Operator's Manual

IRC IMMERSIONRC

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Introduction, and History

Back in early 2013, when FPV was still in its infancy, and mini-quads hadn't been invented yet, ImmersionRC introduced the EzUHF 433MHz remote control system.

In the early days, this system was used for some of the most iconic fixed-wing FPV flights, pushing limits out past 10s of km.

Since then, FPV has evolved massively, and now, 7 years later (4 years after development started), it is time to bring a new innovative R/C link to the market.

Ghost doesn't run on 433MHz, nor does it run on 868/900MHz. Ghost uses an innovative new chipset on the 2.4GHz band for some very good reasons.

Why 2.4GHz, Are We Nuts?

At first glance this seems to be a questionable design decision, after all, shouldn't 'UHF' systems run on 433MHz, or 868/915MHz?

In Europe, the 868MHz band, commonly used for controlling hobby-class drones, has a couple of serious limitations. Firstly, the entire (legal) band is only 2MHz wide (vs. 76MHz for 2.4GHz). This is just not enough bandwidth to run more than a small number of systems simultaneously, and is just not suitable for racing.

Secondly, duty-cycle limitations which allow other potentially life-saving equipment (fire alarms, home automation, medical systems) to co-exist on this band, make it a poor choice for low-latency, high duty-cycle model control.

The chirp-spread-spectrum technology used by the Internet of Things (LoRa WAN, etc.) when run on the 2.4GHz band has some serious advantages, including:
- Tiny antennas, 2.4GHz antennas are only 36% of the size of the equivalent on 868MHz
- Much wider band, 76MHz vs. 2MHz on 868MHz (or 26MHz on 915MHz)
- Much better sensitivity (= much longer range) than traditional 2.4GHz systems
- Much better selectivity (adjacent channel rejection) than traditional 2.4GHz systems
- Much smaller directional antennas for the really crazy long range missions
- More range than 99% of pilots need, and with a higher gain (but still small) Tx antenna, comparable range with 868/915MHz systems.
- Enough bandwidth to run 250Hz+ modes using the advantages of LoRa modulation
- Lower power consumption than Sub-GHz systems for longer radio battery life

Specifications

Ghost General	
Frequency Range, Ghost 2G4	2406 - 2479MHz [3]

Ghost Protocol	
Modulation	Chirp Spread Spectrum + Adaptive FHSS [3] (With LBT for EU versions)
Binding	Bidirectional, with confirmation and protocol negotiation
RF Profiles	Solid250, Race500, Race250, Pure Race, Race, 'Normal', and Long Range, more to come

Ghost Transmitter	
Uplink Tx Power	16uW - 350mW (100mW EU) (+/- 0.5dB) [3]
Frame Rate	500Hz (Race500), 250Hz (Race250, PureRace, Solid250), 160Hz (race), 55Hz (normal), 15Hz (long range)
Format	Standard JR Module, tested with most common OpenTx compatible radios or Standard 'Lite' Module, testing with most X-Lite™ and similar radios.
Antennas	JR Module: Twin antenna, with Tx-side diversity. Antennas are 2.1dBi Dipoles Lite Module: Single antenna.
Serial Formats	SBus, GHST [1] - Auto-Sense
Firmware	USB Upgradable (with OTA updates for receivers)
Power Supply	6V-20V, 1.75W @ 350mW, ~250mA at 7.4V

Ghost Atto/Atto Duo/Zepto Receiver	
Downlink Tx Power	+13dBm
Sensitivity	-117dBm in Long Range mode, less in Race modes
Serial Formats	SBus, SBus-Fast (200k) , SRXL-2 (400k), GHST [1], SBus Inverted [2]
Firmware	Over-the-air (OTA) upgradable
Power Supply	5V recommended, 3.6-6.0V (no more than 6.0V!)
vTx Control	Tramp control from 'T' pin on Rx, regardless of selected serial format
Atto/Atto Duo Dimensions	14.8mm x 11.5mm, 0.6g (w/o antenna)
Zepto Dimensions	10.0mm x 10.0mm, 0.38g (w/o antenna)

General Features	
Tx-side Spectrum Analyzer	Supported, full frequency range
Rx-side Noise Floor Analysis	Auto on power-up, or on demand from the tx

[2] *Sbus is inverted by definition, SBus Inverted flips it over so that it doesn't require inverters on F4 FCs*
[3] *Some specifications vary depending upon the regionally-specific product SKU*

Getting Started

OpenTx Configuration

The Ghost transmitters, and high frame rate + low latency that they can supply, are optimized for a new OpenTx protocol, **GHST**.

For transmitters which do not yet support this protocol, either download one of the 'Nightly OpenTx Binaries' from the Ghost page on the ImmersionRC website, or use the commonly-available **SBus** protocol.

The Ghost transmitter auto-senses the R/C control protocol, no need to set anything.

For more details on the OpenTx build, along with the telemetry sensors that it supplies, refer to section 'OpenTx Custom Builds for GHST' later in this document.

⚠️ **Make sure to disable the Internal RF when using the Ghost. Newer OpenTx builds will enforce this, but will mean that if Internal RF is enabled, GHST doesn't appear in the protocol list.**

Binding

Binding **SUCKS**, it really does. How many times have you had to tear apart a model to get access to some buried bind button. How many times have you received a new 'BNF' model only to have to scour the internet for an out of date manual that tells you which of the identical-looking three buttons on the model are the bind button, and whether you need to press it while deftly plugging the battery (three hands would be useful for this), or just after power up. How many times have you had to find some 'secret' betaflight 'CLI' command to figure out how to bind an SPI receiver?
Then once you do find the button does the Tx need to be in E8, E16, E32, or JJAJ mode to bind successfully?

Ghost attempts to be a little different.

New Receivers

New Receivers are shipped with bind mode enabled. For new receivers, just power them on, power up the Tx, enter the Binding menu, and start the bind sequence.

The Rx LED will be blue when in bind mode.
The Tx will show the binding confirmation, if successful, with the ID of the receiver, and the firmware version installed on it.

Note: To prevent surprises if the bind button is pressed during flight, the bind button is deactivated 30 seconds after the Rx is powered up. Simply cycle Rx power to re-enable if bind was intentional.

Deja Vu Binding

Deja Vu Binding records all receivers used by a Ghost transmitter and can bind to them in the future without the need to touch the bind button on the receiver.

Receivers, after powered on, and before they have a valid connection to a Ghost transmitter, periodically scan for transmitters attempting to bind.
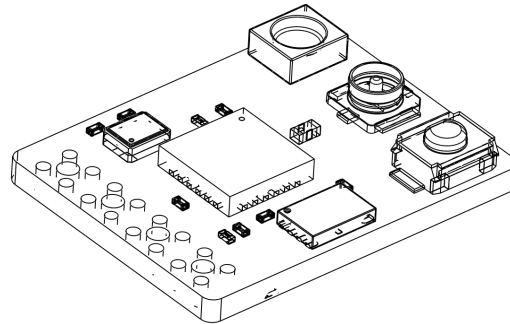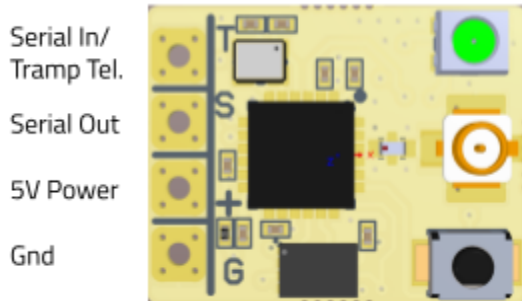
This feature also enables the Ghost Updater to transfer firmware updates only for receivers that you own.
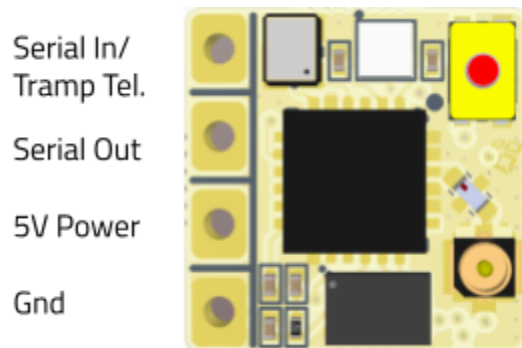
Receiver Pinouts

2G4 Atto

Smaller than most receivers in the hobby, the Atto is optimized for use in race/freestyle quadcopters. it has the following pinout:

2G4 Zepto

By far the smallest receiver in the hobby. 10x10mm. Pinout is the same as the 2G4 Atto shown above, meaning the Zepto and Atto may be used interchangeably on Proton Packs.


Note that the antenna connector on the Zepto is an MHF4, and not a standard U.FL.

2G4 Hybrid

The 2G4 Hybrid board fuses together a Ghost 2.4GHz receiver (with similar specs to the Atto), and a 5.8GHz Tramp Nano video transmitter.

Trivial cabling, just hook up the serial line for control, Video in from the OSD/FC or Camera, and 5V power. *Note that the **TEL** and **N/C** connections are not required at present.*

Serial (GHST)	Green
TEL	Blue
N/C	N/C
Video In	Yellow
Gnd	Black
+5V	Red
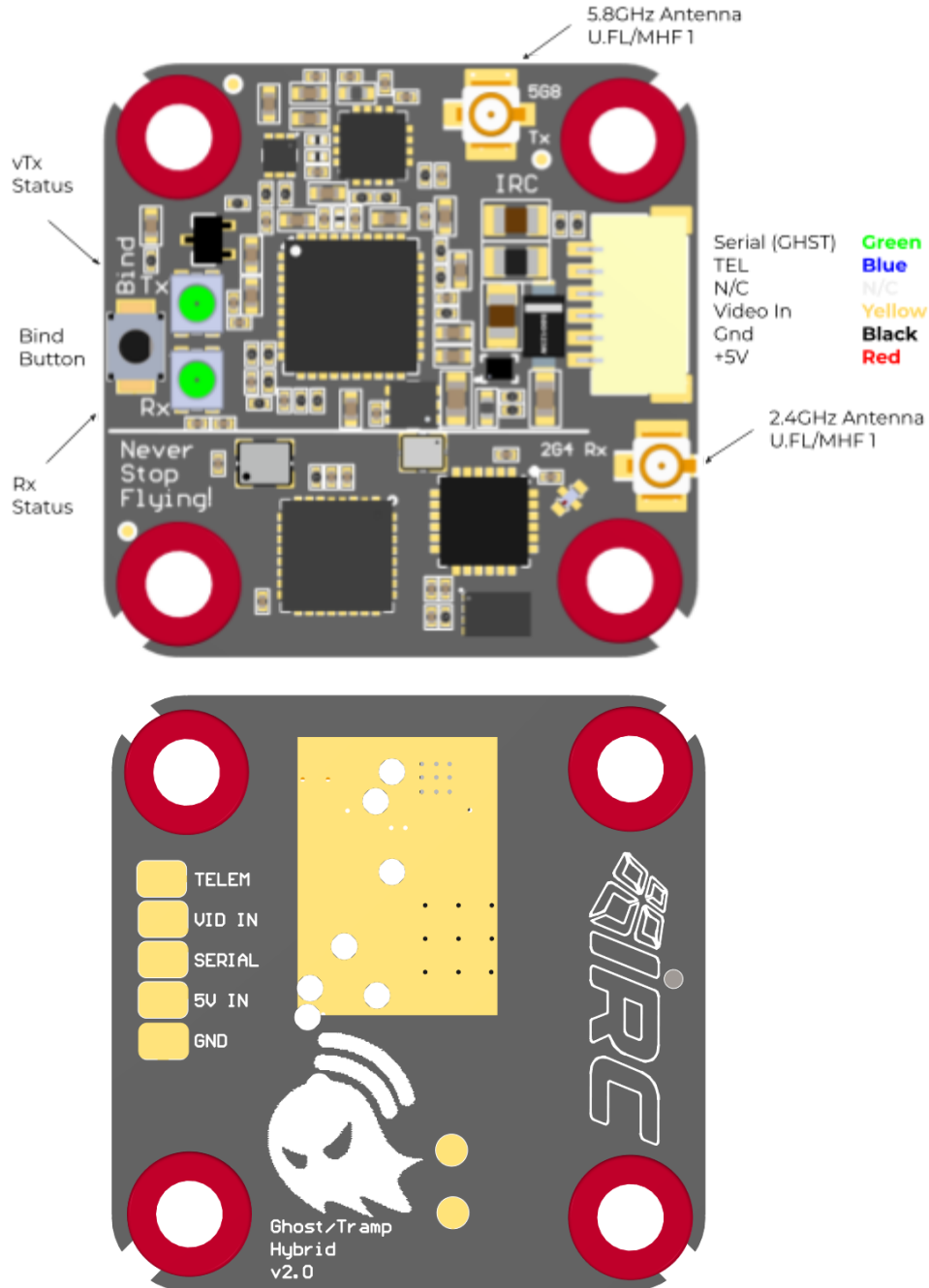
Receiver Protocols

