

wiFred documentation – Documentation for a WiFi throttle for model railroads with withrottle interface

Heiko Rosemann

WIP

This document describes the usage and configuration of the wiFred – a very simple wireless throttle for model railroads to connect to withrottle servers like JMRI. It also contains schematics and BOMs for the device – both the LiPo battery version in active development and the first prototype with 2xAA cells – as well as programming instructions and assembly tips, and also an overview of options for the server side of things.

The most recent version of this document can be found at:

<https://newheiko.github.io/wiFred>,

<https://github.com/newHeiko/wiFred/raw/master/documentation/docu.pdf>

and

<https://github.com/newHeiko/wiFred/blob/master/documentation/docu.tex>.

If you want to know more about the development history of the wiFred, skip ahead to section 5 – otherwise read on with section 1 if you have a wiFred powered by an internal lithium battery or with section 4 if you have one of the few prototypes powered by AA cells.

Contents

1	wiFred Wireless throttle hardware	3
1.1	Quickstart Guide	3
1.2	Usage	5
1.3	Charging the wiFred	7
1.4	Hardware description	7
1.5	Hints for building the wiFred	8
1.6	Programming instructions	12
2	wiFred Wireless throttle configuration	16
2.1	Entering configuration mode	16
2.2	Throttle configuration	16
2.2.1	General configuration	17
2.2.2	WiFi configuration	17
2.2.3	Loco server configuration	19
2.2.4	Loco configuration	19
2.2.5	DCC function configuration	20
2.2.6	wiFred status	21
2.2.7	wiFred system	21
3	Options for server setup	23
3.1	Out-of-the-box server-side options	24
3.2	Step by step instructions for a Windows computer	24
3.3	WiFi access point requirements	25
3.4	JMRI server requirements	25
3.5	Layout connection options	25
3.6	Computer or smartphone to configure wiFred	25
4	wiFred Wireless throttle prototype	27
4.1	Quickstart Guide	27
4.2	Usage	28
4.3	Hardware description	30
4.4	Hints for building the wiFred	30
4.5	Programming instructions	34
5	Background for wiFred development	38
5.1	Specification wishlist	38
5.2	Development history	39
5.3	Wireless clock	39

1 wiFred Wireless throttle hardware

1.1 Quickstart Guide

Follow these steps for a new throttle (see later chapters for more explanation or if you run into trouble)

- 5. Use PCB to determine positions of holes and cutouts in housing
- 4. Make said cutouts
- 3. Solder components to PCB
- 2. Connect lithium battery to PCB, charge with Micro USB charger if required
- 1. Flash firmware to ATmega 328P
0. Move any of the loco selection switches to “enabled” to power ESP8266, then flash firmware to ESP8266, move loco selection switch back to “disabled” to turn off power to ESP8266 again
1. Test fit PCB into housing, removing plastic parts of housing as required
2. Fit PCB into housing, insert four screws to fix PCB to housing
3. Fit lithium battery into other half of housing, fix with double sided tape or similar, taking care that the battery will not be squeezed or pinched by any parts on the PCB when the housing is closed
4. Make sure communication jumpers are set correctly, close housing and fix back cover with two screws
5. Add throttle knob
6. Move any loco selection switch to “enabled” to power ESP8266
7. Using any WiFi client (laptop, smartphone, tablet...), find and connect to network *wiFred-configXXXX*
8. Using any web browser, navigate to *http://192.168.4.1* or *http://config.local*
9. Enter your WiFi configuration or scan for available networks (and a throttle ID if you like – highly recommended to easier tell them apart) **and hit the *Submit-Button***
10. For every loco you want to control with this throttle, enter the appropriate details below
11. **Hit the *Submit-Button*** for every loco
12. Configure function settings for each loco on the respective sub pages if required
13. Restart the throttle by clicking on **Restart system to enable new WiFi settings**

Table 1: LED patterns and their meaning on the wiFred throttle

Red LED	Green LED (Left)	Green LED (Right)	Status
Slow Blinking (0.5 Hz)	Off	Off	Trying to connect to WiFi network
Fast Blinking (2 Hz)	Off	Off	Successful WiFi connection, trying to connect to wiThrottle server and acquire locos
Off	Off	On	Regular operation, forward direction
Off	On	Off	Regular operation, reverse direction
Off	Flashing	On	Emergency stop, forward direction. Also happens when switching direction with speed potentiometer not at zero
Off	On	Flashing	Emergency stop, reverse direction. Also happens when switching direction with speed potentiometer not at zero
Off	Off	Blinking	Battery low, regular operation, forward direction
Off	Blinking	Off	Battery low, regular operation, reverse direction
Off	Flashing	Blinking	Battery low, Emergency stop, forward direction
Off	Blinking	Flashing	Battery low, Emergency stop, reverse direction
Short flashes	Off	Off	Throttle in low-power mode
Off	Off	Off	Battery empty or no battery inserted
On	Off	Off	No connection to existing WiFi network. Created internal configuration WiFi network
On	On	On	Configuration mode enabled while connected to existing WiFi network. All locos emergency stop to avoid runaways. Push SHIFT + ESTOP again to exit configuration mode

To recover from an emergency stop, turn speed potentiometer to zero to re-gain control.

Your throttle should now be ready to use and connect to your wiThrottle server on startup. Refer to the chapters below if it does not or contact the author of this document.

Before operating the throttle, fully charge the battery which will also calibrate the internal battery voltage measurements. Before the first full charge, the throttle may not shut down when the battery is empty which can lead to damage to the battery. This can be checked by comparing the device's battery voltage measurement on the status subpage of the configuration website to voltage readings from a multimeter on the battery terminals – an accuracy of 50 mV to 100 mV is OK.

1.2 Usage



Figure 1: Controls and features of the wiFred-throttle

Figure 1 shows the controls of the wireless throttle. They consist of the following:

- Four loco selection switches (loco 1 on the left, loco 4 on the right, move towards speed potentiometer to enable)
- Speed potentiometer (Counter-clockwise endstop: Stop, clockwise endstop: Full speed)
- Direction switch – move right for forward movement, left for reverse movement

- Black function keys F0 to F8
- Yellow shift key to trigger F9-F16 and turn on flashlight function
- Red emergency stop key
- Two green direction indicator LEDs next to speed potentiometer
- Red status LED next to speed potentiometer
- Red charging indicator LED at lower end of device – lit while charging
- Green fully charged indicator LED at lower end of device – lit when fully charged as long as charger still connected

As soon as any of the loco selection switches is moved into the “enabled” position, the throttle will boot up and try to connect to a wireless network. When all four loco selection switches are “disabled”, the throttle will disconnect from the wireless network after a grace period of five seconds. The device will then go into low power mode, in which the battery will last for more than a year.

If no connection to the network configured into the device can be established within 60 seconds, the throttle will create it’s own wireless network named *wiFred-config* plus four hex digits taken from the MAC address of the throttle WiFi interface, for example *wiFred-config0CAC*, to enable configuration as described in section 2.

Four different locos with long DCC addresses can be assigned to the four loco selection switches. Commands derived from the speed potentiometer, the direction switch and the function keys will be transmitted to all selected locos (near) simultaneously, with a certain translation table enabling some locos to go backwards when others go forwards and also limiting function keys to some of the four locos only – this is described in more detail in sections 2.2.4 and 2.2.5.

Pushing the red emergency stop key will cause the throttle to send an emergency stop signal to all four locos attached. After an emergency stop, turn the speed potentiometer to zero to re-enable control of the locos.

Pushing the red emergency stop key while holding down the shift key will place the device into configuration mode (as well as issuing an emergency stop to all attached locos). See section 2 for more details on how to access the throttle to do the configuration.

Any change in the loco selection switches will cause the throttle to send an emergency stop command to all attached locos. This makes sure that any loco that is deselected will stop on the layout and avoids newly selected locos suddenly taking off at speed. The same is true for a change in the direction switch, to avoid high-speed reverse maneuvers. Turn the speed potentiometer to zero to re-enable control of the locos.

When the battery is low, the device will not re-activate before charging the batteries, but continue operating for approximately an hour if active. When the battery is empty, it will disconnect and enter low power mode. Expected runtime is around 20 hours of

full time operations, more if the throttle is placed in low power mode when the locos are not running.

During startup and operation, the LEDs will show the patterns explained in table 1.

1.3 Charging the wiFred

The wiFred can be charged through the Micro-USB connector at the lower end of the device. Maximum charging current is approximately 400 mA and the device does not communicate with the USB host, so technically there is no guarantee that charging from a USB cable will work, but most chargers, computer ports or power banks do not check the current before powering up.

As long as the battery is being charged, the red charging indicator LED will be lit. When the battery is fully charged, the green charged indicator LED will be lit as long as the charger is still connected. Expected charging time is around five to six hours for a full charge.

Even while charging, the device can still be operated (particularly helpful with a power bank) but since the operating current will come out of the battery, the battery will never be fully charged.

If both charging status LEDs light up when a charging cable is connected, probably the internal connection to the battery is faulty.

1.4 Hardware description

The wiFred hardware is centered around an ESP8266 for the WiFi connection. The ESP8266 communicates through it's serial port with an ATmega 328P microcontroller which manages the power, controls the LEDs, reads the loco selection switches, speed potentiometer, direction switch and pushbutton switches for functions and emergency stop. The communication goes through a 2x3 pin header which enables the user to connect a programming cable to the same serial port if removing the jumpers.

Optionally, two white 5 mm-LEDs protruding from the top of the PCB can be installed to serve as a flashlight. They are driven by a constant-current source directly from the battery and enabled when pushing the yellow SHIFT key.

The wiFred is powered by a single cell LiPo battery. The ATmega 328P is connected directly to the LiPo cell, going into sleep mode when no loco selection switch is active, thereby reducing the power consumption to less than 1 mA. The ESP8266 is powered by a low-drop linear voltage regulator with an output voltage of 3 V which is disabled by the ATmega 328P when the device goes into standby.

The schematic is split into several pages and can be found in figures 2 to 5. It has been created with kicad and is available on the github repository at <http://github.com/newHeiko/wiFred> along with the PCB design.

