Radio Communications Troubleshooting

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*The Piccolo Autopilot avionics system and all of its versions (such as Piccolo, Piccolo Plus, Piccolo II, Piccolo LT, and Piccolo SL) were designed for use **only** on un-manned aircraft.* ***USE OF THESE PICCOLO AUTOPILOT PRODUCTS IN AIRCRAFT WITH HUMAN OCCUPANTS IS PROHIBITED BY THE FEDERAL AVIATION ADMINISTRATION.*** *Cloud Cap Technology, Inc. is not permitted to sell the Piccolo Autopilot to any customer that intends to use the product on aircraft with human occupants.*

1 Introduction

This document covers some basic testing procedures, information, and tools you can use to help diagnose Piccolo radio communication problems.

1.1 Common Problems

The most common communications problems are caused by the following:

- There are three different 2.4 GHz radio models that exist in our systems because of radio manufacturer changes due to obsolete components, performance improvements, and miniaturization. Intermittent communications can occur if operating with a mix of the oldest MHX2400 and newer models of 2.4 GHz radios. To ensure that this does not happen, **ONLY** use hopping patterns (Channels) 8 through 43.
- Poor antenna cables or bad crimps on connectors (it is best to obtain professionally made custom cables such as those from Pasternack).
- Poor electrical connection between ground-plane and antenna for monopole antennas.
- Poor antenna mounting location, including lack of line of sight between the ground station antenna and the aircraft antenna, or obstruction by the aircraft itself.
- Other active systems on board the aircraft (e.g. payloads, computers, video transmitters and other aircraft systems) can also affect communications. It is a good idea to compare communications performance with these systems turned on and with them off.
- Antenna and cable separation is important. Try to keep at least 1 meter separation between the Piccolo communications antenna and any other active antenna.

In other cases a poorly tuned antenna cable running next to a servo cable could induce servo motion with high power RF transmissions. Careful cable routing and verifying antenna tuning and cabling can resolve these issues.

1.2 Definitions

RSSI is the receive signal strength indication from the radio. This is displayed for both the ground station and for the aircraft radios. An RSSI of -71 dB should indicate good communications. The receiver sensitivity is about -105 dB so if RSSI reads close to -105 you are pushing the receiver about as far as it can go. RSSI indicates the presence of a strong RF signal but does not necessarily indicate good communications (for example another Piccolo ground station nearby could create a strong RSSI reading on your system).

A VSWR (Voltage Standing Wave Ratio) measurement is also available for some radios (currently only the MHX320). This provides a very useful measure of reflected power to transmitted power. If your antenna is not connected or is poorly tuned (or you have some other impedance mismatch) VSWR will indicate this (So a check of this is worth adding to your checklist!). A VSWR of 1.0 indicates a theoretical best performance (100% transmitted, 0% reflected power). Numbers higher than this indicate an issue. VSWR of 2.6:1 causes about 20% reflected power but only about 1 dB of transmission loss. VSWR of 4.5:1 would be over 40% reflected power.

AckRatio (Link number) is an indication of bidirectional communications performance. Since the system operates via polled communications, the ground station requests data from the aircraft, and then responds

The ground station keeps track of the acknowledgements from the aircraft. If communications are solid the link number will typically be 95 to 100. Anything less than 85 could be cause for concern particularly for manual control.

Note: *During flight you may fly through the antenna null directly overhead, or you may experience reduced sensitivity during turns or corners of your flight plan.*

- In the Piccolo Command Center (PCC) the **Link** number appears in the **Aircraft** window under the **Com** section. The **Aircraft** window is under **Window** » **Aircraft**.
- In the Operator Interface (OI), the link number appears in the second column of the aircraft list in the ground station dialog after the aircraft serial number

