# Flight-Pi ~FlightAware PiAware on the Raspberry Pi

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## 1. Introduction

Flight-Pi is a packaged implementation of the FlightAware ADS-B receiver and a Raspberry Pi computer running FlightAware PiAware software (figure 1). Builders can implement Flight-Pi for < 80 USD. The work described here is mostly mechanical (drilling and cutting) with a small amount of soldering. Packaging the receiver and Raspberry Pi as described here reduces the possibility of accidental disconnection and damage to the relatively fragile connectors on the devices.

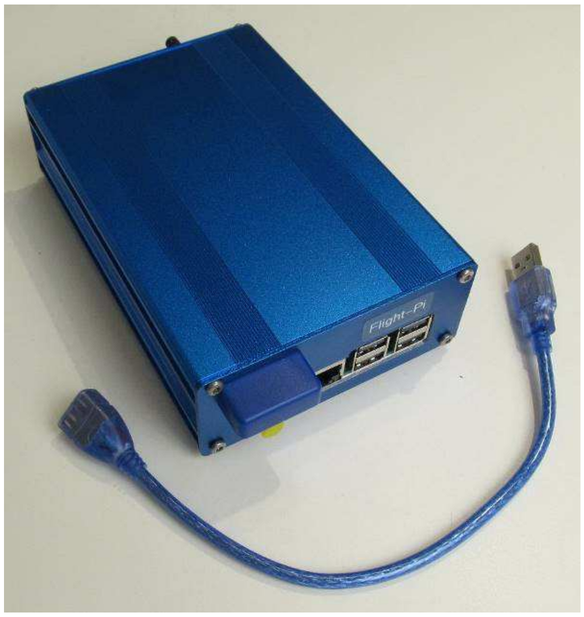


Figure 1 ~ Flight-Pi eliminates flying leads and exposed electronics by packaging the receiver, Raspberry Pi computer and a converter power supply in an extruded aluminum enclosure. The USB-A extension cable in the foreground is used to connect the receiver USB port on the upper-left of the front panel to one of the Raspberry Pi USB ports on the lower-right. The receiver USB port is shown here with the protective cover. The power jack, power indicating LED and power switch are located on the rear panel. The Flight-Pi principle dimensions are 160 D x 109 W x 45 H mm. Image © 2018 W. Reeve

Flight-Pi's purpose is to receive and process the ADS-B flight information signals transmitted by aircraft at 1090 MHz, display them on a map and provide aircraft tracking and statistical data. ADS-B stands for *Automatic Dependent Surveillance – Broadcast* and is briefly described in the next section. Flight-Pi displays not only the real-time positions of ADS-B-equipped aircraft but also of transponder-equipped aircraft that may not have ADS-B capability or have that capability turned off (for example, some military aircraft). The latter uses a process called *multi-lateralization* (abbreviated *Mlat* or *MLAT*), which computes aircraft position and altitude based on the timing of the signals received by multiple stations whose positions are accurately known and that have accurate timekeeping.

## 2. Automatic Dependent Surveillance – Broadcast

References in braces { } are weblinks, and the full URLs are listed in section 6.

Automatic Dependent Surveillance – Broadcast {ADS-B} is an aircraft surveillance system used by both aircraft and ground stations to track aircraft (figure 2). An ADS-B equipped aircraft determines its position from an onboard Global Navigation Satellite System (GNSS) receiver such as the Global Positioning System (GPS). It then periodically *broadcasts* the aircraft position and other data such as altitude and speed. The transmitted signals can be received by a ground receiver as well as other aircraft. ADS-B currently supplements air traffic control radar for aircraft tracking and allows pilots to be aware of and avoid other aircraft. ADS–B is *automatic* – requires no pilot intervention – and is *dependent* – depends on the aircraft onboard navigation systems and air data sensors.

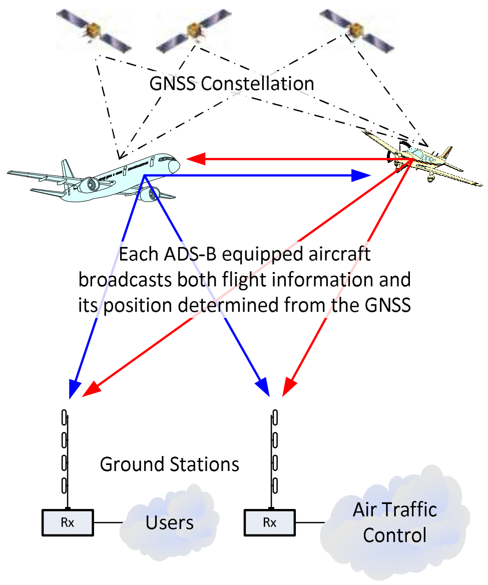

GNSS Constellation
Each ADS-B equipped aircraft broadcasts both flight information and its position determined from the GNSS
Ground Stations
Rx
Users
Rx
Air Traffic Control

Figure 2 ~ ADS-B functional diagram shows the three basic components – Global Satellite Navigation System (GNSS), aircraft equipped with flight data sensors and ADS-B transmitters and receivers, and ground station receivers. The aircraft systems *depend* on onboard sensors and *automatically broadcast* position and other flight information data. The data are processed by receivers to display aircraft positions on a map and provide alerts and other information to ground stations and other aircraft. Flight-Pi is an example of a ground station receiver. Image © 2018 W. Reeve

## 3. Flight-Pi Description

Flight-Pi receives and processes ADS-B and transponder signals and sends the processed data to {FlightAware} where it is shared with other users (figure 3). A map with aircraft data may be displayed on a local PC along with numerous statistics associate with the specific PiAware installation (figure 4). Receivers in the area that receive, process, and share the same flight data as Flight-Pi allow the positions of aircraft that are equipped with transponders but not equipped with ADS-B to be computed. Flight-Pi operates from a nominal 12 Vdc power supply and requires a local area network (LAN) and antenna connection (figure 5).

