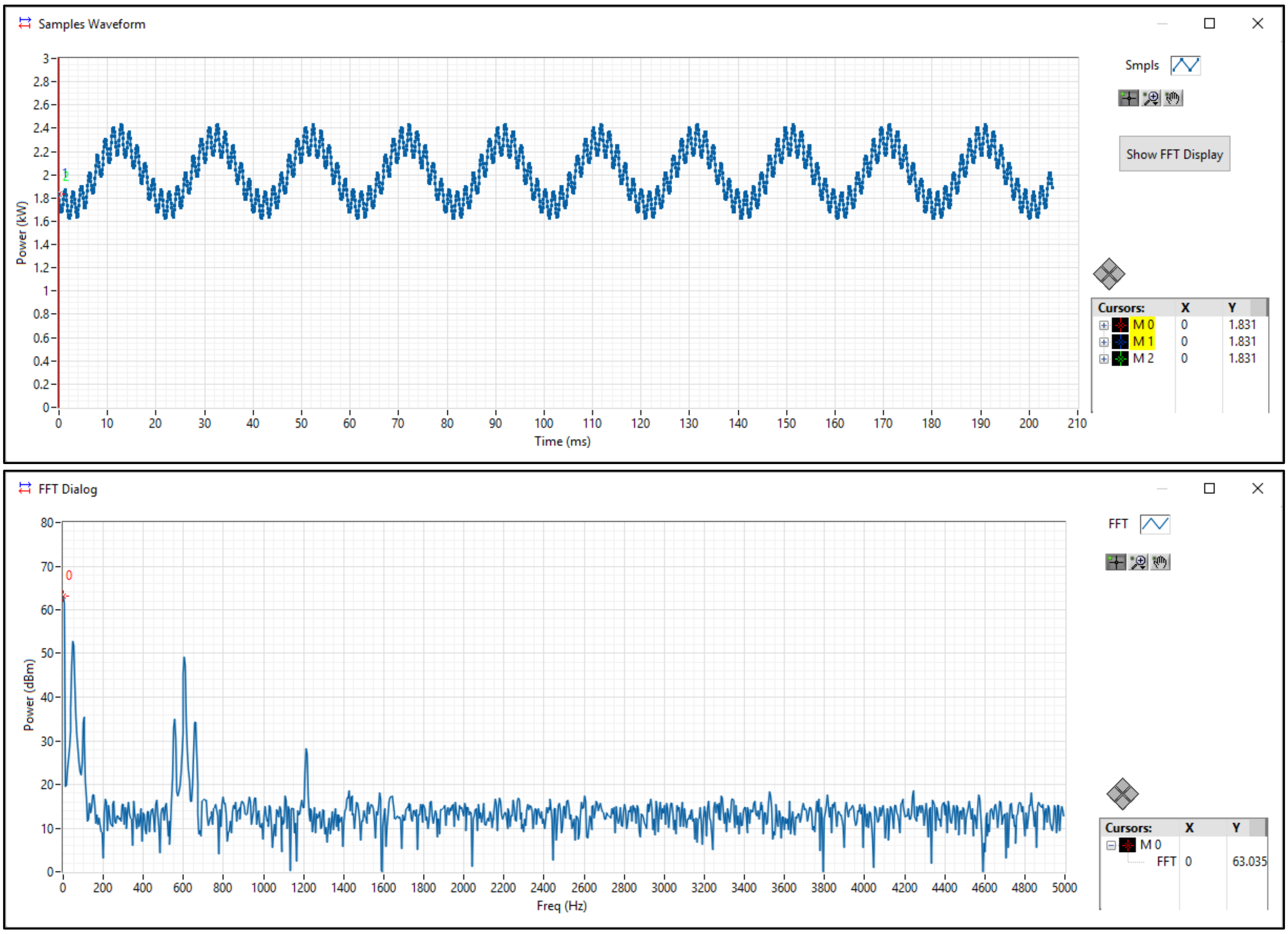

Fig. 12. The BPM Samples Waveform and FFT Dialog windows for a twelve-pulse bridge rectifier.

For LabVIEW programmers wishing to build 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 http://www.s-team.sk/files/?target=BPM_Monitor (zipped in a file such as **BPM_MonitorV2031.ZIP**).
- In case of zipped installation, unpack the zip file.
- Run the installation (**setup.exe**).
- After installing, connect the BPM to your PC. You will need:
  - 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. 15. The same connection applies to the COM Port Terminal emulator.
- On the PC, run **BPM_Monitor.exe** (shortcut BPM found on the PC desktop). In the program, you will be asked to choose an appropriate COM Port. Then the measurement should start.

