

USER MANUAL

ZB-4 CW QRP Transceiver

Four-band CW QRP transceiver for 80/60/40/30 m with AD9850 DDS



DL6ZB

Rolf L. Heine

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for firmware version 1.0.14 (file 24-03-23-006.hex)

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Copyright

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How to use this manual

Read section 2 (safety and legal notices) and section 5 (getting started) before you connect the ZB-4 to an antenna and transmit. Keep this manual for later reference. The latest firmware and information are available on the project page.

Push buttons are written as on the display and the project page: **ENC** is the push button of the rotary encoder (FREQ knob), **WPM** is the multi-function WPM button (S2 in the schematic). Display texts are shown in MONOSPACE CAPITALS. The front panel shown in the photos belongs to the author's build; your build may look different.



WARNING

Indicates a hazard that can cause injury, fire, harmful interference, or serious damage to the transceiver or the connected equipment.



CAUTION

Indicates a situation that can damage the transceiver or the connected equipment or cause malfunction.



NOTE

Useful hints and additional information.

Contents

1	Introduction and intended use	4
1.1	About the ZB-4	4
1.2	Intended use	4
1.3	About this manual	5
2	Safety and legal notices	5
2.1	General safety	5
2.2	Power supply and electrical ratings	6
2.3	Antenna and RF exposure	6
2.4	Spurious emissions and low-pass filters	6
2.5	Electrostatic discharge (ESD)	7
2.6	Homebrew design – your responsibility	7
3	Features and technical data	7
3.1	Features	7
3.2	Technical data	8
3.3	Main modules	8
4	Controls, display and connections	9
4.1	Front panel	9
4.2	Display	10
4.3	Connections	11
4.4	Inside the ZB-4	12
5	Getting started	12
5.1	Before first use	12
5.2	Connecting the transceiver	12
5.3	Switching on	13
5.4	First steps	13
6	Operation	13
6.1	Push buttons	13
6.2	Tuning and tuning step	13
6.3	Band selection	13
6.4	Receiving	14
6.5	Transmitting, QSK, zero beat and RIT	14
6.6	CW speed and keyer options	14
6.7	Sidetone	14
6.8	Entering your callsign	15
6.9	Auto CQ and CQ loop	15
6.10	PC remote control (CAT)	15
7	Menu reference	16
7.1	Display messages	17
7.2	Factory defaults	17
8	Alignment and filters	17
8.1	DDS trimmer (mixer phase)	17
8.2	AD9850 module: serial programming mode	17
8.3	RF low-pass filters	18
8.4	AF band-pass filter (CW filter)	19
9	Firmware	19
9.1	Firmware download	19
9.2	Uploading the firmware with XLoader	19
9.3	Notes	20
10	Schematic and theory of operation	20
10.1	Block diagram	20
10.2	Theory of operation	20
10.3	Main components	22
10.4	Schematic	23
11	Troubleshooting	24
12	Disposal, warranty, license and contact	25
12.1	Disposal	25
12.2	Warranty and liability	25
12.3	License and copyright	25
12.4	Trademarks	25
12.5	Contact	26
A	Quick reference card	26
B	Revision history	27

1 Introduction and intended use

1.1 About the ZB-4

The ZB-4 is a neat, easy-to-build four-band CW QRP transceiver for the 80, 60, 40 and 30 m amateur bands, designed by Rolf L. Heine, DL6ZB, and published as a weekend project for the home builder.

The design is based on a classic direct-conversion (DC) receiver and a class C transmitter. The VFO is an Analog Devices AD9850 DDS module, the heart of this tiny multibander, controlled by a Microchip ATmega328P microcontroller. The receiver uses a 74HC4066 CMOS switch as mixer, a low-noise preamplifier with two NPN transistors, a TL084 quad op-amp for amplification and filtering, and an LM386 audio power amplifier for headphones or a small loudspeaker. The transmitter delivers an output power of 5 W with a MOSFET power stage.

The aim of the development was a transceiver that is as simple as possible to build but still performs reasonably well and is also suitable for battery operation. Its small dimensions make the ZB-4 a real pocket-size rig.



Figure 1: The ZB-4 in the author's station.



Figure 2: The author's ZB-4 with the enclosure open (details in section 4.4).

1.2 Intended use

The ZB-4 is intended exclusively for

- receiving and transmitting Morse code (CW) in the amateur radio bands 80, 60, 40 and 30 m,
- by **licensed radio amateurs** only, within the frequencies, modes and power limits of their license and the national regulations (in Germany: *Amateurfunkgesetz – AFuG* – and *Amateurfunkverordnung – AFuV*),
- with a 50 Ω antenna or dummy load connected via the low-pass filter for the band in use, and within the limits given in the technical data (section 3.2).

Any other use is considered improper. This includes in particular: transmitting without a valid amateur radio license or outside the amateur bands, transmitting without a suitable low-pass filter or into an open or mismatched antenna connector, operating from a supply voltage outside 11 to 14 V, and connecting signals with RS-232 voltage levels to inputs other than the RS-232 jack.

Listening may be possible without a license, depending on national law, but transmitting is permitted only to licensed radio amateurs.

1.3 About this manual

This edition describes firmware version 1.0.14 (file 24-03-23-006.hex) and the schematic dated January 23, 2024. It combines the information from the ZB-4 project page, the schematic, the author's earlier German manual draft ("Handbuch ZB-4", April 2023) and the display texts of the firmware, and adds illustrations, safety and legal notices, a menu reference, troubleshooting hints and a quick reference card.

This is a hobby project. The technical data are approximate values and may change with future firmware or hardware versions. Where the sources do not specify a detail (for example receiver sensitivity or operating temperature), this manual does not specify it either. Check the project page for updates.

2 Safety and legal notices

Read these notices before building, connecting, or transmitting with the ZB-4. They are general information for a hobbyist design and do not replace your own judgment or legal advice.

2.1 General safety



WARNING – THIS IS A TRANSMITTER

The ZB-4 generates radio-frequency power of about 5 W. Never transmit without a suitable antenna or a 50 Ω dummy load connected to the antenna socket, and never touch the antenna, the antenna connector or open RF circuits while transmitting: RF burns are possible.

- Transmitting is permitted only to holders of an amateur radio license (section 1.2).
- Do not operate the transceiver if it, its cables, or the power supply are damaged, wet, or overheated. Protect it from moisture.
- The power transistor (MOSFET RD06HHF1) can become hot during transmission. Make sure that it is adequately cooled in your build and do not touch it during or right after operation.
- Keep the transceiver and small parts away from children.



CAUTION – VOLUME

The direct-conversion receiver has no automatic gain control (AGC). Strong signals can produce painfully loud audio in the headphones. Turn AF GAIN down before putting on headphones and before switching bands. Two anti-parallel diodes in the AF chain limit the level, but they do not replace a careful volume setting.

2.2 Power supply and electrical ratings

Supply voltage	+11 to 14 V DC at the power socket X4
Power connector	DC barrel jack 5.5 × 2.5 mm (outer × inner diameter), centre positive : centre pin = +11 to 14 V, outer contact = GND 
Fuse	F1, 2.5 A fast-acting, in the supply line
Reverse-polarity protection	diode D1 (1N4001) across the supply behind the fuse
Current consumption	receive approx. 120 mA, transmit approx. 450 mA

- Never connect any part of the transceiver to the mains. Use a regulated DC power supply or a battery suitable for 11 to 14 V that complies with the applicable safety standards.
- Observe the polarity: the power socket is centre positive. Check with a meter that the centre pin of your supply cable's plug carries plus before you connect it. With reverse polarity, D1 conducts and the fuse F1 blows; replace it only with a fuse of the same rating (2.5 A, fast-acting).
- A very clean supply is important for the first AF stage; hum and noise in a direct-conversion receiver usually originate there.
- Make and change connections only while the transceiver is not transmitting.