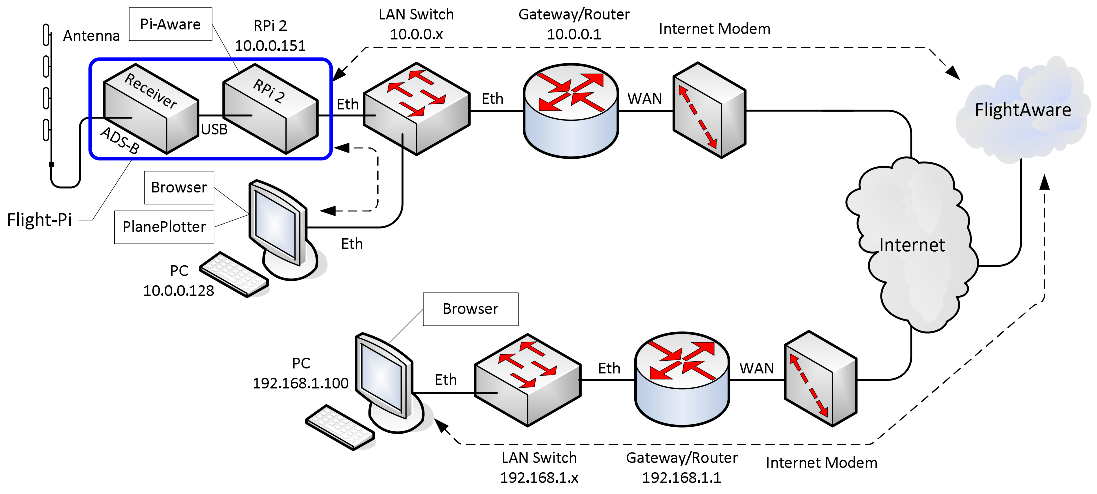
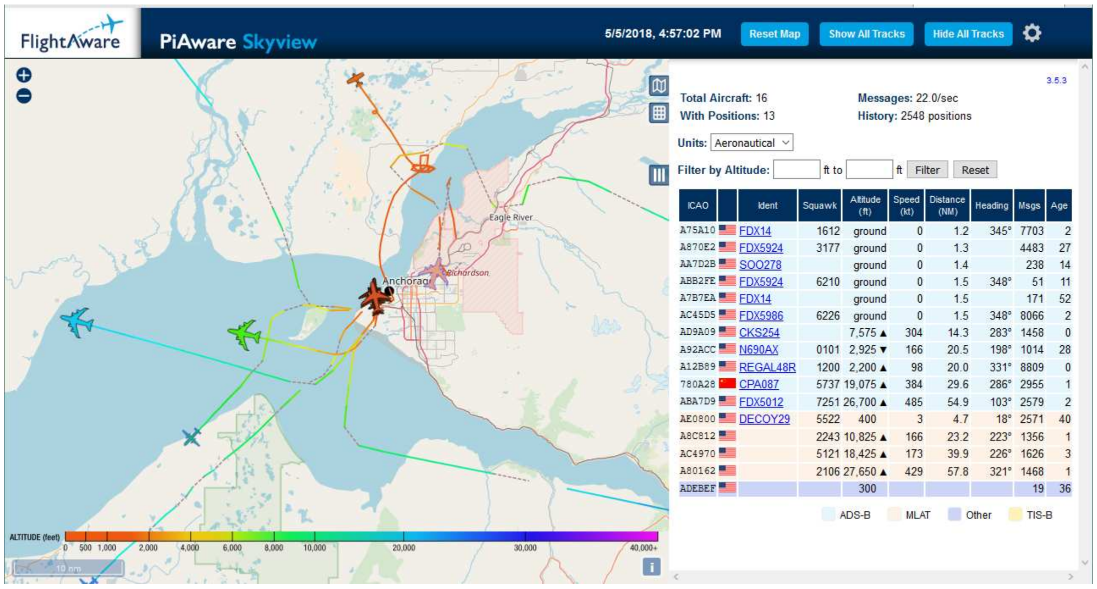


Figure 3 ~ Block diagram of the Flight-Pi application. The only Raspberry Pi software required besides the operating systems are the PiAware software and a web browser. The PlanePlotter application shown here is optional. Image © 2018 W. Reeve

