

1 Flashing Firmware

The .hex file (in the download) may be flashed e.g. with BASCOM, AVR Studio (ATMEL Studio) or myARV Prog Tool via ISP. Details can be found here:

<http://dl6gl.de/avr-programmieren-mit-bascom-und-avr-studio.html>

Before flashing, the fuses should be set, for example with AVR Studio:

(Translated with Google Translate. Sorry, probably not the best English...)

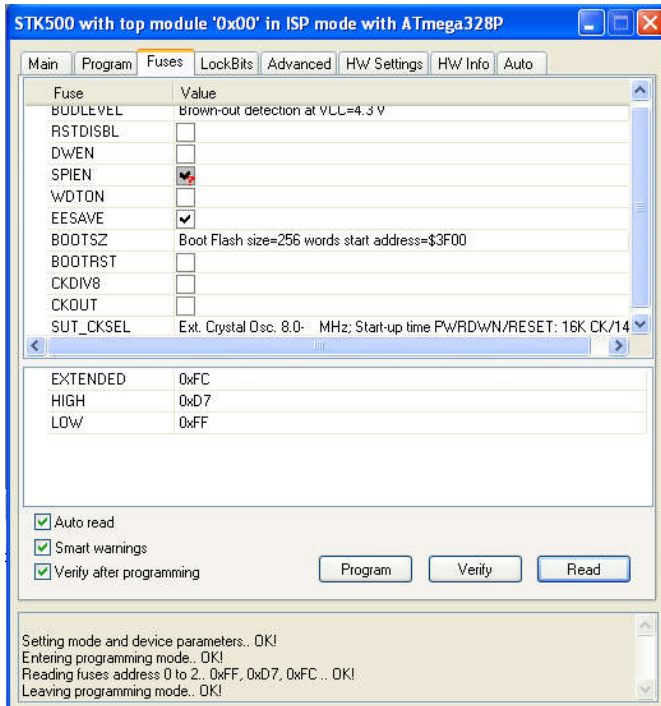


Fig. 1: Setting the fuses (Ext: FC, Hi: D7, Lo: FF hex).

Flashing the firmware, please note the following:

- With the first flashing of a virgin ATmega and subsequent program start, the EEPROM is initialized with some data. These data are then changed or supplemented in the setup. The EEPROM of a factory-fresh or an erased controller is preset with decimal 255 = 0xFF. When the program finds this, it initializes the EEPROM.
- The programmed (checked) fuse bit EESAVE prevents EEPROM data from being deleted when reflashing program updates, which means that data already stored in the EEPROM will be lost.
- Flashing with **BASCOM**
No further special considerations.
- Flashing with **AVR Studio** (ATMEL Studio)
Remove the default checkmark for "Erase device before flash programming" (Figure 2).

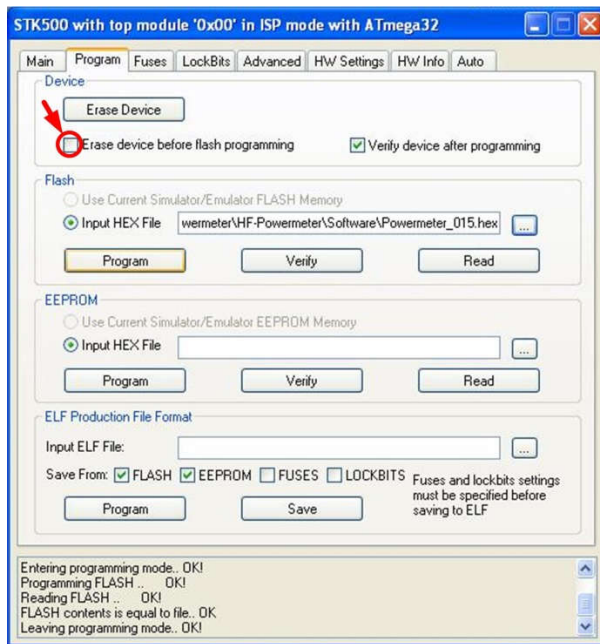


Fig. 2: Flashing with AVR Studio.

2 Usable SWR / Power couplers

The device can be configured for up to four different couplers using the data stored in the EEPROM, such as tandem match couplers with toroid cores designed for the desired maximum power for the shortwave range or those in stripline technology for the UHF / SHF range. Each coupler is equipped with two logarithmic amplifiers suitable for the respective frequency range, such as AD8307 for HF and VHF, for the transmission (forward) and the reflection channel (reverse).