2.3 Antenna and RF exposure



WARNING – ANTENNA SAFETY

Install antennas well away from power lines; contact can be fatal. Outdoor antennas must be protected against lightning and static charges in accordance with the applicable installation rules. Disconnect the antenna cable from the transceiver during thunderstorms.

Radio amateurs are responsible for the protection of persons against electromagnetic fields generated by their station. Depending on the transmitter power, the antenna gain and the location, national regulations may require you to assess the safety distances and, in some cases, to notify the authorities before operation. In Germany, these requirements are laid down in the Ordinance on Procedures for Limiting Electromagnetic Fields (BEMFV). Check the current requirements for your station and keep the antenna away from places where people stay.

2.4 Spurious emissions and low-pass filters

The class C power stage generates harmonics. The ZB-4 therefore uses relay-switched Cauer (elliptic) low-pass filters for 80/60 m and 40/30 m between the transmitter and the antenna (section 8.3). The filter values published by the author are examples.



WARNING – HARMFUL INTERFERENCE

As the operator of a self-built transmitter, you are responsible for ensuring that its spurious emissions and harmonics comply with the limits of your license and national regulations. Check the output signal of your build on all bands, ideally with a spectrum analyzer and a dummy load, before you connect it to an antenna. Never transmit with a missing, defective, or wrongly selected low-pass filter, and stop transmitting immediately if you cause interference.

2.5 Electrostatic discharge (ESD)

The microcontroller, the DDS module, the CMOS logic ICs (74HC4066, 74HC00) and the MOSFET are sensitive to electrostatic discharge. When building, programming or servicing the transceiver, discharge yourself on a grounded object first, work on an antistatic mat if possible, handle boards by their edges and avoid touching component pins.

2.6 Homebrew design – your responsibility

The ZB-4 is a non-commercial do-it-yourself design published free of charge by a radio amateur for radio amateurs. It is not a product placed on the market by the author. Therefore, the design carries **no CE marking**, and no EU declaration of conformity is issued for it.

Radio equipment built by radio amateurs for their own use and not made available on the market is generally excluded from the scope of the EU Radio Equipment Directive 2014/53/EU and the EMC Directive 2014/30/EU. This does not release you from your responsibilities. If you build or operate a ZB-4, you are responsible for your build and its use, in particular for

- the electrical safety of your build,
- the electromagnetic compatibility (EMC) of your build and your station – it must not cause harmful interference to other radio services or electronic equipment,
- the spectral purity of the transmitted signal (section 2.4), and
- compliance with the amateur radio regulations of your country (in Germany: AFuG and AFuV) and with the RF exposure regulations (section 2.3).

Anyone who makes built units available to others may become a manufacturer with additional legal obligations (for example product safety, radio equipment and EMC requirements, CE marking, and registration for electrical equipment). Note that the license terms do not allow commercial use of the firmware (section 12.3).

This information is provided for orientation only and does not constitute legal advice.

3 Features and technical data

3.1 Features

- AD9850 DDS generator module
- Microchip ATmega328P-PU, 20 MHz clock
- Rotary encoder with push button for frequency, RIT and menu
- 9600 baud RS-232 remote control, Kenwood protocol (partial TS-480 emulation)
- QSK with frequency shift and RX mute
- Microcontroller sidetone generator
- Automatic CQ call, also with CQ loop
- CQ loop contest mode
- Setup of your individual callsign for CQ
- Fixed CW filter, 700 Hz center frequency
- Receiver RIT for split-mode operation
- Relative signal strength display
- Battery (supply) voltage display
- I²C OLED display, 128 × 64
- Smooth iambic keyer, 5 to 50 WPM
- Single-lever and straight key option
- Bug key simulation option
- Output power 5 watts, MOSFET
- Elliptic LPFs: 80 & 60 m and 40 & 30 m

3.2 Technical data

Parameter	Value
Bands	80, 60, 40 and 30 m (frequency range 3.5–10.5 MHz according to the schematic)
Band presets (menu)	3560, 5353, 7030 and 10116 kHz
Tuning steps (menu)	10 Hz, 50 Hz, 100 Hz, 1 kHz, 10 kHz, 50 kHz
Mode	CW, QSK with frequency shift and RX mute
Output power	5 W, MOSFET RD06HHF1 (class C)
Low-pass filters	Cauer (elliptic), 50 Ω, 80/60 m and 40/30 m, relay-switched
Receiver	direct conversion (both sidebands), 74HC4066 switching mixer, 3.3 MHz high-pass filter at the input, no AGC
AF filter	fixed CW band-pass filter, 700 Hz center frequency
AF output	LM386, headphones or small loudspeaker, 3.5 mm jack (X3)
VFO	AD9850 DDS module, 125 MHz clock
Microcontroller	Microchip ATmega328P-PU, 20 MHz crystal
Display	0.96" SSD1306 I ² C OLED, 128 × 64 pixels
Keyer	iambic, 5 to 50 WPM; single-lever, straight key and bug simulation options
Remote control	RS-232 (MAX232), 9600 baud, 8N1, Kenwood TS-480 protocol (partial), 3.5 mm jack (X2)
Supply voltage	+11 to 14 V DC (power socket X4), fuse 2.5 A fast-acting
Current consumption	receive approx. 120 mA, transmit approx. 450 mA
Antenna connector	SO-239 (PL/UHF) socket, 50 Ω
Power connector	DC barrel jack 5.5 × 2.5 mm, centre positive
Dimensions (W × L × H)	100 × 100 × 40 mm (3.9 × 3.9 × 1.6 in)
Weight	approx. 400 g (14 oz)
Internal supplies	+5 V (7805), +7 V (78L07) for the mixer and the TX driver
Firmware	version 1.0.14, file 24-03-23-006.hex (Intel HEX, 20 MHz)
Not specified	receiver sensitivity, operating temperature

3.3 Main modules

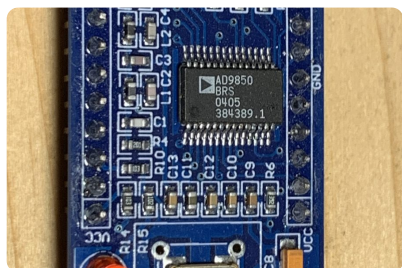


Figure 3: AD9850 DDS module. The blue trimmer potentiometer sets the 180° phase relationship of the mixer clocks (section 8.1).



Figure 4: 0.96" SSD1306 I²C OLED display, 128 × 64 (connections GND, VCC, SCL, SDA).

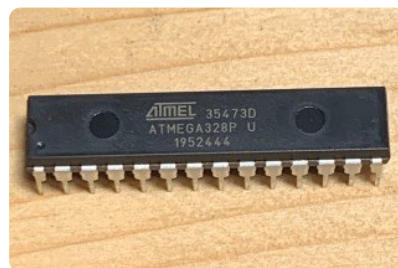


Figure 5: Microchip ATmega328P-PU microcontroller (DIP-28).

The DDS modules are usually available for less than US\$15 / €15 from online marketplaces. They are characterized by high frequency stability and low phase noise; the internal comparator of the AD9850 makes it particularly interesting for this application, because it supplies the clock signals for the mixer.

4 Controls, display and connections

4.1 Front panel



Figure 6: Front panel of the author's build. The panel legend “40/30 METER CW QRP” is struck through on this unit; the ZB-4 covers 80/60/40/30 m.