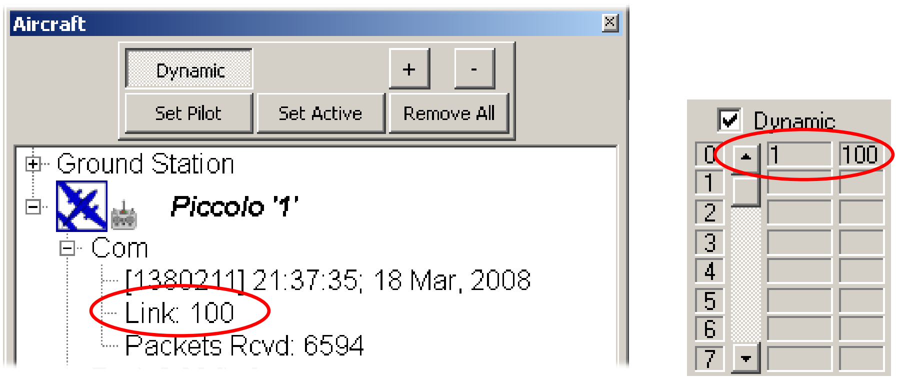

Figure 1 - PCC and OI Link Number

1.3 Communications Testing

To verify that you have sufficient gain margin for manual control, obtain a variable attenuator with approximately 100 dB of total switch selectable attenuation. A string of individual fixed attenuators may be used in place of a variable attenuator.

Figure 2 - Variable Attenuator

Note: *Many variable attenuators are limited to 1 GHz and so are only suitable for the 900 MHz radios and not the 2.4 GHz radio. In addition, when link margin testing 2.4 GHz radios, you should complete the test with the Ground Station and Piccolo physically separated by at least 50 feet if possible.*

Attenuator sources:

www.paternack.com - PE7036-3, 1 watt, DC to 1 GHz BNC Female Toggle Switch Attenuator

www.rflambda.com - RKT2G3A90, Manual Step Attenuator, 0-2.5 GHz, 90 dB

www.jfwindustries.com - 50R-234, Rotary Attenuator, 0-2.5 GHz, 100 dB

1.3.1 Ground Communications Testing

Perform range testing and switch in and out the attenuation. Observe and understand the link performance in the Piccolo system (AckRatio and RSSI).

Typically range testing is done at the launch site by placing the aircraft at each end of the runway. The aircraft is set down and RSSI and AckRatio are monitored.

A manual controls check is done to verify that manual control is working smoothly. Look for any hesitation of the control surface motion as the sticks are moved on each axis. An observer may call out the control surface and direction (via radio if needed) as each axis is moved.

About 40 dB of attenuation is dialed in and the RSSI should still indicate 5-10 dB of link margin better than -105 dB. The aircraft is then rotated 90 degrees and the test repeated for all 4 quadrants. Be aware of any ground based obstructions (i.e. metal reflectors like buildings, fences, etc).

Test Notes:

- It is critical to perform some ground testing with ground hardware in the same configuration used for manual flight. Make sure the antenna is not blocked by vehicles etc; usually the mag mount ground station antenna on top of a vehicle will have the best performance.
- There should be no line of sight obstructions at any point along the takeoff or approach path.
- The receiver has about -115 dB of sensitivity and you need a solid 10 dB of gain margin according to Microhard.
- This can see be seen in real-time with the RSSI numbers (treat these numbers with some caution).
- Typically -71 dB or so on the RSSI is seen at short range.
- Also look at the ack ratio number (link number). If this is dropping below 90 on a regular basis, then there is a problem.
- Suggested checklist items to add just before takeoff:
  - Verify aircraft antenna connected.
  - Verify ground station attenuator disconnected and ground station antenna connected.
  - Check RSSI, link ratio, and VSWR if available.

1.4 Hard Wired Test

The best way to validate receiver performance is to use a hard wired pad-down test. For this test to work, approximately 130 dB of attenuation is needed (make sure to account for cable loss).

This test works for all of our current Microhard radios, including the 350MHz radio in the wide band mode of operation.

Note: *This test should only to be done if a problem is suspected or to verify that you are attaining the absolute best performance from the system.*

The attenuation should not be less than 60 dB or damage to the receivers may result.

Hard wire the transceivers together with a minimum of 60dB attenuation. The attenuation is increased in increments. The system should still be functioning with 100% link at 120 dB of attenuation, and should begin to drop off at 125 to 130 dB.

If link margin testing 2.4 GHz radios, the Ground Station and Piccolo should be physically separated by at least 50 feet.

Note: *When testing the 310-390MHz radio in narrow band mode, it is possible to insert approximately 5 to 7dB more of attenuation (total of ~136dB instead of 130dB) before dropping below a 90% link rate.*

1.4.1 Cable Loss

Typical RG-316 cable has the following loss and should to be taken into account when adding up your total attenuation.