Ghost receivers support a number of common protocols, selected during binding.
Each has its own merits, and performance characteristics.

PWM should be used for fixed-wing flight, with 4 PWM outputs capable of driving servos, and motor ESC.

SBus is offered (with it's 'Fast' variant) as a compatibility mode, since it is supported by most flight controllers, whether running Betaflight, iNav, PX4, etc.
Note: Watch out when using fast RF modes with the SBus protocol. SBus packets are relatively slow, and FC firmware such as iNav can have a problem with SBus at 250Hz.

SRXL-2 is the preferred protocol for Betaflight 4.2 and later, since it supports passing Link Quality (LQ) to the OSD for a little more confidence while flying.

Wherever possible, the GHST protocol should be used. It is available in development builds of most flight controller firmware. For BetaFlight it will be released in the 4.3 major release.

Protocol	Frame Time	Baud Rate	Packet Duration	Channels	Telemetry
PWM	20ms	N/A	N/A	4	None
SBus	Same as RF	100k	3ms	12	None
SBus Fast	Same as RF	200k	1.5ms	12	None
SRXL-2	Same as RF	400k	800us	12	LQ passed as RSSI
GHST	Same as RF	420k	300us	12	Yes

Receiver Wiring

SRXL-2 Wiring to Betaflight Flight Controllers

SRXL-2 is a bidirectional protocol which requires connecting via a single wire to a UART **TX** pin, **NOT** a **RX** pin. This is the preferred protocol for Ghost receiver hookup if native GHST protocol is not supported on your flight controller.
GHST is now the preferred protocol for receiver to flight controller hookup.

Note that F4 flight controllers may require a 'cli' command to enable the high speed SRXL-2 mode:
```
set srxl2_baud_fast = ON
```

Specification	Value
Gnd	Ground
5V Power	Clean 5V Power, from FC pin
Serial Out	Wire to **TX** pin on an unused UART. No inversion required (incompatible with most S.Bus inputs)
Serial In	Optionally wire to Tramp Telemetry pin, for Ghost control of Tramp vTx channel

SBus Wiring to Betaflight Flight Controllers

SBus, unlike SRXL-2, requires an inverted UART signal. Flight controllers that support S-Bus generally have a dedicated S-Bus input, with any required inverters.

Ghost does allow SBus to be wired to a non-inverted UART input on the FC by selecting the 'SBus Inv' mode while binding. This causes Ghost Rx to emit a pre-inverted SBus signal.

Specification	Value
Gnd	Ground
5V Power	Clean 5V Power, from FC pin
Serial Out	Wire to **SBUS** pin on an unused UART. FC pin generally labelled **SBus**
Serial In	Optionally wire to Tramp Telemetry pin, for Ghost control of Tramp vTx channel

⚠️ *NOTE: If your Flight Controller does not detect a valid serial connection from the Ghost Rx, ensure that the **Ports** tab in the Betaflight Configurator only has one single port enabled for Serial Rx. If more than one is selected, the serial Rx will not work.*

⚠️ *NOTE: The standard SBus protocol is not recommended with fast RF Modes, such as those which generate packets at 250Hz. **Normal**, **Race**, or **Long Range** modes are fully supported however.*
(This is due to an issue in the SBus driver for iNav for example, which expects a longer delay between packets)

PWM Operation for micro-Fixed wing

The Atto receiver may be used for fixed-wing applications with up to 4 servos without any additional hardware. In this mode, Tramp Control is disabled.

Pinout for PWM mode is as follows:

Specification	Value
CH1	SBus Output 'S'
CH2	Telemetry Input Pin 'T'
CH3	'3' Pad on bottom side of PCB
CH4	'4' Pad on bottom side of PCB

Note: Production PCBs have '3' and '4' marked on the bottom of the board, pre-production doesn't have the markings, but pad location and function is the same.

PWM3

PWM4
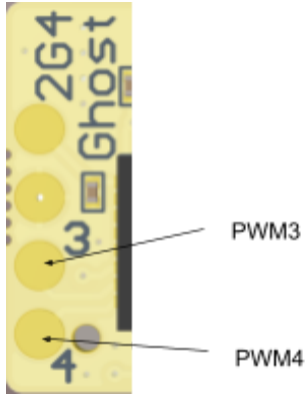
| Specification	Value
Power	20mW downlink
Sensitivity (approx)	Variable, -112dBm Normal Mode, -106dBm Race/PureRace -117dBm Long Range, -105dBm Race250
PWM Channels	4
UARTs	One, Serial_TX/Telemetry
Protocols	SBus, SBus Fast (200k)
USB	None
Firmware Upgrades	Over the air (OTA)

Link Quality (passed as RSSI)

If using the SRXL-2, or GHST protocols, link quality is automatically communicated to BetaFlight, and does not need to be passed via an unused R/C channel.

If using other protocols, the link quality may be passed down an unused R/C channel, and betaflight configured to that channel's value as RSSI.
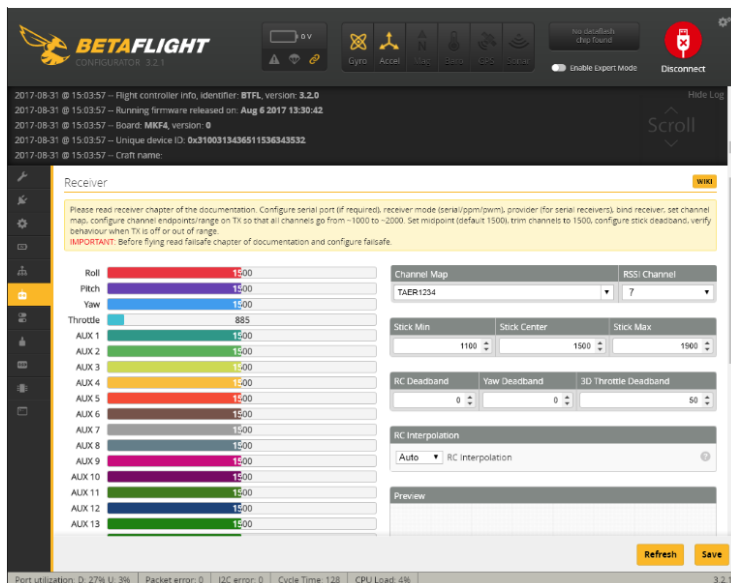
And enable the value in the OSD setup (if present):
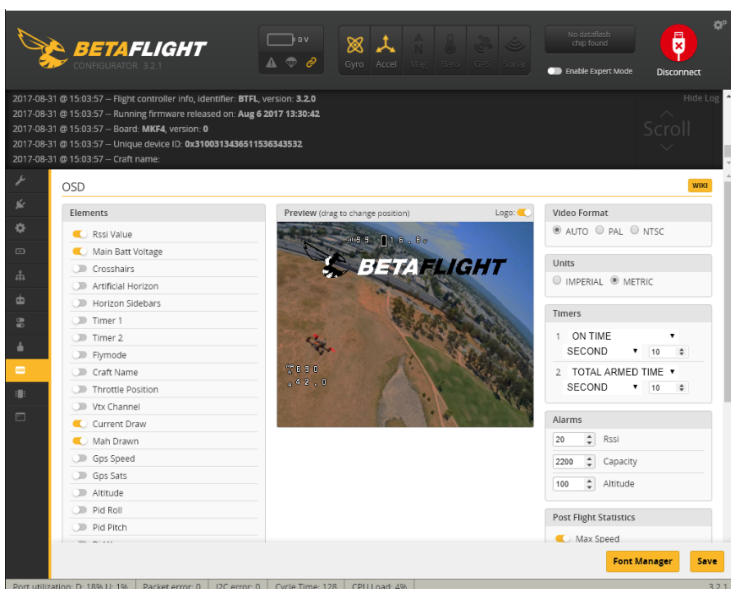
Direct Tramp Control

To control the frequency and power of a Tramp HV/Tramp Nano vTx, simply run a single wire from the 'T' pin of the Ghost to the 'TEL' pin of the Tramp.
Note that this replaces any connection between the Tramp and the Flight Controller, which is not required with direct control.

To set the channel/power, joystick click left from the main Ghost screen.
Move up/down to change settings, then click **Send**.