Analog Voltage Outputs Wiring

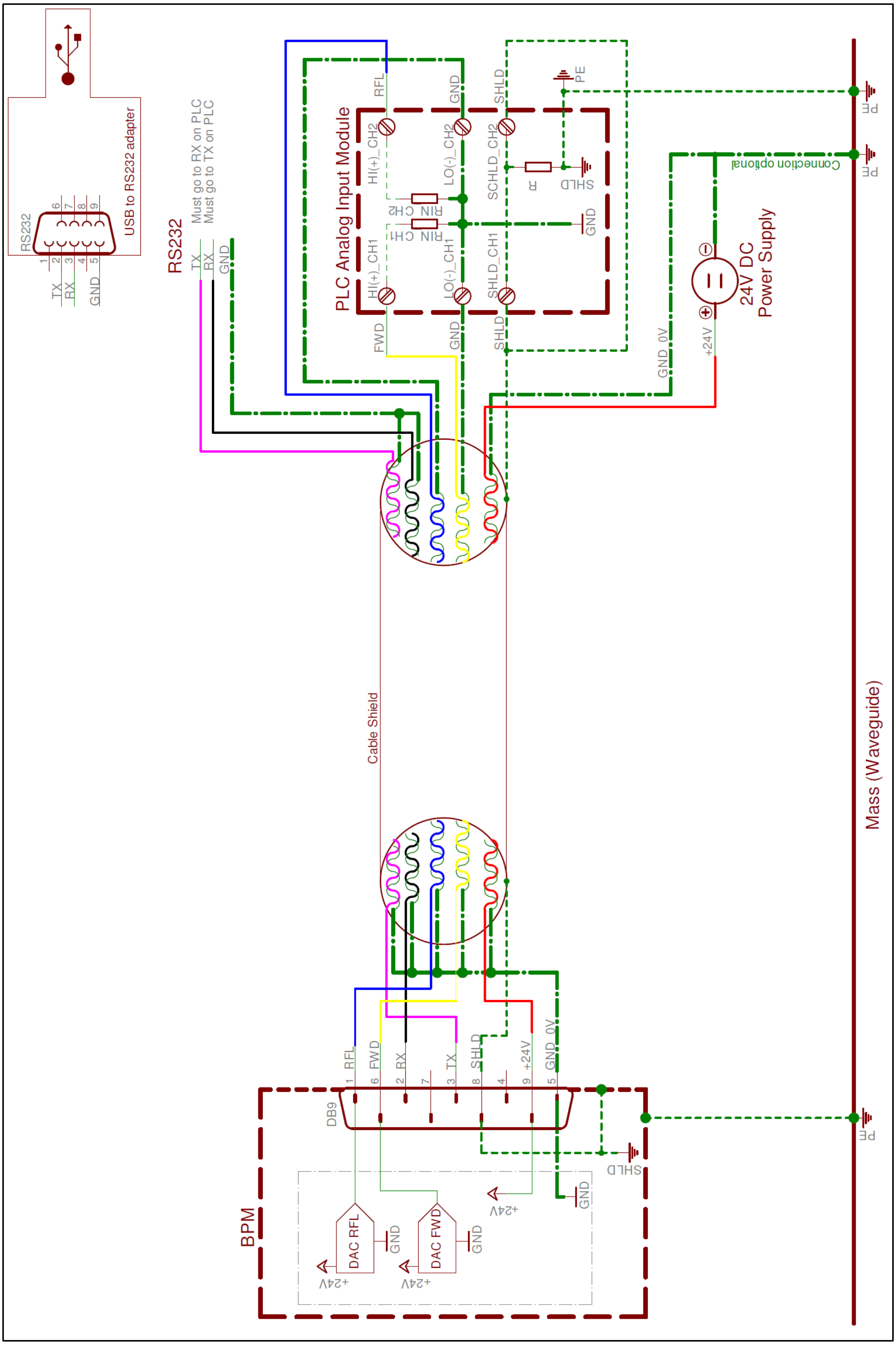

Fig. 13. Example of BPM – PLC wiring for the analog voltage outputs.