Approximate cable loss using RG-316 cable:

~ 0.2dB p/ft @ 350MHz

~ 0.3dB p/ft @ 900MHz

~ 0.48dB p/ft @ 2400MHz

1.5 Piccolo LT / Maxstream Radio

The receive sensitivity of the Maxstream radio is not as good the Microhard radio. The Maxstream radio can also be saturated at short range and high power. The output power may need to be turned down on both sides to as low as 0.01W for the units to talk successfully at very short range. For distances over 10 ft, this should not be an issue.

1.6 Omni Antennas

Standard omni antennas get approximately 8-10 miles range with either the 900 MHz or 2.4 GHz radios. Theoretically, the 900 MHz units have slightly less path loss. (In the United States the band is more crowded and possibly less desirable to use).

1.7 Gain Margin Calculation

The Microhard manual has an example section on estimating the gain margin (from the MHX-910 manual).

1. On the transmitter side, the transmitter power is 30 dBm (1W), cable loss is ~2 dB, antenna gain ~ 6 dB.
2. On the receiver side, the antenna gain is ~ 3 dB, cable loss ~2 dB, and the receiver sensitivity is -105 dB (specific to the MHX-910).
3. Calculate the system gain as the following: 30-2+6+3-2+105 = 140 dB
4. Next, the path loss must be considered. Microhard recommends designing for a gain margin of at least 10 dB for reliable communication.

For example if the path loss were 130 dB then in the above example the gain margin would be 140-130 = 10 dB.

The Microhard radio manual gives an example table of path loss numbers (designed more for surface vehicles than aircraft) using varying antenna heights and antenna separation.

Table 1 - Path Loss Numbers Example

Distance(km)	Base height(m)	Mobile height(m)	Path loss (dB)
5	15	2.5	116.5
5	30	2.5	110.9
8	15	2.5	124.1
16	15	2.5	135.3

- The antenna gain numbers need to be set to the correct values (the numbers shown are only an example).
- There are other calculators to estimate path loss. The key is to minimize signal loss (short/low loss ground station cable such as LMR 400/600/1700, and short aircraft RF cables), and to use appropriate antennas (and ground planes).
- Customers who need very long range tend to use automatically steered parabolic antennas on the ground.
- An intermediate range solution is an omni antenna or directional yagi mounted on a telescoping pole, or an omni, one or more yagi's, and an additional antenna switch.
- If a longer range is needed, CCT has done some work with integrating external radios such as the Dataradio / Teledesign / full duplex links (and of course Iridium SATCOMM is an option).

Other references and calculators:

http://www.gmsinc.com/calc_Free_Space_Loss.asp

http://www.gmsinc.com/support.asp?content_idno=225

http://www.pmicrowave.com/ant_perf.htm

1.8 Antenna Mounting Location

The following should be considered when deciding to mount the antenna on the top or the bottom of the aircraft:

- With a duck type antenna with a ground plane, there is a null at the tip of the antenna and behind the ground plane.
- If you mount a monopole antenna with ground-plane on the top of the aircraft and are flying circuits nearby, the antenna is pointing away from you half of the time and you are in the antenna null behind the ground plane. A better choice could be a dipole antenna (no ground-plane required), which has coverage lobes at both ends of the antenna.

- If the aircraft is far away and mostly flying long straight segments, it may be advantageous to have the antenna on the top.
- If you mount the antenna on the bottom of the aircraft and are flying circuits nearby, you are almost always within a high gain portion of the antenna pattern (unless the antenna points directly at you). However, this type of mounting runs the risk of obstructing communications during some part of taxiing or takeoff, possibly from line of sight blockage from the aircraft / engine.

Caution should be observed when testing antenna mounting locations.

- Due to the obstruction issue (particularly during takeoff and landing), most customers install the antenna on top of the aircraft. The top of the vertical stabilizer should also be a considered as well.

2 Piccolo Spectrum Analyzer Plots

The spectrum analyzer feature in the user interface provides an indication of other RF users and potential sources of interference.

2.1 Spectrum Plot Generation

Warning! Do not request a spectrum while the aircraft is flying. Requesting a spectrum causes an interruption in communications, which can cause serious consequences to the aircraft while flying.

Piccolo Command Center (PCC)

In PCC, go to **Window** » **Ground Station**. The spectrum analysis is generated by clicking the **Get Spectrum** button in the **Ground Station** window (**Figure 3**).