Note that Receivers will remember the requested vTx parameters, and will reload them into the vTx upon next powerup.
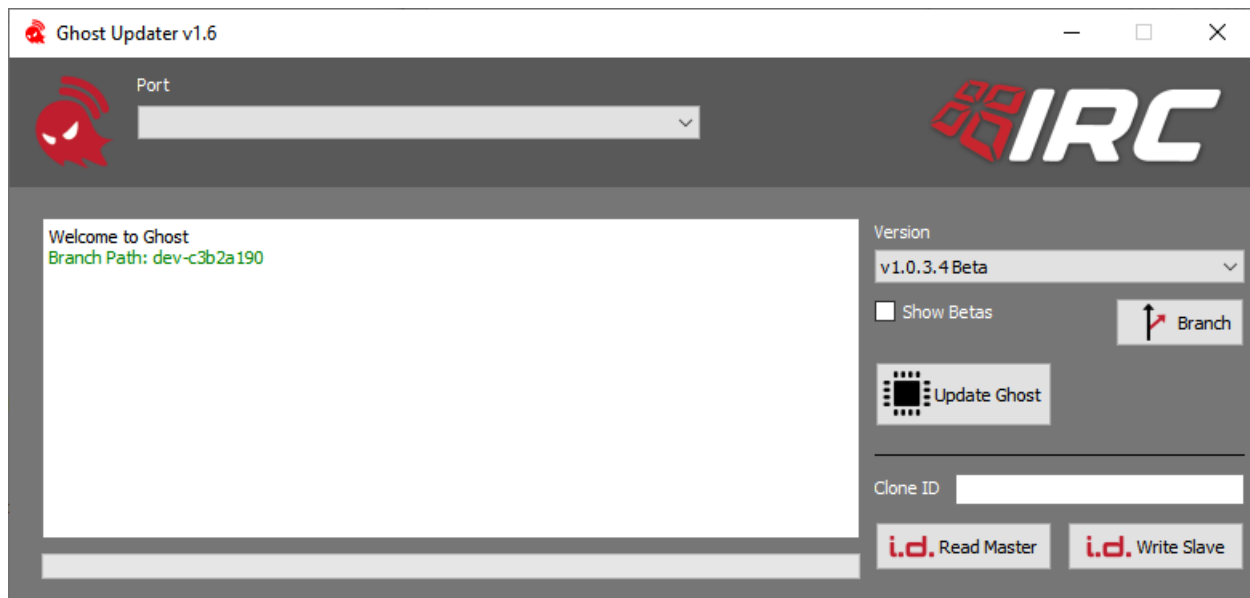
Updating Firmware

JR Module

Connect your PC to the Ghost JR module using a micro-USB cable.

Press the **Start Update** button to start the procedure.

If for any reason the Ghost Tx display does not turn on, power up the module with the joystick pressed to force boot load mode.

Receivers

All Ghost receivers are updated using an over-the-air technology during binding.

⚠️ *If a Rx firmware update was necessary, once complete, <u>don't immediately power down</u> the Rx, leave it for 10-20 seconds to finalize the update. (LED will flash a few times to indicate update progress)*
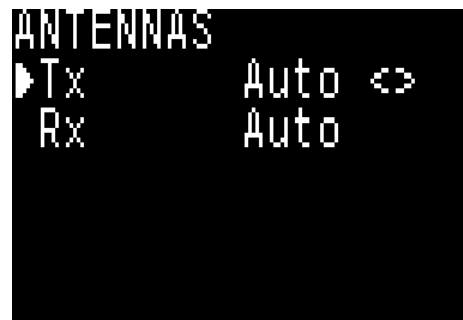
Antennas

JR Module Transmitter

The JR module is equipped with two antenna connectors, creating a diversity antenna configuration even for tiny micro-sized quads equipped with a single antenna.

> ⚠️ *To comply with current FCC regulations the JR module uses RP-SMA (reverse-polarity SMA) antennas, an unfortunate departure from ImmersionRC's traditional SMA bias.*

If only one antenna is available, the **Antennas** menu may be used to configure which antenna (or both) is used. **<** for the left antenna, **>** for the right antenna, and **<>** for both.

> ⚠️ *Running the Ghost transmitter without antennas, or without an antenna on the port(s) selected in the Antennas menu can cause permanent damage, and should be avoided.*

An alternative antenna for the JR module side is TrueRC's [Singularity](#).
Currently this is only available in an SMA version, but a RP-SMA version is expected to be available before Ghost customer shipments.


Note that for any antenna used on the Ghost transmitters equipped with dual SMAs, it is advisable to orient them about 90 degrees from each other, in a 'V'.

Atto Receiver

The IRC qT Antenna - Balanced Dipole

The Atto receiver ships with a small balanced dipole antenna, which does not have a 'ground' and 'live' end. Both antenna elements are 'balanced'. This means that the common practice of finding the 'ground' end of the antenna, and placing it near Carbon Fiber is not recommended.
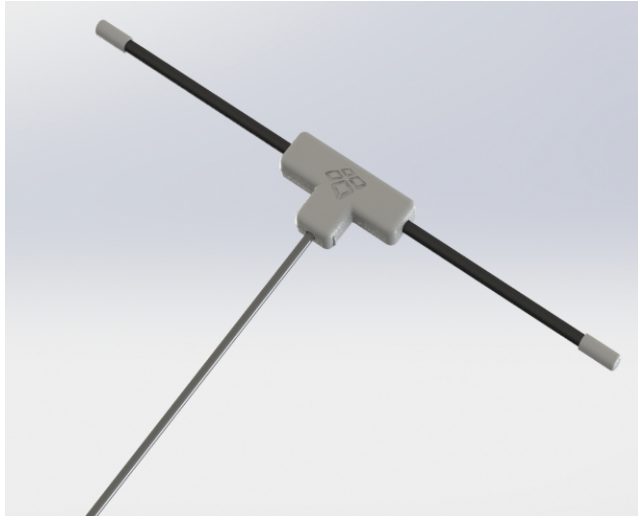
Mount the antenna with the elements as far as possible from carbon fiber, or other materials, and somewhere with a good view of the ground-based Tx for most model orientations.

When integrating the antenna into a model, keep in mind that if the antenna gets ripped off of the quad/plane during crash, you don't really want to rip the U.FL connector off of the Ghost Rx.

Try to restrain the antenna cable possibly in part of a 3d printed part so that if the antenna does get destroyed in a crash, only the antenna needs replacing.

> ⚠️ *The Tiny Zepto receivers use a similar antenna, but with slightly shorter cable, and a smaller 'MHF4/IPEX4' connector instead of the traditional U.FL.*

Self Adhesive Flexible Antennas

An antenna that was popular with testers during the development of Ghost is the TaoGlas FXP73. A tiny, lightweight self-adhesive antenna that integrates nicely into 3d printed 'flip sticks', or fins on mini quads. Also superb for fixed-wing models, where it can be simply stuck onto the wings made of foam or balsa.

These antennas are available from most online electronics stores, including Mouser, and Digikey, for just a few dollars.

Part number is: FXP73.07.0100A

ImmersionRC Limited, Kwai Chung, NT, Hong Kong, www.immersionrc.com

Antenna Placement

The Ghost receiver is incredibly sensitive, and works best when distanced from the typically high power video transmitter antenna of long range drones.

Try to space the two antennas as much as possible if maximum range is required, as should be common practice for any FPV control system.

U.FL Connector Care

The Ghost Atto receivers use U.FL connectors. These tiny high-frequency connectors require a bit of care when removing and inserting.

When removing, try to pull vertically, with a finger-nail each side. Pulling to the side can damage the antenna-side of the connector.

When inserting, make sure that the connector is lined up correctly before putting any pressure on the connector. If it is lined up, it will easily click into place.

The supplied heat-shrink should be applied after connecting the antenna, and will keep the U.FL in place, preventing any surprises in-flight.

Note that ghost antennas sold since late 2020 are equipped with a 'locking U.FL' connector to prevent accidental disconnection during flight/crashes.
To connect this connector to the Ghost receiver, carefully slide the metal locking part away from the cable, mate the connector with the PCB-mounted female connector, and carefully slide the locking part towards the cable.

Transmitter User Interface

JR Module

The main OLED user interface is navigated using the left/right joystick functions. The following 'pages' are available.
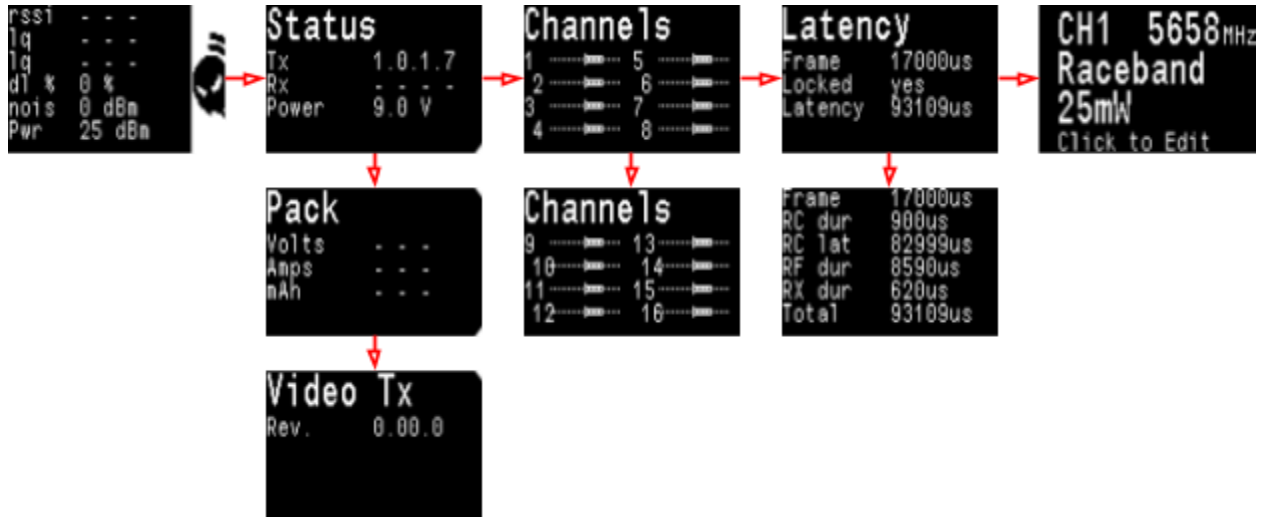
Note: Latency numbers in these images are from a PC-based simulator, and don't reflect actual performance.

Link Page
The link page is shown by default by the transmitter, and contains all data relating to the 'health' of the control link.

The **nois** value is the detected baseline noise level measured at the rx end at power up. Not so interesting on 2.4GHz, but useful on sub-GHz versions.

When in team race mode, the noise measurement is replaced by the currently selected receiver (Rx1, Rx2, etc.)

![ghost logo]

Status Page
The status page shows the current JR Module bay voltage, along with a low voltage warning.

Note that the Rx version only shows when using a bidirectional protocol (currently all protocols but **PureRace**)

```
Status
Tx        0.4.0.1
Rx        - -
Power     9.0 V
```

Pack (Battery Pack) Status Page
Valid when using GHST protocol to communicate with Betaflight. Shows the betaflight-reported battery pack voltage, current, and mAh consumed.
Only valid in bidirectional modes, such as Normal, Race, and Long Range. Not valid in PureRace mode.

```
Pack
Volts     0.00V
Amps      0.00A
mAh       0mAh
```

Channels Page
The channels page shows the positions of each of the R/C channels. Up/Down to scroll through all 12/16 channels..

```
Channels
1 ===---    5 ===|---
 2 ===---    6 ===|---
3 ===---    7 ===---
 4 ===---    8 ===---
```

Latency Page
The latency page shows an estimation of the current system latency, using both fixed elements, and measured values.
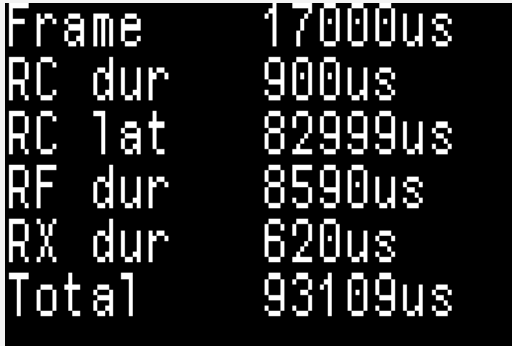
First page shows a summary, scroll up to see more detail.