Analog Current Outputs Wiring

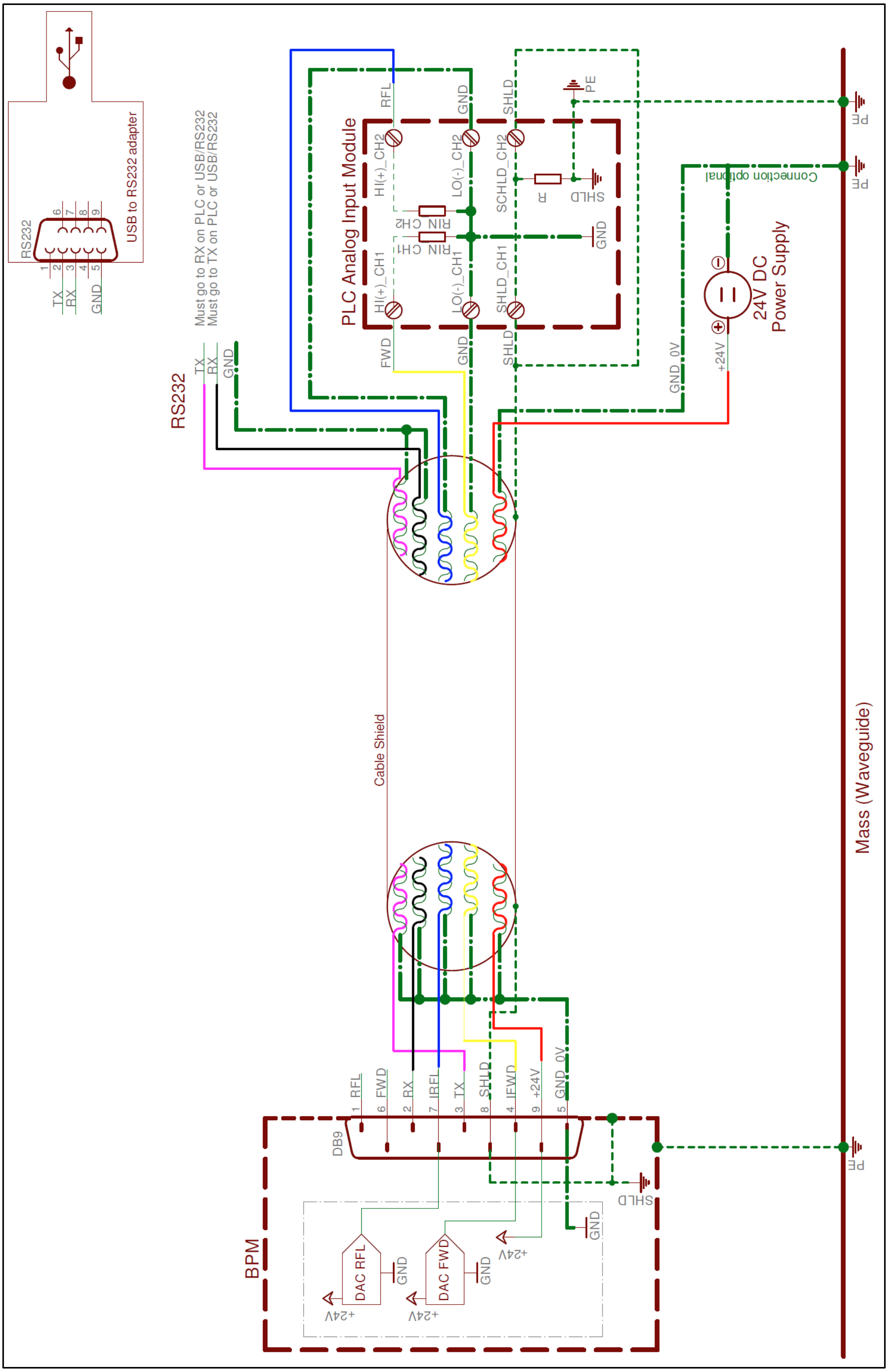

Fig. 14. Example of BPM – PLC wiring for the analog current outputs.