1 wiFred Wireless throttle hardware

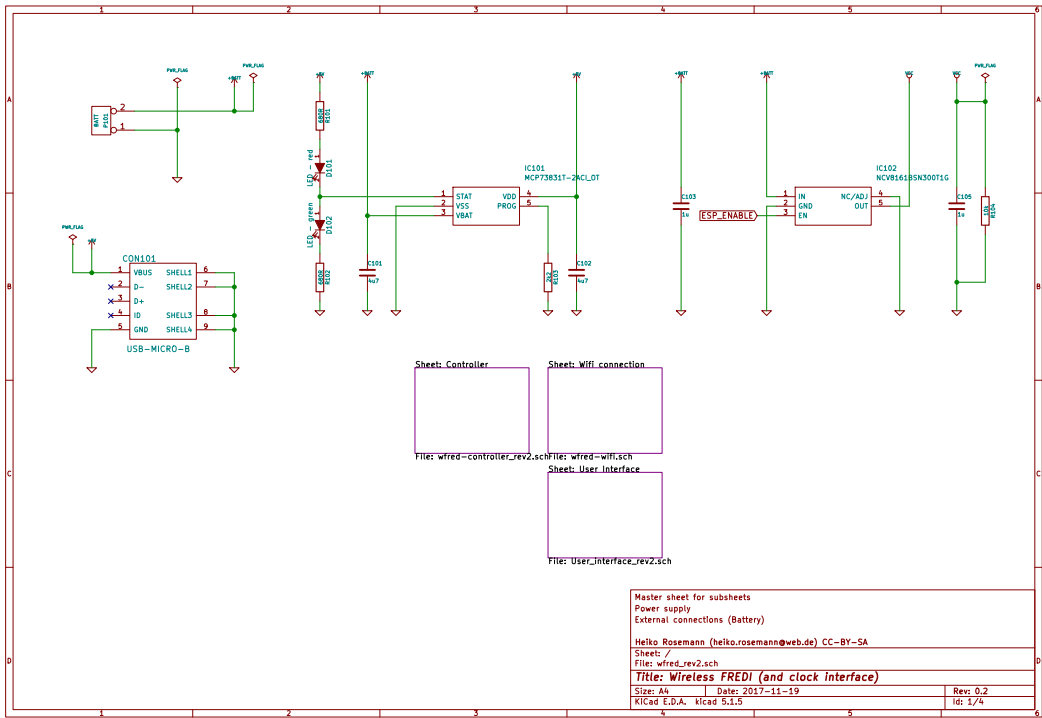


Figure 2: Master schematic sheet with battery connector, charging circuit and power supply

1.5 Hints for building the wiFred

The PCB has holes in the center of the LED footprints to enable transferring their positions to a StrapuBox housing with a sharp needle or to drill pilot holes with a 1 mm drill. For all other holes, there is a drill jig available which also allows the drilling of pilot holes for the pushbutton switches, the direction control switch and the speed potentiometer. Figure 6 shows the process and it's results. Holes for the pushbutton switches should be drilled at 3.5 mm diameter. Holes for the LEDs should be drilled at 3 mm diameter and holes for the speed potentiometer at 8 mm, for the direction switch at 6.5 mm diameter. The cutouts for the loco selection switches are best drilled at 5 mm or 5.5 mm and extended to fit when the PCB is assembled with a sharp hobby knife and a file.

The remaining assembly is a basic exercise in installing all the components to the PCB, listed in table 2. From assembling the prototypes, the suggested order of installing the components is as follows:

1. IC101, IC102, IC201 (note: Rotate PCB so Designator is right side up, then Pin 1 is on top left) and IC301

1 wiFred Wireless throttle hardware

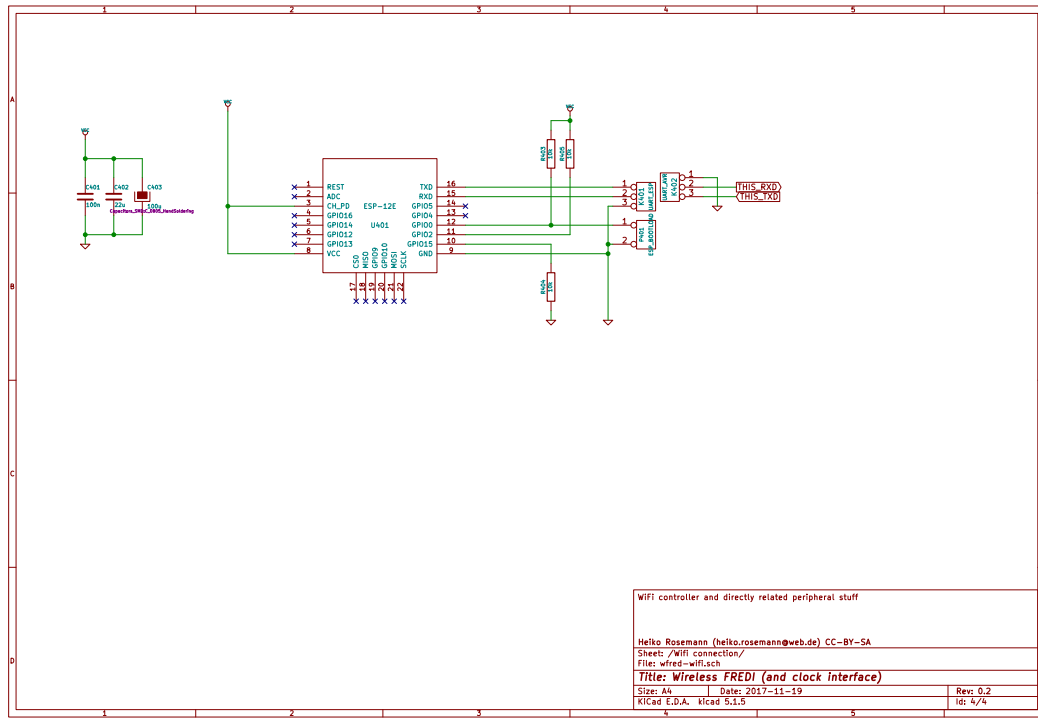


Figure 3: Schematic sheet including ESP8266 for WiFi connection with bootloader enabling jumper and connection to programming cable

2. X201 and D201
3. USB connector CON101
4. Capacitors and Resistors in 0805 size (first those on the same side as the items before)
5. U401
6. Capacitors and Resistors not installed in step 4 – that is R403, R404, R405, C401, C402 and C403
7. Pushbutton switches SW305 to SW312 and SW314 to SW316 – taking care to put the red one at SW312 and the yellow one at SW311
8. Pin headers K401, K402 and P401 (correct alignment of K401 and K402 can be assured by adding a jumper before soldering)
9. Pin headers P101 and P201
10. Loco selection switches SW301 to SW304

1 wiFred Wireless throttle hardware

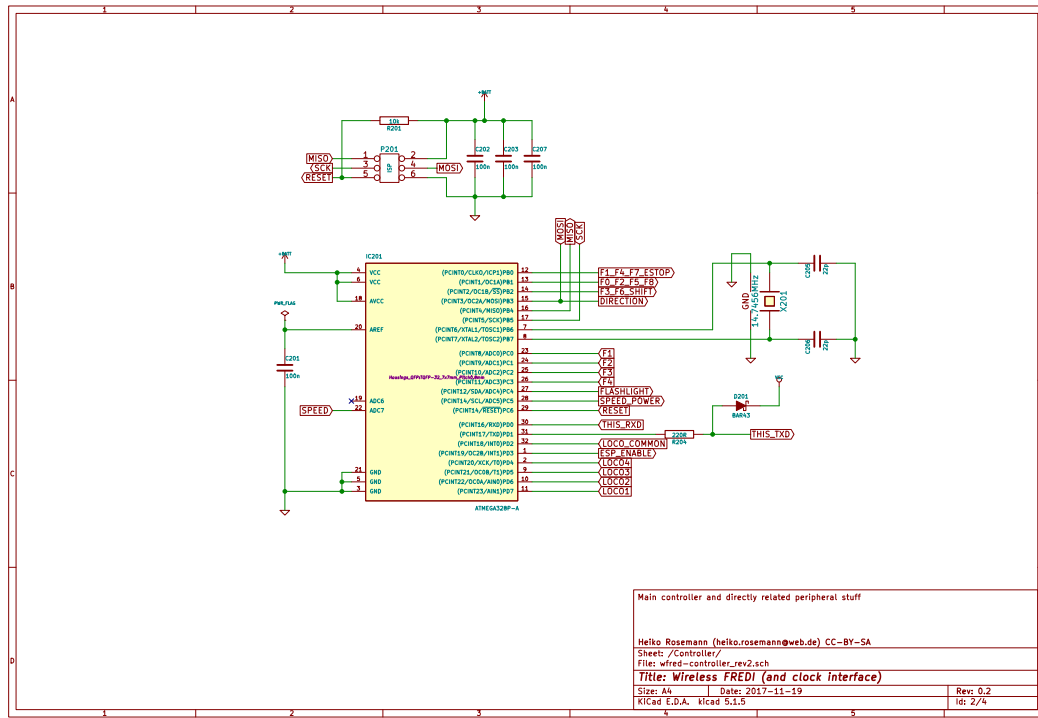


Figure 4: Schematic sheet including ATMega 328P along with crystal and in system programming header

11. LEDs D101, D102 and D301 to D303 with 3mm spacers to the PCB – making sure the Anode (long pin) is aligned with the square pad on all of them
12. LEDs D304 and D305 – making sure the Anode (long pin) is aligned with the square pad on both, they can be installed on top or bottom of the PCB as desired
13. Direction switch SW313 (screwed into the PCB with an 8 mm hex nut first, then attached to it's pads using the cutoffs from D301, D302 and D303) and Speed potentiometer RV301 (screwed into the PCB with a 10 mm hex nut first)

To form a complete BOM, also include the parts listed in table 3 which are not soldered to the PCB but used in assembly later on.

