

wiFred

**WiFi throttle for model railroads using the wiThrottle
protocol**

REVISION HISTORY

NUMBER	DATE	DESCRIPTION	NAME
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Abstract

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 - for both LiPo battery versions in active development - 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.adoc>.

If you want to know more about the development history of the wiFred, skip ahead to [?] - otherwise read on with Section 1.



1 Quickstart Guide

1.1 Finish assembly (laser engraved enclosure)

1. Make cutout for micro USB connector
2. Install LEDs — long pin (positive) into square pad
 - Red LEDs at D101 and D301 with 3mm spacers
 - Green LEDs at D102, D302 and D303 with 3mm spacers
 - White LEDs at D304 and D305 — choose where and how long they should stick out of housing
3. Install potentiometer and loco selection switches
4. Install direction selection switch and connect pins to PCB with short wires or cutoffs from LEDs
5. Drill holes in enclosure - 3mm for LEDs, 3.5mm for push buttons, 6.5mm for direction switch, 8mm for potentiometer, 1.5mm for slide switches and carefully file slide switch slots to match switch handles
6. If push button switches are not installed: Place them on PCB (red at SW204, yellow at SW215) screw PCB into housing so they fit into the holes and solder them to the PCB
7. Connect battery to P101 - BATT-connector
8. Arrange battery so it fits between direction selection switch and PCB screws and glue into back housing



Warning

Make sure red wire is connected to + and black wire connected to GND. Reversing the connection may destroy the wiFred.

**Warning**

Make sure nothing pinches the battery. LiIon batteries are susceptible to mechanical damage.

1.2 Finish assembly (blank enclosure)

1. Use drilling jig to drill holes into housing
2. Make cutout for micro USB connector
3. Use PCB to drill holes for LEDs next to micro USB connector (D101, D102)
4. Install LEDs — long pin (positive) into square pad
 - Red LEDs at D101 and D301 with 3mm spacers
 - Green LEDs at D102, D302 and D303 with 3mm spacers
 - White LEDs at D304 and D305 — choose where and how long they should stick out of housing
5. Install potentiometer and loco selection switches
6. Install direction selection switch and connect pins to PCB with short wires or cutoffs from LEDs
7. Make cut-outs in housing fit slide switches and flashlight LEDs
8. If push button switches are not installed: Place them on PCB (red at SW204, yellow at SW215) screw PCB into housing so they fit into the holes and solder them to the PCB
9. Connect battery to P101 - BATT-connector
10. Arrange battery so it fits between direction selection switch and PCB screws and glue into back housing

**Warning**

Make sure red wire is connected to + and black wire connected to GND. Reversing the connection may destroy the wiFred.

**Warning**

Make sure nothing pinches the battery. LiIon batteries are susceptible to mechanical damage.

1.3 First startup

1. Charge device with a micro USB charger until charging LED switches to green
2. Turn on device with charger still connected (calibrates low battery threshold)
3. Wait for red LED on top to stop flashing and stay lit
4. Use any WiFi device to search for and connect to network wiFred-configXXXX
5. Connect to <http://config.local> and configure device

More information can be found at <https://newHeiko.github.io/wiFred>.

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.			

Table 1: LED patterns and their meaning on the wiFred

2 Usage

2.1 Operating locos



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 its 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 3.

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 Section 3.5 and Section 3.6.

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 3 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.

2.2 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.

3 Configuring the wiFred

Before using the device, it must be configured. At the very least, the General Configuration page Figure 2 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.

**Important**

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.

3.1 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>.

**Note**

This has been tested with Mozilla Firefox and Opera on Linux with Avahi (a Zeroconf implementation), FOSS Browser on Android 9/10 and Safari on iOS 13/14.

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 4.7 for an explanation what is required to have your device read Bonjour/Zeroconf announcements.

**Note**

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. This is mostly untested and therefore not recommended while the throttle is running locos.

**Note**

This has been tested with Mozilla Firefox and Opera on Linux with Avahi (a Zeroconf implementation) and BonjourBrowser on Android 10.

Figure 2 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.

wiFred configuration page

General configuration

Throttle name: Heiko Prototype 2-1

[Save name](#)

WiFi configuration

Active WiFi network SSID: not connected

[Scan for networks](#)

Known WiFi networks:

SSID: RPi-JMRI

PSK: rpI-jmri

[Remove SSID](#)

New SSID:

New PSK:

[Manually add network](#)

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

Loco server configuration

Loco server and port:

http://

:

Find server automatically through Zeroconf/Bonjour? Using :12090

[Save loco server settings](#)

Loco configuration for loco: 1

DCC address: (-1 to disable) -1



Long Address?



Reverse?



[Function mapping](#)

[Save loco config](#)

Loco configuration for loco: 2

DCC address: (-1 to disable) -1



Long Address?



Reverse?



[Function mapping](#)

[Save loco config](#)

Loco configuration for loco: 3

DCC address: (-1 to disable) -1



Long Address?



Reverse?



[Function mapping](#)

[Save loco config](#)

Loco configuration for loco: 4

DCC address: (-1 to disable) -1



Long Address?



Reverse?



[Function mapping](#)

[Save loco config](#)

wiFred status

Battery voltage: 4133 mV

wiFred system

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

Figure 2: Screenshot of wiFred main configuration page

3.2 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 7 and can be used to identify the throttle during configuration.

**Note**

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.

3.3 WiFi configuration

The "WiFi configuration" section shows a list of configured WiFi networks. The wiFred will connect to any network in this list, choosing the strongest 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 3.

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 3: Screenshot of wiFred "Scan for WiFi"-page

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 PSK¹ in the field next to it.

**Note**

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 4.

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.

3.4 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.

¹ Pre-Shared Key, often just called password

3.5 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, and many DCC systems do not support all those addresses.

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 3.6. Clicking this link will lose all information entered on the current page and take the web browser to a different subpage.