No.	Element (schematic)	Function
1	WPM button (labelled FILTER on the author's unit)	Push button S2 “WpM” of the schematic. On the author's unit, this button is mislabelled FILTER; it is the WPM button. Functions: section 6.1.
2	AF GAIN (R26, 10 kΩ log)	Volume. There is no AGC – start with a low setting.
3	PHONES (X3, 3.5 mm jack)	Headphones or small loudspeaker (LM386 output; both channels of a stereo plug are connected).
4	OLED display (0.96" SSD1306)	Frequencies, signal strength, supply voltage, CW speed, menus (section 4.2).
5	FREQ knob – rotary encoder ENC1 with push button ENC	Tuning; short press: TX zero beat; long press (0.5 s): RIT on/off (section 6.1).

4.2 Display



Figure 7: Main screen on 30 m. In this example, the receiver is tuned 0.05 kHz (50 Hz) above the transmit frequency.

No.	Indication	Meaning
1	Large frequency, e.g. 10115.85	Receive frequency in kHz
2	Bar graph	Relative signal strength (S-meter)
3	TX: 10115.80	Transmit frequency in kHz
4	+0.05	Receive offset from the transmit frequency in kHz (RIT)
5	Ub: 12.0 V	Supply (battery) voltage
6	WpM: 22	CW speed in words per minute
–	CAT	Shown in the upper right corner (see the cover photo): PC remote control (CAT) indication



Figure 8: Main screen (display module before installation).



Figure 9: The RIG SETUP menu with item 1 highlighted (section 7).



Figure 10: Callsign entry: CALL : NO CALLSIGN (section 6.8).

4.3 Connections

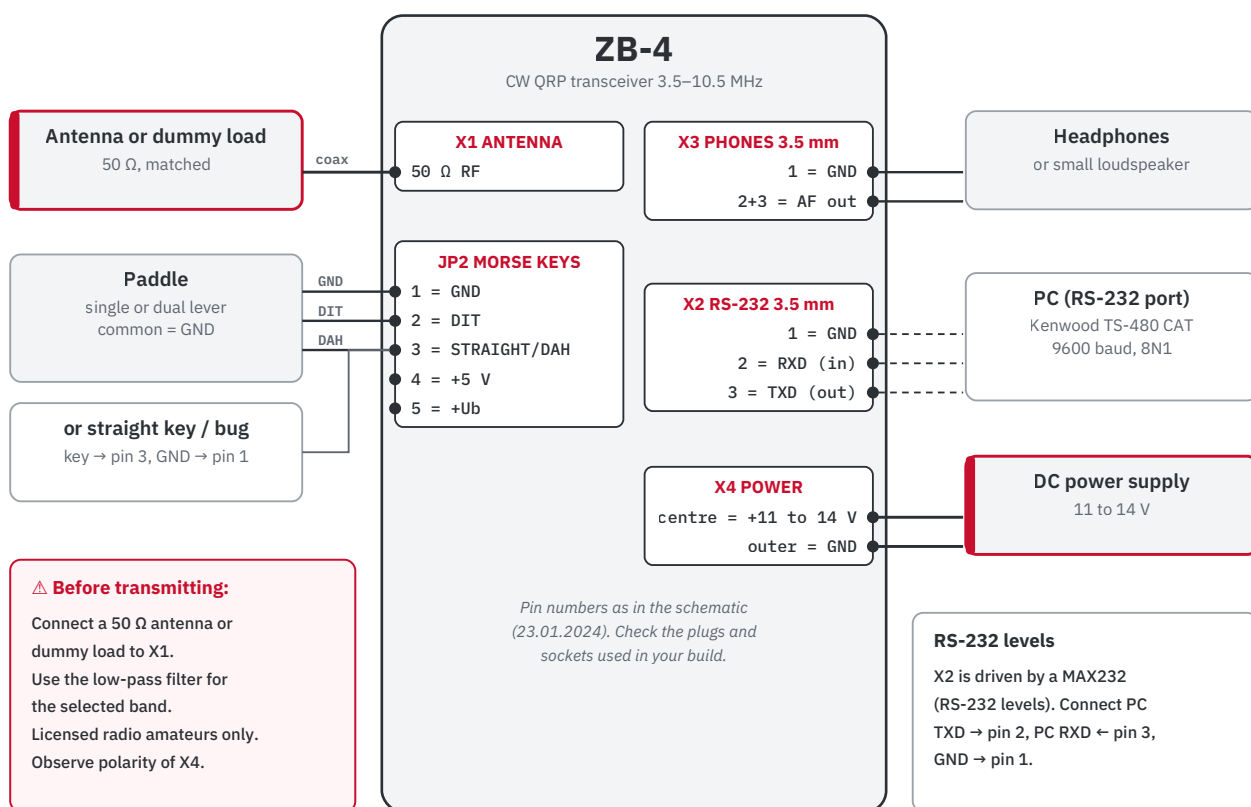


Figure 11: Connection overview. Connector names and pin numbers are those of the schematic (January 23, 2024).

Connector (schematic)	Pins	Connect to
X1 ANT , SO-239 (PL/UHF) socket	RF, 50 Ω	Antenna or dummy load, 50 Ω
X4 POWER SOCKET , DC barrel jack 5.5 × 2.5 mm	centre pin = +11 to 14 V · outer contact = GND (centre positive)	Regulated DC power supply or battery
X3 phones , 3.5 mm jack	1 = GND · 2 and 3 = AF output (connected)	Headphones or small loudspeaker
X2 RS232 , 3.5 mm jack	1 = GND · 2 = RXD (data into the ZB-4) · 3 = TXD (data from the ZB-4)	RS-232 serial port of a PC (section 6.10)
JP2 MORSE KEYS (board header)	1 = GND · 2 = DIT · 3 = STRAIGHT/DAH · 4 = +5 V · 5 = +Ub	Paddle (DIT, DAH, GND) or straight key / bug (pin 3 and GND)

The antenna socket is an SO-239 (PL/UHF) socket, and the power socket is a DC barrel jack 5.5 × 2.5 mm, centre positive; check the polarity of your supply cable before connecting it. The sources do not specify the jack used for the key on the author's build; wire it according to the table. Pins 4 (+5 V) and 5 (+Ub) of JP2 carry supply voltages – do not short them to the key lines or to ground.



CAUTION – RS-232 LEVELS

X2 is driven by a MAX232 level converter and uses RS-232 voltage levels. Connect it only to an RS-232 port (or a USB-to-RS-232 adapter with RS-232 levels). Never connect the RS-232 lines to the key inputs.

4.4 Inside the ZB-4



Figure 12: The author's ZB-4 with the enclosure open. Callout positions are approximate.

The receiver is housed in a tinplate enclosure, which is hidden beneath the transmitter and the low-pass filters. The transmitter, with its output transistor, is mounted on top of the tinplate case. Behind it are the two low-pass filters for 80/60 and 40/30 meters. The DDS module and the microcontroller are located at the side.

5 Getting started

5.1 Before first use

- ☐ The ATmega328P has been programmed with the current firmware for 20 MHz (section 9).
- ☐ The RESET line of the AD9850 module is connected to GND (section 8.2).
- ☐ Both low-pass filters are installed and checked (section 8.3); the DDS trimmer has been adjusted (section 8.1).
- ☐ The output signal has been checked into a 50 Ω dummy load, ideally with a spectrum analyzer (section 2.4).
- ☐ You hold an amateur radio license that permits transmitting on the band you want to use.