Example of BPM Connection

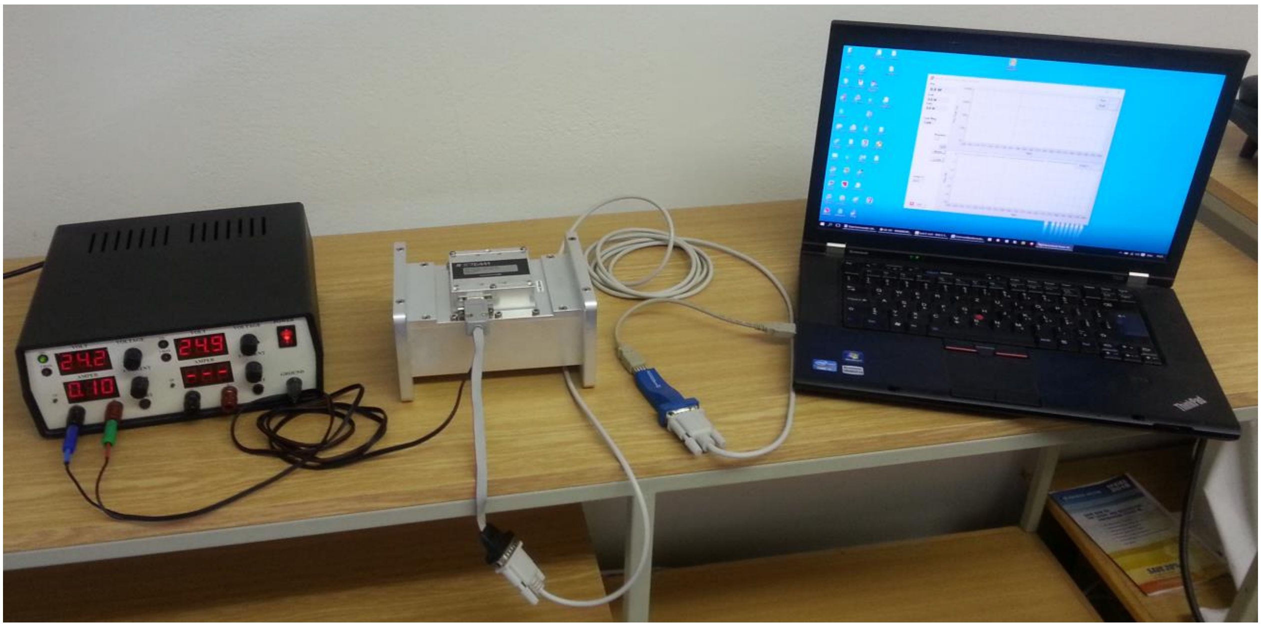

Fig. 15. Illustration of BPM – PC connection.