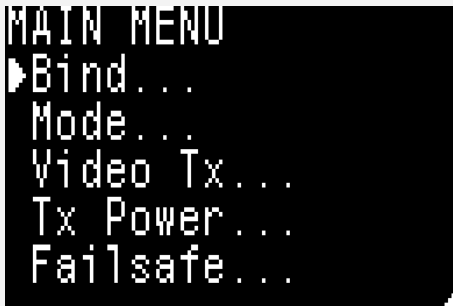The 'Locked' value shows whether OpenTx sync is active.

```
Latency
Frame     17000us
Locked    yes
Latency   93109us
```
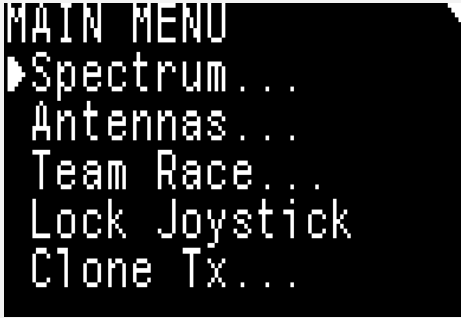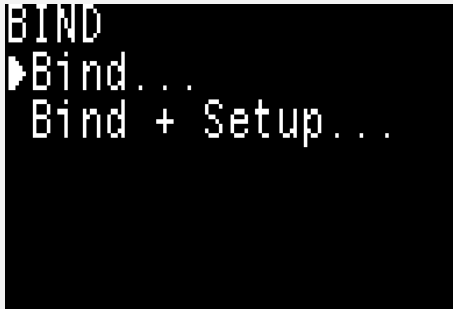
Latency Page (More Detail)

Frame : Current frame rate
RC dur: Duration of packet OpenTx to Ghost
RC lat: Latency of packet OpenTx to Ghost RF
RF dur: Duration of RF packet
RX dur: Duration of Ghost to FC packet
Total: Sum total of the above values

```
Frame     17000us
RC dur     900us
RC lat   82999us
RF dur    8590us
RX dur     620us
Total    93109us
```

vTx Page

A Tramp (Nano, or HV), connected to the 'T' pin of a Ghost Rx is controlled using the vTx page.

Scroll up/down to select the value to change, scroll down to 'Send', and send the setting to the model.

```
CH1   5658 MHz
Raceband
25mW
Click to Edit
```

Pressing the center joystick button enters the setup menu:

Root Menu, First Page

Use the Failsafe menu to set failsafe servo positions for **PWM** Rx output mode only.

```
MAIN MENU
▶Bind...
 Mode...
 Video Tx...
 Tx Power...
 Failsafe...
```

Root Menu, Second Page	**MAIN MENU** ▶Spectrum... Antennas... Team Race... Lock Joystick Clone Tx...
Bind Menu Receivers are bound from the Bind menu Two options are available, a simple 'Bind', which preserves all Rx-specific setup (Rx Protocol, etc.), and a 'Bind + Setup', which allows all Rx parameters to be specified (including Rx ID for team racing).	**BIND** ▶Bind... Bind + Setup...
To start a bind operation, power up the Rx, press the button briefly, wait for the blue LED, and select 'Start Bind' on the Tx menu	**BIND** ▶Start Bind
	BIND + SETUP ▶Start Bind Rx ProtoGHST Rx ID Rx1 Rx LQ CH12 Rx RSSI None

Mode Menu

The RF mode, and transmitter protocol is selected in this menu.

For the RF Mode, 'Normal' is a good compromise between long range, and race. 'Race' is great for the race track with 160Hz frame updates, and bidirectional link. 'Pure Race' is for the bonkers racer, who wants to live on the edge, with 250Hz frame updates.

In the vast majority of cases the Tx Mode (Protocol) can be left in 'Auto' mode. In fringe cases, the protocol can be forced by selecting **Tx Mode** Manual, and manually selecting the protocol.

See Appendix B for details on regional settings.

```
MODE
▶RF Mode  Normal
 Tx Mode  Auto
 Region   EU
```

```
MODE
 RF Mode  Normal
▶Tx Mode  Manual
 Protocol GHST
 Region   EU
```

The **Video Tx** menu is an alternative way to configure the Tramp Video Tx from the menu, instead of from the main OLED-menu screens. This duplication allows the menu to be accessed from the OpenTx menu system, on the front of the radio, instead of on the Ghost module.

Simply configure the desired Video Tx settings, and select **'Send'**

```
VIDEO TX
▶Channel  1 5740MHz
 Band        IRC
 Power       25mW
 Send
 On/Off    None
```

Spectrum Menu

The Spectrum Analyzer may be used to analyze noise floor on the 2.4GHz band.
Set the start/stop frequencies, and press Start.

Note that the vertical scaling is -40dBm at the top of the display, and -127dBm at the bottom. No auto scaling.

```
SPECTRUM
▶Start      2400.0MHz
 End        2500.0MHz
 Start
```

Antennas Menu

In most cases, leave these settings at their default setting. Ghost will decide which antenna to use for both Tx and Rx.

For 'special cases', such as using directional antennas for extreme range, manually set the desired antenna.

```
ANTENNAS
▶Tx       Auto <>
 Rx       Auto
```

Tx Power Menu

Auto power mode will decide which power level to use for the uplink transmission based on the signal strength received at the receiver.

Note that in PureRace, a unidirectional mode, Tx power in Auto mode defaults to 100mW (or the max. allowed by the selected region)

```
TX POWER
▶Mode     Manual
 Power    100mW
```

Team Race Menu

Described later in this manual, the Team Race menu may be used to configure switches on the R/C transmitter to switch seamlessly between multiple quads, used in a race, or team race environment.

To disable the team race functionality, set 'None' in 'Mod Chn', and 'Grp Chn' menu options.

```
TEAM RACE
 Mod Chn CH11
 Mod Ctl 6-Pos
▶Grp Chn CH12
 Grp Ctl 3-Pos
 Rx Id   Rx1
```

Failsafe Menu

Used only when a Rx is set in PWM mode. Set the servo positions to be used in the event of a failsafe.
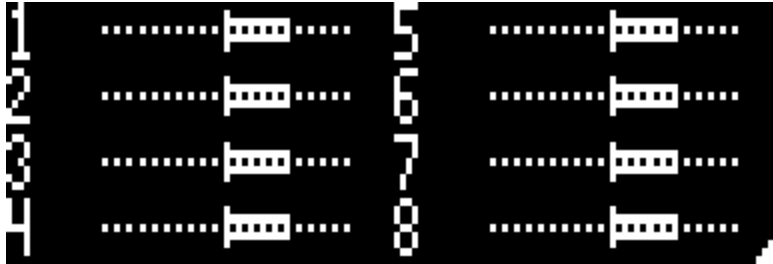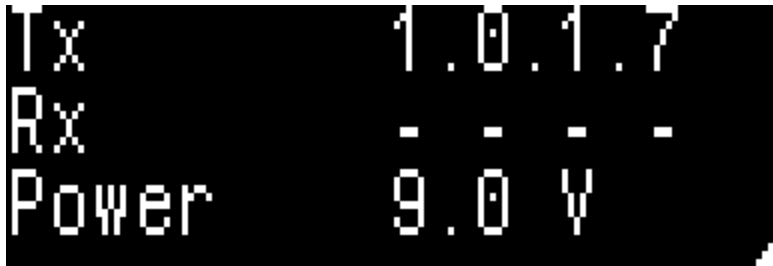
Note that for serial protocols (SBus, GHST, SRXL-2) failsafe is indicated by missing packets, as preferred by FC firmware authors.

```
FAILSAFE
▶Set Failsafe
```

'Lite' Module

The tiny 'Lite' module shares a very similar UI to the JR module, but with a screen which is half the size. The descriptions above for the menus all apply to the Lite module.

```
rssi    - - -
lq      - - -
Pwr   14 dBm
```

```
Tx      1.0.1.7
Rx      - - - -
Power   9.0 V
```

```
1         5
2         6
3         7
4         8
```

```
CH1        5740
IRC
25mW   Click Edit
```

OpenTx Ghost Tools Menu

An alternative user-interface is available to Ghost users using OpenTx build 2.3.11 (official, or IRC synced build).

This mirrors the Ghost menu system on the radio's LCD, and avoids the need to keep turning the radio around.

Refer to the manual for the specific radio that you use to learn how to enter this tools menu. (TX16s requires holding the **Sys** button for example).
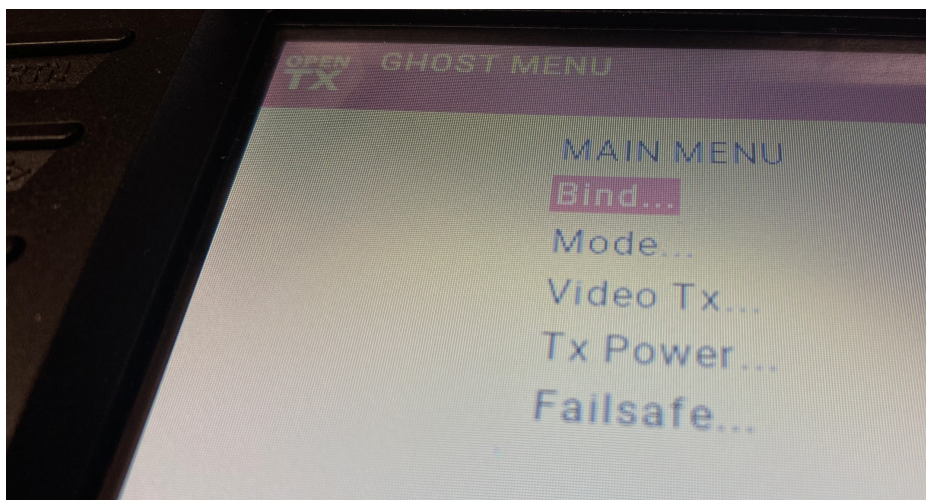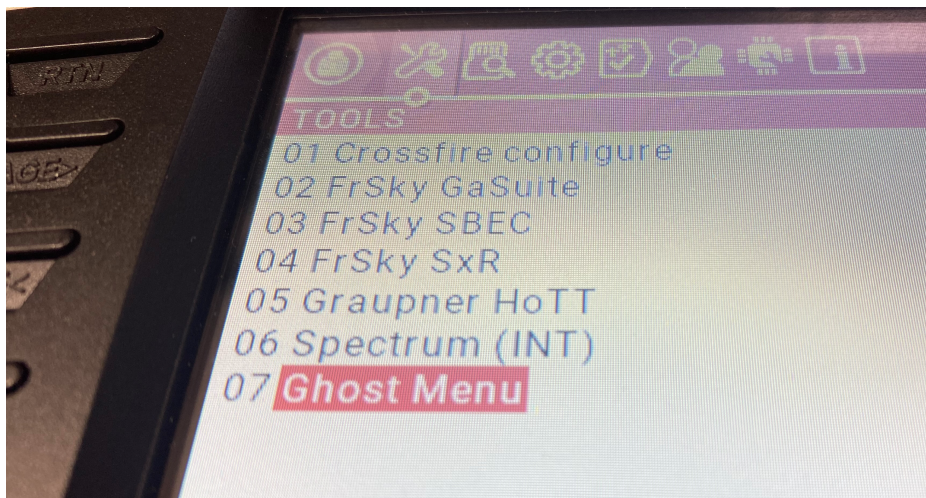
OpenTx Custom Builds for GHST

Full support for Ghost has been added to OpenTx thanks to the efforts of the OpenTx team.