5.2 Connecting the transceiver

- 1** Connect a 50 Ω antenna for the desired band, or a dummy load, to the antenna socket X1 (SO-239, PL plug).
- 2** Connect the paddle (DIT, DAH, GND) or a straight key / bug (pin 3 and GND) to the MORSE KEYS connection.
- 3** Turn AF GAIN down and connect headphones or a small loudspeaker to the phones jack X3.
- 4** Optionally connect the RS-232 port of your PC to X2 (section 6.10).
- 5** Connect the DC supply (+11 to 14 V) to the power socket X4 (DC barrel jack 5.5 $\times$ 2.5 mm, centre positive). Check the polarity of your supply first (section 2.2).

5.3 Switching on

The schematic shows no power switch; the ZB-4 is switched on and off with its external supply. After switching on, the display shows a start-up sequence with the texts HELLO, SETUP TRANSCEIVER . . . and READY ., together with the copyright notice and the firmware version (VERSION 1.0.14). The main screen then appears (section 4.2). Check the supply voltage U_b on the display.

5.4 First steps

- 1 **Select the band:** after switching on, the ZB-4 starts on 7030 kHz (section 7.2). To change the band, open the menu (section 7), select 2: HAM BAND and choose 3560, 5353, 7030 or 10116 kHz.
- 2 **Listen:** slowly raise AF GAIN and tune with the FREQ knob. Select a convenient tuning step in 4: FRQ STEP.
- 3 **Set the CW speed:** press **WPM**, then use the paddle: dots = faster, dashes = slower; press **WPM** again to finish (section 6.6).
- 4 **Enter your callsign:** menu 3: RIG SETUP → 1: CALLSIGN (section 6.8). Auto CQ remains disabled until a valid callsign has been entered.
- 5 **Transmit:** make sure that the frequency is free, then key the transmitter with the paddle or key. To answer a station, zero beat with a short press of **ENC** (section 6.5).

6 Operation

6.1 Push buttons

The transceiver has two push buttons: **ENC** is the push button built into the FREQ knob (rotary encoder), and **WPM** is the multi-function WPM button (labelled FILTER on the author's unit). A long press lasts about 0.5 s.

Button	Short press	Long press
ENC	TX zero beat	RIT on / off
WPM	CW speed (words per minute)	Auto CQ
ENC + WPM	QSO mode: auto CQ loop, CQ 10 times, 10-second spacing	Contest mode: auto CQ loop, 10 times, 2-second spacing

Functions of the two push buttons. In the menus and dialogs, the display shows the keys to use, for example <ENC> = ENTER and <WpM> = ESCAPE, or WpM=YES ENC=NO.

6.2 Tuning and tuning step

Turn the FREQ knob (rotary encoder) to tune. The tuning step is selected in the menu item 4: FRQ STEP: 10 Hz, 50 Hz, 100 Hz, 1 kHz, 10 kHz or 50 kHz. Use a small step for tuning in CW stations and a large step for moving quickly within the band.

6.3 Band selection

Select the band in the menu item 2: HAM BAND. The presets are 3560 kHz (80 m), 5353 kHz (60 m), 7030 kHz (40 m) and 10116 kHz (30 m). The microcontroller selects the low-pass filter for 80/60 m or 40/30 m with the band relay K4.

**NOTE**

If the frequency is outside an amateur band, the transmitter is not keyed and the display shows OUT OF BAND – TRANSMITTER OFF – CHANGE FREQUENCY. The 60 m allocation and its conditions differ from country to country; observe your national regulations.

6.4 Receiving

- The direct-conversion receiver receives both sidebands. In practice, the author found that this is not a real drawback.
- The fixed CW filter boosts the signal of interest around 700 Hz, while the activity around that frequency remains slightly audible (section 8.4).
- There is no AGC. Adjust AF GAIN to the signal level; anti-parallel diodes in the AF chain limit very strong signals.
- The bar graph on the display shows the relative signal strength.
- While transmitting, the receiver is muted (JFET BF245), and the sidetone generated by the microcontroller is audible in the headphones.

6.5 Transmitting, QSK, zero beat and RIT

- **Keying:** the transmitter is keyed with the paddle (iambic keyer) or a straight key. The ZB-4 works with full break-in (QSK) with frequency shift and RX mute; the RX/TX relay K1 and the receiver mute are controlled by the microcontroller.
- **TX zero beat:** short press **ENC**.
- **RIT:** the receiver RIT allows split-mode operation. A long press (about 0.5 s) on the FREQ knob switches the RIT on; while the RIT is on, turn the FREQ knob to set the receive offset. Another long press (0.5 s) switches the RIT off. The display shows the transmit frequency (TX:) and the receive offset in kHz (section 4.2).
- While the frequency is outside an amateur band, the transmitter remains off (section 6.3).

**CAUTION**

Before transmitting, make sure that the low-pass filter for the band in use is effective and that an antenna or dummy load is connected. Listen first to make sure that the frequency is free.

6.6 CW speed and keyer options

To set the CW speed (5 to 50 WPM), press **WPM** (labelled FILTER on the author's unit), then set the speed with the paddle: **dots = faster, dashes = slower**. Press **WPM** again to end the speed setting. The current speed is shown on the main screen as WpM. The factory default is 20 WPM with a dot/dash ratio of 1:3 (section 7.2).

The keyer is a smooth iambic keyer for dual-lever paddles. In the menu 3: RIG SETUP → 2: KEYER & CONTEST, you can select the single-lever and straight key option (STRAIGHT KEY), the bug key simulation (EL-BUG), and the contest mode (CONTEST ? – confirm with WpM=YES or reject with <ENC>=NO).

6.7 Sidetone

The sidetone is generated by the microcontroller. Its pitch is set in the menu 3: RIG SETUP → 3: SIDETONE. The display shows SIDETONE: ... Hz and the prompt PRESS MORSE KEY FOR AUDIO: operate the key to hear the current setting. <ENC> = ENTER confirms, <WpM> = ESCAPE leaves the setting.

6.8 Entering your callsign

Auto CQ uses your individual callsign. Enter it in the menu 3: RIG SETUP → 1: CALLSIGN. The display guides you through the entry:

- 1 TURN <ENC> FOR LETTER – turn the FREQ knob to select a character.
- 2 (S)HORT:SELECT LETTER – a short press of **ENC** selects the character.
- 3 (L)ONG :SAVE NEW CALL – a long press of **ENC** finishes the entry.
- 4 NEW CALLSIGN? WpM=YES ENC=NO – press **WPM** to save the new callsign or **ENC** to keep the old one (NO CHANGE).

The display counts the characters (... OF 14); a longer entry is rejected with CALL TOO LONG. If the entry is not a valid amateur radio callsign, the display shows NO VALID CALLSIGN.

6.9 Auto CQ and CQ loop

This transceiver has an auto-CQ feature. To use it, enter your callsign first (section 6.8). The auto-CQ feature remains disabled until a valid amateur radio callsign has been entered; otherwise, the display shows NO REAL CALLSIGN – GO TO RIG SETUP.

Procedure	Function
WPM long	Auto CQ: a CQ call (beginning with CQ CQ CQ CQ DE) with your callsign
ENC + WPM short	QSO mode: auto CQ loop, CQ 10 times, 10-second spacing
ENC + WPM long	Contest mode: auto CQ loop, 10 times, 2-second spacing
WPM or ENC	Interrupts auto CQ (display: AUTO CQ STOPPED)

During a CQ loop, the display shows a countdown (COUNT DOWN:) until the next call.



CAUTION

Auto CQ transmits without your intervention. Stay at the station during a CQ loop, listen for replies between the calls, and make sure that the frequency is free.

6.10 PC remote control (CAT)

The transceiver partially emulates the Kenwood TS-480 PC remote control. The RS-232 speed is 9600 baud, 8N1. The author has tested the remote control with several PC ham radio programs, such as CQRLOG and DXLab. However, not every Kenwood command is implemented, so it cannot be guaranteed that the remote control works with every available PC program.