Dimensional Drawing

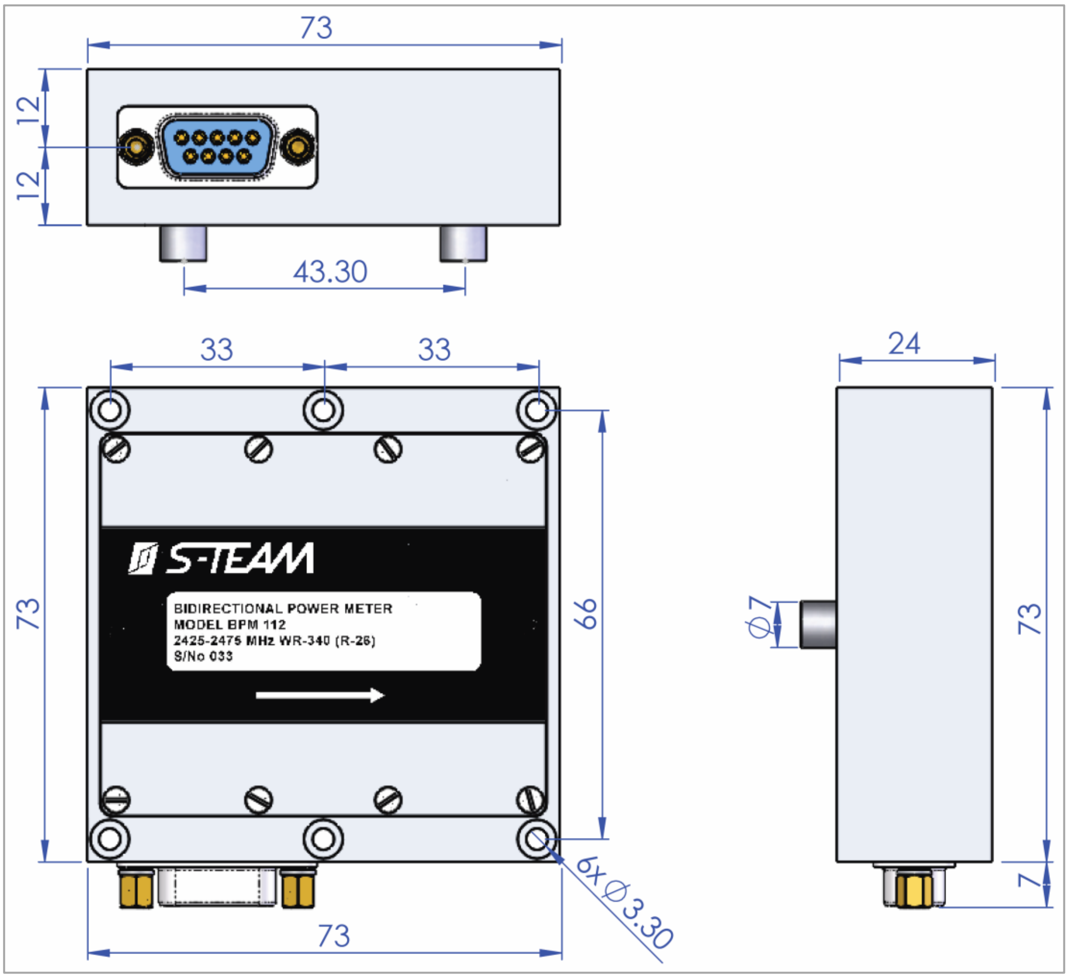

Fig. 16. Basic BPM112 dimensions. All dimensions are in millimeters.

Waveguide Machining Template

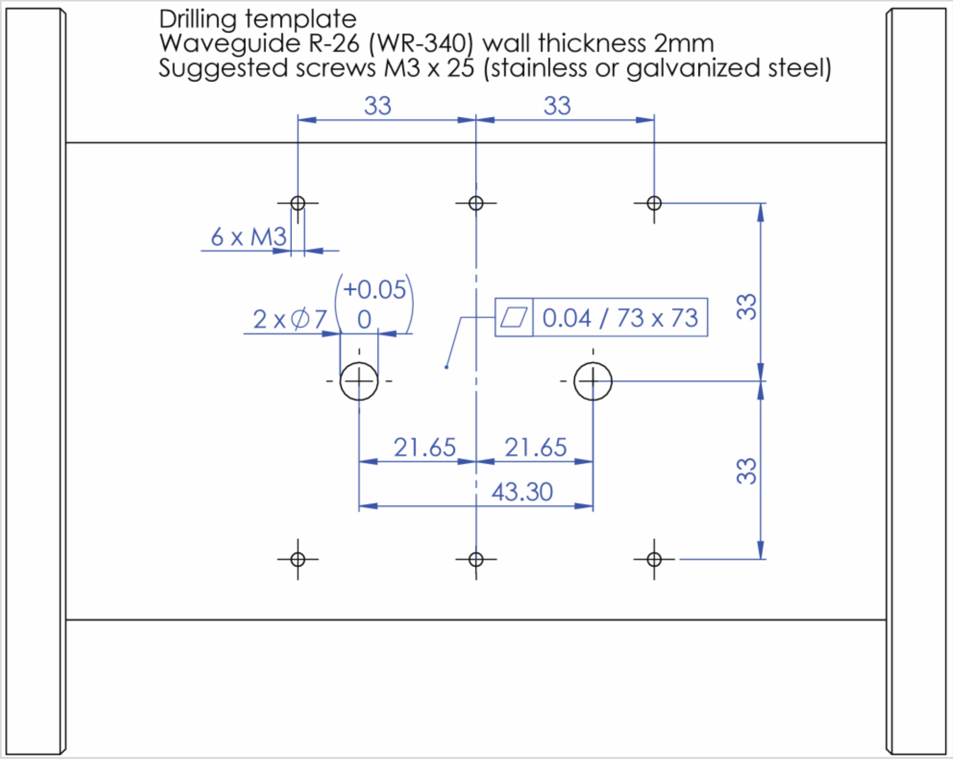

Fig. 17. Waveguide machining template. All dimensions are in millimeters. The pattern is centered about the waveguide axis. The waveguide wall thickness must be 4 mm.

Important Note

Complying with the specified waveguide wall thickness and flatness of its surface interfacing with the BPM is essential for the specified measurement accuracy. The slope of the coupling factor as a function of the wall thickness is about -0.6 dB/mm (increasing the wall thickness decreases the output power readings).

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

To avoid problems with manufacturing precision waveguide components, a calibrated assembly consisting of a BPM module fixed to a parent waveguide can be ordered. Standard waveguide length is 174 mm; customizing the length is possible.