**Important**

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

3.6 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 4 - 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: Always On Throttle controlled Always Off
Function 1: Always On Throttle controlled Always Off
Function 2: Always On Throttle controlled Always Off
Function 3: Always On Throttle controlled Always Off
Function 4: Always On Throttle controlled Always Off
Function 5: Always On Throttle controlled Always Off
Function 6: Always On Throttle controlled Always Off
Function 7: Always On Throttle controlled Always Off
Function 8: Always On Throttle controlled Always Off
Function 9: Always On Throttle controlled Always Off
Function 10: Always On Throttle controlled Always Off
Function 11: Always On Throttle controlled Always Off
Function 12: Always On Throttle controlled Always Off
Function 13: Always On Throttle controlled Always Off
Function 14: Always On Throttle controlled Always Off
Function 15: Always On Throttle controlled Always Off
Function 16: Always On Throttle controlled Always Off

[Save function configuration and return to main page](#)

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

Figure 4: 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 function status is set to be the same. 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.



Important

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

3.7 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.

3.8 wiFred system

The "wiFred system" section consists of two links:

- Reset wiFred to factory defaults - which leads to a confirmation page shown in Figure 5 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 Figure 6 to update the wiFred firmware of the ESP8266. Find the .bin-file from the arduino build folder or from the github repository, 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 5: Screenshot of wiFred configuration reset page



Figure 6: Screenshot of wiFred firmware update page

4 Options for server setup

4.1 Components required to get the wiFred running

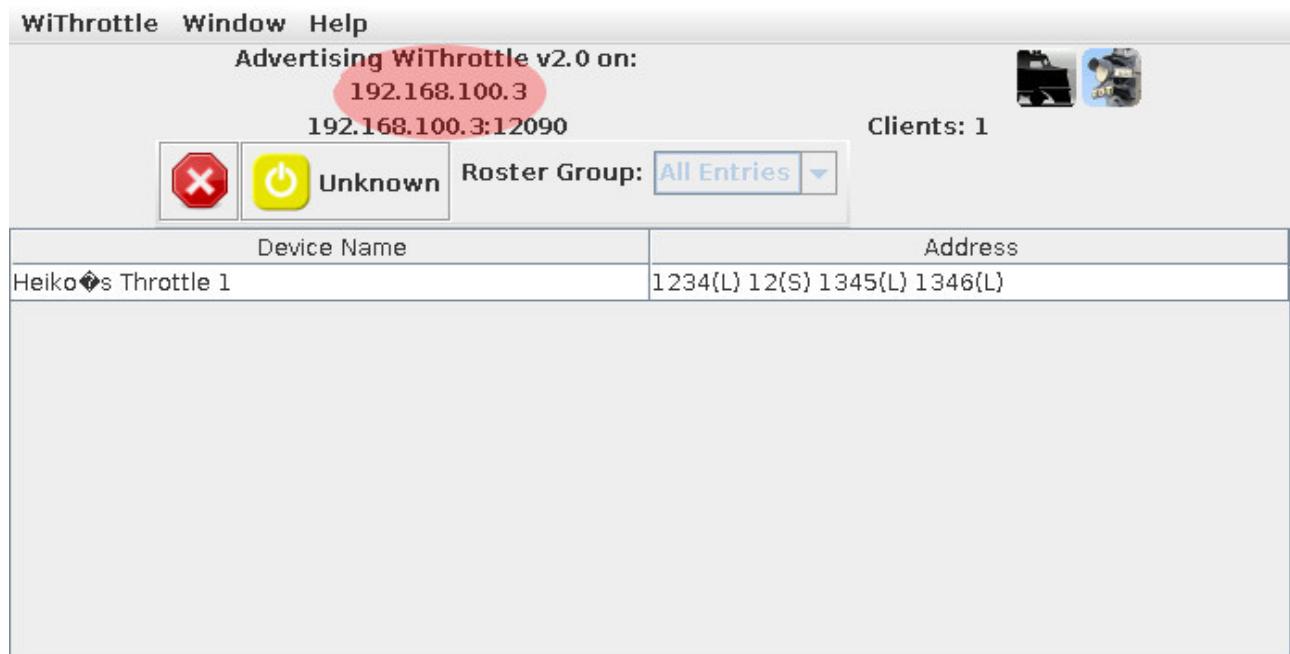


Figure 7: Screenshot of wiThrottle screen showing one throttle connected

Figure 8 shows the connections between the devices required to run trains using the wiFred.

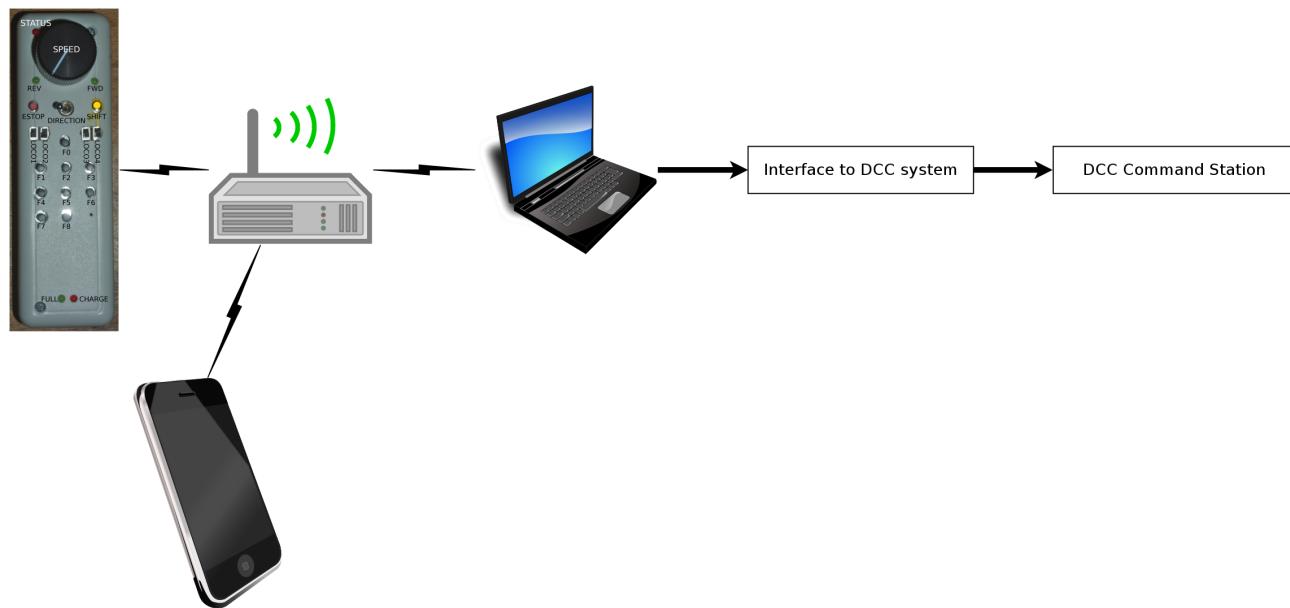


Figure 8: Overview of devices required to run trains with the wiFred

The symbols in Figure 8 symbolize the following parts:

1. An IEEE 802.11b/g/n 2.4 GHz WiFi access point described in detail in Section 4.4
2. A PC or laptop computer with Windows, Linux or MacOS to run the JMRI server described in detail in Section 4.5
3. A way to connect the JMRI server to the model railroading layout described in detail in Section 4.6
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 the one running the server, if it meets the requirements in Section 4.7

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

Note

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.

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

A pretty much out-of-the-box solution is provided by Steve Todd at <https://mstevetodd.com/rpi>, 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** to a Digitrax system or an **MRC Prodigy WiFi** to an MRC system should allow the wiFred to run locos out-of-the-box as well.

4.3 Step by step instructions for a Windows computer

4.3.1 Tested on Windows 7 64Bit

4.3.2 Requirements: WiFi 2.4GHz

4.3.3 Installation

1. Install **HostedNetworkStarter**
2. Install **DHCP server** - 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, **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** - versions tested to run with the wiFred include 4.14, 4.16, 4.18 and 4.20. Most recent production version recommended.

Note

Windows 10 provides a Hotspot feature that will work in place of HostedNetworkStarter and DHCP server, so you can jump right into installing JDK and JMRI.

4.3.4 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:\DHCP\Server\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.
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.

4.3.5 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

4.4 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.

4.5 JMRI server requirements

Any PC.

4.6 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...

4.7 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 9, only a WiFi capable device with a web browser is required.



Figure 9: For initial configuration, the requirements are very small

5 Hardware description

5.1 From revision 0.6 onwards



Figure 10: Using the original PCB and drilling jig to transfer the positions of the holes to the housing - better results will be achieved when the PCBs are screwed in position

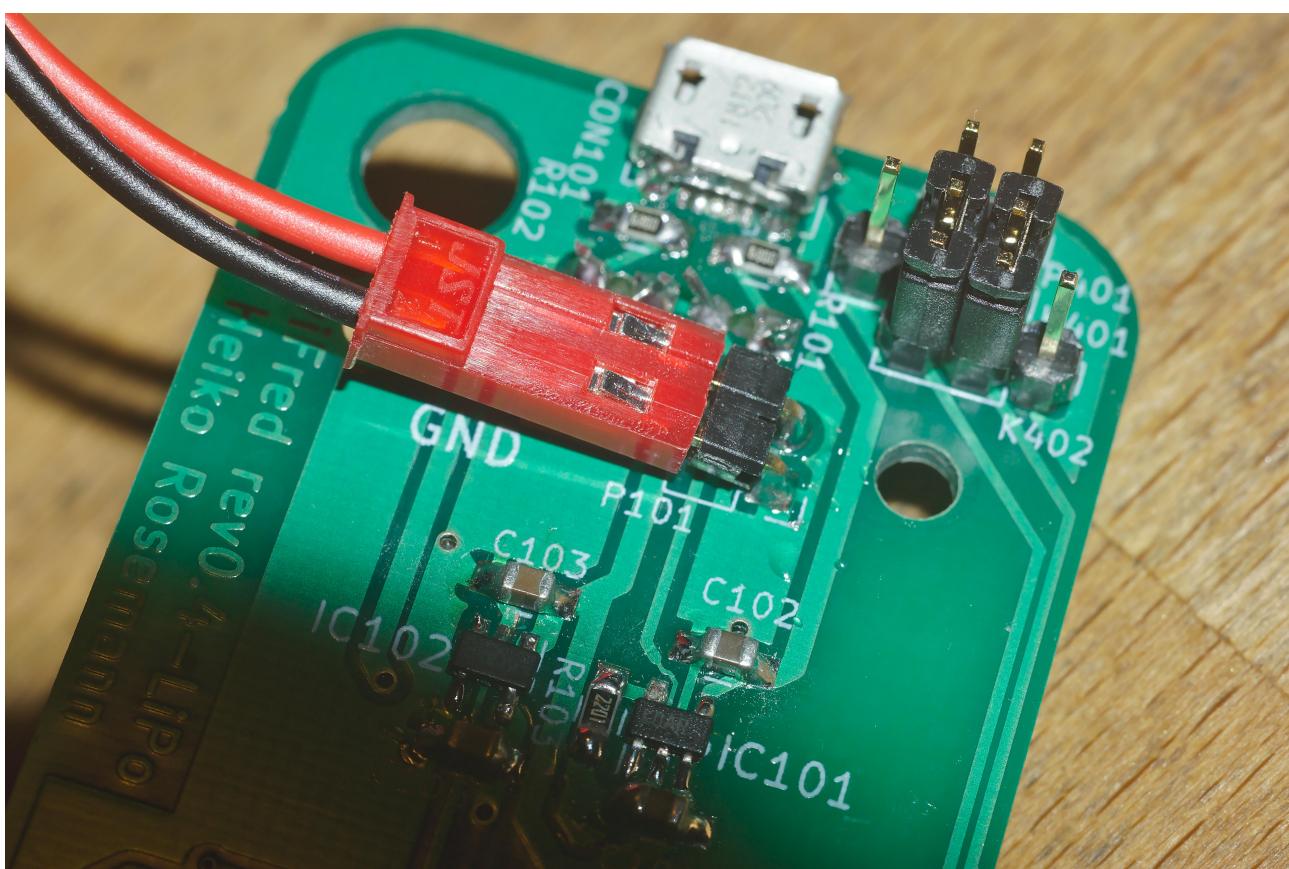


Figure 11: Connection of battery to P101 - black wire is GND, red wire is positive

5.2 Up to revision 0.5

The wiFred hardware is centered around an ESP8266 for the WiFi connection. The ESP8266 communicates through its 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 $1 \mu\text{A}$. 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 Figure 12 to Figure 15. It has been created with kicad and is available on the github repository at <http://github.com/newHeiko/wiFred> along with the PCB design.