After assembling the PCB with all the components, the holes and cutouts in the enclosure most likely will have to be reworked / extended to actually fit the PCB, then the PCB can be screwed into the enclosure with four screws. Afterwards the battery should be connected to P101 making sure the orientation is correct as shown in figure 7 and printed on the PCB, then the battery should be glued to the bottom of the enclosure with double-sided tape so it does not collide with any parts on the PCB, particularly

Table 2: List of components for the wiFred PCB

Designator	Package	Designation
C102,C101	C_0805_HandSoldering	4u7
C105,C103, C302	C_0805_HandSoldering	1u
C206,C205	C_0805_HandSoldering	22p
C401,C203, C202,C201, C207	C_0805_HandSoldering	100n
C402,C301	C_0805_HandSoldering	22u
C403	C_0805_HandSoldering	100u
CON101	USB_Micro-B_Molex-105017-0001	USB-MICRO-B
D101	LED_D3.0mm	LED - red
D102	LED_D3.0mm	LED - green
D201	SOT-23_Handsoldering	BAR43
D301	LED_D3.0mm	STOP - red
D302	LED_D3.0mm	FORWARD - green
D303	LED_D3.0mm	REVERSE - green
D303,D302, D301,D101, D102	LED Spacer	3mm
D304	LED_D5.0mm_Horicontal_FLIPPED_O1.27mm	LED white
D305	LED_D5.0mm_Horicontal_O1.27mm	LED white
IC101	SOT95P270X145-5N	MCP73831T-2ACLOT
IC102	SOT95P275X110-5N	NCV8161BSN300T1G
IC201	TQFP-32_7x7mm_Pitch0.8mm	ATMEGA328P-A
IC301	SOT-23-6_Handsoldering	MIC2860-2PYD6
K401	Pin_Header_Straight_1x03_Pitch2.54mm	UART_ESP
K402	Pin_Header_Straight_1x03_Pitch2.54mm	UART_AVR
P1	PCB	124mm x 35mm x 1.6mm
P101	Pin_Header_Angled_1x02_Pitch2.54mm	BATT
P201	Pin_Header_Straight_2x03_Pitch2.54mm_SMD	ISP
P401	Pin_Header_Straight_1x02_Pitch2.54mm	ESP_BOOTLOAD
R101,R102	C_0805_HandSoldering	680R
R103	C_0805_HandSoldering	2k2
R301	C_0805_HandSoldering	4k7
R304,R303, R302,R204	C_0805_HandSoldering	220R
R305	C_0805_HandSoldering	15k
R405,R404, R403,R201, R104	C_0805_HandSoldering	10k
RV301	P160KNPD	10k lin P160KNPD-4FC20B10K
SW301	OS102011MS2Q	LOCO1
SW302	OS102011MS2Q	LOCO2
SW303	OS102011MS2Q	LOCO3
SW304	OS102011MS2Q	LOCO4
SW305	SW_SPST_PTS645	F0
SW306	SW_SPST_PTS645	F1
SW307	SW_SPST_PTS645	F2
SW308	SW_SPST_PTS645	F3
SW309	SW_SPST_PTS645	F4
SW310	SW_SPST_PTS645	F5
SW311	SW_SPST_PTS645	SHIFT
SW312	SW_SPST_PTS645	ESTOP
SW313	100SP1T1B1M1QEH	DIRECTION
SW314	SW_SPST_PTS645	F6
SW315	SW_SPST_PTS645	F7
SW316	SW_SPST_PTS645	F8
U401	ESP-12E_SMD	ESP-12E
X201	Crystal_SMD_TXC_7M-4pin_3.2x2.5mm_HandSoldering	14.7456MHz

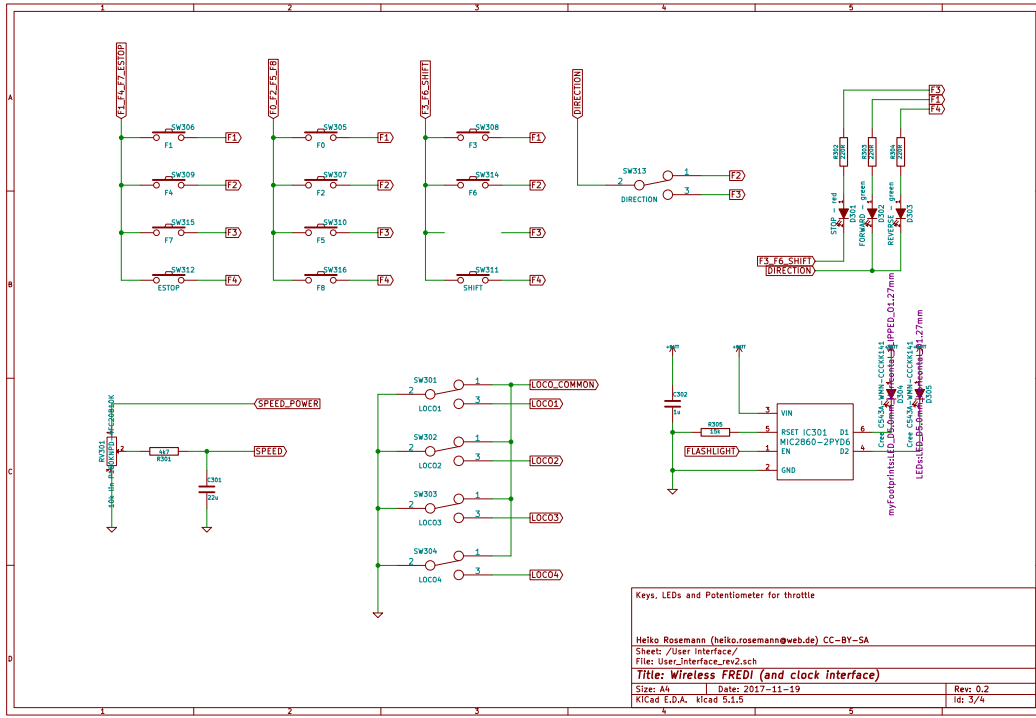


Figure 5: Schematic sheet including pushbutton switches, loco selection switches, direction switch, speed potentiometer and flashlight LEDs with controller

P101 and SW313. Finally, both the ATmega 328P and the ESP8266 will need to be programmed as described in the next section.

1.6 Programming instructions

The ATmega 328P is programmed using the regular AVR ISP connection on P201. Pin 1 – GND – is towards the PCB edge, as shown in figure 8. An ISP dongle with either automatic voltage selection or 3.3 V supply voltage should be used to avoid placing too high voltage on the ESP8266, which can only support 3.3 V power. The firmware for the ATmega 328P can be found in the *software/avr-firmware* subdirectory of the github repository with both a precompiled hexfile and all source code including a Makefile to recompile as needed. After writing the firmware file and the eeprom file, also the fuse bits need to be set properly as detailed in the *main.c*-file.

The ESP8266 is programmed using the Arduino IDE connected via a serial or USB-to-serial port to the K401 header as shown in figure 9. The serial port needs to be at 3.3 V-levels like from an FTDI232-device run at 3.3 V. To program the ESP8266, first the ATmega 328P has to be programmed, a battery has to be connected and reasonably



Figure 6: Using the original PCB and the drilling jig to transfer the positions of the holes to the housing – better results will be achieved when the PCBs are screwed in position

Table 3: List of components for the wiFred excluding electronic parts to solder to PCB

Designator	Package	Designation
B1	Battery	Lithium battery 1700mAh
H1a	Housing black	Strapubox 2090
or H1b	Housing white	Strapubox 2090
J1,J2	Jumper	
K1a	Potentiometer Knob silver	24mm
or K1b	Potentiometer Knob black	24mm
P1	PCB	124mm x 35mm x 1.6mm
S1,S2, S3,S4	Mounting Screws	2,9mm x 6,5mm

charged and one of the loco selection switches needs to be moved to the “enabled” position

All files in the *software/esp-firmware*-subdirectory of the github repository need to be placed in a folder, then the main sketch *arduino_main_sketch.ino.ino* needs to be opened with the Arduino IDE. Settings for the Arduino IDE can be found inside the main file, programming the device should work using the *Upload*-button in the *Sketch*-menu.

To put the ESP8266 into programming mode, a jumper needs to be placed across the P401 header before powering up the ESP8266 by enabling one of the loco selection switches to start the device in programming mode. The red STOP LED should start flashing and the bootloader should show some results on the serial port and during download the LED on the ESP8266 module should flash as well.

After programming, two jumpers need to be placed between the K401 and K402 pin headers to re-enable communication between the ESP8266 and the ATmega 328P as shown in figure 10.

1 wiFred Wireless throttle hardware

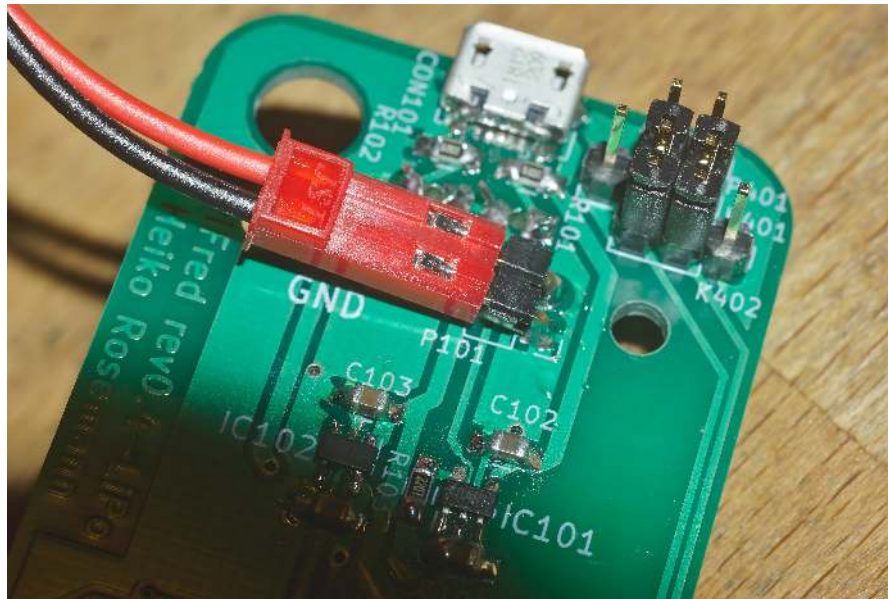


Figure 7: Connection of battery to P101 – black wire is GND, red wire is positive