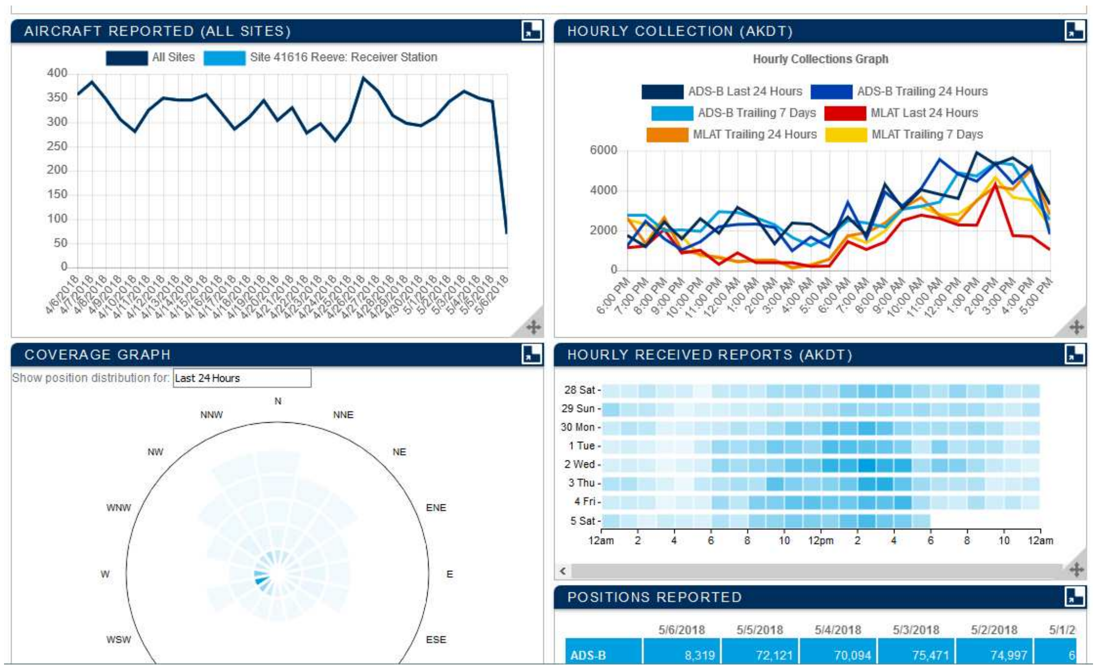


Total Aircraft: 16 Messages: 22.0/sec
With Positions: 13 History: 2548 positions

| ICAO | | Ident | Squawk | Altitude (ft) | Speed (kt) | Distance (NM) | Heading | Msgs | Age |
|---|---|---|---|---|---|---|---|---|---|
| A75A10 | | FDX14 | 1612 | ground | 0 | 1.2 | 345° | 7703 | 2 |
| A870E2 | | FDX5924 | 3177 | ground | 0 | 1.3 | | 4483 | 27 |
| AA7D2B | | SOO278 | | ground | 0 | 1.4 | | 238 | 14 |
| ABB2FE | | FDX5924 | 6210 | ground | 0 | 1.5 | 348° | 51 | 11 |
| A7B7EA | | FDX14 | | ground | 0 | 1.5 | | 171 | 52 |
| AC45D5 | | FDX5986 | 6226 | ground | 0 | 1.5 | 348° | 8066 | 2 |
| AD9A09 | | CKS254 | | 7,575 ▲ | 304 | 14.3 | 283° | 1458 | 0 |
| A92ACC | | N690AX | 0101 | 2,925 ▼ | 166 | 20.5 | 198° | 1014 | 28 |
| A12B89 | | REGAL48R | 1200 | 2,200 ▲ | 98 | 20.0 | 331° | 8809 | 0 |
| 780A28 | | CPA087 | 5737 | 19,075 ▲ | 384 | 29.6 | 286° | 2955 | 1 |
| ABA7D9 | | FDX5012 | 7251 | 26,700 ▲ | 485 | 54.9 | 103° | 2579 | 2 |
| AE0800 | | DECOY29 | 5522 | 400 | 3 | 4.7 | 18° | 2571 | 40 |
| A8C812 | | | 2243 | 10,825 ▲ | 166 | 23.2 | 223° | 1356 | 1 |
| AC4970 | | | 5121 | 18,425 ▲ | 173 | 39.9 | 226° | 1626 | 3 |
| A80162 | | | 2106 | 27,650 ▲ | 429 | 57.8 | 321° | 1468 | 1 |
| ADEBEF | | | | 300 | | | | 19 | 36 |

ADS-B MLAT Other TIS-B

Figure 4.a ~ Web browser screenshot of PiAware map as well as tabulated aircraft data being received at Anchorage, Alaska early Saturday evening. The table may be turned off. This map is about 60 nm across. Aircraft tracks are turned on. To access the map, the IP address of the Flight-Pi is entered in the browser.



| | 5/6/2018 | 5/5/2018 | 5/4/2018 | 5/3/2018 | 5/2/2018 | 5/1/2 |
|---|---|---|---|---|---|---|
| ADS-B | 8,319 | 72,121 | 70,094 | 75,471 | 74,997 | 6 |

Figure 4.b ~ Web browser screenshot of PiAware statistics for my Flight-Pi installation. Only some of the statistics are shown here. The statistics are accessed through an individual FlightAware webpage assigned to that station.

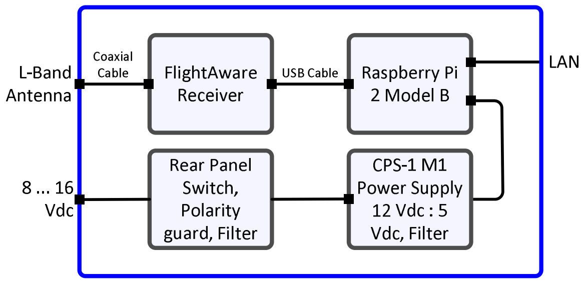


Figure 5 ~ Flight-Pi interconnections. All components are enclosed in an extruded aluminum enclosure, and all device interconnections except the USB cable are internal. Image © 2018 W. Reeve

A working flight tracking system may be built by simply connecting the FlightAware receiver to a Raspberry Pi, inserting a preprogrammed memory card with the PiAware software image and connecting 5 Vdc power, LAN and antenna. Such a setup would be considered temporary because the components are exposed to damage or accidental disconnection. The Flight-Pi includes all components in an enclosure with a dc-dc converter so that the system may be powered from a 12 Vdc station power supply. The package makes the system more permanent, reliable and easier to physically manage.

Receiver: The FlightAware receiver is an RTL-dongle-type software defined radio (SDR) receiver that has been optimized for reception of ADS-B signals at 1090 MHz (L-band). The receiver digitizes the radio frequency signals and converts them to an in-phase and quadrature-phase (I/Q) digital bit stream that is processed and demodulated by the software on the Raspberry Pi computer. The receiver version used here is the *FlightAware USB Pro Stick Plus* (figure 6), which has a built-in bandpass filter to reduce interference from extraneous transmissions. As of May 2018 the receiver costs about 19 USD and it is available in the USA through eBay and Amazon. A version of the receiver, the *FlightAware USB Pro Stick*, is available without the internal filter for 18 USD but an external bandpass filter is recommended for use with that receiver. The receiver is powered through the USB connection to the Raspberry Pi. A short USB-A extension cable is used on Flight-Pi to connect the receiver to a Raspberry Pi USB port.

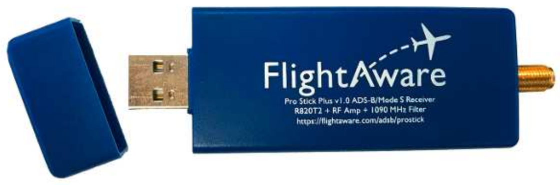

FlightAware
Pro Stick Plus v1.0 ADS-B/Mode S Receiver
R820T2 + RF Amp + 1090 MHz Filter
https://flightaware.com/adsb/prostick

Figure 6 ~ FlightAware USB Pro Stick Plus receiver. The receiver is powered by 5 Vdc through the USB connection on the left. The SMA antenna connector is on the right. This version of the receiver has a built-in bandpass filter to reduce interference. Principle dimensions are 70 L x 30 W x 13 D mm. Image source: FlightAware

Raspberry Pi: While building this system I tried both the Raspberry Pi 2 model B (RPi2) and Raspberry Pi 3 model B (RPi3) platforms. The RPi3 has built-in Wi-Fi capability (2.4 GHz); however, the built-in Wi-Fi will not work when installed in the aluminum enclosure. A Wi-Fi USB dongle can be used in its place where wireless operation is desired. I will refer to both platforms as RPi except where differentiation is needed. Both types use a micro-SD memory card to store the operating system and application software.

Power supply: The power supply is based on a modular dc-dc converter that has an input range of 6.5 to 18 Vdc and approximately 90% efficiency. The minimum input voltage is increased to 8 Vdc by the polarity guard diode voltage drop plus a margin. The converter is mounted on a small PCB, which also includes a power input connector, power output cable and an inductor and capacitors for filtering. Power is supplied through a 2.1 x 5.5 mm coaxial dc power jack (center positive).

Enclosure: The enclosure is the Box Enclosures B3-160. The Raspberry Pi Ethernet and USB connectors, receiver USB connector and antenna are on the front panel and dc input connector, power switch and power indicating LED are on the rear panel (figure 7).