An identifier (coupler selection) can be created in the coupler module connector by means of two wire bridges.

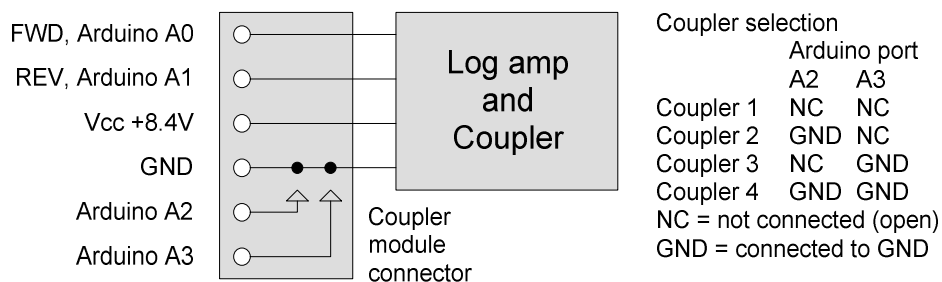


Fig. 3: Coupler selection.

It would be a good idea to roughly check the assembly, wiring and connection of the coupler at first:

- connect the TX to the TX input of the coupler,
- Dummy load to the antenna output.
- At ADC input A0 (Figure 3), the forward voltage (FWD) should be significantly greater than the reverse voltage (REV) at A1.

3 Keyboard

There are three buttons available to manage the **setup procedure**:

- Up: Increase values by single operation (short press) or auto-repeat (long press)
- Down: Decrease values by single operation (short press) or auto-repeat (long press).
- OK / Set: Short press: walk through the setup menu without changing the data, Long press: saves the current value in the EEPROM.
- Up + OK / Set: one menu item back.

In **measurement mode** (section 5), the down button toggles display of PEP or average power alternatively. The other keys are not used in measurement mode.

The setup is activated if

- the connected coupler is not yet calibrated or
- the OK button is pressed during power-on until the splash screen appears.

4 Program start

After displaying the splash screen with program name and version, the EEPROM is checked. If it does not contain any data, display will be

Line 1	Init EEPROM...
Line 2	... Init done

Subsequently the setup has to be carried out.

If the EEPROM is already initialized, the data associated with the connected coupler are read.

Line 1	Read EEPROM...
--------	----------------

Depending on the data found, it will be displayed, e.g. for coupler (Unit) 1:

Line 2	Unit1 calibrated
--------	------------------

The connected coupler is calibrated and ready for measurement, or

Line 2	Unit1 not calib.
--------	------------------

The connected coupler is not calibrated. The setup must be carried out.

For setup see section 6.

If the coupler is detected as calibrated, the device is ready for use.

5 SWR and Power measurement

For the connected coupler (see Fig. 3), the decoupled signal level measured by the log amps is calculated in dBm from the ADC measurements for the transmission channel (Forward, FWD) and the reflection channel (Reverse, REV) using the calibration lines stored in the EEPROM. The actual TX and reflected power (dBm) fed into the coupler is obtained by adding the coupling factor of the coupler and the attenuation of the attenuator ahead of the log amps. Displayed are powers in Watts.

The two ADCs (0 and 1) for FWD and REV measure three quantities:

1. The maximum FWD amplitude within a specified sample & hold time to determine the peak envelope power (PEP).

2. The mean value of the FWD amplitude over n individual measurements. The number n of single measurements is defined in the setup.
3. The mean value of the REV amplitude over n individual measurements.

Pressing the Down key toggles between displaying the averaged power (avg. power) or the peak power (PEP) from the FWD channel. In position avg. Power, LED D2 (Avg. Power, see circuit diagram) lights up. For the REV channel the reflected averaged power is always displayed.

The SWR is calculated from the averaged powers.

Line 1	F 10.2 R 0.00W
Line 2	SWR 1.23

F = FWD power (W), either PEP or avg. Power
 R = REV power (W), avg. Power

The SWR bar display in line 2 has full scale at SWR=3. The numerical display goes up to 9.99.

At SWR > 3 LED SWR>3 lights up (see circuit diagram).