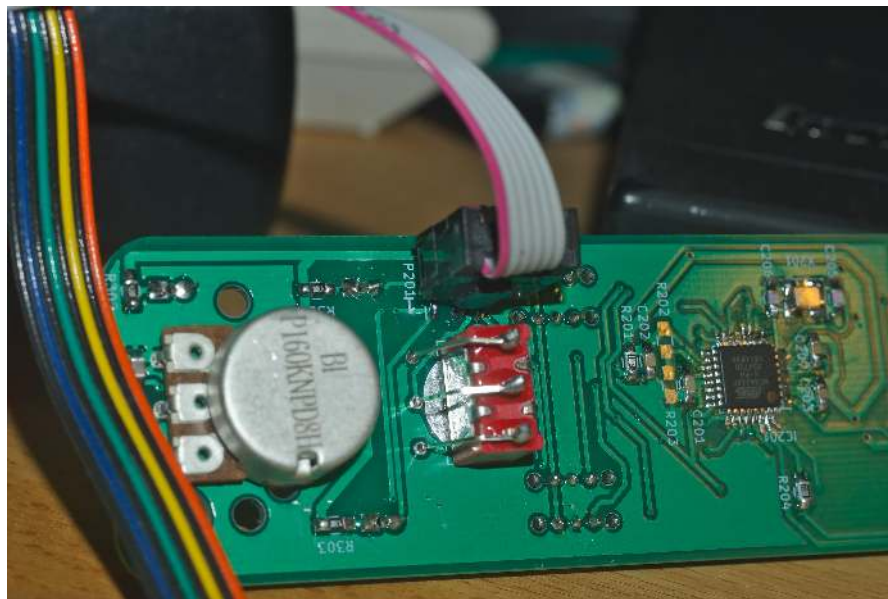


Figure 8: Programming connection for ATmega 328P – Pin 1 on purple cable

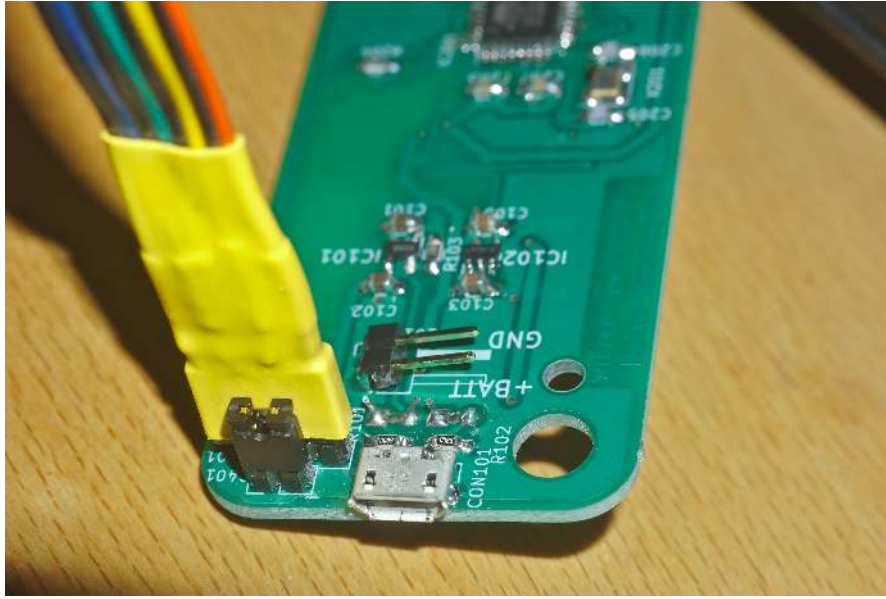


Figure 9: Programming connection for ESP8266 – GND on orange wire, then TXD of programming cable (RXD of ESP8266), then RXD of programming cable (TXD of ESP8266) – also note the jumper on P401

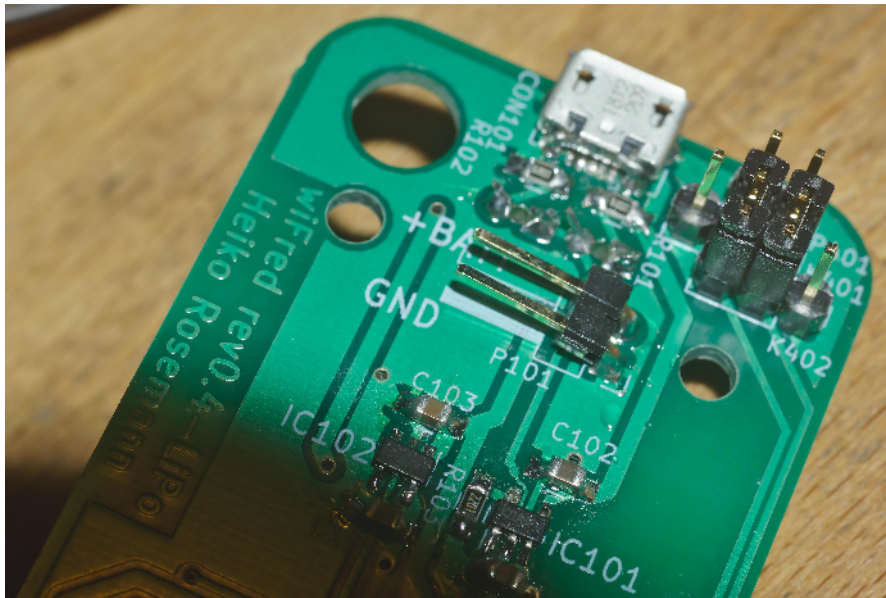


Figure 10: Communication jumpers for connecting the ESP8266 and the ATmega 328P

2 wiFred Wireless throttle configuration

Before using the device, it must be configured. At the very least, the General Configuration page 12 has to be submitted once to be saved to non-volatile memory. If no valid configuration is detected at startup, the device will start with a default configuration with no locos enabled and no WiFi settings, so it won't be able to connect to any WiFi network.

After entering any kind of text (names, numbers...) into text fields, the corresponding "Save" button has to be pressed to submit the changes to the wiFred.

2.1 Entering configuration mode

There are two ways to enter configuration mode:

1. Power up the throttle/select a loco when the configured WiFi network is not in range (or when there is no valid configuration – the first startup of a new throttle will fall into this category)
2. Press SHIFT and ESTOP together when the throttle is connected

In the first case, the throttle will create a wireless network named *wiFred-config* plus four hex digits taken from the MAC address of the throttle WiFi interface, for example *wiFred-config0CAC* and announce its presence under the name *config.local* as well as creating a captive portal. Any WiFi device with a web browser can connect to that network and open a web browser to point to <http://192.168.4.1> or <http://config.local>. This has been tested with Mozilla Firefox and Opera on Linux with Avahi (a Zeroconf implementation) and Safari on iOS 13.

In the second case, the throttle will only announce its presence under the name *config.local* using the Bonjour/Zeroconf-protocol. Any device on the same WiFi network with Bonjour/Zeroconf can use a web browser to access the configuration at <http://config.local>. See section 3.6 for an explanation what is required to have your device read Bonjour/Zeroconf announcements. This has been tested with Mozilla Firefox and Opera on Linux with Avahi (a Zeroconf implementation).

If the IP address or the name of the throttle during normal operation is known, the configuration pages can also be accessed by pointing a web browser to it at any time while it is connected. Note that this is mostly untested and therefore not recommended while the throttle is running locos.

2.2 Throttle configuration

Figure 12 shows the first page you will see when you point a web browser at your wiFred throttle. It is divided into multiple sections explained in the following chapters.

2 wiFred Wireless throttle configuration

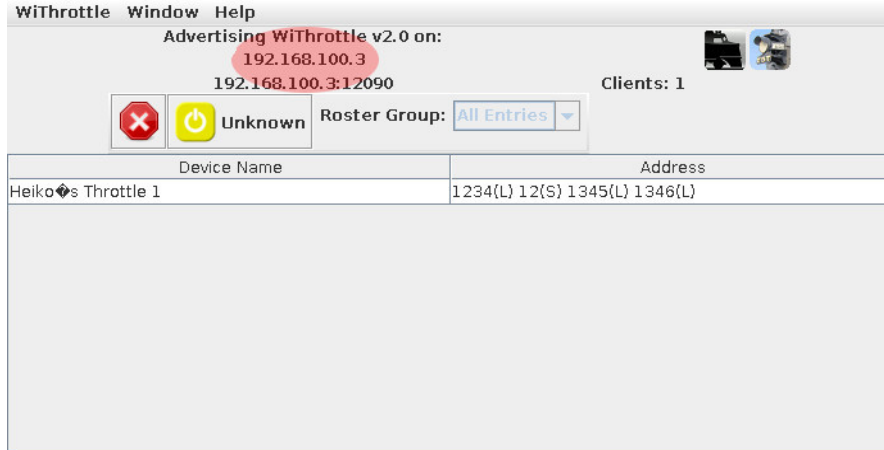


Figure 11: Screenshot of wiThrottle screen showing one throttle connected

2.2.1 General configuration

In the “General configuration” section there is only one configuration option: The throttle name. This is a free-form identification string of the throttle. It shows up in the wiThrottle window of JMRI as shown in figure 11 and can be used to identify the throttle during configuration. The wiFred also announces its presence on the WiFi network through Bonjour/Zeroconf using a sanitized version of the name, i.e. a throttle called “Heiko Prototype 2-2” will announce its presence as *heikoprototype22.local* when not in configuration mode.

2.2.2 WiFi configuration

The “WiFi configuration” section shows a list of configured WiFi networks. The wiFred will connect to any network in this list, more or less randomly choosing one if multiple configured networks are in range.

Existing entries can be removed by clicking on the “Remove SSID” button in the line of the network that shall be removed.

New entries can be added either by manually entering the SSID and PSK¹ if required and clicking the “Manually add network” button or by clicking on the “Scan for networks” link which takes the user to the page shown in figure 13.

This page will take a few seconds to load, since the scan for networks has to be completed first. It shows all the networks found during the scan. Networks can be added to the list by clicking the “Add network” button, after entering the PSK² in the field next to it.

¹Pre-Shared Key, often just called password

²Pre-Shared Key, often just called password

2 wiFred Wireless throttle configuration

wiFred configuration page

General configuration

Throttle name:

WiFi configuration

Active WiFi network SSID: not connected [Scan for networks](#)

Known WiFi networks:

SSID: RPi-JMRI PSK: rpl-jmri

New SSID: New PSK:

[Restart wiFred to enable new WiFi settings](#) WiFi settings will not be active until restart.