GHST protocol support without Sync capability is available in OpenTx release 2.3.11, with a version with sync capability (much lower latency), in a custom IRC build of the same release.

For up to date information on firmware, and open source tool support (OpenTx, Betaflight, etc.) please refer to the following page:
https://www.immersionrc.com/ghostlatestrelease/

With the GHST protocol, several telemetry sensors are available:

Sensor	Purpose
VFrq	Video tx frequency, in MHz
VPwr	Video tx power, in mW
VBan	Video tx band name
RSSI	Ghost receiver RSSI in dB
RQly	Ghost receiver link quality
RSNR	Ghost receiver signal to noise ratio
TPWR	Ghost transmitter transmit power, in mW
FRat	Ghost link frame rate, in Hz
TLat	Total estimated latency, in microseconds
RFMD	RF Mode name
RxBT	Pack Voltage [*]
Curr	Instantaneous Current Consumption [*]
Capa	mAh Consumed [*]
RxID	Team Race Receiver ID [2]

[*] Introduced with Betaflight 4.3
[2] Introduced with Ghost v1.0.2.0

Receiver RGB LED Interpretation

All Ghost receivers are equipped with a tiny RGB LED which shows the receivers status at all times.

LED Sequence	Meaning
🟢 🔴	Packet Reception
🔵	Binding
🟣	Scanning for transmitter
🔵 🔵 🔵 …	Updating Firmware
🔵	Team Race mode, receiver active, but not currently selected.

Hint: Some say that if receiving packets, and staring at the RGB LED, while shaking your head, you can see 'ghost trails'...

Range Estimations

To estimate the range of the Ghost 2G4 link the following assumptions will be made:

Tx Antenna:	**2.15dBi gain**
Rx Antenna:	**2.15dBi gain**
Connector Loss:	**0.5dB**
Tx Power:	**26dBm**
Link Margin:	**12dB** *(a relatively 'safe' number, see below)*

With these values we can estimate range in each of the 3 primary modes as follows:

Mode	Rx Sensitivity	Range
Pure Race	-106dBm	11.5km
Race	-106dBm	11.5km
Normal	-112dBm	23.0km
Long Range	-117dBm	40.0km

Note: Tool used to estimate FSL (Free Space Loss) is an online IRC tool located here:
https://www.immersionrc.com/rf-range-demystified/

Note that these numbers don't take into consideration factors such as antenna cross-polarization, interference on the Rx end of the link, atmospheric effects, etc.

Due to the relatively short wavelength of 2.4GHz signals, and the small antenna size, if better range
(or better link margin) is required, directional patches may be used on the transmitter.
An 8dBi patch can easily double range when compared with a ~2dBi dipole.

Link Margin Definition:
In a wireless communication system, the link margin, measured in dB, is the difference between the
receiver's sensitivity (i.e., the received power at which the receiver will stop working) and the actual received
power. A 15 dB link margin means that the system could tolerate an additional 15 dB of attenuation
between the transmitter and the receiver, and it would still just barely work.

Source: fpvlab.com

Range Test Mode

The JR module has a power option of 16uW (0.000016W, or -18dBm). This mode is ideal for range testing.

Place the transmitter on (ideally) a non-conducting object, in the RF mode that you wish to test, with Transmitter power set to 16uW.

Power up the receiver, with antenna attached, and walk away from the Tx until the LED starts blinking erratically, and eventually stops blinking.

Measure that distance, and multiply it by approx. 148x to get the range on full Tx power 350mW.

I.e. Range on 16uW = 100m, full range is 100 * 148 = 14.8km

Note: the 148x number comes from the difference in power between 16uW, and 350mW, in dB, of 43.44dB. Each 6dB increase in power results in double range, so 43.55dB corresponds to a range increase of 148x.

After testing, remember to restore the Tx power back to the normal setting (typically 100mW) before flying to avoid any unnecessary surprises.

Latency and Frame Rate

Latency in an R/C control system consists of several parts.

1) Time from stick/switch movement to packet sent to RF module (R/C packet)
2) R/C packet length duration (SBus, GHST, etc.)
3) Time from packet received to RF packet sent over the air
4) RF packet length duration
5) Time from RF packet received over the air to Flight Controller/Servo packet
6) Servo/FC packet duration (SBus, SRXL-2, GHST, etc.)

In modern control systems most of these items occur synchronously, except the synchronization between R/C control data reaching the RF module, and RF packets being sent over the air.

In 2019, thanks to some awesome work by the OpenTx team, the first two items may now be synchronized with the RF packets sent over the air.
OpenTx v2.4, along with some private development builds, include this feature, and this is used by ImmersionRC's GHST protocol described here.

Frame 1					Frame 2			
Sticks	R/C	RF	RX		Sticks	R/C	RF	RX
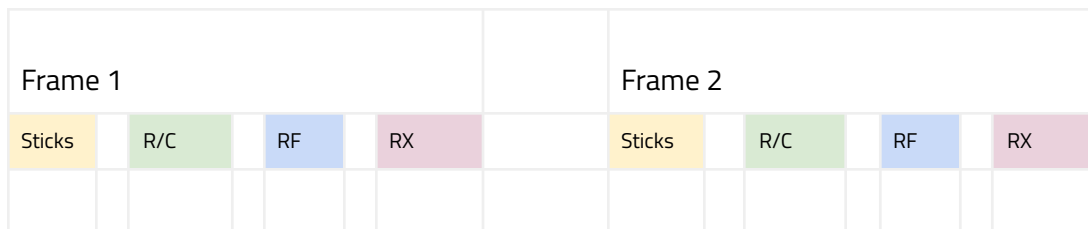
Ghost was designed with latency minimization in mind, and has optimized each part of this process.

In **PureRace** mode, with a version of OpenTx that supports 'mixer synchronization', and the **GHST** protocol installed in the radio, latencies of around **4.2ms** from start of R/C packet to end of Rx packet are achievable.

Note that for the first item in the latency list, this is the only variable part of the 'latency stack' remaining in modern systems. RF packets are sent at regular intervals, but the time from the stick/switch movement to these regular packets is still variable, and varies between zero, and the frame period.

Note for reviewers: Ghost always prioritizes the first 4 flight channels, critical for crisp, precise model control. When testing latency, don't use a switch assigned to anything but these first 4 channels.

RF Modes

The Ghost family supports (currently) 5 different RF modes, each of which has its own tradeoff between telemetry, frame rate, and range.

Mode	Rx Sensitivity	Frame Rate	Telemetry	
Solid250	-105dBm	250Hz	No	'Robust Mode', which uses various diversity techniques for the lowest-possible packet loss for the best of the best.
Race500	-105dBm	500Hz	No	Unidirectional, no telemetry, Lowest latency for racing with Coherent MSK modulation (Not LoRa)
Race250	-105dBm	250Hz	Yes	Bidirectional, with full telemetry. Awesome latency for racing with Coherent MSK modulation (Not LoRa)
Pure Race	-106dBm	250Hz	No	Unidirectional, no telemetry, top performance for racing with robust LoRa protocol.
Race	-106dBm	166Hz	Yes	Robust LoRa protocol, with telemetry feedback
Normal	-112dBm	55Hz	Yes	Fixed wing, general quad use, bags of range
Long Range	-117dBm	15Hz	Yes	For the extreme stuff, crazy range

⚠️ *For all of the faster modes (Race, PureRace, Race250, Race500, Solid250) use the **GHST** protocol between the R/C transmitter and the Ghost transmitter, and also between the Ghost receiver and the flight controller.*

Solid250

A unique mode, not available on any other R/C link, fuses antenna diversity, frequency diversity, and time diversity, to provide a packet-loss rate which is unmatched.

Race500

For those who want the absolute minimum control latency, Race500 provides it.

Race250

Faster than most pilots will ever need. Fastest link which includes full telemetry, for racers who need it.

Pure Race

A robust LoRa protocol suitable for racing in noisy environments where telemetry feedback is not required. To take advantage of this mode (or **Race** mode) ensure that the **GHST** protocol is used between the R/C Transmitter (OpenTx) and the Ghost module.

Race

Race should be selected by anyone involved in serious quad racing. It has ample range, faster update rate than most other systems, and includes a telemetry downlink.

Normal

Normal is the default mode, and is a good compromise between performance and range. Certainly for beginners, this is a suitable mode.
Safe control ranges of 20-30km are very possible in this mode.

Long Range

Not very appropriately named, since all of these 4 modes above will get you further than most pilots will ever fly.
Long range mode prioritizes range over frame rate, but still achieves a frame rate that for most extreme range flights is quite flyable.

Note that auto mode switching is NOT supported yet (and may never be). A couple of years of testing has convinced us that reliably doing this, especially in a RF polluted race environment, doesn't reach the reliability level that we desire.

Race/Team Race

A unique feature of the Ghost ecosystem is integrated support for Race, and Team Race environments.

The Team Race menu supports assigning up to two switches (or banks of buttons) to the selection of the active receiver. These switches then support split-second switching between up to 16 quads.

To define the receiver 'ID' of a Ghost, configure it in the bind menu. Once defined, that receiver will only emit serial data to the flight controller when selected. When not selected, the receiver's LED will illuminate Cyan.

Note that the team race support also controls the video transmitter, without the need for complex configurations on the flight controller side.
When a receiver is de-selected, the video transmitter will automatically shut down. When a receiver is selected, the video transmitter will be enabled (assuming any assigned vTx enable switch is also selected).

All of this functionality is just as useful in the simple race scenario, where selecting quickly between a primary, and backup quad is required.

Transmitter Cloning (Clone Tx)

To explain what transmitter cloning is, consider the following common use case:
- You have a primary JR-module based transmitter installed in your full-sized radio.
- You also have a 'lite' module in a travel radio.
- You would like to interchange the two radios, without rebinding your quads.

To clone a transmitter (or rather a transmitter ID) you need to run the PC/MAC based Ghost Updater app (v1.6 or later).
Connect the master transmitter and click **i.d. Read Master**.
Connect the slave transmitter (the one that will inherit the Master transmitter's ID, and click **i.d. Write Slave**.
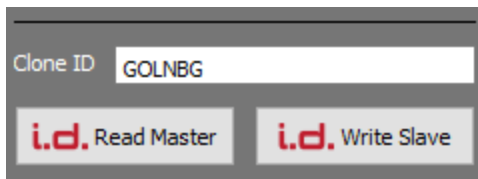
Once the slave has been written, it will inherit the Master's ID, and may be used interchangeably with the Master radio.