Introduced with V3.01: The lower measurement limit set in Setup #8 is used to detect whether the TX is on or not. If the FWD signal falls below the lower measurement limit, it will be displayed:

Line 1	F 0.0 R 0.00W
Line 2	TX is off

The following error states are displayed instead of the numerical values:

Line 1	F >>>> R 0.00W
--------	----------------

FWD power greater than upper measurement limit.

Line 1	F Ovfl R 0.00W
--------	----------------

ADC overflow in FWD channel (input voltage > reference voltage).

Line 1	F 10.2 R <<<<W
--------	----------------

REV power smaller than lower measuring limit.

Line 1	F 10.2 R >>>>W
--------	----------------

REV power greater than upper measurement limit.

Line 1	F 10.2 R Ovfl
--------	---------------

ADC overflow in REV channel (input voltage > reference voltage).

A SWR display in line 2 is omitted in these cases.

5.1 Measuring principle

Before we begin with the determination of the quantities in the setup and the calibration, actually at the very beginning with the design of the toroidal cores and the attenuators with the Excel sheet, the measuring principle with the relevant measured quantities is explained here first.

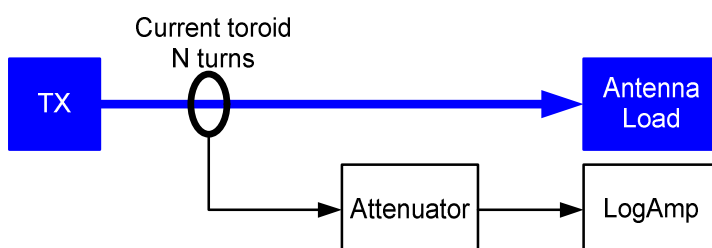


Fig. 4: Measuring principle of power measurement with current coupler.

- The current coupler couples out a fraction of the TX power, coupling factor (negative):
 $Cp - Fac = 20 * LOG_{10}(1/N) [dB]$ with $N = \text{number of turns}$
- TX power in dBm is
 $P(dBm) = 10 * LOG_{10}[1000 * P(W)]$
- The power at the input of the LogAmp is therefore:
 $LogAmp-Input (dBm) = P(dBm) + Cp-Fac (dB) - Attenuator (dB)$.

5.2 Calibration and coupling parameter

The LogAmp AD8307 used has a linear characteristic from approx. -60 to +10dBm input power. Calibration should be performed at or near these widely spaced points to determine the calibration line as accurately as possible.

Regardless of the calibration, e.g. at the -60 and +10dBm characteristic points, two additional limit values can be defined in the setup - also subsequently - up to which the calibration line is extrapolated. These determine the usable measuring range. If, for example, the upper limit value is set to +13dBm, here the characteristic curve is still linear, the measurable TX power is doubled.

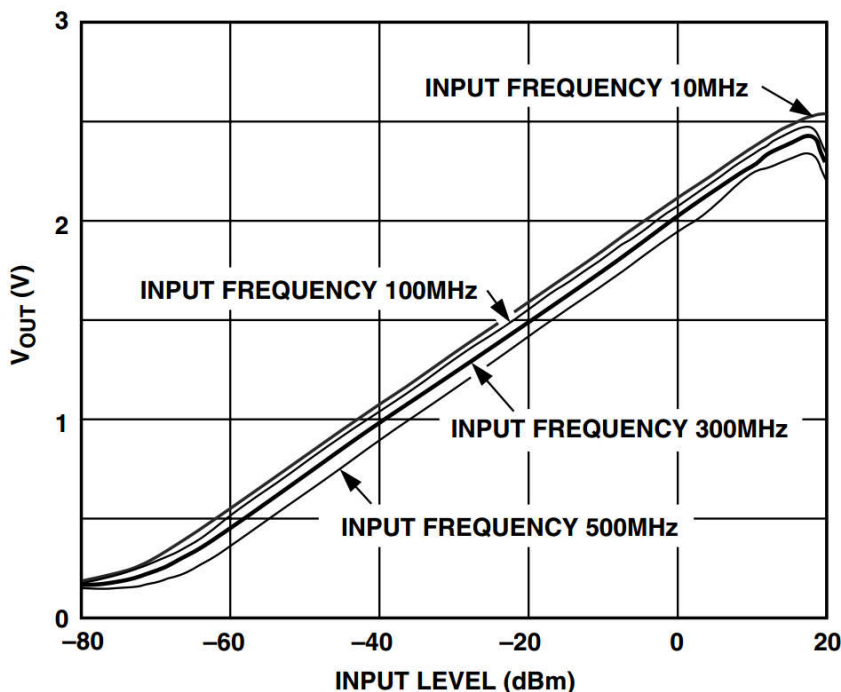


Fig. 5: AD8307 characteristics.