Loco server configuration

Loco server and port: :12090

Find server automatically through Zeroconf/Bonjour? ☒ Using undef:12090

Loco configuration for loco: 1

DCC address: (-1 to disable)

Long Address? ☒

Reverse? ☐

[Function mapping](#)

Loco configuration for loco: 2

DCC address: (-1 to disable)

Long Address? ☒

Reverse? ☐

[Function mapping](#)

Loco configuration for loco: 3

DCC address: (-1 to disable)

Long Address? ☒

Reverse? ☐

[Function mapping](#)

Loco configuration for loco: 4

DCC address: (-1 to disable)

Long Address? ☒

Reverse? ☐

[Function mapping](#)

wiFred status

Battery voltage: 4133 mV

wiFred system

[Reset wiFred to factory defaults](#) [Update wiFred firmware](#)

Figure 12: Screenshot of wiFred main configuration page

Results of WiFi scan

FRITZ!Box Fon WLAN 7360	Enter PSK here if required:	<input type="text"/>	<input type="button" value="Add network"/>
Vodafone Homespot	Enter PSK here if required:	<input type="text"/>	<input type="button" value="Add network"/>
FRITZ!Box Fon WLAN 7360	Enter PSK here if required:	<input type="text"/>	<input type="button" value="Add network"/>

[Return to main page](#)

Figure 13: Screenshot of wiFred “Scan for WiFi”-page

Note that the wiFred does not support WPS and it won’t accept multiple networks with the same SSID but different PSKs. More details regarding the network requirements can be found in section 3.

The new WiFi configuration will not be activated until the wiFred is restarted, either through a power-cycle or by clicking on the “Restart wiFred to enable new WiFi-settings” link on the configuration page.

2.2.3 Loco server configuration

Following the WiFi configuration, the section “Loco server configuration” allows configuring the wiThrottle server to which the wiFred shall connect. The default setting – automatically detect server – works well if there is only one wiThrottle server on the network. It will connect to any server announcing its presence on port 12090 through Zeroconf/Bonjour, the result of the Zeroconf/Bonjour-search will be shown here when the wiFred has automatically discovered a server.

2.2.4 Loco configuration

Following the “Loco server configuration”, there are four identical sections assigned to the four different locomotives which can be controlled with this throttle. Each section consists of the following settings:

DCC address: Can be a short address between 1 and 127 (also used for consists) or a long address between 0 and 10239. Note: Short addresses between 1 and 127 are not the same as long addresses between 1 and 127. If this is set to -1, the corresponding loco is disabled.

Long address?: Checkbox to change the behaviour of the DCC address input field described above.

Reverse?: If checked, the corresponding loco will invert it’s travel direction. Mainly intended for back-to-back consists without decoder reconfiguration.

Function mapping: Link to the function mapping subpage for the corresponding loco, as described in section 2.2.5. Clicking this link will lose all information entered on the current page and take the web browser to a different subpage.

Reminder: Changes are saved using the “Save loco config” button which may look different in different web browsers (firefox shown).

2.2.5 DCC function configuration

By default, if a function key is pressed, the throttle will send the appropriate commands to every loco under control. Under certain circumstances, this may not be desired – the obvious example being a loco in the middle of a multi-unit consist, which should not have lights or ditchlights. So this page – shown in figure 14 – offers the option to chose between three different settings for every function on each of the four locomotives (one page per locomotive):

Function mapping for Loco: 1

Function configuration for loco 1 (DCC address: -1)

Function 0:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 1:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 2:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 3:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 4:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 5:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 6:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 7:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 8:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 9:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 10:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 11:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 12:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 13:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 14:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 15:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off
Function 16:	<input type="radio"/> Always On	<input checked="" type="radio"/> Throttle controlled	<input type="radio"/> Always Off

[Back to main configuration page \(unsaved data will be lost\)](#)

Figure 14: Screenshot of wiFred function handling config page

Always Off: When the loco is enabled by moving the selection switch to the “selected” position, the current status of the function is queried. If the function is on, a

function key press will be simulated to turn it off. No other function key events will be sent to this loco for this function.

Throttle controlled: When the first loco is enabled by moving the selection switch to the “selected” position, the current status of the function is queried and saved. When selecting the next loco, the status is queried. If it does not match the first loco, the function status is changed by simulating a function key press. Afterwards, key presses are handed through to the loco.

Always On: Similar to the “Always Off” setting, but the throttle will attempt to enable the function when the locomotive is selected and ignore any further function key presses. This will probably not work with so-called momentary functions that are only active as long as the function key is pressed.

Reminder: Changes are saved using the “Save function configuration” button which may look different in different web browsers (firefox shown).

2.2.6 wiFred status

The “wiFred status” section shows the current battery voltage, as measured by the wiFred. This is updated on reloading the page, not continuously.

2.2.7 wiFred system

The “wiFred system” section consists of two links:

- Reset wiFred to factory defaults – which leads to a confirmation page shown in 15 to reset all configuration data to factory defaults as on a new wiFred.
- Update wiFred firmware – which leads to a firmware update page shown in 16 to update the wiFred firmware of the ESP8266. Find the .bin-file from the arduino build folder, click on “Choose file”, navigate to the .bin-file and finally initiate the update with a click on “Update” – which will take a while.

Reset wiFred to factory defaults?

[Yes, really reset the wiFred to factory defaults](#)
[No, return to configuration page](#)

Figure 15: Screenshot of wiFred configuration reset page

2 *wiFred Wireless throttle configuration*



Figure 16: Screenshot of wiFred firmware update page

3 Options for server setup

Figure 17 shows the connections between the devices required to run trains using the wiFred.

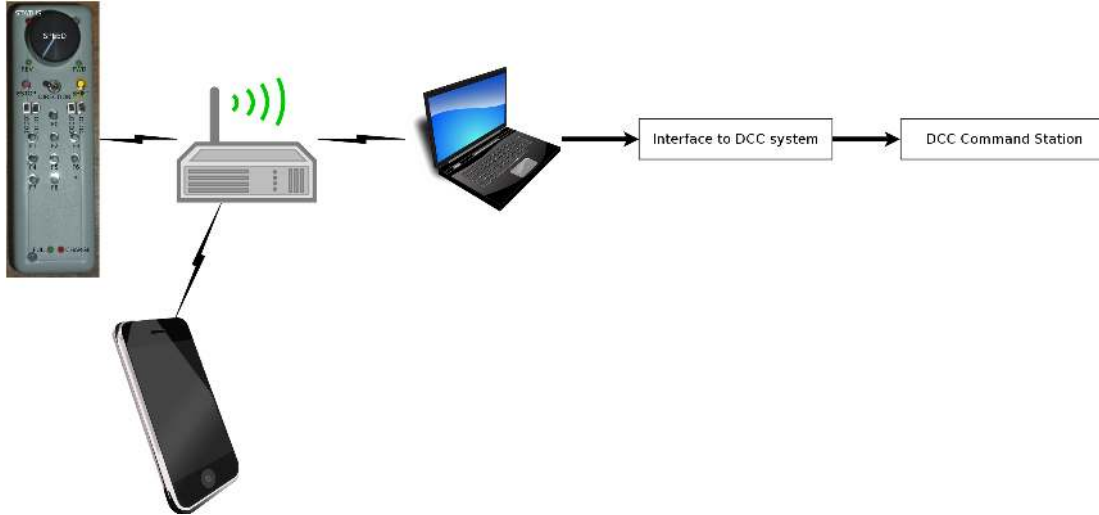


Figure 17: Overview of devices required to run trains with the wiFred

The symbols in figure 17 symbolize the following parts:

1. An IEEE 802.11b/g/n 2.4 GHz WiFi access point described in detail in section 3.3
2. A PC or laptop computer with Windows, Linux or MacOS to run the JMRI server described in detail in section 3.4
3. A way to connect the JMRI server to the model railroading layout described in detail in section 3.5
4. A device with a web browser connected to the same network as the wiFred to configure it – can be the same physical device as 2 if requirements in section 3.6 are met

Multiple options for every step or combining these steps are described in the following sections.

Basically, if a layout is set up to run trains with a smartphone running wiThrottle or EngineDriver, a wiFred should work with no changes to the layout configuration.

If a layout is set up in a way that trains can be run from a JMRI screen throttle on a computer, only a WiFi connection to the JMRI computer needs to be added.

3.1 Out-of-the-box server-side options

A pretty much out-of-the-box solution is provided by Steve Todd at [10] which auto-detects multiple options to interface to a DCC layout and has been tested in the JMRI 4.16 version to work with the wiFred, connecting to a Z21 black through both an RRCircuits LocoBuffer USB and a Digitrax PR3 via Loconet.

Although untested so far, adding a Digitrax LNWI [9] to a Digitrax system or an MRC Prodigy WiFi [8] to an MRC system should allow the wiFred to run locos out-of-the-box as well.

3.2 Step by step instructions for a Windows computer

Tested on Windows 7 64Bit

Requirements: WiFi 2.4GHz

Installation:

1. Install HostedNetworkStarter from https://www.nirsoft.net/utils/wifi_hotspot_starter.html
2. Install DHCP server from <https://www.dhcpserver.de/cms/download/> – download and extract all the files from the zip file to somewhere on your harddrive, for example C:\DHCPServer
3. Install a JDK, version 8 and 11 have been tested. For example, <https://adoptopenjdk.net/releases.htm> Version OpenJDK 11 (LTS), JVM HotSpot. Choose the 64bit version for most modern hardware, 32bit only if you are running a 32bit operating system. Easiest option: MSI file, download and install.
4. Install JMRI from <https://www.jmri.org> – versions tested to run with the wiFred include 4.14, 4.16, 4.18 and 4.20. Most recent production version recommended.

Configuration:

1. Start HostedNetworkStarter from the start menu, enter a Network Name and Network Key, then hit the Start button. Note the “Hosted Network Connection Name” for the next step
2. Start the DHCP server wizard from C:\DHCPServer\dhcpwiz.exe, select the network with the name that’s the same as the “Hosted Network Connection Name” from the step before, hit “Next” a few times (deselecting all additional supported protocols), Write INI file, Start Service and Configure Firewall Exceptions
3. Start JMRI using the DecoderPro icon on the desktop, setup your layout connection, test if you can run a loco with a JMRI throttle
4. Within JMRI, start the WiThrottle Server from the Actions menu. If a firewall popup comes up, allow all.

3 Options for server setup

5. Within JMRI, edit the Preferences from the Edit menu, choose WiThrottle on the left pane, click the “Start automatically with application” checkbox. All the Allowed Controls can be disabled.

Running:

1. Start HostedNetworkStarter from the start menu, enter a Network Name and Network Key, then hit the Start button.
2. Start JMRI using the DecoderPro icon on the desktop

3.3 WiFi access point requirements

IEEE802.11bg 2.4GHz DHCP server comm between clients

Linux: hostapd (tested: netbook, Raspberry Pi 3 in a PiTop) Windows: link to ... Hardware.