If this is no longer required (or two enable/disable the clone ID in the field, use the **Clone Tx** menu.
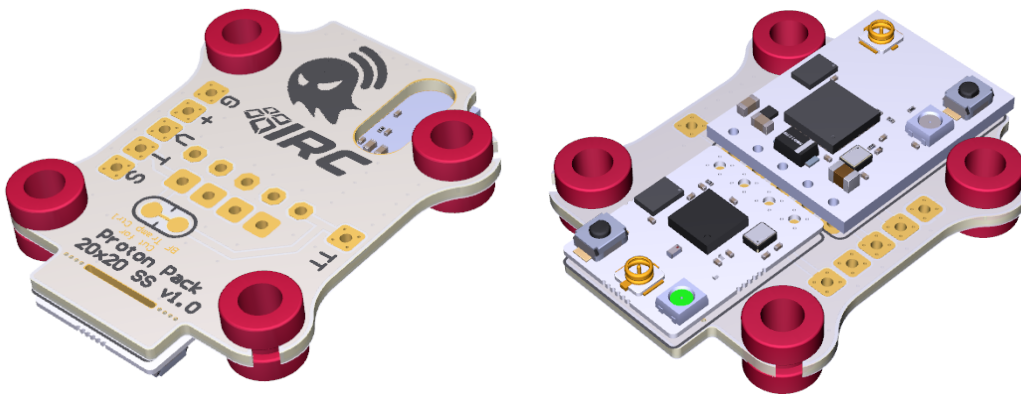
Proton Packs

'Proton Packs' greatly simplify the installation of a 5.8GHz Video Transmitter, and Ghost Control Link in most quads. Connection between the two products is automatic, and video frequency can be set directly by the Ghost without the need to configure vTx Tables in Betaflight.

As a bonus, add a dab of heat sink compound under the vTx before soldering and the entire PCB becomes an extra heat sink.

Silicone 'gummies' should always be used to reduce the damage caused by vibration and shock during the more extreme 'landings.

Proton Pack 2020 SS (Single Sided)

20mm hole centers, single sided, mounting for Ghost Atto, and Tramp Nano.
Just 33mm total length, shorter than most 20x20 ESCs.

Proton Pack 3636

30.5mm hole centers, single-sided, mounting for Ghost Atto, and Tramp Nano.
The 36x36 variant has a snap-off 'shelf' for the TNR tag, along with a hole in the PCB through which the TNR pads may be soldered to the Tramp.
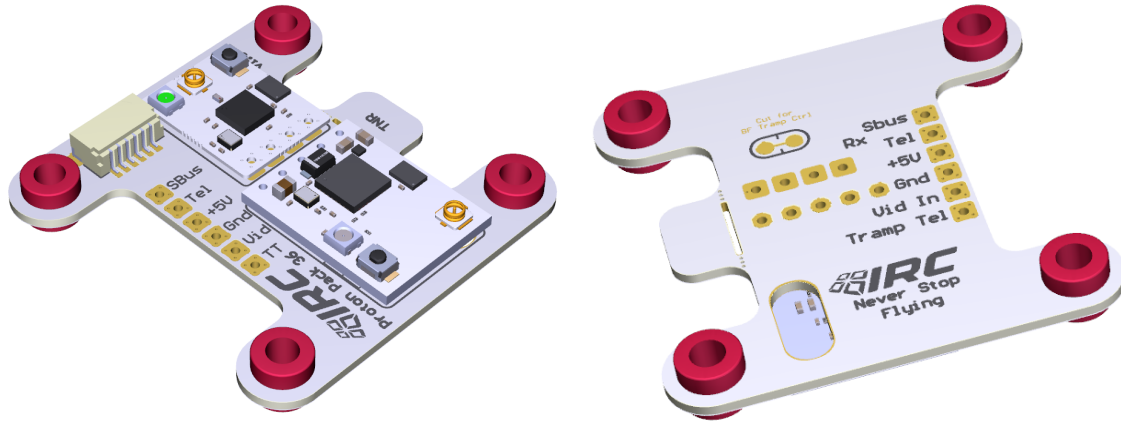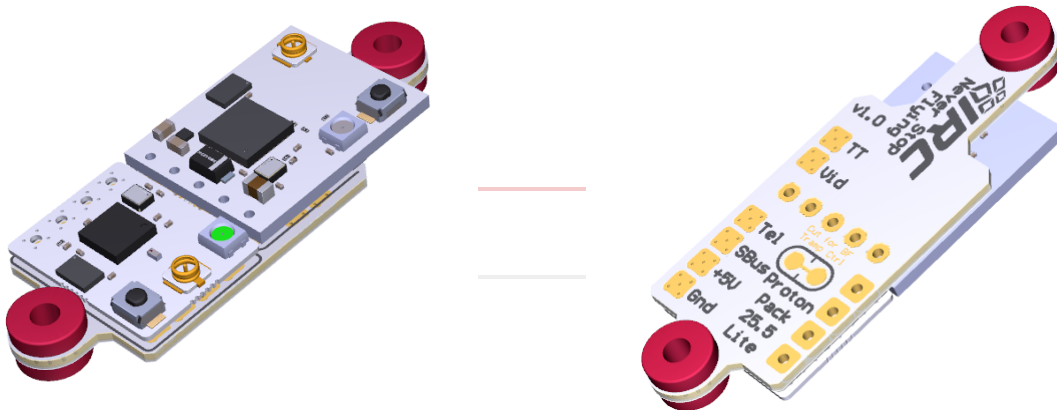
Proton Pack Tiny Trainer™

The Tiny Trainer is a wonderful little quad from the Five33 team. The Tiny Trainer Proton pack is designed to sit comfortably above the AIO FC, with plenty of space for the optional LED board above it. This board uses 25.5mm hole centers, so fits above most AIO FCs designed for Whoops/Micros.

Check out the quad at https://flyfive33.com/

Assembling Proton Packs

To assemble the proton packs, use the installed 0.1" headers to solder the Tramp Nano, and Ghost Atto/Zepto to the boards.
Be careful to install on the side with the outline of the board, and not the back side of the board.

For a simple install, without worrying too much about stack height, simply use the header as-is, leaving the black plastic part between the proton pack and the Tramp/Ghost.

For a cleaner, low profile install, which requires a bit more 'fiddling:

1) Insert the headers from the bottom of the proton pack, until the black plastic shroud touches the board. Turn the board over, and flow some solder into the holes that the pins poke through (doesn't need much).

2) Install the Tramp Nano/Ghost on the correct side of the board, until it is touching the Proton Pack. For the Tramp, a small dab of thermal paste on the two black ICs that will touch the Proton Pack will improve thermal performance (this is available from any computer store).

3) Solder the pins to the Tramp/Ghost, and trim them very carefully, ensuring that the cutters do not knock any of the tiny components from the PCBs.

4) Turn the board over, and with cutters, very carefully remove the black plastic shroud, and trim the pins flush with the PCB.

Wiring the proton packs is simple, 4 wires required:
+   5V Supply voltage
G   Ground
S   Serial data (Rx serial input)
V   Video signal

Wiring Diagrams

Wiring diagrams for Ghost/Tramp on various common flight controllers are located on the IRC website here: https://www.immersionrc.com/ghosttrampwiring

As an example, this shows the wiring for the Diatone Mamba F722, with a Ghost Atto/Zepto, and Tramp nano, using SRXL-2 mode.
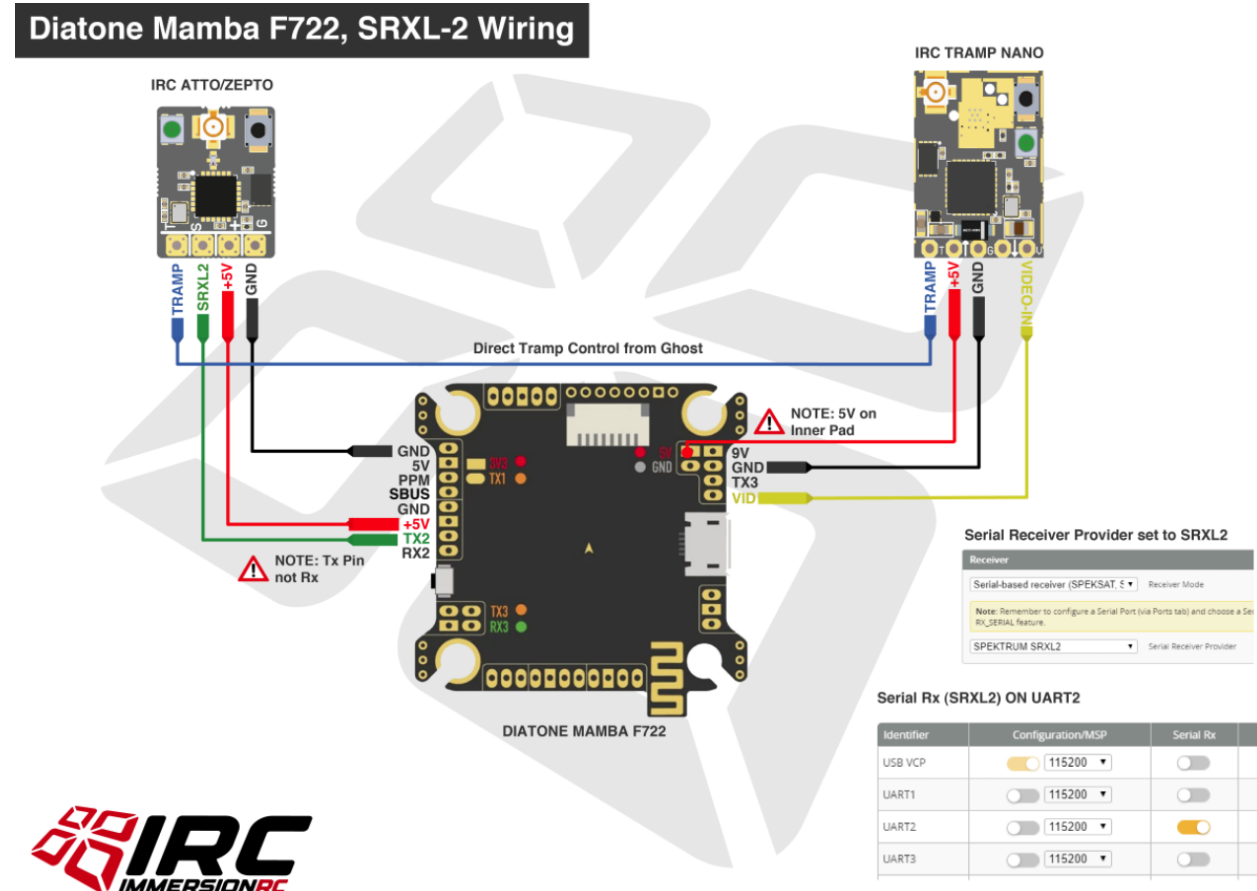
Troubleshooting

General Debug

Downlink Link Quality is poor, even when sitting on the bench

Ensure that the internal 2.4GHz transmitter of your R/C radio is completely disabled.

OTA Firmware Upgrade is unreliable, rarely succeeds

As above, ensure that the internal 2.4GHz transmitter of your R/C radio is completely disabled.

A high power transmitter in such close proximity to the receiver can create issues for the upgrade process.

No Stick Movements between R/C Radio, and Ghost Tx

Ensure that the internal 2.4GHz transmitter of your R/C radio is completely disabled.

A 'feature' of many new FrSky™ radios is that the interface to the external module has it's voltage levels halved (down to 2.0V peak to peak) when the internal module is enabled.

Newer OpenTx builds should prevent this from happening.