In advance it is therefore necessary to consider,

- a) which maximum TX power the coupler has to measure,
- b) how large the coupling factor of the current coupler and the attenuator must be in order not to exceed the +10dBm at the LogAmp,
- c) which TX powers have to be set in order to hit the two calibration points.

This is what the Excel sheet in the download is for.

Point c) above is not easily accomplished with a TX. For the upper +10dBm calibration point, the coupling factor and attenuator must be selected so that this can be done with the available TX power. The -60dBm calibration point is only adjustable with an additional power attenuator at minimum TX power, better, if available, with a calibrated signal generator. Example calculation for a common 100W TX:

Sample calculation for standard TX power 100W

Max power (PEP)	100 W	50,00 dBm
System impedance	50 Ω	
LogAmp max input level for calibration	10 dBm	
LogAmp extrapolated input level	13 dBm	

LogAmp input level [dBm] = TX power [dBm] + toroid coupling factor [dB] - attenuator [dB]

Toroid turns	25	26	27	28	29	30
Coupling factor [dB]	-27,96	-28,30	-28,63	-28,94	-29,25	-29,54
Attenuator input [dBm]	22,04	21,70	21,37	21,06	20,75	20,46
Attenuator [dB]	12,00	11,50	11,00	11,00	10,50	10,00
LogAmp input [dBm]	10,04	10,20	10,37	10,06	10,25	10,46
TX power [dBm] for 10dBm LogAmp input	49,96	49,80	49,63	49,94	49,75	49,54
TX power [W] for 10dBm LogAmp input	99,06	95,49	91,78	98,70	94,36	90,00
TX power [dBm] for 13dBm LogAmp input	52,96	52,80	52,63	52,94	52,75	52,54
TX power [W] for 13dBm LogAmp input	197,64	190,52	183,12	196,93	188,28	179,57

The attenuators were selected with a given coupling factor so that the 10dBm point can still be safely calibrated with 100W TX power. With extrapolation of the calibration line to 13dBm, twice the power can still be measured.

6 Setup

The program enters the setup mode if, when switching on the device, the OK button is pressed until the appearance of the splash screen or if the coupler is not yet calibrated. In setup, the data required for the measurements are entered and stored in the EEPROM. The first time you burn a virgin controller, setup data 1...10 are pre-set in the EEPROM. If an already used controller is used, the EEPROM should be cleared before the first flashing.

Setup data exemplary for 100W TX power, 28 toroidal windings (positive coupling factor 28.9dB) and 11dB attenuator.

6.1 Setup 1 to 10

According to the jumper setting (Fig. 3), the data block for the currently used coupler (= "Unit") is selected. The first two setup steps apply to all couplers.

1. Setup 1 of 10: LCD backlight

In order to be able to operate the device also portable with battery supply, the main consumer, the LCD backlight, can be dimmed. This is done with pulse width modulation (PWM) via the MOSFET T1 (see schematic).

Line 1	Setup 1/10		
Line 2	LCD PWM 100	Minimal value	0
		Maximum value	240
		Step width Up	10
		Step width Down	10

The background brightness is set immediately by pressing the Up or Down buttons.

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.

2. Setup 2 of 10: Number of ADC measurements for averages

Line 1	Setup 2/10		
Line 2	ADC Rep 20	Minimal value	1
		Maximum value	50
		Step width Up	10
		Step width Down	1

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.

3. Setup 3 of 10: Coupling factor

Line 1	Setup 3/10 Unit1		
Line 2	Cp-Fac 28.9dB	Minimal value	10,0
		Maximum value	40,0
		Step width Up	1,0
		Step width Down	0,1

The coupling factor is the fraction (dB) of the input power taken for the measurement. For toroid cores for the HF range it can be calculated as

$$Cp - Fac = 20 * LOG_{10}(1/N), \quad N = \text{number of toroid turns}$$

Optionally, it can be determined by measurement.

The value to be entered is positive!

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.