- 1 Connect the RS-232 port of the PC to X2: PC TXD → pin 2 (RXD), PC RXD ← pin 3 (TXD), GND → pin 1.
- 2 In the PC program, select the Kenwood TS-480 as the radio, 9600 baud, 8 data bits, no parity, 1 stop bit.
- 3 The display shows CAT for the PC remote control (section 4.2).

For reference: the firmware answers the identification command ID; with ID020; (the TS-480 identifier) and the mode query MD; with MD3; (CW). Its command set also contains FA, FB and IF.

7 Menu reference

The menu contains the band presets, the tuning step and the operator settings. In the menus, **ENC** confirms (<ENC> = ENTER) and **WPM** goes back (<WpM> = ESCAPE). The menu texts below are those of firmware 1.0.14.

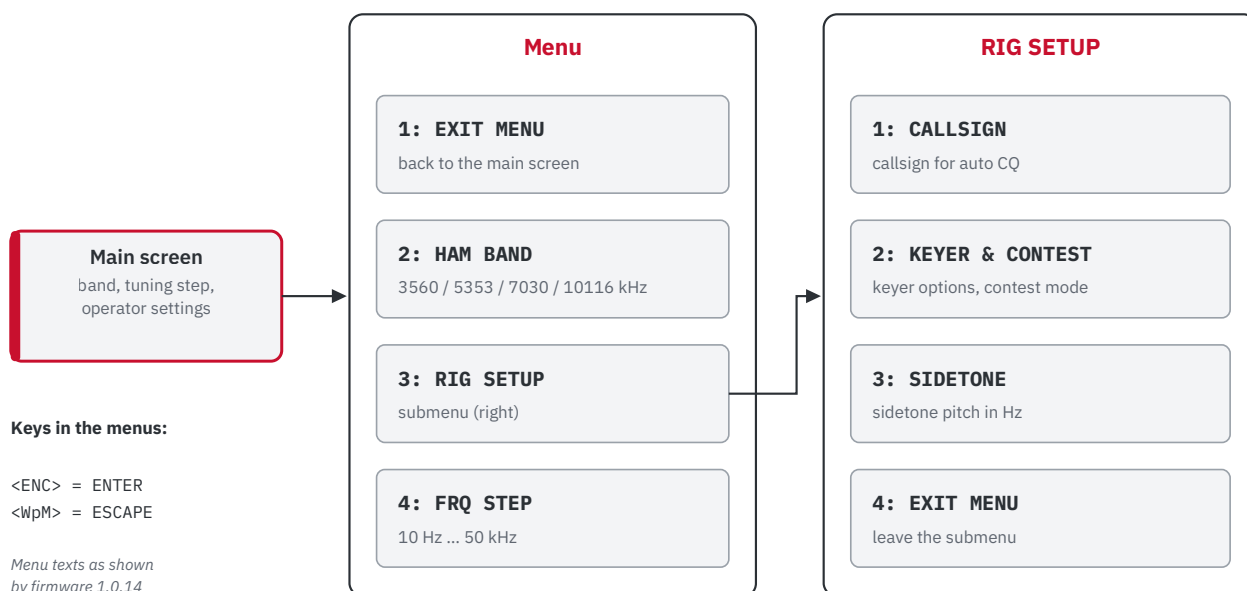


Figure 13: Menu structure. The RIG SETUP submenu contains the operator settings.

Menu item	Options	Notes
1: EXIT MENU	–	Back to the main screen
2: HAM BAND	3560 / 5353 / 7030 / 10116 kHz	Band presets for 80, 60, 40 and 30 m; the low-pass filter is selected automatically
3: RIG SETUP	submenu	see below
4: FRQ STEP	10 Hz, 50 Hz, 100 Hz, 1 kHz, 10 kHz, 50 kHz	Tuning step of the FREQ knob
RIG SETUP > 1: CALLSIGN	callsign entry	Required for auto CQ (section 6.8)
RIG SETUP > 2: KEYS & CONTEST	STRAIGHT KEY, EL-BUG, CONTEST	Keyer options and contest mode (section 6.6)
RIG SETUP > 3: SIDETONE	pitch in Hz	Section 6.7
RIG SETUP > 4: EXIT MENU	–	Leaves the submenu

7.1 Display messages

Message	Meaning / action
HELLO · SETUP TRANSCEIVER... · READY.	Start-up sequence after switching on
OUT OF BAND · TRANSMITTER OFF · CHANGE FREQUENCY	The frequency is outside an amateur band; the transmitter is not keyed. Tune into the band.
NO REAL CALLSIGN · GO TO RIG SETUP	Auto CQ requires a valid callsign (section 6.8).
AUTO CQ STOPPED · AUTOTEXT STOPPED	An automatic transmission was interrupted with a push button.
COUNT DOWN:	Countdown to the next call in a CQ loop
CALL TOO LONG · NO VALID CALLSIGN	The callsign entry was rejected (section 6.8).
CAT	PC remote control indication (section 6.10)

7.2 Factory defaults

A new transceiver uses the following settings.

Setting	Factory default
Frequency	7030 kHz (40 m)
Speed	20 WPM
Dot/dash ratio	1:3

8 Alignment and filters

8.1 DDS trimmer (mixer phase)

Almost no alignment is necessary. The receiver's performance depends greatly on the setting of the DDS trimmer potentiometer on the AD9850 module. This trimmer sets the required 180-degree phase relationship of the two DDS output signals (SQUARE1 and SQUARE2) that drive the 74HC4066 mixer.

- 1 Connect an antenna and tune in a weak signal or the band noise.
- 2 Adjust the trimmer with a small screwdriver for best reception. An oscilloscope is a great help: adjust for two clock signals with a 180-degree phase relationship.

8.2 AD9850 module: serial programming mode

The microcontroller loads the AD9850 serially (lines W_CLK, FQ_UD and DATA). By default, the AD9850 is in parallel mode, as set at the factory. As soon as the microcontroller has successfully sent the first data packet in serial mode to the AD9850 DDS, the DDS oscillator stays in serial mode as long as the RESET line is connected to GND. This can easily be checked with a monitor receiver.

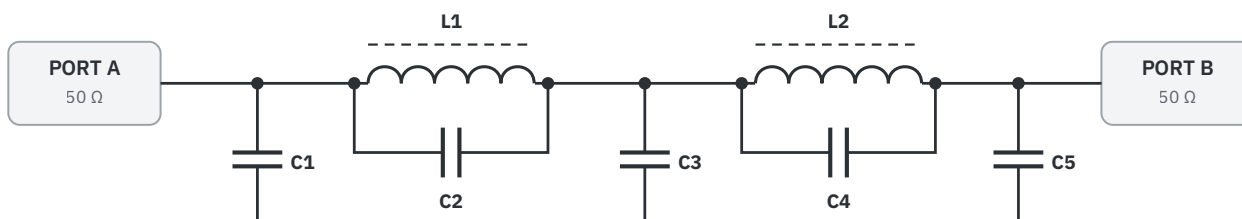
**CAUTION – CHECK THE RESET LINE**

Some pre-assembled AD9850 boards available online do not have the RESET line connected to GND. If in doubt, check the RESET pin's connection to GND on your board; in the schematic, RESET is connected to GND.

8.3 RF low-pass filters

The filters have an input and output impedance of 50 Ω. Cauer (elliptic) filters are recommended for sufficient harmonic suppression. The ZB-4 has one filter for 80/60 m and one for 40/30 m; the band relay K4 selects the filter.