Software: The PiAware software is a free download that must be installed on a micro-SD memory card. The installation uses two partitions with a total requirement of about 4.8 GB. I used an 8 GB, Class 10 card but larger and slower cards may be used. Once installed, the software is ready to use and no configuration is needed with a wired Ethernet LAN. Configuring it for Wi-Fi operation requires a temporary wired LAN connection to access and specify the Wi-Fi settings. PiAware is compatible with other ADS-B receivers but their implementation is beyond the scope of this article.

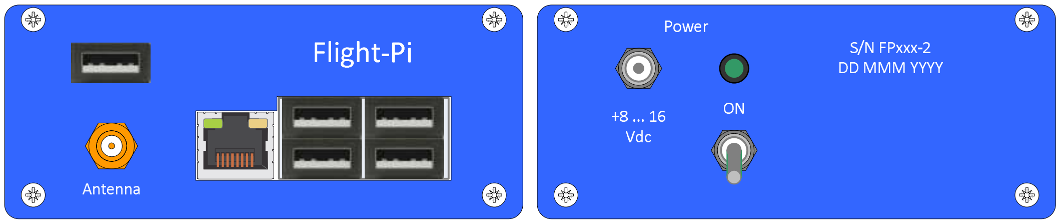
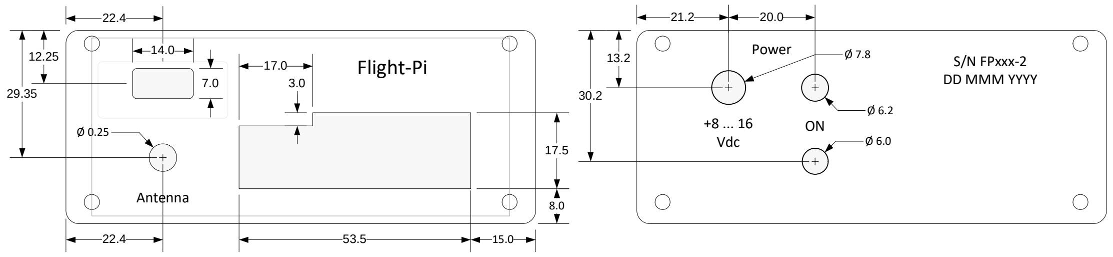


Figure 7 ~ Front and rear end panels. Image © 2018 W. Reeve

## 4. Construction

Enclosure: The extruded aluminum enclosure includes two sheet aluminum end panels (figure 8). The front panel requires cutouts for the RPi USB and Ethernet connectors, receiver USB connector and antenna connector. The rear end panel requires cutouts for a power indicating LED, power toggle switch and coaxial dc power jack. The enclosure body requires drilled holes for mounting the internal power supply and Raspberry Pi, both of which are installed on 6 mm brass standoffs. The polarity guard diode and capacitors that are part of the input filter for the dc-dc converter power supply are installed on the rear panel (figure 9).



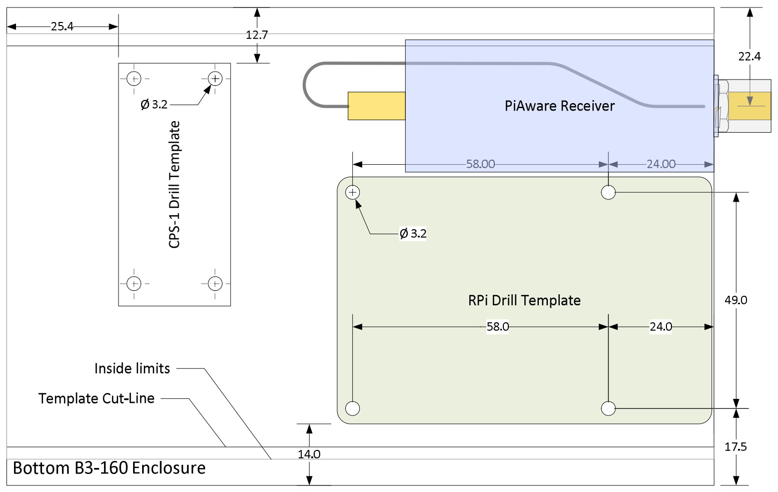


Figure 8 ~ Upper: Front and rear end panels require circular and rectangular cutouts. Lower: The RPi and power supply PCB are mounted to the bottom of the enclosure body with brass standoffs.

I print paper templates from scaled drawings, tape them to the panels and body and mark with a center punch. After scribing the outline of the rectangular cutouts with a hobby knife, I drill pilot holes. The pilot holes are then enlarged as required for each cutout. The rectangular holes are finished to the outline with small files. Image © 2018 W. Reeve

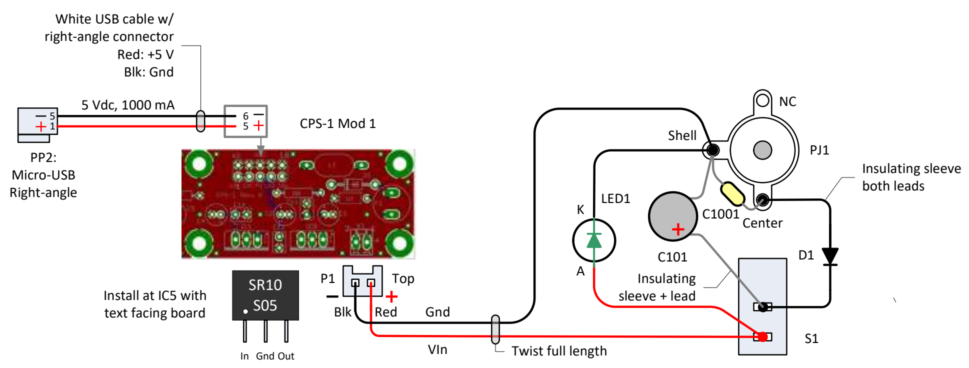


Figure 9 ~ Power circuit wiring diagram. All components on the right are installed on the rear panel. LED (LED1) has a built-in current limiting/voltage dropping resistor for 12 V operation. C101 is used with L1 and C11 on the power supply PCB as a pi-filter for the input of the dc-dc converter. Image © 2018 W. Reeve

Power supply: The main component of the internal power supply is a 10 W, 12 V nominal input, 5 V output dc-dc converter and a printed circuit board. Also included is a PTC resettable fuse for overcurrent protection and capacitor and inductor filter components, which together with the capacitors on the rear panel form a Pi input filter for the dc-dc converter.

Bill of material: The BOM is straight-forward and requires only a few unique parts (table 1). Although certain part numbers are called out, substitutions may be made that have equivalent voltage, current and power ratings.