3.4 JMRI server requirements

Any PC.

3.5 Layout connection options

Loconet: LocoBufferUSB Digitrax PR3 / PR4

Tested: Intellibox, Z21 black, DCS 51 Zephyr xtra

Should work: Anything JMRI can control trains on, even SPROG as command station plus boosters...

3.6 Computer or smartphone to configure wiFred

Webbrowser, Zeroconf. Avahi. Bonjour (iTunes?). MacOS out of the box? iOS? Android?

For initial configuration of the wiFred, most of the devices mentioned above can be omitted. As shown in figure 18, only a WiFi capable device with a web browser is required.

3 Options for server setup



Figure 18: For initial configuration, the requirements are very small

4 wiFred Wireless throttle prototype

4.1 Quickstart Guide

Follow these steps for a new throttle (see later chapters for more explanation or if you run into trouble)

- 3. Use PCB to determine positions of holes and cutouts in housing
- 2. Make said cutouts and glue little pieces of 3mm thick plastic or wood underneath PCB screw holes
- 1. Solder components to PCB
0. Flash firmware to ESP8266 and to ATmega 328P
1. Test fit PCB into housing, removing plastic parts of housing as required
2. Fit PCB into housing, insert three screws to fix PCB to housing
3. Make sure communication jumpers are set correctly, close housing and fix back cover with two screws
4. Add throttle knob
5. Insert batteries
6. Using any WiFi client (laptop, smartphone, tablet...), find and connect to network *wiFred-configXXXX*
7. Using any web browser, navigate to *http://192.168.4.1*
8. Enter your WiFi configuration (and a throttle ID if you like – highly recommended to easier tell them apart) **and hit the *Submit-Button***
9. Click on **Loco configuration subpage**
10. Enter your wiThrottle server settings
11. For every loco you want to control with this throttle, enter the appropriate details below
12. Finish by **hitting the *Submit-Button***
13. Configure function settings for each loco on the respective sub pages if required
14. Restart the throttle by navigating back to the main configuration page and clicking on **Restart system to enable new WiFi settings**

Your throttle should now be ready to use and connect to your wiThrottle server on startup. Refer to the chapters below if it does not or contact the author of this document.



Figure 19: Controls and features of the wiFred-throttle – prototype version

4.2 Usage

Figure 19 shows the controls of the wireless throttle. They consist of the following:

- Four loco selection switches (loco 1 on the left, loco 4 on the right, move towards speed potentiometer to enable)
- Speed potentiometer (Counter-clockwise endstop: Stop, clockwise endstop: Full speed)
- Direction switch – move right for forward movement, left for reverse movement
- Black function keys F0 to F4
- Two yellow shift keys to trigger F5-F8 (SHIFT1, lower key), F9-F12 (SHIFT2, upper key) and F13-F16 (both shift keys)
- Red emergency stop key
- Two green direction indicator LEDs
- One red status LED
- Battery compartment (on the rear) for two AA cells, 1.2 V to 1.5 V nominal voltage

4 *wiFred* Wireless throttle prototype

As soon as a pair of batteries is inserted into the battery compartment as the symbols inside the battery compartment show, the throttle will boot up and try to connect to a wireless network. The throttle will not be damaged if batteries are inserted wrongly, but it will not work either. Use NiMH- or primary AA cells with 1.2 V to 1.5 V nominal voltage, low self discharge NiMH cells like Eneloop® or similar are recommended. Do not insert 3 V or 3.6 V AA size lithium batteries as this may damage the throttle.

If no connection to the network configured into the device can be established within 60 seconds, the throttle will create it's own wireless network named *wiFred-config* plus four hex digits taken from the MAC address of the throttle WiFi interface, for example *wiFred-config0CAC*, to enable configuration as described in section 2.

Four different locos with long DCC addresses can be assigned to the four loco selection switches. Commands derived from the speed potentiometer, the direction switch and the function keys will be transmitted to all selected locos (near) simultaneously, with a certain translation table enabling some locos to go backwards when others go forwards and also limiting function keys to some of the four locos only – this is described in more detail in sections 2.2.4 and 2.2.5.

Pushing the red emergency stop key will cause the throttle to send an emergency stop signal to all four locos attached. After an emergency stop, turn the speed potentiometer to zero to re-enable control of the locos.

Pushing the red emergency stop key while holding down either of the shift keys will place the device into configuration mode (as well as issuing an emergency stop to all attached locos). See section 2 for more details on how to access the throttle to do the configuration.

Any change in the loco selection switches will cause the throttle to send an emergency stop command to all attached locos. This makes sure that any loco that is deselected will stop on the layout and avoids newly selected locos suddenly taking off at speed. The same is true for a change in the direction switch, to avoid high-speed reverse maneuvers. Turn the speed potentiometer to zero to re-enable control of the locos.

When all four loco selection switches are set to the disabled state, the throttle will send an emergency stop command to all four locos attached and – after a wait time of 30 seconds – it will disconnect from the network and go into low power mode. To reconnect, re-enable any loco selection switch.

The same happens when the batteries are empty, but the throttle will not reactivate before changing the batteries. Expected runtime with a pair of 2500 mAh-NiMH-batteries is around 8-10 hours of full time operations, more if the throttle is placed in low power mode when the locos are not running.

During startup and operation, the LEDs will show the patterns explained in table 1.

4.3 Hardware description

The wiFred hardware is centered around an ESP8266 for the WiFi connection. The ESP8266 also reads the loco selection switches and the battery voltage and communicates through it's serial port with an ATmega 328P microcontroller which controls the LEDs, reads the speed potentiometer, direction switch and pushbutton switches for functions and emergency stop. The communication goes through a 2x3 pin header which enables the user to connect a programming cable to the same serial port if removing the jumpers.

The wiFred is powered by two AA size battery cells connected to a step-up converter creating 3.3 V for the entire device.

The schematic is split into several pages and can be found in figures 20 to 23. It has been created with kicad and is available on the github repository at <http://github.com/newHeiko/wiFred> along with the PCB design.

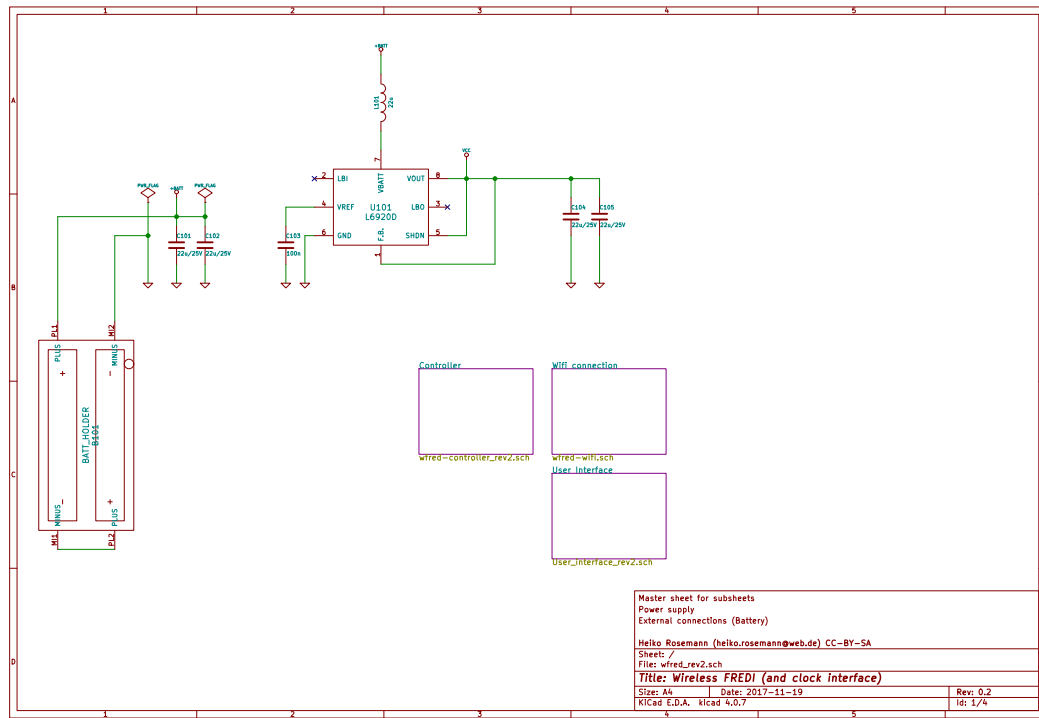


Figure 20: Master schematic sheet with batteries and power supply

4.4 Hints for building the wiFred

The PCB has holes in the center of the pushbutton switch footprints and LED footprints to enable transferring their positions to a StrapuBox housing with a sharp needle or

4 wiFred Wireless throttle prototype

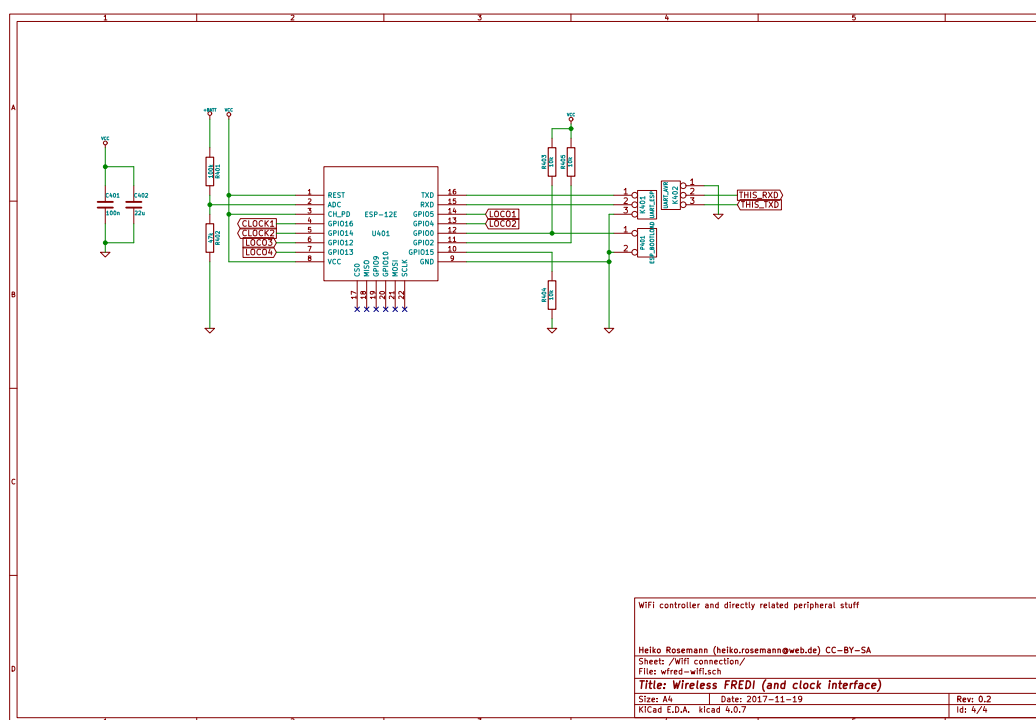


Figure 21: Schematic sheet including ESP8266 for WiFi connection with bootloader enabling jumper and connection to programming cable

similar, and the position of the loco selection switches can also be transferred to the housing by marking it through the non-copper holes at their ends. Figure 24 shows the process and it's results. Holes for the pushbutton switches should be drilled at 3.5 mm diameter and countersunk from the inside. Holes for the LEDs should be drilled at 3 mm diameter and holes for the speed potentiometer and direction switch at 6.5 mm or 7 mm diameter and countersunk. The cutouts for the loco selection switches are best created when the PCB is assembled and carefully cut out with a sharp hobby knife and a file until they fit.