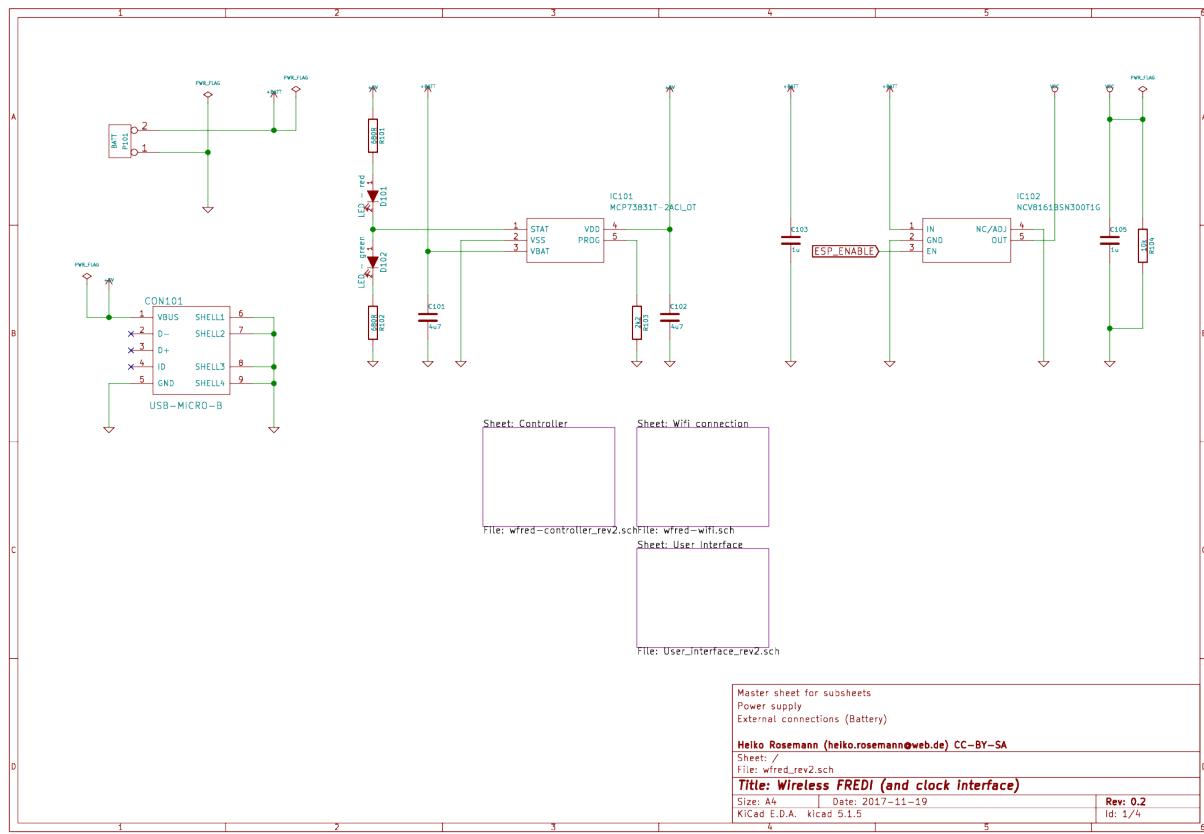


Figure 12: Master schematic sheet with battery connector, charging circuit and power supply