Table 1 ~ Flight-Pi material list (NPN: No Part Number)

| **Item** | **Qty** | **P/N** | **Mfr or Vendor** | **Description** |
|---|---|---|---|---|
| 1 | 1 | RPi | Raspberry Pi | Raspberry Pi 2 model B (or Raspberry Pi 3 model B) |
| 2 | 1 | NPN | Generic | Micro-SD memory card, 8 GB, Class 10 |
| 3 | 1 | NPN | FlightAware | FlightAware Pro Stick Plus USB Receiver |
| 4 | 1 | NPN | RFSupplier | Coaxial jumper cable, SMA-M to SMA-F bulkhead mount, 150 mm |
| 5 | 1 | NPN | Generic | USB-A extension cable, 150 mm |
| 6 | 1 | CPS-1 M1 | Reeve | Power supply printed circuit board, mod 1 |
| 7 | 1 | 22-23-2021 | Molex | Header, 2C, with friction lock |
| 8 | 1 | 22-01-3027 | Molex | Wire mount housing, 2C, with friction lock and polarizing ribs |
| 9 | 2 | 08-50-0114 | Molex | Contact, spring-type, 24-26 AWG |
| 10 | 1 | NPN | Generic | Micro-USB-B to blunt power cable, 150 mm |
| 11 | 4 | NPN | Generic | Rubber bumper feet, self-adhesive, 10 x 3 mm |
| 12 | 1 | B3-160xx | Box Enclosures | Enclosure, extruded aluminum, 160 x 109 x 45 mm (xx = color) |
| 13 | 1 | 317228 | Jameco | Toggle switch, miniature, SPST |
| 14 | 1 | L722A | Switchcraft | DC coaxial power jack, locking, 2.1 x 5.5 mm |
| 15 | 1 | 767K | Switchcraft | DC coaxial power plug, long barrel (locking), 2.1 x 5.5 mm |
| 16 | 2 | 860020474014 | Wurth | Capacitor, 470 μF, 25 V, electrolytic, 105 °C, 3.5 mm LS, C102, C11 |
| 17 | 3 | NPN | Generic | Capacitor, 10 nF, 50 V, MLCC, 2.5 mm LS, C1001 |
| 18 | 1 | AIAP-01-6R8K-T | Abracon | Inductor, 6.8 μH, 1.6 A, epoxy coated, L1 |
| 19 | 1 | MF-R090 | Bourns | PTC resettable fuse, 900 mA, 60 V |
| 20 | 1 | SR10S05 | XP Power | Encapsulated power supply, 12 V:5V, 10 W |
| 21 | 1 | 637183 | Jameco | LED, 12 V, Green, panel mount (with internal dropping resistor) |
| 22 | 1 | 1N5819 | Generic | Schottky diode, 40 V, 1 A |
| 23 | 2 | WH24-xx | NTE | Hookup wire, stranded 7x32, 24 AWG, 300 V PVC, red and black |
| 24 | 4 | 92005A116 | McMaster | Machine screw, M3 x 6 mm, phillips pan head |

|  |  |  |  |  |
|---|---|---|---|---|
| 25 | 4 | 91106A122 | McMaster | Washer, internal star, 3 mm |
| 26 | 4 | 92148A150 | McMaster | Washer, split lock, 3 mm |
| 27 | 4 | 90591A250 | McMaster | Hex nut, M3 |
| 28 | 4 | NPN | Generic | Hex standoff, male-female, M3 x 6 x 6 mm, brass |
| 29 | 4 | 92005A066 | McMaster | Machine screw, phillips pan head, M2.5 x 6 mm |
| 30 | 4 | 91106A150 | McMaster | Washer, internal star, 2.5 mm |
| 31 | 4 | 92148A070 | McMaster | Washer, split lock, 2.5 M |
| 32 | 4 | 90591A270 | McMaster | Hex nut, M2.5 |
| 33 | 4 | NPN | Generic | Hex standoff, male-female, M2.5 x 6 x 6 mm, brass |

Assembly: The components are built into subassemblies – power supply and front and rear panels – and, with the RPi, are installed on the enclosure body (figure 10). The receiver is mounted on the front panel along with an SMA-F bulkhead mount antenna connector.

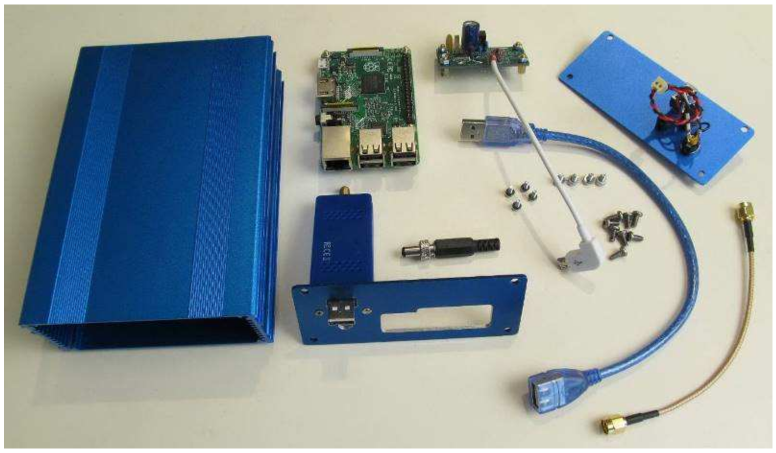


Figure 10 ~ Collection of prototype Flight-Pi components. The RPi is top-middle of image and the fully assembled power supply PCB is just to the right of it. The front panel (lower-middle) has the receiver fastened to it and the rear panel (upper-right) has power wiring installed. The prototype is shown here with a coaxial jumper cable (lower-right corner) that uses SMA-M connectors at both ends and connects to a bulkhead mount SMA-F to SMA-F coupler on the front panel. The BOM eliminates the coupler and uses a jumper cable with SMA-M to SMA-F bulkhead mount connectors. Image © 2018 W. Reeve

The receiver is not designed for panel mounting but I adapted it. The receiver has a small, raised plastic reinforcement ridge around the USB connector. The front panel cutout shown on the drawings matches this reinforced area allowing the receiver to be epoxied in place with clearance for the connector. I used two small screws to add support, although they probably are not necessary. For these screws I carefully drilled two #50 holes through the panel and into the receiver plastic housing and then enlarged the panel holes to #43. These holes were placed to ensure that drilling would clear the receiver PCB inside the plastic enclosure but I was careful to prevent the drill bit from penetrating the housing. I inserted two 2-56 flat-head screws just long enough to fit the panel and plastic housing and added a small amount of adhesive to the threads. To complete the front panel subassembly after the receiver was mounted, I added a coaxial jumper cable from the receiver RF input connector to the front panel. Prior to installing the RPi in the enclosure, load the PiAware software on a memory card as described in the next section and insert into the card slot on the RPi PCB.