The remaining assembly is a basic exercise in installing all the components to the PCB, listed in table 4. From assembling the prototypes, the suggested order of installing the components is as follows:

1. IC201 and U101 (note: Rotate PCB so Designator is right side up, then Pin 1 is on top left)
2. X201
3. Capacitors and Resistors in 0805 size (only those on the same side as the items before)

4 wiFred Wireless throttle prototype

Table 4: List of components for the wiFred

Designator	Package	Designation
B101	KEYSTONE1013	BATT_HOLDER
C206,C205	C_0805_HandSoldering	22p
C301,C105, C104,C102, C101	C_0805_HandSoldering	22u/25V
C401,C204, C203,C202, C201,C103	C_0805_HandSoldering	100n
C402	C_0805_HandSoldering	22u
D301	LED_D3.0mm	STOP - red
D302	LED_D3.0mm	FORWARD - green
D303	LED_D3.0mm	REVERSE - green
IC201	TQFP-32_7x7mm_Pitch0.8mm	ATMEGA328P-A
K401	Pin_Header_Straight_1x03_Pitch2.54mm	UART_ESP
K402	Pin_Header_Straight_1x03_Pitch2.54mm	UART_AVR
L101	L_2424_HandSoldering	22u
P201	Pin_Header_Straight_2x03_Pitch2.54mm_SMD	ISP
P401	Pin_Header_Straight_1x02_Pitch2.54mm	ESP_BOOTLOAD
R301	C_0805_HandSoldering	4k7
R304,R303, R302	C_0805_HandSoldering	470R
R401	C_0805_HandSoldering	100k
R402	C_0805_HandSoldering	47k
R405,R404, R403,R201	C_0805_HandSoldering	10k
RV301	P160KNPD	10k lin P160KNPD-4FC20B10K
SW301	OS102011MS2Q	LOCO1
SW302	OS102011MS2Q	LOCO2
SW303	OS102011MS2Q	LOCO3
SW304	OS102011MS2Q	LOCO4
SW305	KSC621G	F0
SW306	KSC621G	F1
SW307	KSC621G	F2
SW308	KSC621G	F3
SW309	KSC621G	F4
SW310	KSC621G	SHIFT2
SW311	KSC621G	SHIFT
SW312	KSC621G	ESTOP
SW313	100SP1T1B1M1QEH	DIRECTION
U101	TSSOP-8_4.4x3mm_Pitch0.65mm	L6920D
U401	ESP-12E_SMD	ESP-12E
X201	Crystal_SMD_TXC_7M-4pin_3.2x2.5mm_HandSoldering	14.7456MHz
	Housing StrapuBox 6090 Two Jumpers, 2.54mm Potentiometer Knob, 21 mm Three fastening screws, 2.9 mm dia x 6.5 mm	

4 wiFred Wireless throttle prototype

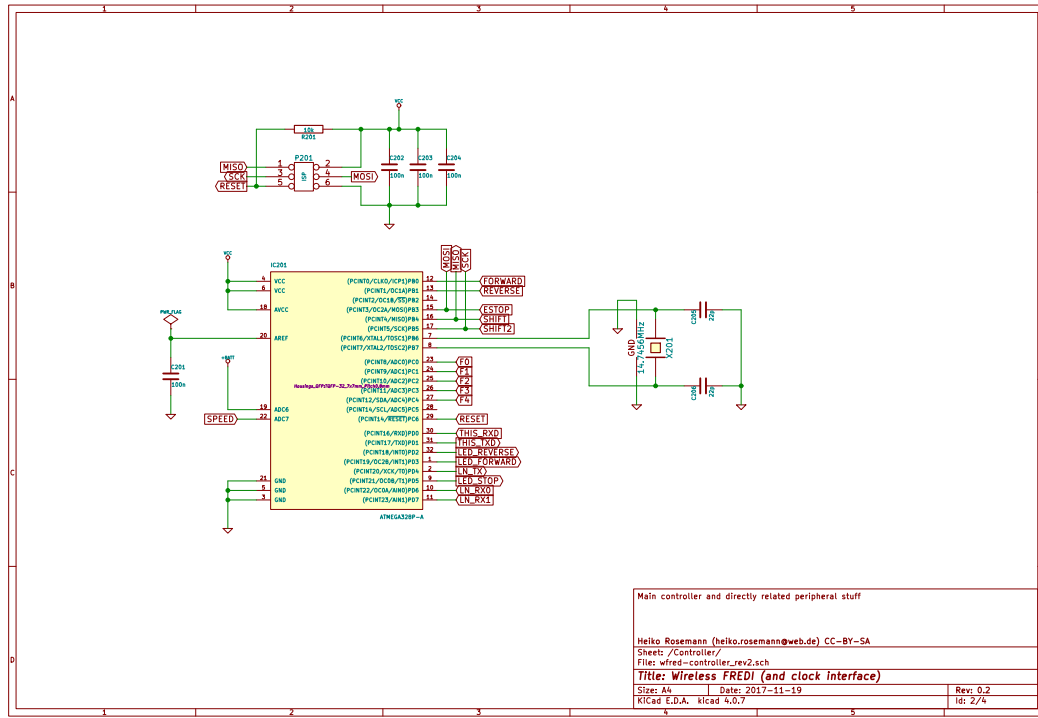


Figure 22: Schematic sheet including ATmega 328P along with crystal and in system programming header

4. U401
5. LEDs D301 to D303
6. Pushbutton switches SW305 to SW312
7. Loco selection switches SW301 to SW304
8. L101
9. Capacitors and Resistors not installed in step 3
10. Pin header P201
11. Pin headers K401, K402 and P401 (correct alignment of K401 and K402 can be assured by adding a jumper before soldering)
12. Direction switch SW313 (screwed into the PCB with an 8 mm hex nut first, then attached to it's pads using the cutoffs from D301, D302 and D303) and Speed potentiometer RV301 (screwed into the PCB with a 10 mm hex nut first and slightly shortening the pins before soldering)
13. Battery holder B101

4 wiFred Wireless throttle prototype

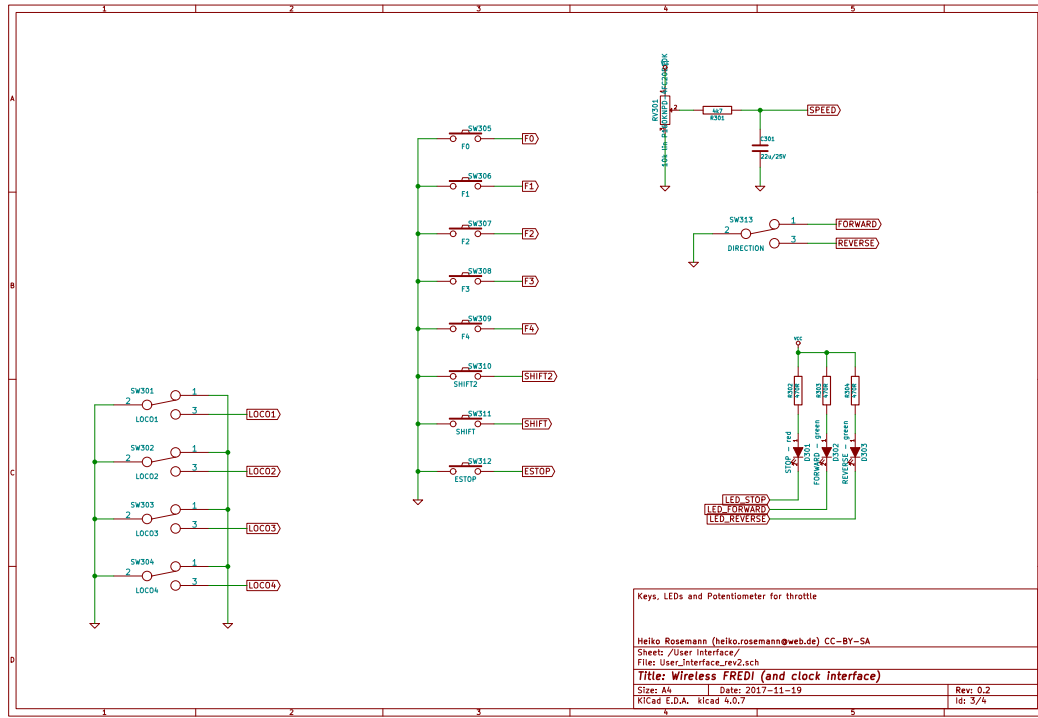


Figure 23: Schematic sheet including pushbutton switches, loco selection switches, direction switch and speed potentiometer

After assembling the PCB with all the components and drilling and cutting the holes and cutouts into the housing, there are few steps left. First, a few protrusions inside the housing need to be removed so the PCB fits properly. Figure 25 shows how they can be removed easily, remains may be cut off with a hobby knife. Second, new PCB mounting pads need to be installed as shown in figure 26. For the prototype, Forex PVC foam was used, cut with a pair of scissors and glued to the housing with superglue, making sure not to be in the way of any components on the PCB, but any kind of easily worked upon material with a thickness of 3 mm can be used, as long as it will take self-driving screws (prototype uses 2.9 mm by 6.5 mm DIN 7981 screws). Third, the two shift keys need yellow paint on the top and the emergency stop key needs red paint – either any kind of paint or a paint marker like Edding 751 will do. Finally, both the ESP8266 and the ATmega 328P will need to be programmed as described in the next section.