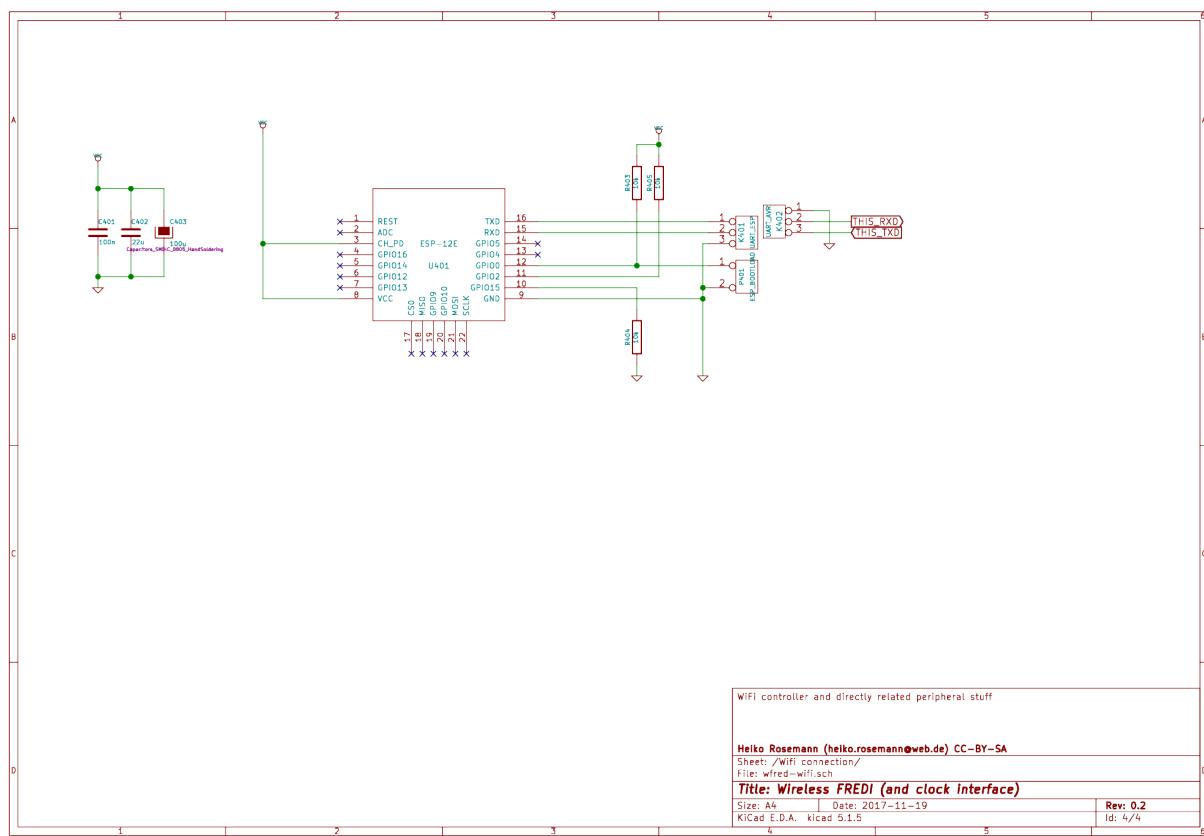


Figure 13: Schematic sheet including ESP8266 for WiFi connection with bootloader enabling jumper and connection to programming cable

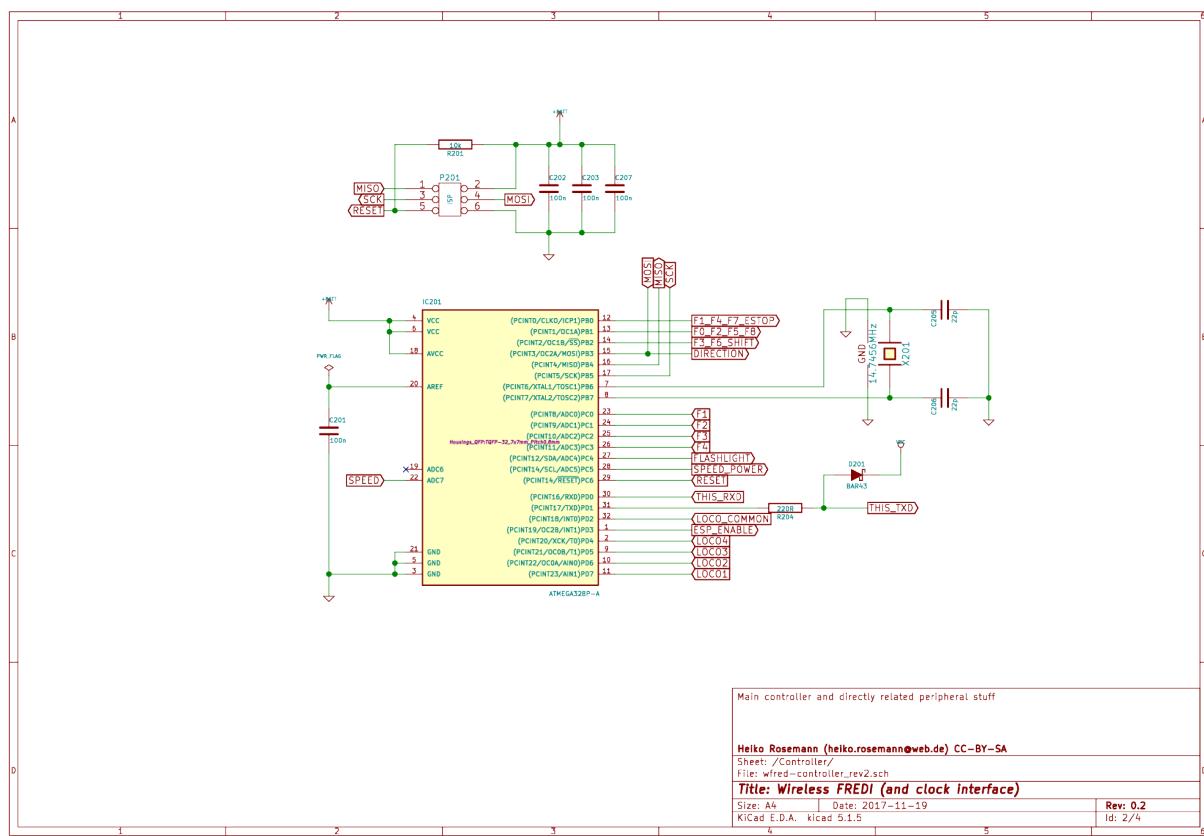


Figure 14: Schematic sheet including ATMega 328P along with crystal and in system programming header