The power switch, LED and coaxial power jack are mounted and wired. The rear panel includes a connectorized 2-conductor pigtail, which connects to the power supply mounted in the enclosure body. After the two panels are finished and the power supply and RPi are connected and mounted in the enclosure body, the panels may be installed. The first time the panels are mounted on the body, the screws cut their own threads. This is made easier with a very small amount of thread-cutting oil on the screws before inserting them. I withdraw the screws to clean any left-over oil and metal fragments and then reinsert.

## 5. Setup

Detailed information on installing the PiAware software on a memory card is available at {PiAware}. Where a wired LAN connection is used, no additional setup is needed (Wi-Fi is discussed at the end of this section). With the Flight-Pi connected to the antenna, LAN and power, the PiAware application software automatically loads when power is applied and obtains a free account from {FlightAware}. Allow a couple minutes for the RPi to boot. If after obtaining the FlightAware account a new image is loaded on the RPi memory card, PiAware will automatically obtain a new but different account. This could lead to multiple accounts assigned to one user, but it can be avoided as explained later. If the extra accounts go unused for a month, they will disappear and any statistics associated with them will be lost.

Flight-Pi management: Flight-Pi is operated in a "headless" mode in which no keyboard, mouse or display is connected. All provisioning is through a LAN connected PC that is running a terminal emulator program such as PuTTY or Tera Term. Refer to {RPiBasic} for details. First, determine the IP address of the RPi. The IP address may be determined with the free NetScan, AngryIP or Advanced IP programs running on a Windows PC. The address also may be obtained from the LAN router network map, although I find a dedicated program is much better.

Now, access Flight-Pi from the PC running PuTTY or Tera Term and login. The default user and password are:

Default user: `pi`
Default password: `flightaware`

Password: After logging into the RPi be sure to change the default password. To change the password, follow the on-screen prompts after entering:

```
passwd
```

Status: Check the status of PiAware by entering:

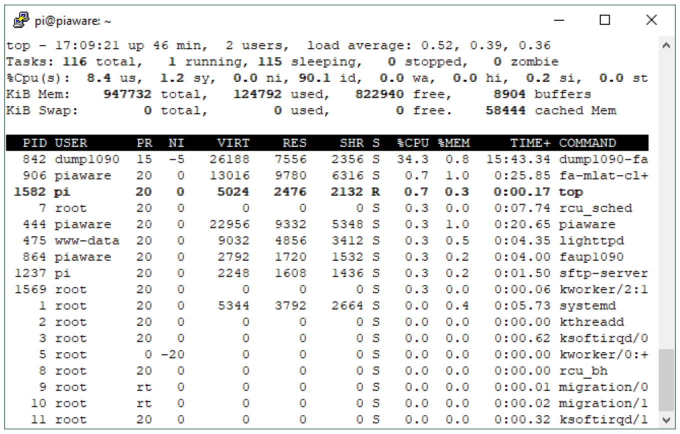
```
sudo piaware-status
```

If necessary PiAware may be restarted if there had been a problem or configuration change. To restart enter:

```
sudo systemctl restart piaware
```

The CPU load can be determined from the *top* command (figure 11). Top is a built-in tool that shows all running processes and is similar in function to the Windows Task Manager. At the console prompt enter:

```
top
```



pi@piaware: ~

```
top - 17:09:21 up 46 min,  2 users,  load average: 0.52, 0.39, 0.36
Tasks: 116 total,   1 running, 115 sleeping,   0 stopped,   0 zombie
%Cpu(s):  8.4 us,  1.2 sy,  0.0 ni, 90.1 id,  0.0 wa,  0.0 hi,  0.2 si,  0.0 st
KiB Mem:    947732 total,   124792 used,   822940 free,     8904 buffers
KiB Swap:        0 total,        0 used,        0 free.    58444 cached Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU %MEM     TIME+ COMMAND
  842 dump1090  15  -5   26188   7556   2356 S  34.3  0.8  15:43.34 dump1090-fa
  906 piaware   20   0   13016   9780   6316 S   0.7  1.0   0:25.85 fa-mlat-cl+
 1582 pi        20   0    5024   2476   2132 R   0.7  0.3   0:00.17 top
    7 root      20   0       0      0      0 S   0.3  0.0   0:07.74 rcu_sched
  444 piaware   20   0   22956   9332   5348 S   0.3  1.0   0:20.65 piaware
  475 www-data  20   0    9032   4856   3412 S   0.3  0.5   0:04.35 lighttpd
  864 piaware   20   0    2792   1720   1532 S   0.3  0.2   0:04.00 faup1090
 1237 pi        20   0    2248   1608   1436 S   0.3  0.2   0:01.50 sftp-server
 1569 root      20   0       0      0      0 S   0.3  0.0   0:00.06 kworker/2:1
    1 root      20   0    5344   3792   2664 S   0.0  0.4   0:05.73 systemd
    2 root      20   0       0      0      0 S   0.0  0.0   0:00.00 kthreadd
    3 root      20   0       0      0      0 S   0.0  0.0   0:00.62 ksoftirqd/0
    5 root       0 -20       0      0      0 S   0.0  0.0   0:00.00 kworker/0:+
    8 root      20   0       0      0      0 S   0.0  0.0   0:00.00 rcu_bh
    9 root      rt   0       0      0      0 S   0.0  0.0   0:00.01 migration/0
   10 root      rt   0       0      0      0 S   0.0  0.0   0:00.02 migration/1
   11 root      20   0       0      0      0 S   0.0  0.0   0:00.32 ksoftirqd/1
```

Figure 11 ~ PuTTY screenshot shows the results of the *top* command. As indicated just below the dark column header, the dump1090 application (program ID 842), which processes the signals from the ADS-B receiver, places the highest load, in this case about 34%.

To return to the prompt, enter `q` or CTRL-C.

The SoC (System on a Chip, or CPU) internal temperature is measured by entering the following string at the PuTTY command line prompt:

```
   sudo vcgencmd measure_temp && date
```

The appended date command (`&& date`) helps to track the temperature over time. The indicated SoC temperature will depend on the ambient temperature but should be below approximately 50 °C.

After Flight-Pi is in service, its unique FlightAware account number, called *feeder_id*, should be determined and saved for future reference. It will be needed to prevent extra accounts from being assigned and statistics lost in case the PiAware image has to be reinstalled on the RPi memory card.