Tx Shows 'Bind Button Not Pressed' Even Though It Was

Make sure that there is not a second Ghost Rx nearby, also in bind mode. This problem typically occurs when there are multiple receivers in bind mode.

Windows Updater Fails to Update Ghost

In very rare cases, a Windows PC may have multiple COM ports with the same name (e.g. COM3). Not quite sure why this is possible, but it needs to be resolved before the updater can work correctly. In one case the conflicting port was a Bluetooth->Serial port that needed disabling. .

Every Attempt at Binding Starts Update

When in the bind page, a right click of the joystick toggles 'force update' mode. Should not be needed in normal use, but if accidentally turned on, then every bind attempt will try to update the receiver.

Long Range mode, Combined With SRXL-2 Protocol, Won't Arm

Ensure that Ghost firmware v1.0.0.8 is installed when using the SRXL-2 Protocol. This version of Ghost contains the necessary 'idle packets' to keep the Betaflight SRXL-2 protocol driver happy.

Rx Flashes Error Code

If the Ghost Rx fails diagnostic testing, it will blink an error code, the most common of which are documented below:

One Red, 4 Orange Flashes

This means that the Rx initialization failed, check the circled component on the Atto PCB. It is located quite close to the solder pads, and is easy to accidentally remove with a soldering iron.
The part is a 0201 '600z' ferrite bead, used for noise suppression, and in most cases may be simply shorted out with a thin strand of wire.
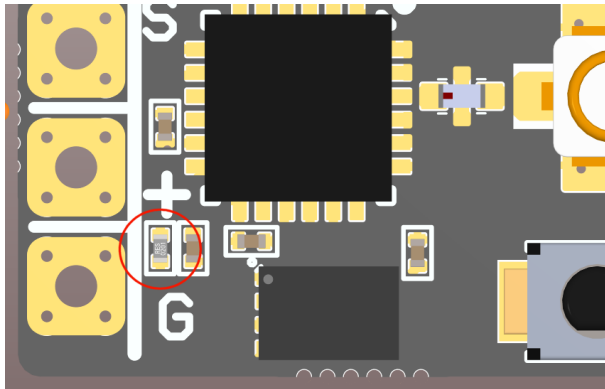
One Red, 5 Orange Flashes

Failed to find the small flash memory device. Generally caused by a prop strike (where the device is removed from the board), or excessive flexing in the case of the hybrid.
This type of failure will require a repair by one of our service centers (repairs@immersionrc.com)

One Red, 6 Orange Flashes

Internal firmware error, failed to bind the receiver, may be caused by incompatible firmware versions.
Switch the Tx to **Normal** RF Mode and try to bind again.

One Red, 7 Orange Flashes

Duo Receivers only - caused by one of the two receivers being defective.
This type of failure will require a repair by one of our service centers (repairs@immersionrc.com)

Rx 'Unbricking'

Over-The-Air (OTA) updating of tiny devices without handy serial ports always raises the question about how to avoid 'bricking', which renders a device unusable.

In theory, all firmware releases will be fully forwards/backwards compatible, so that when you grab a 2-year old ghost-equipped Whoop™ from under the bed and want to go fly, everything should just work…

Reality is that this isn't always possible, and the chances of you remembering the firmware version that was installed on this under-bed Whoop™ is about the same chances of you remembering your mother's birthday.

So we have built in a mechanism to learn the firmware version installed in any ghost receiver.

Simply hold down the bind button <u>while applying power</u> and make a note of what the LED is doing.

As an example:
V1.0.0.0 would flash

V2.3.1.1 would flash

Once the Rx firmware version is known, use the Ghost Updater to find a matching transmitter update, flash the transmitter to that version, and then update to the latest and greatest.

Support, Social Media, and Repairs

ImmersionRC does not do any direct sales, and instead sells through a worldwide network of resellers. We do however provide a support network, with repair centers in the EU, and USA.

If you experience any problems with your product, please use the following resources.

ImmersionRC Community Hub
The IRC Hub is where fans of IRC hang out on social media. A friendly place where users are happy to help out with any question that you might throw at them.
Please use the search feature, many topics have already been discussed.

Retailer Support
Your retailer is generally located close to you, speaks your language, no inter-country customs, and can replace a failed product quicker than we can. Please contact them first if you have any issue that looks like equipment failure.

ImmersionRC Support
Repair centers located in the West coast of the USA, and the UK (covering the EU). A quick email to repairs@immersionrc.com starts the support/repair process.
Even though most responses happen within a few hours, please give this small team at least 48 hours to respond to you.

System Integrators/Manufacturers

ImmersionRC is open to discuss with manufacturers who wish to integrate Ghost into other systems (Hobby, or Industrial). An embedded Ghost receiver occupies approx. 10x10mm of PCB space.

For customers interested in Sub-GHz versions of Ghost (~200MHz -> 1GHz) for Industrial/Law Enforcement (for appropriately licensed frequency bands) we also have solutions.
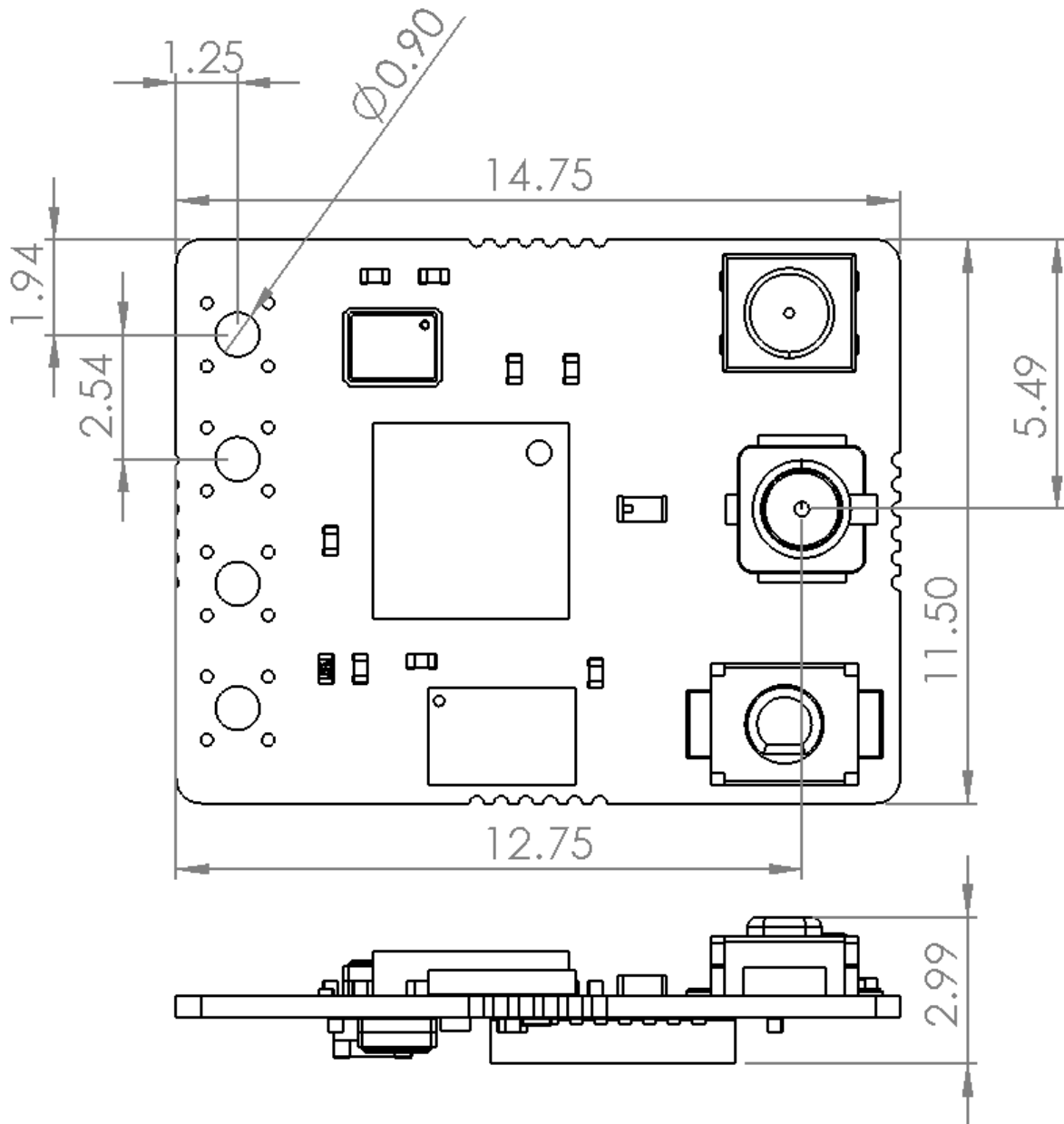
Please contact us at: info@immersionrc.com, or at our ImmersionRC Hub on facebook.
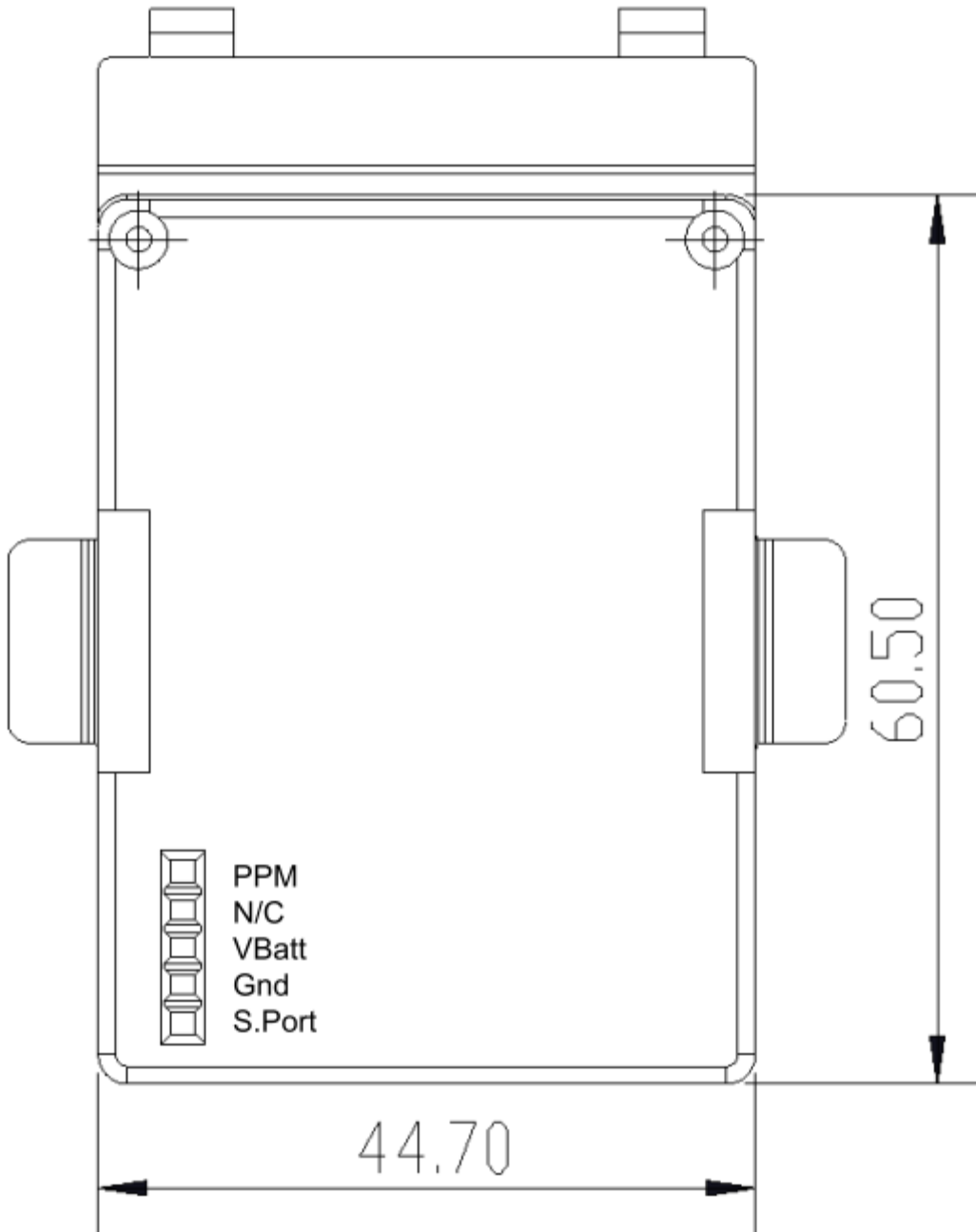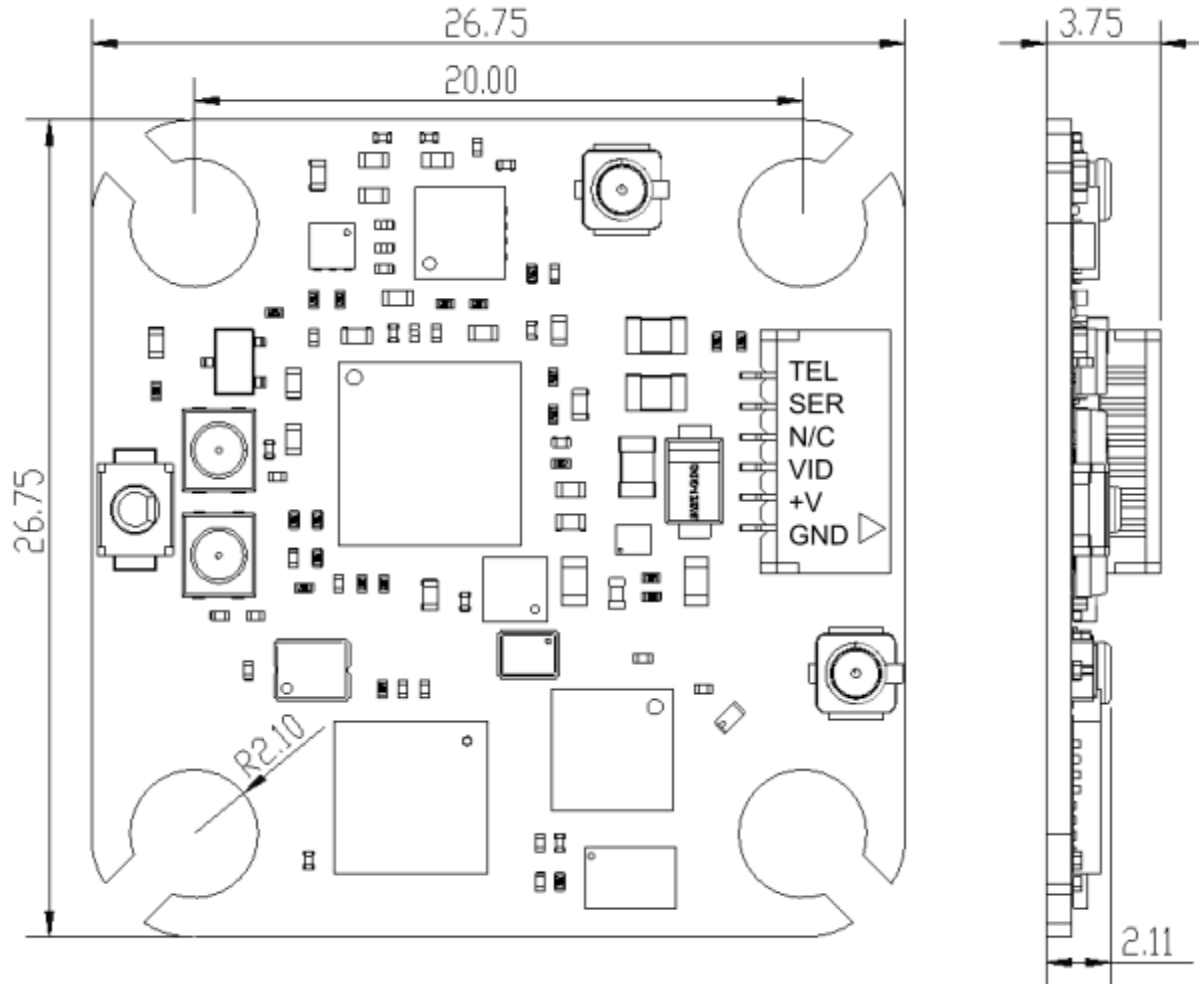
Appendix A: Mechanical Drawings