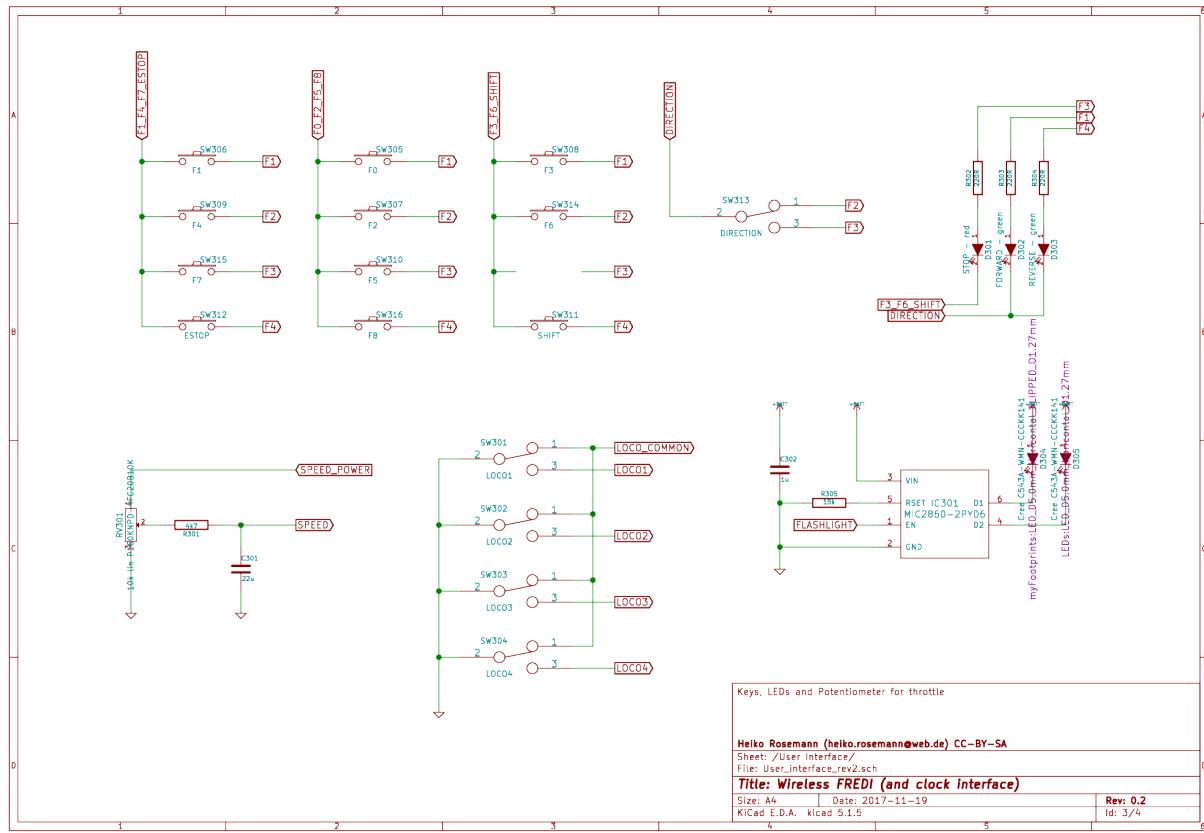


Figure 15: Schematic sheet including pushbutton switches, loco selection switches, direction switch, speed potentiometer and flashlight LEDs with controller

5.3 Hints for building revisions up to 0.5

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 10 shows the process and its 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 1.5 mm and extended to fit when the PCB is assembled with a jigsaw or 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
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 before - that is R403, R404, R405, C401, C402 and C403

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_Horizontal_FLIPPED_O1.27mm	LED white
D305	LED_D5.0mm_Horizontal_O1.27mm	LED white
IC101	SOT95P270X145-5N	MCP73831T-2ACI_OT
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	100SP1T1B1M1QE1H	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

Table 2: List of components for the wiFred PCB

7. Pushbutton switches SW305 to SW312 and SW314 to SW316 - taking care to place 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
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.

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

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

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 11 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 P101 and SW313. Finally, both the ATMega 328P and the ESP8266 will need to be programmed with firmware as described in Section 5.4.

5.4 Writing the firmware to revision 0.5 and older wiFreds

5.4.1 AVR firmware

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 16. 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.

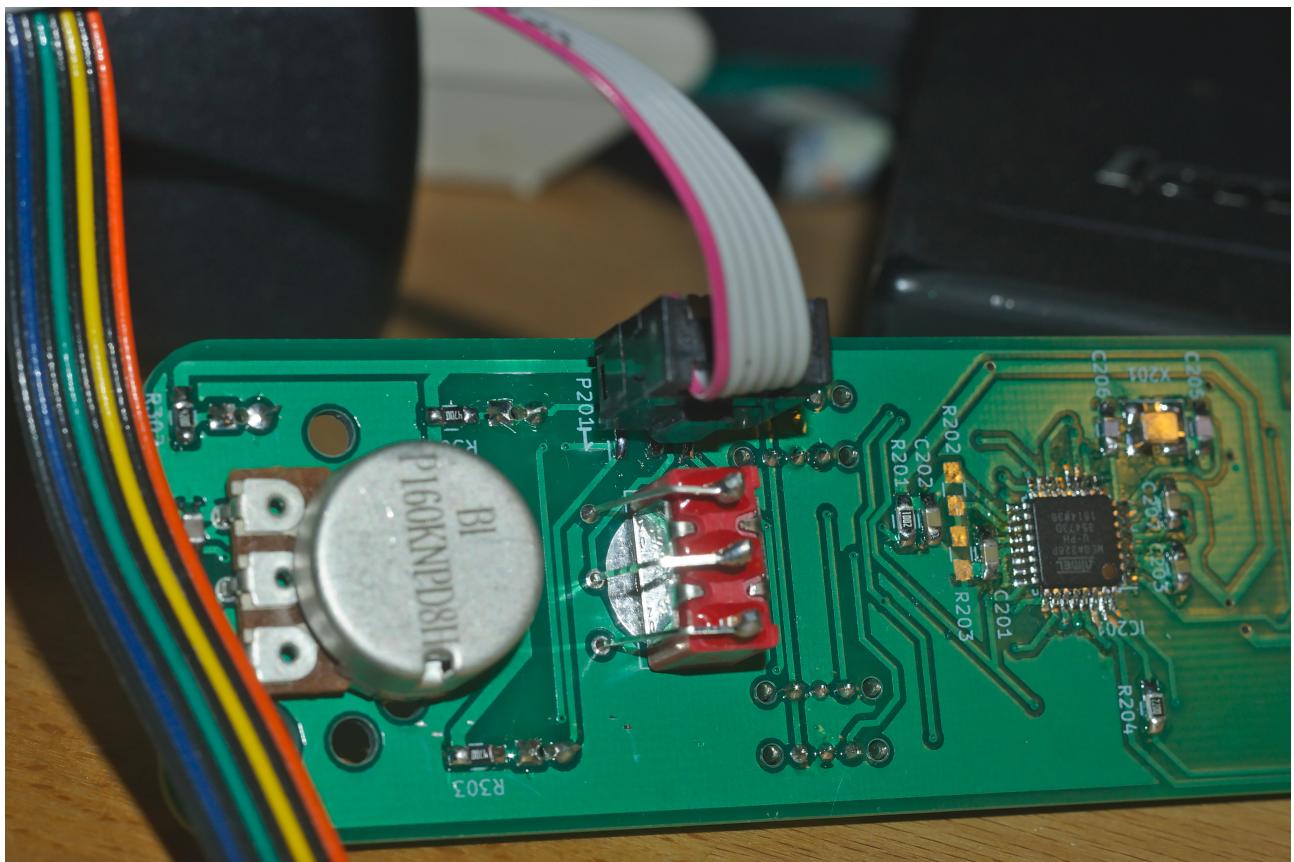


Figure 16: Programming connection for ATMega_328P - Pin 1 on purple cable

5.4.2 ESP8266 firmware

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 17. 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 charged and one of the loco selection switches needs to be moved to the "enabled" position to power up the ESP8266.