To find the assigned feeder_id, use WinSCP and go to the `/var/cache/piaware` directory. Open the file labeled `feeder_id` using the WinSCP editor. The feeder ID is a 32 hex digit string of the form:

```
   hhhhhhhh-hhhh-hhhh-hhhh-hhhhhhhhhhhh.
```

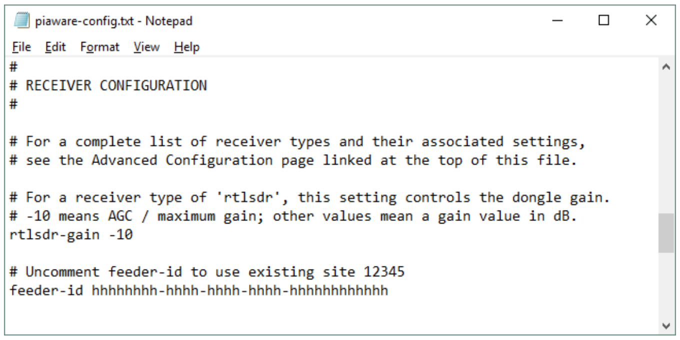
Alternately, the ID also can be found on the user's online FlightAware account (view the My ADS-B tab and look for the *Unique Identifier* field in the Site Information section) or it may be determined from the PuTTY or Tera Term console. At the prompt enter:

```
   sudo nano /var/cache/piaware/feeder_id
```

If, in the future, it is necessary to reload the PiAware image from scratch to the RPi memory card, a new FlightAware account is automatically assigned when the Flight-Pi is reconnected. To avoid this and retain the original account and associated statistics, it is necessary to slightly modify the PiAware configuration file before first powering the Flight-Pi with the new image. To load a new image, the Flight-Pi enclosure needs to be opened and the RPi removed for access to the memory card slot. Remove the memory card from the RPi and insert in a card reader/writer device then connect the reader/writer to a PC.

After loading the new image on the memory card but before removing it from the PC, open the piaware-config.txt file on the card using a text editor such as NotePad or NotePad++. Scroll down to the `Receiver Configuration` section and add the text `feeder_id` and the ID determined previously, separated by one space (figure 12). Save the file to the memory card, eject it from the PC and install it in the Flight-Pi. Now, when the

Flight-Pi is started with the new image, it will use the existing account. After the new PiAware image has connected to FlightAware, the ID will be inserted automatically in the `/var/cache/piaware` directory and the `feeder_id` entry in the configuration file may be commented out with the # character.



```
#
# RECEIVER CONFIGURATION
#

# For a complete list of receiver types and their associated settings,
# see the Advanced Configuration page linked at the top of this file.

# For a receiver type of 'rtlsdr', this setting controls the dongle gain.
# -10 means AGC / maximum gain; other values mean a gain value in dB.
rtlsdr-gain -10

# Uncomment feeder-id to use existing site 12345
feeder-id hhhhhhhh-hhhh-hhhh-hhhh-hhhhhhhhhhhh
```

Figure 12 ~ NotePad screenshot shows the changes to the PiAware configuration file `piaware-config.txt`. Add the two lines shown bottom-left at any convenient location in the file. One line is commented with the # character and has the existing FlightAware site number for reference, and the other line has the 32 digit `feeder_id` string associated with the existing FlightAware account. The account number is a series of hex characters shown here as h, where h = *0* to *9* and *a* to *f*.

Timing: Accurate timing is required for multi-lateralization (Mlat) computations. Accurate receiver station position also is required. The PiAware software uses Coordinated Universal Time (UTC) as the time reference and the Network Time Protocol (NTP) for timekeeping. The default NTP configuration file in PiAware uses four time server pools and can be improved by using specific geographically nearby time servers. The best timing is obtained from local time servers (such as, for example, {GpsNtp-Pi}) with time server pools as backup. The NTP chooses the best time server from all of those listed in the NTP configuration file – usually a local time server if one is available.

The NTP configuration file can be edited to change, delete or add time servers:

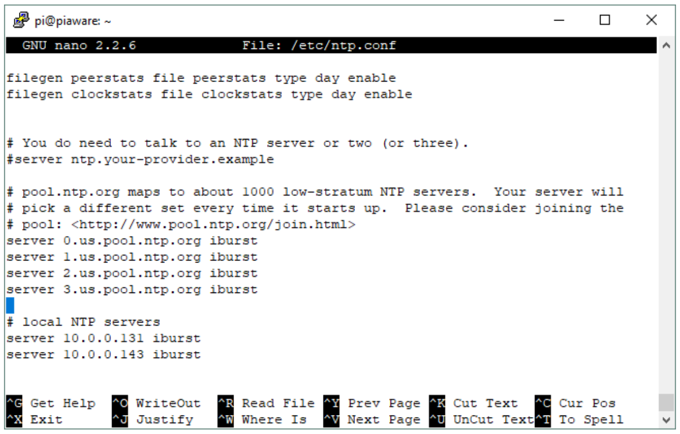
```
sudo nano /etc/ntp.conf
```

Scroll down to the server pools (`server x.debian.pool.ntp.org iburst` where x is 0 to 3) and change each of the four from *debian* to use the pool of choice (figure 13). Users in the USA should select the US pools as shown below (the first three lines beginning with the # character are existing comments). Users in other countries can select a regional, continental or country pool from {NTPPool}.

```
# pool.ntp.org maps to about 1000 low-stratum NTP servers.  Your server will
# pick a different set every time it starts up.  Please consider joining the
# pool: <http://www.pool.ntp.org/join.html>
server 0.us.pool.ntp.org iburst
server 1.us.pool.ntp.org iburst
server 2.us.pool.ntp.org iburst
server 3.us.pool.ntp.org iburst
```

If local time servers are available, they should be added to the configuration file, one on each line before or after the server pools (their actual location in the configuration file does not matter but it is convenient to have them near the pools list). The example below shows the IP addresses of two local time servers in my network (substitute the addresses of your own time servers).

```
# local NTP servers
server 10.0.0.131 iburst
server 10.0.0.143 iburst
```



```
  GNU nano 2.2.6              File: /etc/ntp.conf

filegen peerstats file peerstats type day enable
filegen clockstats file clockstats type day enable


# You do need to talk to an NTP server or two (or three).
#server ntp.your-provider.example

# pool.ntp.org maps to about 1000 low-stratum NTP servers.  Your server will
# pick a different set every time it starts up.  Please consider joining the
# pool: <http://www.pool.ntp.org/join.html>
server 0.us.pool.ntp.org iburst
server 1.us.pool.ntp.org iburst
server 2.us.pool.ntp.org iburst
server 3.us.pool.ntp.org iburst

# local NTP servers
server 10.0.0.131 iburst
server 10.0.0.143 iburst


^G Get Help  ^O WriteOut  ^R Read File ^Y Prev Page ^K Cut Text  ^C Cur Pos
^X Exit      ^J Justify   ^W Where Is  ^V Next Page ^U UnCut Text^T To Spell
```