4.5 Programming instructions

The ESP8266 is programmed using the Arduino IDE connected via a serial or USB-to-serial port to the K401 header as shown in figure 27. The serial port needs to be at



Figure 24: Using the PCB to transfer the positions of the holes to the housing



Figure 25: Removing protrusions inside the housing so the PCB fits

3.3 V-levels like from an FTDI232-device run at 3.3 V.

All files in the *software/esp-firmware*-subdirectory of the github repository need to be placed in a folder, then the main sketch *arduino_main_sketch.ino.ino* needs to be opened with the Arduino IDE. Settings for the Arduino IDE can be found inside the main file, programming the device should work using the *Upload*-button in the *Sketch*-menu.

To put the ESP8266 into programming mode, a jumper needs to be placed across the P401 header before inserting batteries to start the device in programming mode. The bootloader should show some results on the serial port and during download the LED on the ESP8266 module should flash.

The ATmega 328P is programmed using the regular AVR ISP connection on P201. Pin 1 – GND – is towards the PCB edge, as shown in figure 28. An ISP dongle with either automatic voltage selection or 3.3 V supply voltage should be used to avoid placing too high voltage on the ESP8266, which can only support 3.3 V power. The firmware for the ATmega 328P can be found in the *software/avr-firmware*-subdirectory of the github repository with both a precompiled hexfile and all source code including a Makefile to

4 wiFred Wireless throttle prototype

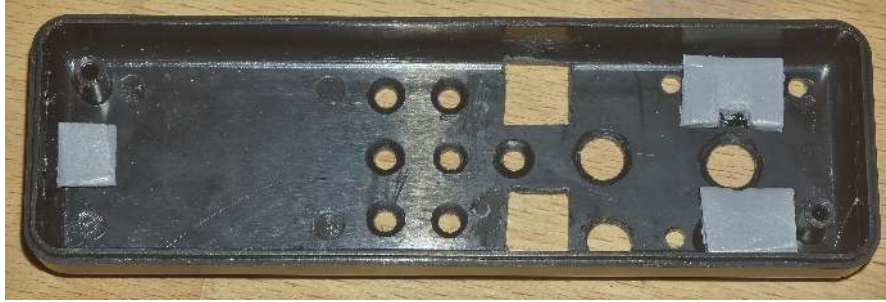


Figure 26: New PCB mounting pads made from 3 mm thick Forex PVC

recompile as needed. After writing the firmware file, also the fuse bits need to be set properly as detailed in the *main.c*-file.

After programming, two jumpers need to be placed between the K401 and K402 pin headers to re-enable communication between the ESP8266 and the ATmega 328P.

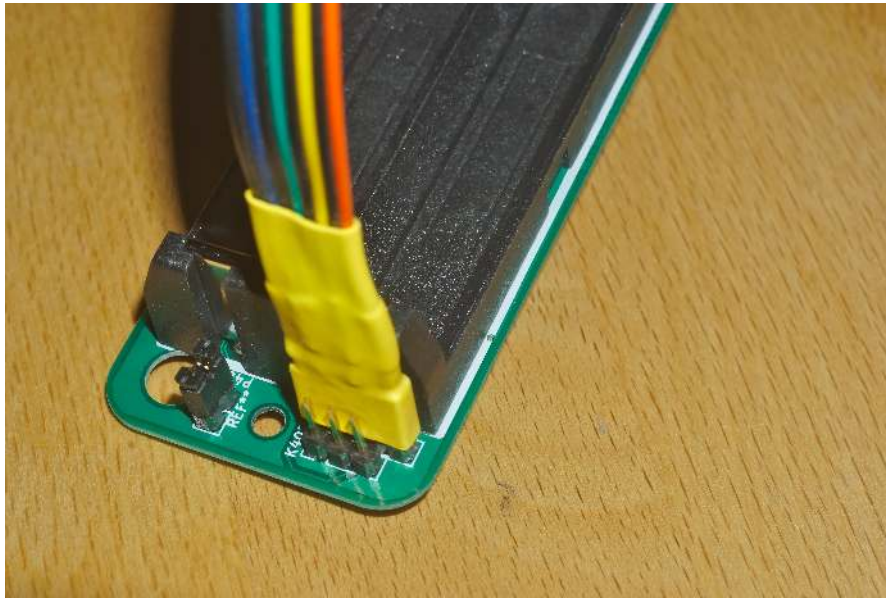


Figure 27: Programming connection for ESP8266 – GND on orange wire, then TXD of programming cable (RXD of ESP8266), then RXD of programming cable (TXD of ESP8266)

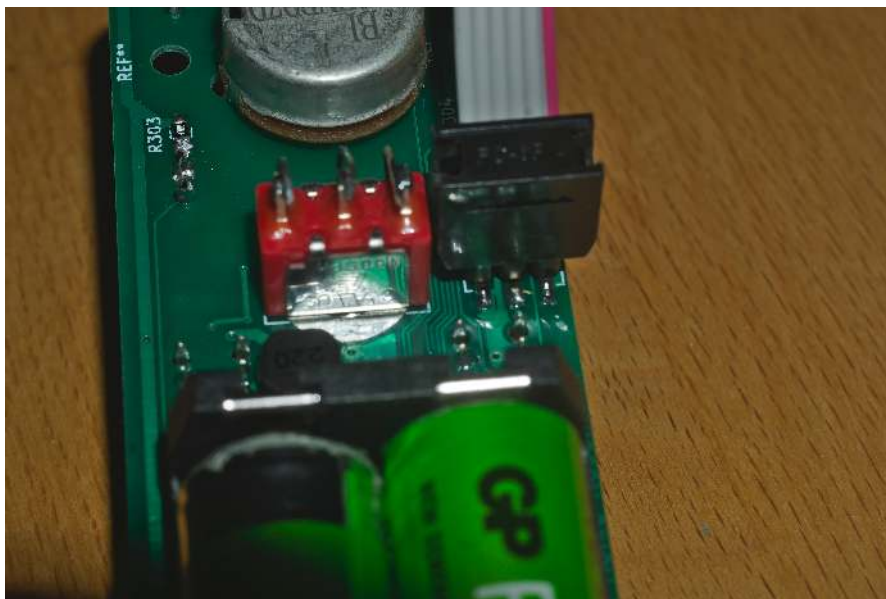


Figure 28: Programming connection for ATmega 328P – Pin 1 on purple cable

5 Background for wiFred development

As of the writing of this document, JMRI [1] has a long track record of offering a server for using smartphones as wireless model railroad throttles, along with apps like withrottle [3]³ and EngineDriver [4]. This server will enable WiFi throttles to control locos any model railroading layout to which JMRI can build a connection [2]. In addition, Digitrax [9] and MRC [8] offer specific hardware solutions to enable the connection of the abovementioned smartphone apps to their DCC systems through a WiFi network.

The Fremo [5] is a European modular model railroading club whose unique requirements on it's DCC throttles led to the creation of the throttles FRED and FREDI [6] – a series of LocoNet®-throttles which started their life as hobbyist projects with large numbers in circulation but were also commercially available from Uhlenbrock [7].

5.1 Specification wishlist

In modular railroading events, particularly of the Fremo-americaN-group [5], multiple people have evaluated the smartphone throttle solutions and found them lacking a nice, haptical feedback. But the idea of wireless control without locking into a specific vendor and their necessarily expensive equipment found great approval. So a wishlist was compiled to define the requirements for a wireless throttle:

- Same form factor as the FRED [6] with similar controls
- Option to control at least two, better four locomotives for double/triple traction (similar to the double FRED)
- Battery runtime of at least six hours
- Exchangeable batteries, so when the battery runs down, they can be quickly exchanged for a charged set or cheap primary cells
- Easy configuration, but not too easy to prevent operators from accidentally selecting other locomotives
- As little change to the existing Fremo Loconet® network as possible
- Use of withrottle protocol, so the server side of the communication can be assumed to work and does not have to be developed as well

³withrottle is also the name JMRI uses for the protocol and the server.

5.2 Development history

The first prototype versions of the wiFred were built to run from two AA cells, either dry batteries or rechargeable NiMH cells. As described in section 4, this led to some special adaptations of the housing to fit all components. Even then, experience with the prototypes showed the battery compartment cover did not really fit and easily broke when trying to open and close the battery compartment. So the next versions were built around an integrated lithium battery, losing the ability to exchange empty batteries, but with increased runtime and proper fit into the housing. Recharging of the second generation is done through a Micro USB connector, so a powerbank can extend the runtime of the device when the internal battery is exhausted. Also, the loco selection switches act as more of a power switch than they did with the first prototypes, reducing power consumption to a negligible amount when all locos are deselected.

5.3 Wireless clock

During the development of this wiFred another topic came up in the americaN group of the Fremo, namely wireless clocks with adjustable clock rate for Timetable & Trainorder operations. This led to the spinoff of the wiClock project[11].

References

- [1] JMRI: A Java Model Railroad Interface, <http://www.jmri.org>
- [2] JMRI: Hardware Support, <http://www.jmri.org/help/en/html/hardware/index.shtml>
- [3] WiThrottle, <http://www.withrottle.com/html/home.html>
- [4] Home | EngineDriver, <https://enginedriver.mstevetodd.com/>
- [5] Home - FREMO - Freundeskreis Europäischer Modelleisenbahner e.V., <https://www.fremo-net.eu/en/home/>
- [6] Throttle, <http://fremodcc.sourceforge.net/throttle/throttle.en.html>
- [7] Uhlenbrock | FRED, der Handregler für die Intellibox, https://uhlenbrock.de/de_DE/produkte/prodarch/I62AD172-001.htm!ArcEntryInfo=0004.41.I62AD172
- [8] Prodigy WiFi, <http://www.modelrectifier.com/Prodigy-WiFi-s/332.htm>
- [9] LocoNet WiFi interface, <http://www.digitrax.com/products/wireless/lwni/>
- [10] JMRI RaspberryPi as Access Point | M Steve Todd, <https://mstevetodd.com/rpi>
- [11] wiClock, a WiFi-JMRI-Clock, found at <https://github.com/newHeiko/WiFi-JMRI-Clock> or its documentation at <https://newHeiko.github.io/WiFi-JMRI-Clock>