Ghost 2G4 Atto

Ghost JR Module

PPM
N/C
VBatt
Gnd
S.Port

60.50

44.70

Ghost 2G4 Hybrid

Mechanical drawing dimensions: 26.75 × 26.75, 20.00, 3.75, 2.11, R2.10

Pinout: TEL, SER, N/C, VID, +V, GND

Appendix B: Standards and Regions

Ghost strives to provide a legal R/C control link regardless of where in the world it is used.

This is accomplished by selling multiple transmitter models (SKUs) which enable only the modes permitted within a geographic region.

Note that for race organizers with special licensing permissions (Drone Champions League, DCL for example), and races in multiple geographic regions, special models are available which can comply with their licensing agreements.

2.4GHz Power Limits and Standards

The following power limits are enforced by the Ghost ecosystem for the 2.4GHz control band.

Region	ITU Region	Legislative Body	2.4GHz Power Limit	Ghost Power	LBT	Standard
USA	2	FCC	1W (DSSS)	350mW	No	FCC Part 15.247
USA (Ham)	2	FCC/ARRL	10W PEP	350mW	No	No FCC Standard, ARRL Administration
EU (and CH)	1	ETSI	100mW/ 20dBm	100mW	Yes	https://www.ofcomnet.ch/api/rir/1010/01
AUS	3	ACMA	1W for DSSS < 25mW per 3kHz, and 6dB > 500kHz	350mW	No	Australia follows FCC part 15.247, with slight differences. https://www.legislation.gov.au/Details/F2014C00930
KOR	3	*TBD*	*TBD*	100mW	*TBD*	*TBD*

5.8GHz Power Limits and Standards

The following power limits are enforced by the Ghost ecosystem when controlling a Tramp HV/Tramp Nano transmitter, or an integrated Tramp in the case of the Ghost Hybrids.
Attempting to set a channel that is not legal for the region selected results in a **! Not Auth !** message instead of **Send**.

| Region	ITU Region	Legislative Body	5.8GHz Power Limit	Tramp Power	Standard
USA	2	FCC	50mV/m	1mW	FCC Part 15.247
USA (Ham)	2	FCC/ARRL	1500W	600mW	No FCC Standard, ARRL Administration
EU (and CH)	1	ETSI	25mW/ 14dBm	25mW e.i.r.p	https://www.ofcomnet.ch/api/rir/1008/12
AUS	3	ACMA	25mW/ 14dBm	25mW	Australia follows FCC part 15.247, with slight differences. https://www.legislation.gov.au/Details/F2014C00930
KOR	3	*TBD*	*TBD*	100mW	

Note on the use of the RP-SMA connector on Ghost Transmitters

In May, 2000, the FCC removed RP-SMA from the accepted list of 'non standard' connectors permitted for intentional radiators with removable antennas.

In September 2000, this requirement was suspended indefinitely, permitting again the use of RP-SMA connectors.
 (https://docs.fcc.gov/public/attachments/DA-00-2225A1.pdf)
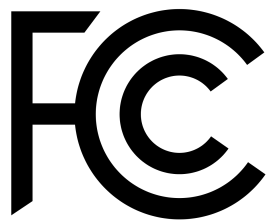
Appendix C: Terms and Conditions

1.0 Ordering products

The ownership, use and operation of FPV radio equipment (such as UHF long range systems or video transmission equipment) which are technically considered to be RF devices may require a license and some countries may forbid its use or ownership entirely. In many countries you will need an amateur radio license in order to operate FPV radio equipment. It is your responsibility to ensure that the use of products you purchase from ImmersionRC Limited Hong Kong meet the requirements imposed by your government's rules and regulations for RF devices. Do not purchase products from ImmersionRC Limited Hong Kong, or an authorized reseller, if you are unsure of your government's requirements or are not able to comply with them. ImmersionRC Limited Hong Kong cannot be held responsible for your actions under any circumstance, including but not limited to if you use products purchased from ImmersionRC Limited Hong Kong in violation of your government's regulations.

2.0 Injury, Damages and Liability

You acknowledge that you fully understand the inherent danger involved when operating (scale) models such as quad rotors and other models. Spinning propellers can cause severe injury, as can flying into people with a model. Under no condition ImmersionRC Limited Hong Kong can be held responsible for injury or damage to people or property including but not limited to products purchased from ImmersionRC Limited Hong Kong.

3.0 Warranty

ImmersionRC Limited Hong Kong provides a 2-year warranty to the products it sells or otherwise distributes, but this warranty is limited to manufacturing defects and does not cover normal wear and tear nor abuse or use for purposes the products have not been designed for. ImmersionRC Limited Hong Kong is not liable in case you cause injury to yourself and/or others or if you damage or destroy property with any of the products you purchased and/or otherwise received from ImmersionRC Limited Hongkong, no other warranties are expressed or implied.

3.1 Faulty Items

If an item you received from ImmersionRC Limited Hong Kong is deemed to have been faulty as determined in the sole discretion of ImmersionRC Limited Hong Kong, ImmersionRC Limited Hong Kong may replace the faulty item only. ImmersionRC Limited Hong Kong will not be liable for equipment that might have been lost and/or damaged as a result of the faulty item. As an example, if a video transmitter you received from ImmersionRC Limited Hong Kong is faulty and stops working during flight causing you to lose your model, ImmersionRC Limited Hong Kong may replace the faulty video transmitter, but not any other equipment that might have been lost and/or damaged due to the faulty video transmitter.

3.2 Incorrectly Published Product Details

ImmersionRC Limited Hong Kong is not liable for any issues that may result from incorrectly published product details, manuals or any other information on the ImmersionRC Limited Hong Kong website which includes, but is not limited to, the downloads available from it.

4.0 Legal exempt status

If any of the aforementioned terms and conditions are held by a court or other tribunal of competent jurisdiction to be void or unenforceable, such policy shall be limited or eliminated to the minimum extent necessary and replaced with a valid provision that best embodies the intent of the policy, so that the policies shall remain in full force and effect.

ImmersionRC Limited, Hong Kong