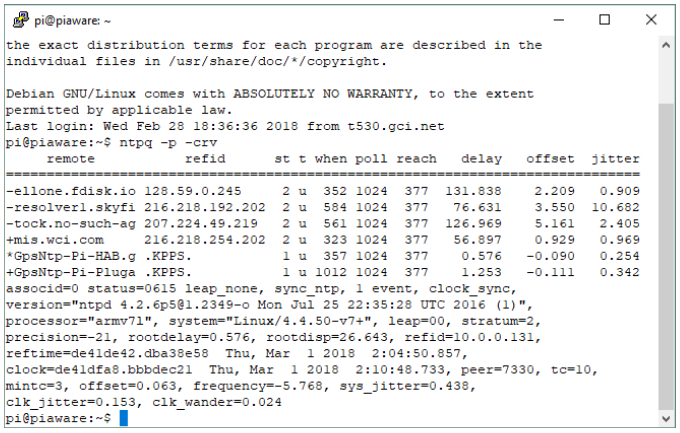
Figure 13 ~ PuTTY screenshot shows the NTP configuration file. Changes have been made to the time server pools, and local time servers have been added as described in the text.

When finished editing the NTP configuration file, save the changes by entering CTRL-X, Y, Enter. After saving the changes, restart NTP:

```
sudo service ntp restart
```

Wait a few minutes and then check the time servers with the NTP query tool (figure 14):

```
ntpq -crv -p
```



```
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Wed Feb 28 18:36:36 2018 from t530.gci.net
pi@piaware:~$ ntpq -p -crv
     remote           refid      st t when poll reach   delay   offset  jitter
==============================================================================
-ellone.fdisk.io 128.59.0.245     2 u  352 1024  377  131.838    2.209   0.909
-resolver1.skyfi 216.218.192.202  2 u  584 1024  377   76.631    3.550  10.682
-tock.no-such-ag 207.224.49.219   2 u  561 1024  377  126.969    5.161   2.405
+mis.wci.com     216.218.254.202  2 u  323 1024  377   56.897    0.929   0.969
*GpsNtp-Pi-HAB.g .KPPS.           1 u  357 1024  377    0.576   -0.090   0.254
+GpsNtp-Pi-Pluga .KPPS.           1 u 1012 1024  377    1.253   -0.111   0.342
associd=0 status=0615 leap_none, sync_ntp, 1 event, clock_sync,
version="ntpd 4.2.6p5@1.2349-o Mon Jul 25 22:35:28 UTC 2016 (1)",
processor="armv7l", system="Linux/4.4.50-v7+", leap=00, stratum=2,
precision=-21, rootdelay=0.576, rootdisp=26.643, refid=10.0.0.131,
reftime=de41de42.dba38e58  Thu, Mar  1 2018  2:04:50.857,
clock=de41dfa8.bbbdec21  Thu, Mar  1 2018  2:10:48.733, peer=7330, tc=10,
mintc=3, offset=0.063, frequency=-5.768, sys_jitter=0.438,
clk_jitter=0.153, clk_wander=0.024
pi@piaware:~$
```

Figure 14 ~ PuTTY screenshot shows the results of an NTP query. This example shows four pools and two local time servers and other details. The symbols next to the servers are:
* = current time source
# = source selected, distance exceeds maximum value
o = source selected, Pulse Per Second (PPS) used
+ = source selected, included in final set
x = source false ticker
. = source selected from end of candidate list
– = source discarded by cluster algorithm
blank = source discarded high stratum, failed sanity

The setup described above uses a wired LAN connection. If a Wi-Fi (also called WLAN) connection is desired, follow the description at {RPiWLAN}.

## 6. RF Notes

Low noise amplifier: Where the system layout requires long cable runs from the antenna to receiver, an LNA can be used to improve the system noise figure. For example, 30 m of LMR-400 (10 mm diameter) coaxial cable has a loss of 4.7 dB (including connectors) at 1090 MHz. The receiver noise figure is around 3 to 4 dB, so this cable would increase the system noise figure to 8 or 9 dB. A higher noise figure indicates lower sensitivity; therefore, the receiver range will be significantly reduced. An LNA located close to the antenna will improve the system noise figure, but it may be necessary to reduce the receiver gain or to insert an attenuator between the LNA and receiver to prevent overload. LNAs with a built-in bandpass filter for 1090 MHz and bias-tee powering or external powering are available from {Uputronics}.

Antenna: For the best performance, use a high-gain, omni-directional antenna mounted as high as possible. Foliage and building loss at L-band can be significant, so the antenna should be clear of trees and obstructions and have a clear view of the sky in all directions if at all possible. The range of a system with a good antenna and no obstructions or foliage can approach 200 nm. An example of a purpose-built ADS-B antenna is the DPD Productions ADS-B omni-directional, collinear dipole antenna, which has an advertised gain of 9.0 dBi {DPD}. A 1/4-wavelength indoor whip antenna placed near a window may be used to confirm system operation but is not recommended for a permanent installation because of low overall performance.

Coaxial cable and connectors: Use only high quality coaxial cable and connectors for all RF connections. RG-58 and equivalent cables introduce high loss at 1090 MHz and are not recommended in lengths > 10 m unless a low noise amplifier is used at the antenna. Never use push-on (tool-less) RF connectors.

## 6. Weblinks and References

| | |
|---|---|
| {ADS-B} | https://en.wikipedia.org/wiki/Automatic_dependent_surveillance_%E2%80%93_broadcast |
| {DPD} | http://www.dpdproductions.com/page_vhf_air.html#adsbout |
| {FlightAware} | https://flightaware.com/adsb/ |
| {GpsNtp-Pi} | http://www.reeve.com/RadioScience/Raspberry%20Pi/GpsNtp-Pi.htm |
| {NTPPool} | https://support.ntp.org/bin/view/Servers/NTPPoolServers |
| {PiAware} | https://flightaware.com/adsb/piaware/ |
| {RPiBasic} | http://www.reeve.com/Documents/Articles%20Papers/Reeve_RPi_BasicSetup.pdf |
| {RPIWLAN} | http://www.reeve.com/Documents/Articles%20Papers/Reeve_RPi_WLANSetup.pdf |
| {Uputronics} | https://store.uputronics.com/index.php?route=product/product&path=59&product_id=50 |

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