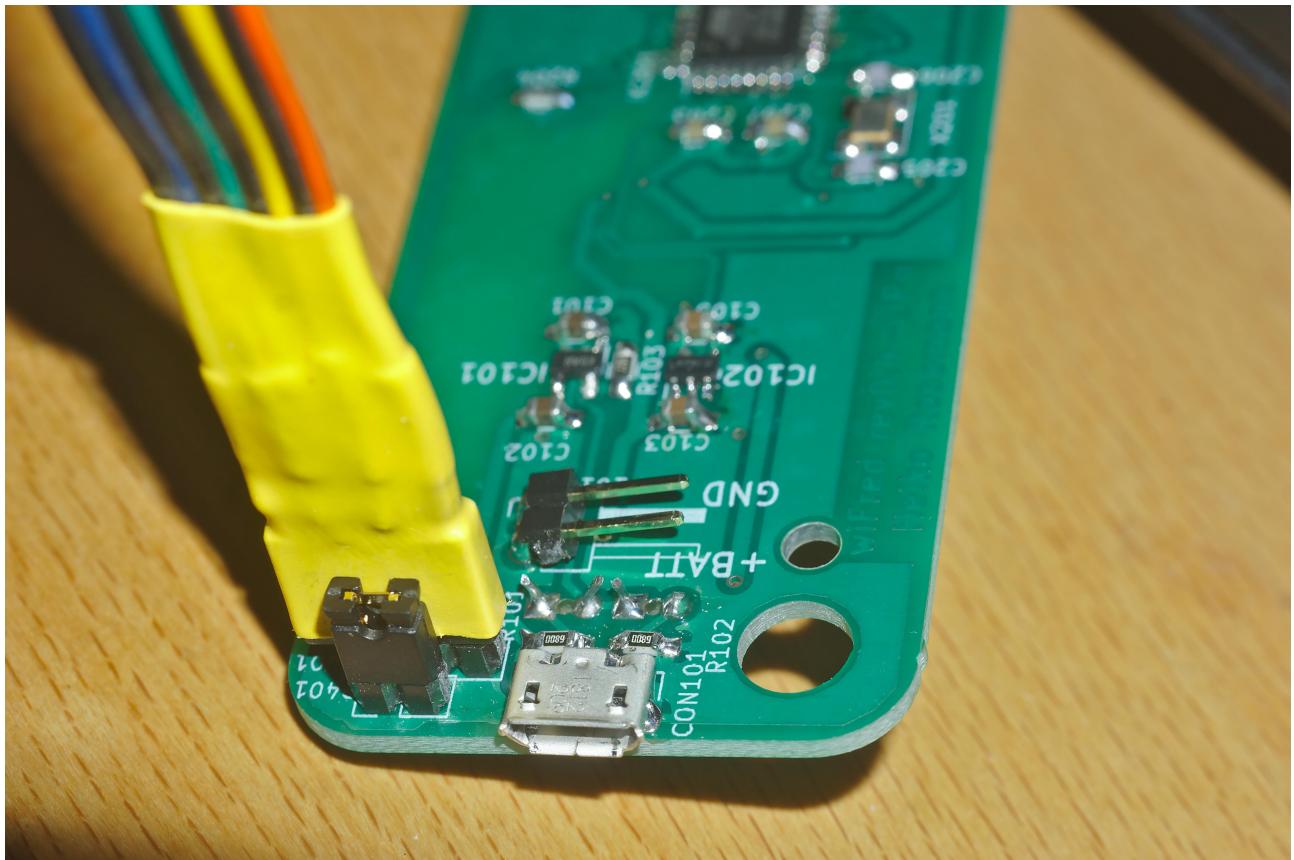


Figure 17: Programming connection for ESP8266 - GND on orange wire, then TXD of programming cable (RXD of ESP8266), then RXD of programming cable (TXD of ESP8266) - also note the jumper on P401

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 18.