4. Setup 4 of 10: Log Amplifier attenuator

The Pi attenuator between coupler and Log Amplifier reduces the decoupled RF signal to a compatible level for the log amp.

Line 1	Setup 4/10 Unit1		
Line 2	Amp Att 11.0dB	Minimal value	0,0
		Maximum value	40,0
		Step width Up	1,0
		Step width Down	0,1

5. Setup 5 of 10: Calibration frequency (for information only)

Zeile 1	Setup 5/10 Unit1		
Zeile 2	Freq 10MHz	Minimal value	1
		Maximum value	3.000
		Step width Up	10
		Step width Down	1

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.

6. Setup 6 of 10: Lower Log Amp calibration level

Line 1	Setup 6/10 Unit1		
Line 2	CalLo -60.0dBm	Minimal value	-80,0
		Maximum value	-30,0
		Step width Up	1,0
		Step width Down	0,1

The calibration assumes that the coupler incl. log amp converts the RF power logarithmical linearly into the measuring voltage in the intended measuring range. For the AD8307, this condition is valid between -60 and + 10dBm. Here, as in the next chapter, the levels at the input of the log amps are meant, not the TX levels at the coupler input.

Both values may be chosen arbitrarily at the ends of the linear characteristic. It could be convenient to check at first, which values can be set at the upper or lower end. With the TX signal level (dBm) minus coupling factor (dB) minus attenuator attenuation (dB) you get the values for setup 6 and 7.

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.

7. Setup 7 of 10: Upper Log Amp calibration level

Line 1	Setup 7/10 Unit1		
Line 2	CalHi 10.0dBm	Minimal value	-20,0
		Maximum value	30,0
		Step width Up	1,0
		Step width Down	0,1

From the lower and upper calibration points, a calibration line is calculated from which the log amp input level (dBm) is determined as function of the ADC counts. By adding the coupling factor (dB) and the log amp attenuator attenuation (dB) the TX power is calculated.

The margin between minimum and maximum value should be as large as possible to define the calibration line with sufficient accuracy. Depending on the log amps used, R11 on IC1 (LM336 2.5V, see schematic) can be used to adjust the reference voltage of the ADC to the maximum output voltage of the log amps within limits. The max. AD8307 DC output is about 2.5V. Preliminary considerations are possible with the Excel sheet in the download.

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.

8. Setup 8 of 10: Lower Log Amp measuring limit

Lower limit of the log amp input level, down to which a power or SWR display takes place. The calibration line is extrapolated to this point.

A FWD level less than the lower measuring limit is interpreted as "TX off". It should be noted that the high sensitivity of the FWD log amp still might detect the suppressed carrier with TX on, but without voice modulation.

If the lower measurement limit is set to a value within the calibration range (Setup 6, 7), which may be necessary for a bad carrier suppression for TX off detection, the lower measurement limit in the REV channel is set to the lower calibration point (Setup 6).

Line 1	Setup 8/10 Unit1		
Line 2	LimLo -63.0dBm	Minimal value	-80,0
		Maximum value	-20,0
		Step width Up	1,0
		Step width Down	0,1

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.

9. Setup 9 of 10: Upper Log Amp measuring limit

Upper limit of the log amp input level, up to which a power or SWR display takes place. The calibration line is extrapolated to this point.

Line 1	Setup 9/10 Unit1		
Line 2	LimHi 13.0dBm	Minimal value	-10,0
		Maximum value	30,0
		Step width Up	1,0
		Step width Down	0,1

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.

10. Setup 10 of 10: PEP sample & hold time

Line 1	Setup10/10 Unit1		
Line 2	PEP hold 2.0sec	Minimal value	0,1
		Maximum value	9,9
		Step width Up	1
		Step width Down	0,1

Measuring peak envelope power (PEP), the maximum amplitude signal is sampled with the ADC over this time. With the settings of the controller:

Controller clock 16MHz
 ADC divider 128, so ADC clock 125kHz
 13 ADC clocks for one measurement ADC sample rate 9.6kHz

This should be enough, according to Nyquist, to scan the modulated speech spectrum for peaks.

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.

6.2 Calibration

The calibration must be carried out separately for each coupler to be used, subsequently for the coupler (Unit) 1. Calibration shall be carried out with a CW signal at the frequency specified in setup #5. The ADC values are averaged over the number of individual measurements specified in setup #2. 50 individual measurements would be appropriate here.