Cauer (elliptic) low-pass filter, 50 Ω in and out – one filter per band pair



Topology redrawn from the author's low-pass filter table; values in the table below.

Figure 14: Topology of the low-pass filters (redrawn from the author's filter table).

Part	80/60 m value	80/60 m turns, Amidon T50-2 (red)	40/30 m value	40/30 m turns, Amidon T50-6 (yellow)
L1	1.6 μH	19	0.82 μH	19
L2	1.3 μH	13	0.62 μH	13
C1	910 pF	–	470 pF	–
C2	100 pF	–	51 pF	–
C3	1200 pF	–	620 pF	–
C4	270 pF	–	130 pF	–
C5	750 pF	–	390 pF	–

Low-pass filter example values from the author's table “QRP transceiver ZB-4 – low pass filter examples”.

The values in the table are examples. In the photos, the author does not use the red-coded cores (T-50-2); of course, you can use them as listed in the table. T37 cores should work without heating up too much. There is still some room for experimentation here – suggestions for improvement are welcome by e-mail.

**WARNING**

After building or changing a filter, check its harmonic suppression and the output signal on all bands into a dummy load before transmitting on the air (section 2.4).

8.4 AF band-pass filter (CW filter)

The fixed CW filter boosts the CW signal of interest around 700 Hz, but the activity around that frequency remains slightly audible. If you prefer a sharper CW filter, there is plenty of room for experimentation.

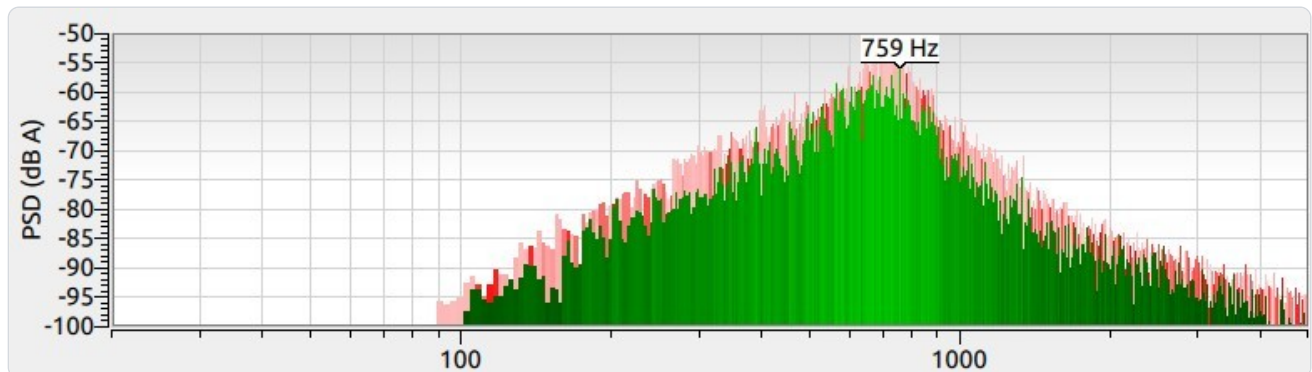


Figure 15: Frequency response of the AF filter, measured with a noise generator and plotted by SDR software. The dB scale is only relative.

9 Firmware

9.1 Firmware download

The firmware for the ZB-4 is available as a hex file on the project page. Check the website for updates.

Version	1.0.14 (shown at start-up)
Download	zb-4-firmware-24-03-23-006.zip (25,792 bytes)
Content	24-03-23-006.hex – Intel HEX file for the ATmega328P (file date March 31, 2023)
Clock	20 MHz crystal
SHA-256 (ZIP)	5e313d37df6213b332d591a2b4eac262ebf5a4709858e6ff63079436496f9c76
SHA-256 (HEX)	be4518f0e666f7468152064b0717832e7d64ed4e673aabedcee666e291db5901
License	Freeware with restrictions – no modification, no commercial use (section 12.3)

9.2 Uploading the firmware with XLoader

Upload the hex file to the ATmega328P (Arduino environment) with the XLoader software: <https://github.com/binaryupdates/xLoader>.

1. Unpack the ZIP file and, if desired, check the SHA-256 checksum.
2. Start XLoader and select the hex file, the device (ATmega328P-based Arduino board), the COM port and the baud rate.
3. Click “Upload” and wait until the upload is reported as complete.

**NOTE**

XLoader uploads through the serial bootloader of an Arduino board. The firmware is built for a clock of 20 MHz, the crystal frequency in the ZB-4 schematic; the microcontroller must run with this 20 MHz crystal in the transceiver.

9.3 Notes

- The display text VERSION at start-up shows the installed firmware version.
- Questions about the project: dl6zb@dl6zb.de.
- Observe ESD precautions (section 2.5).

10 Schematic and theory of operation

10.1 Block diagram

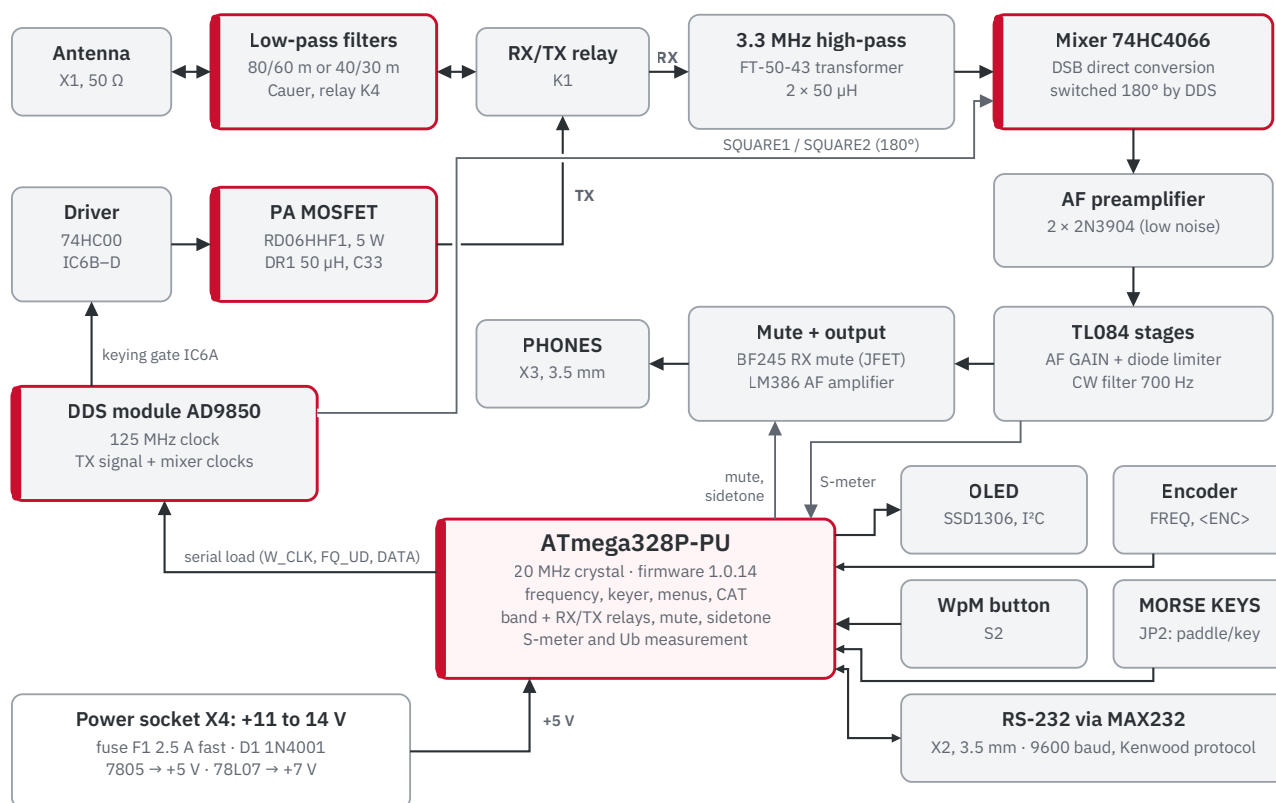


Figure 16: Block diagram of the ZB-4, derived from the schematic dated January 23, 2024.