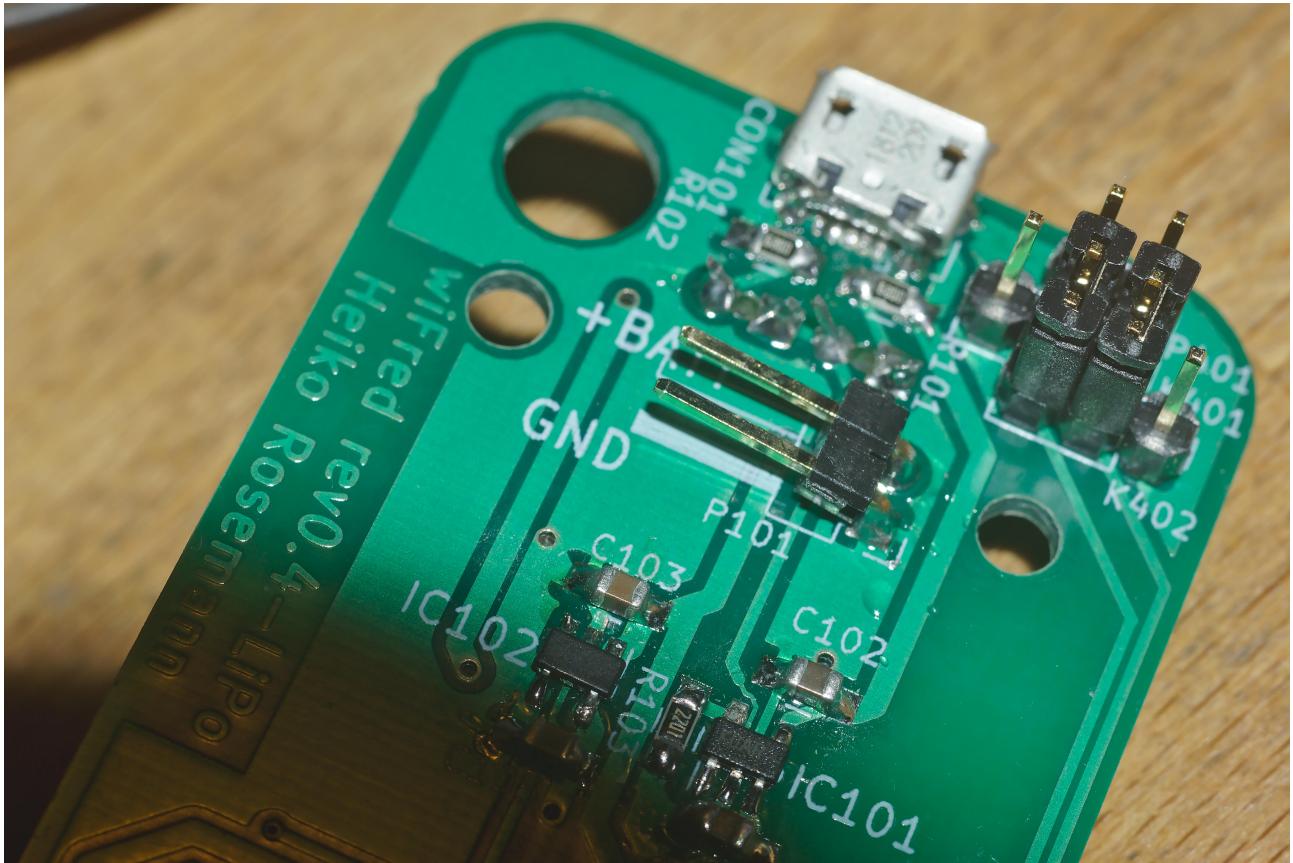


Figure 18: Communication jumpers for connecting the ESP8266 and the ATMega 328P

5.5 AA battery first prototype

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

The schematic is split into several pages and can be found in figures [23](#oldSchematicPage1){reference-type="ref" reference="oldSchematicPage1"} to [26](#oldSchematicPage4){reference-type="ref" reference="oldSchematicPage4"}. It has been created with kicad and is available on the github repository at <http://github.com/newHeiko/wiFred> along with the PCB design.

```
\centering ![Master schematic sheet with batteries and power supply[]{label="oldSchematicPage1"}](images/old_wfred_rev2){#oldSchematicPage1 width="\textwidth"}
```

```
\centering ![Schematic sheet including ESP8266 for WiFi connection with bootloader enabling jumper and connection to programming cable[]{label="oldSchematicPage2"}](images/old_wfred-wifi-Wifi_connection){#oldSchematicPage2 width="\textwidth"}
```

```
\centering ![Schematic sheet including ATmega 328P along with crystal and in system programming header[]{label="oldSchematicPage3"}](images/old_wfred-controller_rev2-Controller){#oldSchematicPage3 width="\textwidth"}
```

```
\centering ![Schematic sheet including pushbutton switches, loco selection switches, direction switch and speed potentiometer[]{label="oldSchematicPage4"}](images/old_wfred-User_Interface){#oldSchematicPage4 width="\textwidth"}
```

5.6 Hints for building the wiFred prototype

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 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 [28](#oldTransferHoles){reference-type="ref" reference="oldTransferHoles"} 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.

\centering !Using the PCB to transfer the positions of the holes to the housing[]{label="oldTransferHoles"}](images/_DSC8652 "fig:"){\#oldTransferHoles width="0.49 \textwidth"} !Using the PCB to transfer the positions of the holes to the housing[]{label="oldTransferHoles"}](images/_DSC8653 "fig:"){\#oldTransferHoles width="0.49 \textwidth"}

The remaining assembly is a basic exercise in installing all the components to the PCB, listed in table [\oldWiFredBOM\](#oldWiFredBOM type="ref" reference="oldWiFredBOM"). From assembling the prototypes, the suggested order of installing the components is as follows:

```
\vspace{0.5em} \centering 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
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
```

: List of components for the wiFred[]{label="oldWiFredBOM"}

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) [\old0805devices\](#old0805devices label="old0805devices")
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 [\old0805devices\](#old0805devices){reference-type="ref" reference="old0805devices"}
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 its 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

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 [30](#breakProtrusions){reference-type="ref" reference="breakProtrusions"} 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 [31](#mountingPads){reference-type="ref" reference="mountingPads"}. 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.

\centering ! [Removing protrusions inside the housing so the PCB fits[] {label="breakProtrusions"}] (images/_DSC8654 "fig:") (#breakProtrusions width="0.49 \textwidth") ! [Removing protrusions inside the housing so the PCB fits[] {label="breakProtrusion"}] (images/_DSC8655 "fig:") (#breakProtrusions width="0.49 \textwidth")

\centering ! [New PCB mounting pads made from 3 mm thick Forex PVC[] {label="mountingPads"}] (images/_DSC8658) (#mountingPad width="0.8 \textwidth")

6 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 [32](#oldProgESP){reference-type="ref" reference="oldProgESP"}. The serial port needs to be at 3.3 V-levels like from an FT232-device run at 3.3 V.

\centering ! [Programming connection for ESP8266 — GND on orange wire, then TXD of programming cable (RXD of ESP8266), then RXD of programming cable (TXD of ESP8266)] (#oldProgESP width="0.8 \textwidth")

\centering ! [Programming connection for ATMega 328P — Pin 1 on purple cable] (#oldProgAVR width="0.8 \textwidth")

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 [33](#oldProgAVR){reference-type="ref" reference="oldProgAVR"}. 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, 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.

\clearpage Background for wiFred development {#background}

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

The Fremo [@fremo] 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 [@fred]—a series of LocoNet-throttles which started their life as hobbyist projects with large numbers in circulation but were also commercially available from Uhlenbrock [@uhlenbrock].

Specification wishlist

In modular railroading events, particularly of the Fremo-americaN-group~[@fremo], 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~[@fred] 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

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] (#oldThrottle){reference-type="ref" reference="oldThrottle"}, 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.

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[@wiClock].

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[^1]: Pre-Shared Key, often just called password

[^2]: Pre-Shared Key, often just called password

[^3]: withrottle is also the name JMRI uses for the protocol and the server.