A calibration with a signal generator without coupler is described in section 8.

The walk through of the previous part to control the data is done quickly. In order to avoid that the calibration for an already calibrated coupler is overwritten by mistake, in this case, and only then, a query is made.

Line 1	Replace calib.?
Line 2	Y (OKlong), N (Up)

Only if the **OK button** has been pressed long the calibration described below will be carried out.

The setup is finished with the **Up button**, see paragraph 15 below.

If the calibration points (above paragraphs 6 and / or 7) or the ADC reference voltage have been changed with the LM336 (see schematic), recalibration is required.

11. Coupler calibration Forward, lower limit

The following four steps calibrate the coupler, including the log amps, at the upper and lower forward and reverse channel calibration points specified above.

Line 1	Cal Unit1 FWD Lo
Line 2	Ant out 50Ω ->OK

Terminate the antenna output "Ant out" of the coupler with 50Ω (Dummy Load), TRX output to "TX in" of the coupler.

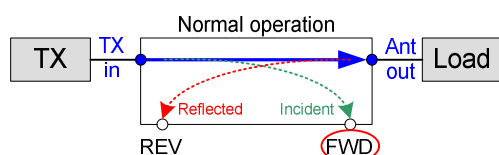


Fig. 6: Coupler operated "forwards". The signal coupled in the FWD channel is measured. "Incident" = "FWD".

Press OK to continue.

Line 1	Cal Unit1 FWD Lo
Line 2	-20.1dBm XXXX

-20.1dBm is the power to be injected in the coupler (~ 9.8µW!) in order to match the in **Setup 3** defined coupling factor (here 28.9dB) and in **Setup 4** defined attenuation of the attenuator in front of the log amp (here 11dB) in **Setup 6** defined calibration point of the LogAmp (here -60dBm).

"XXXX" is the value of that power level measured by the ADC of the forward channel. It should be between 200 and 300 at the lower calibration point.

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.
Short press on "OK": Value is **not** stored.

Conversion factors:

$$P(dBm) = 10 * LOG_{10}[P(mW)] = 10 * LOG_{10}[1000 * P(W)]$$

$$P(W) = 10^{\frac{P(dBm)}{10}} / 1000 \quad P(mW) = 10^{\frac{P(dBm)}{10}}$$

12. Coupler calibration Reverse, lower limit

Line 1	Cal Unit1 REV Lo
Line 2	TRX in 50Ω ->OK

Dummy Load and TRX change their places:
 50Ω (dummy load) at the input "TX in" of the coupler,
 TRX output to the antenna output "Ant out" of the coupler.

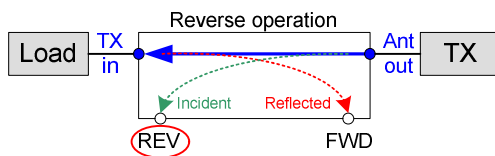


Fig. 7: Coupler operated "backwards". The signal coupled in the REV channel is measured. "Incident" = "REV".

Press OK to continue.

Line 1	Cal Unit1 REV Lo
Line 2	-20.1dBm XXXX

The injected transmission power remains unchanged.

"XXXX" is the value of this power level measured by the ADC of the reverse channel.

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.
Short press on "OK": Value is **not** stored.

13. Coupler calibration Forward, upper limit

Line 1	Cal Unit1 FWD Hi
Line 2	Ant out 50Ω ->OK

Dummy Load and TRX change their places again (as in Fig. 6):
 Terminate the antenna output "Ant out" of the coupler with 50Ω (dummy load);
 TRX output to "TX in" of the coupler.

Press OK to continue.

Line 1	Cal Unit1 FWD Hi
Line 2	49.9dBm XXXX

49.9dBm is the power to be injected in the coupler (~ 98.7W) to match the in **Setup 3** defined coupling factor (here 28.9dB) and in **Setup 4** defined attenuation of the attenuator in front of the log amp (here 11dB) in **Setup 7** defined calibration point of the Log Amp (here + 10dBm).

"XXXX" is the value of that power level measured by the ADC of the forward channel. It should be between 800 and 1,000 at the upper calibration point for the best possible ADC resolution, but less than 1023, the highest possible value of the 10-bit ADC.

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.

Short press on "OK": Value is **not** stored.