10.2 Theory of operation

Frequency generation. The frequency is generated by a ready-made module with the well-known Analog Devices AD9850 DDS chip, clocked at 125 MHz. The AD9850 is controlled by the ATmega328P microcontroller via a serial interface. The comparator outputs of the DDS chip supply the two clock signals with a 180-degree phase offset for the receive mixer; the transmit signal is also supplied by the DDS.

Receiver input. The antenna socket X1 is connected via the low-pass filter selected by the band relay K4 and the antenna relay K1 to a high-pass filter with a cutoff frequency of 3.3 MHz ($2.3\ \mu\text{H}$, $2 \times 1\ \text{nF}$). It keeps strong noise below the filter's cutoff frequency away from the receiver input. A transformer on an FT-50-43 core ($50\ \mu\text{H}$ / $2 \times 50\ \mu\text{H}$) feeds the mixer.

Mixer. The receiver is a DSB direct-conversion receiver with a 74HC4066 CMOS switch IC as the mixer, driven by the clock signals from the comparator of the AD9850. This mixer is so good that almost no additional filtering is required between the antenna and the mixer input. The 74HC4066 is supplied with +7 V from a 78L07 regulator.

AF chain. The mixer is followed by an L/C network (L2, approx. 1 mH) and a low-noise preamplifier with two 2N3904 transistors (T2, T3). A very clean power supply is essential at this point to avoid the hum and noise typical of direct-conversion receivers, which usually originate in the first AF stage. The TL084 quad op-amp provides amplification and filtering: IC2A amplifies, and IC2B contains the AF GAIN control (R26, 10 k Ω log) and the diode limiter (D2, D3, 1N4148). Because the receiver has no AGC, the limiter prevents excessively loud signals from reaching the following stages. The JFET Q1 (BF245) mutes the receiver during transmission. IC2D and IC2C form the CW band-pass filter and a further amplifier stage, followed by the LM386N-1 audio power amplifier (IC3) with the phones jack X3.

Transmitter. The transmitter consists essentially of a 74HC00 as switching driver for a MOSFET. One NAND gate (IC6A) gates the DDS signal with the keying signal from the microcontroller; the remaining three NAND gates (IC6B–D), connected in parallel, drive the MOSFET Q3, type RD06HHF1, via C32/R23. The drain is fed through the choke DR1 ($50\ \mu\text{H}$), and the output is coupled via C33 to the antenna relay and the low-pass filters. An IRF510 was also tried and, after a corresponding adaptation of the output with a 1:4 transformer, found to be well suited.

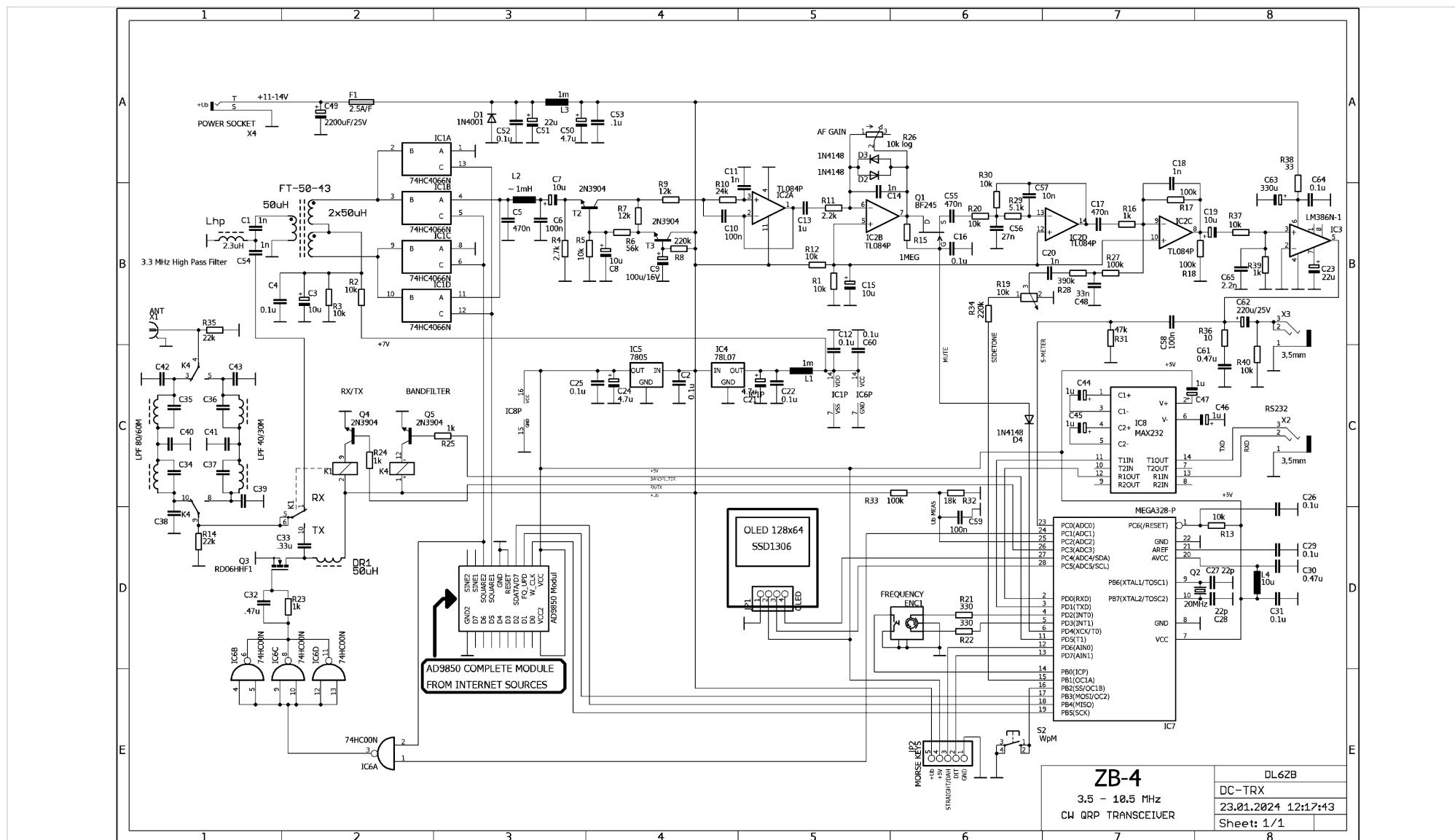
Microcontroller and firmware. The ATmega328P (IC7, 20 MHz crystal) controls the DDS for the TX and RX frequencies, generates the sidetone, provides the iambic keyer (squeeze technique for dual-lever paddles, 5–50 WPM) and simple keying for straight keys, bugs and single-lever paddles, handles the PC remote control via the MAX232 (IC8), stores the individual callsign for automatic CQ calls, monitors the battery/supply voltage (voltage divider R33/R32), controls the transmit/receive switching (relay K1 via Q4) and the band filter selection (relay K4 via Q5), switches to contest mode, displays the relative signal strength (S-meter signal from the AF chain), drives the OLED display via I²C, and evaluates the rotary encoder, the WpM button and the Morse key inputs (JP2).