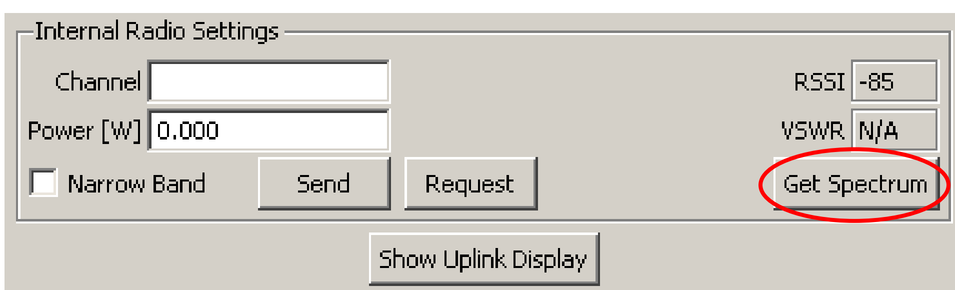

Figure 3 - PCC Ground Station Window

Operator Interface (OI)

In the OI, the spectrum analysis is generated by clicking the **Request Spectrum** button in the **Ground Station** window (**Figure 4**). After the button is clicked a confirmation dialog appears that indicates that communications will be lost for some period of time and that this should not be done in flight.

Note: *You may have to be in* ***Autopilot On*** *mode to reduce bandwidth during the spectrum analysis.*

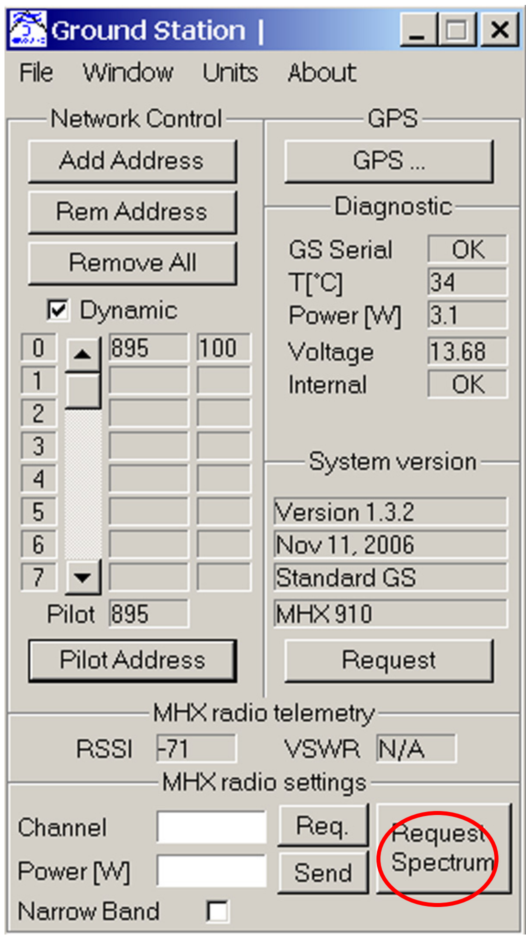

Figure 4 - OI Ground Station Request Spectrum

2.1.1 *Spectrum Analysis Results*

When the analysis is complete a text file titled *Spectrum.tx*t will come up in Notepad. This text file contains the spectrum analysis results.

The example file shown below indicates that there is significant activity on channels 16, 50, 51, 73, and 88 (highlighted in yellow) and lower and/or no activity on others. In this case the channels with high activity should be avoided.