14. Coupler calibration Reverse, upper limit

Line 1	Cal Unit1 REV Hi
Line 2	TRX in 50Ω ->OK

Dummy Load and TRX change their places again (as in Fig. 7): 50Ω (dummy load) at the input "TX in" of the coupler, TRX output to the antenna output "Ant out" of the coupler.

Press OK to continue.

Line 1	Cal Unit1 REV Hi
Line 2	49.9dBm XXXX

The injected transmission power remains unchanged.

"XXXX" is the value of this power level measured by the ADC of the reverse channel.

Long press on "OK": Value is stored, acknowledged with "S" in line 2 on the right.

Short press on "OK": Value is **not** stored.

The calibration line can be visualized using the excel sheet mentioned above.

15. End of Setup

Line 1	Setup finished
--------	----------------

Finally, it is checked whether all the data of the coupler are set in the EEPROM, i.e. are not equal to 0 or ≥ 0 .

If yes

Line 2	Unit 1 complete
--------	-----------------

If no

Line 2	* Data missing *
--------	------------------

16. Litmus test

If an audio two-tone generator is available, connect it to the mic input of the TRX. Measurement mode PEP. Check the balance of both tone amplitudes.

- Modulation with only one tone:
The power meter displays a certain value at "F" (Forward), e.g. 1W.
- Modulation with both tones:
The superposition of the two tones now has twice the amplitude. Thus, instead

1W (one tone) now about 4W (two tone), so the quadruple power displayed. The power results from the square of the voltage amplitudes. In PEP mode, the ADC samples the peak of the modulated RF voltage.

The factor 4 will not come out exactly because of the limited ADC resolution. An ADC bit more or less might result in a slightly wrong conversion of dBm to watts because of the power of ten.

7 Optimizing directivity

With the C-Trimmer in the coupler (see schematic) the directivity and thus the smallest measurable SWR value can be optimized, if it is installed. Although you cannot measure the directivity, you can at least set to the best value at the upper frequency limit.

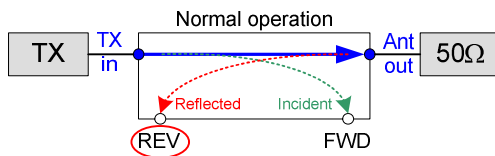


Fig. 6: Coupler "forward" operated.

Termination at the antenna output with a good (!) 50Ω terminator.

TX input e.g. 30 ... 50MHz, about 20dBm (100mW).

- Setup in position 12 or 14 (measurement of the REV channel).
- Use the trimmer to set the minimum ADC display.
- With the OK button, repeatedly pressed short, i.e. without storing, leave the setup.

Alternatively, the voltage supplied by the REV-log amp at port A1 (ADC1) of the Arduino can be measured with a digital voltmeter.

8 Optional calibration method

If you have a (calibrated) signal generator and good attenuators, you can also calibrate the LogAmp module directly, i.e. without the coupler. It is implicitly assumed that its coupling factor, calculated from the number of turns, is actually correct over the desired frequency range. Furthermore, that the coupler is actually symmetrical regarding FWD (Incident) and REV (Reflected). Both can be assumed with careful design.

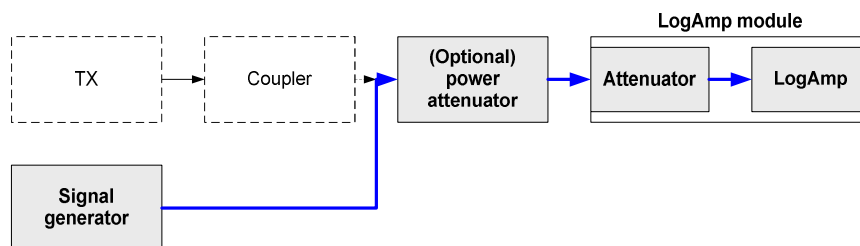


Fig. 8: Calibration with a signal generator.

1. Calculation of the output power of the signal generator (dBm) from the calibration levels of the LogAmp, for example -60 and +10dBm, plus attenuator values, see also Excel sheet "Calibration2" in " SWR coupler & Log amp_Rev4.xlsx.
2. Calibration with the low level, above numbers 11 and 12, immediately one after the other. The annoying turning of the coupler is therefore omitted.
3. Calibration with the High-Level, above numbers 13 and 14, directly one after the other. The annoying turning of the coupler is also omitted here.