Power supply. The supply voltage of +11 to 14 V from X4 passes the fuse F1 (2.5 A fast-acting); D1 (1N4001) protects against reverse polarity, C49 (2200 μF /25 V) buffers the supply, and L3 with C50–C53 filters it. A 7805 (IC5) supplies +5 V for the microcontroller, the DDS module, the display and the MAX232; a 78L07 (IC4) supplies +7 V for the 74HC4066 and the 74HC00.

10.3 Main components

Reference	Component (as shown in the schematic)
IC7	Microchip ATmega328P microcontroller, crystal Q2 20 MHz
DDS	AD9850 complete module (“from internet sources”)
IC1	74HC4066N quad bilateral switch (mixer)
IC2	TL084P quad op-amp
IC3	LM386N-1 audio power amplifier
IC6	74HC00N quad NAND gate (keying gate and MOSFET driver)
IC8	MAX232 RS-232 level converter
IC4, IC5	78L07 and 7805 voltage regulators
Q3	RD06HHF1 RF power MOSFET
Q1	BF245 JFET (RX mute)
T2, T3, Q4, Q5	2N3904 NPN transistors (AF preamplifier, relay drivers)
K1, K4	RX/TX relay and band filter relay
Display	OLED 128 × 64, SSD1306, I ² C (JP1)
ENC1, S2	rotary encoder FREQUENCY with push button; push button WpM
R26	AF GAIN potentiometer, 10 kΩ log
F1, D1	fuse 2.5 A fast-acting; diode 1N4001

This table lists the main components shown in the schematic. It is not a complete parts list; refer to the schematic for all values.



11 Troubleshooting

Problem	Possible cause	Remedy
Display stays dark	No supply voltage, wrong polarity, fuse F1 blown	Check the supply (+11 to 14 V, polarity, section 2.2) and the fuse (2.5 A fast-acting).
	Firmware not programmed or wrong clock	Program the firmware for 20 MHz (section 9).
No signal from the DDS, no reception	AD9850 module not in serial mode	Check that the RESET line of the module is connected to GND (section 8.2); check with a monitor receiver.
Weak or poor reception	DDS trimmer misadjusted	Adjust the trimmer for best reception or with an oscilloscope (section 8.1).
	Antenna or band selection	Check the antenna and the band selection (section 6.3).
Hum or noise in the headphones	Unclean supply voltage	Use a battery or a well-filtered supply; the first AF stage is sensitive (section 2.2).
Painfully loud signals	No AGC	Reduce AF GAIN; take off the headphones before switching bands.
Transmitter not keyed, OUT OF BAND	Frequency outside an amateur band	Tune into the band or select a band preset (section 6.3).
Dots and dashes swapped	DIT and DAH wires interchanged	Check the key wiring: JP2 pin 2 = DIT, pin 3 = DAH.
Auto CQ does not start, NO REAL CALLSIGN	No valid callsign entered	Enter your callsign: RIG SETUP › CALLSIGN (section 6.8).
Auto CQ has to be stopped	–	Press WPM or ENC (section 6.9).
PC remote control does not work	Wrong settings or wiring	Kenwood TS-480, 9600 baud, 8N1; PC TXD → X2 pin 2, PC RXD ← pin 3, GND → pin 1; RS-232 levels (section 6.10). Not every program is supported.
Low output power or hot MOSFET	Low-pass filter, antenna mismatch or cooling	Check the filter values (section 8.3), the 50 Ω load and the cooling of Q3.

If a problem persists, please send a description of your build, the firmware version and the observed behavior to dl6zb@dl6zb.de.

12 Disposal, warranty, license and contact

12.1 Disposal



Electrical and electronic equipment. A finished transceiver is electrical and electronic equipment. At the end of its life, it must not be disposed of with household waste. Take it to a collection point for waste electrical and electronic equipment (in Germany, for example, the municipal recycling center/Wertstoffhof), in accordance with the WEEE Directive 2012/19/EU and, in Germany, the Electrical and Electronic Equipment Act (ElektroG).

Batteries. The ZB-4 contains no battery. If you operate it from an external battery, dispose of that battery separately in accordance with the battery regulations.

Personal data. The transceiver's memory may contain your callsign. Consider this before passing the transceiver on or disposing of it.

12.2 Warranty and liability

The ZB-4 design, its firmware and this manual are provided free of charge for non-commercial amateur radio purposes. This is a hobby project: the technical data are only rough estimates and can change at any time, and the author cannot guarantee that the project will work without errors. No warranty or guarantee of any kind is given. Builders and operators use the design, the firmware and the information in this manual at their own risk and are solely responsible for the lawful operation of their transmitter. To the extent permitted by applicable law, the author accepts no liability for any damage arising from the construction or use of the transceiver, including damage to connected equipment and harmful interference.

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12.5 Contact

Author	Rolf L. Heine, DL6ZB
Address	Kirchenäcker 6, 84048 Mainburg, Germany
E-mail	dl6zb@dl6zb.de – questions, comments and suggestions
Web	https://www.dl6zb.de – more hardware and software projects and legal information

A Quick reference card

Push buttons

ENC short	TX zero beat
ENC long (0.5 s)	RIT on / off; turn FREQ for the offset
WPM + paddle	CW speed (5–50 WPM): dots faster, dashes slower; WPM again = done
WPM long	Auto CQ
ENC + WPM short	CQ loop (QSO): 10×, 10 s spacing
ENC + WPM long	CQ loop (contest): 10×, 2 s spacing
WPM / ENC	Stop auto CQ

Menu

1: EXIT MENU · 2: HAM BAND · 3: RIG SETUP · 4: FRQ STEP

RIG SETUP: 1: CALLSIGN · 2: KEYER & CONTEST · 3: SIDETONE · 4: EXIT MENU

Factory defaults

7030 kHz · 20 WPM · ratio 1:3

Band presets

3560 · 5353 · 7030 · 10116 kHz

Tuning steps

10 Hz · 50 Hz · 100 Hz · 1 kHz · 10 kHz · 50 kHz

Connections

X1 ANT	SO-239 (PL/UHF), 50 Ω
X4 power	barrel 5.5 × 2.5 mm, centre +, 11 to 14 V; F1 2.5 A fast
X3 phones	3.5 mm; 1 = GND, 2+3 = AF
X2 RS-232	3.5 mm; 1 = GND, 2 = RXD, 3 = TXD
JP2 keys	1 GND · 2 DIT · 3 STRAIGHT/DAH · 4 +5 V · 5 +Ub

PC remote control

Kenwood TS-480 (partial) · 9600 baud · 8N1

Before transmitting

License · 50 Ω antenna or dummy load · correct low-pass filter · free frequency · AF GAIN low

Alignment

DDS trimmer: best reception / 180° phase (oscilloscope) · AD9850 RESET to GND

B Revision history

Edition	Date	Changes
–	April 2023	“Handbuch ZB-4” – German manual draft (introduction, construction, firmware tasks).
1.0	October 2026	First illustrated English PDF edition for firmware 1.0.14 (file 24-03-23-006.hex) and the schematic dated January 23, 2024. Content of the German draft translated and combined with the project page; added safety and legal notices, annotated photos, connection and block diagrams, display and menu reference, low-pass filter data, theory of operation, troubleshooting, disposal information and quick reference card.
1.1	October 2026	Information confirmed by the author: WPM button (labelled FILTER on the author's unit) and speed setting with the paddle; RIT on/off with a long press (0.5 s) on the FREQ knob and offset setting with the FREQ knob; ending the speed setting with WPM; high-pass filter 3.3 MHz confirmed; added current consumption, dimensions, weight, antenna connector, power connector (centre positive) and factory defaults (section 7.2).