In other cases the spectrum analysis may indicate peak transmissions higher than the average value, which are indicated by dots after the channel ID. In the example show below, they are not present.

```
ch 0-115dBm*
ch 1-115dBm*
ch 2-116dBm*
ch 3-116dBm*
ch 4-117dBm*
ch 5-116dBm*
ch 6-115dBm*
ch 7-116dBm*
ch 8-116dBm*
ch 9-116dBm*
ch10-117dBm*
ch11-116dBm*
ch12-115dBm*
ch13-113dBm*
ch14-113dBm*
ch15-114dBm*
ch16-107dBm*****
ch17-113dBm*
ch18-115dBm*
ch19-114dBm*
ch20-113dBm*
ch21-114dBm*
ch22-115dBm*
ch23-115dBm*
ch24-116dBm*
ch25-113dBm*
ch26-114dBm*
ch27-116dBm*
ch28-115dBm*
ch29-116dBm*
ch30-114dBm*
ch31-117dBm*
ch32-117dBm*
ch33-117dBm*
ch34-118dBm*
ch35-117dBm*
ch36-117dBm*
ch37-117dBm*
ch38-116dBm*
ch39-114dBm*
ch40-117dBm*
ch41-116dBm*
ch 42 -115dBm *
ch43-110dBm**
ch44-110dBm**
ch45-114dBm*
ch46-116dBm*
ch47-112dBm*
ch48-115dBm*
ch49-116dBm*
ch50-103dBm*********
ch51-105dBm*******
ch52-116dBm*
ch53-118dBm*
ch54-118dBm*
ch55-118dBm*
ch56-117dBm*
ch57-115dBm*
ch58-116dBm*
ch59-115dBm*
ch60-119dBm*
ch61-119dBm*
ch62-119dBm*
ch63-115dBm*
ch64-115dBm*
ch65-119dBm*
ch66-118dBm*
ch67-119dBm*
ch68-119dBm*
ch69-118dBm*
ch70-116dBm*
ch71-113dBm*
ch72-114dBm*
ch73-106dBm******
ch74-116dBm*
ch75-114dBm*
ch76-112dBm*
ch77-116dBm*
ch78-117dBm*
ch79-116dBm*
ch80-117dBm*
ch81-117dBm*
ch82-116dBm*
ch83-111dBm*
ch84-115dBm*
ch85 -111dBm *
ch86-112dBm*
ch87-110dBm**
ch 88 -109dBm ***
ch 89 -114dBm *
ch 90 -115dBm *
ch 91 -115dBm *
ch 92 -114dBm *
ch 93 -116dBm *
ch 94 -117dBm *
ch 95 -118dBm *
ch 96 -115dBm *
ch 97 -118dBm *
ch 98 -115dBm *
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ch 113 -112dBm *
ch 114 -114dBm *
ch 115 -114dBm *
ch 116 -116dBm *
ch 117 -115dBm *
ch 118 -116dBm *
ch 119 -116dBm *
ch 120 -116dBm *
ch 121 -117dBm *
ch 122 -116dBm *
ch 123 -118dBm *
ch 124 -117dBm *
ch 125 -112dBm *
ch 126 -113dBm *
```

Figure 5 - Spectrum Analysis Example

2.2 Plot Interpretation

2.2.1 Asterisks (Stars) and Dots

Asterisks show average values taken from dwelling on the specific frequency over time. Dots are peak values seen over the same dwell interval. This provides a feel for both the power level of any in-band signal as well as the frequency at which it is occurring.

2.2.2 Interference

If there is a strong interference that only happens once in a while, the average value might be low, but the peak could be very high. It is also possible to have a weak interference that is continuous, which would raise the average value, but not give very high max values. Coherent interference would show up on a single channel all the time giving peak and average values very close to each other in amplitude.

2.2.3 Noise Floor

The number on the left of the plot is the average value for that specific channel. Since all the channels have different levels Microhard Systems picked -111dBm as a convenient reference point or baseline for the graphical data being displayed. Any reading at or below -111 dbm has a single asterisk (common baseline)

There is one asterisk for each dB the average value is above the baseline, and one dot for each dBm the maximum value is above the baseline. For example, an average RSSI of -110dBm will give two asterisks, -109dBm three, and so on. It's the same scale for both dots and asterisks. If the plot is turned on its side, a spectrum analyzer view is shown of the relative differences in average and peak values between each channel referenced to a baseline of -111dBm.

2.2.4 Faulty Communications

There are typically two faulty communications scenarios that are encountered in the field. The first one is a high power external interference source, and the second is a link problem such as a faulty antenna, connector, cable or transceiver.

In the external interference source scenario the signal strength indicator (RSSI) numbers are high and link numbers are low on the user interface display. If there are link problems and no local interference, the RSSI numbers and link numbers should be low.

2.2.5 Summary

In any of the cases outlined above, it is important to make a judgment call as to what the problem is. This is best done by looking at the spectrum plot(s) and checking the quality of the RSSI and link numbers in the user interface.

3 Flight Data Link Plot

Example of a latitude and longitude plot of a flight with the AckRatio color coded.

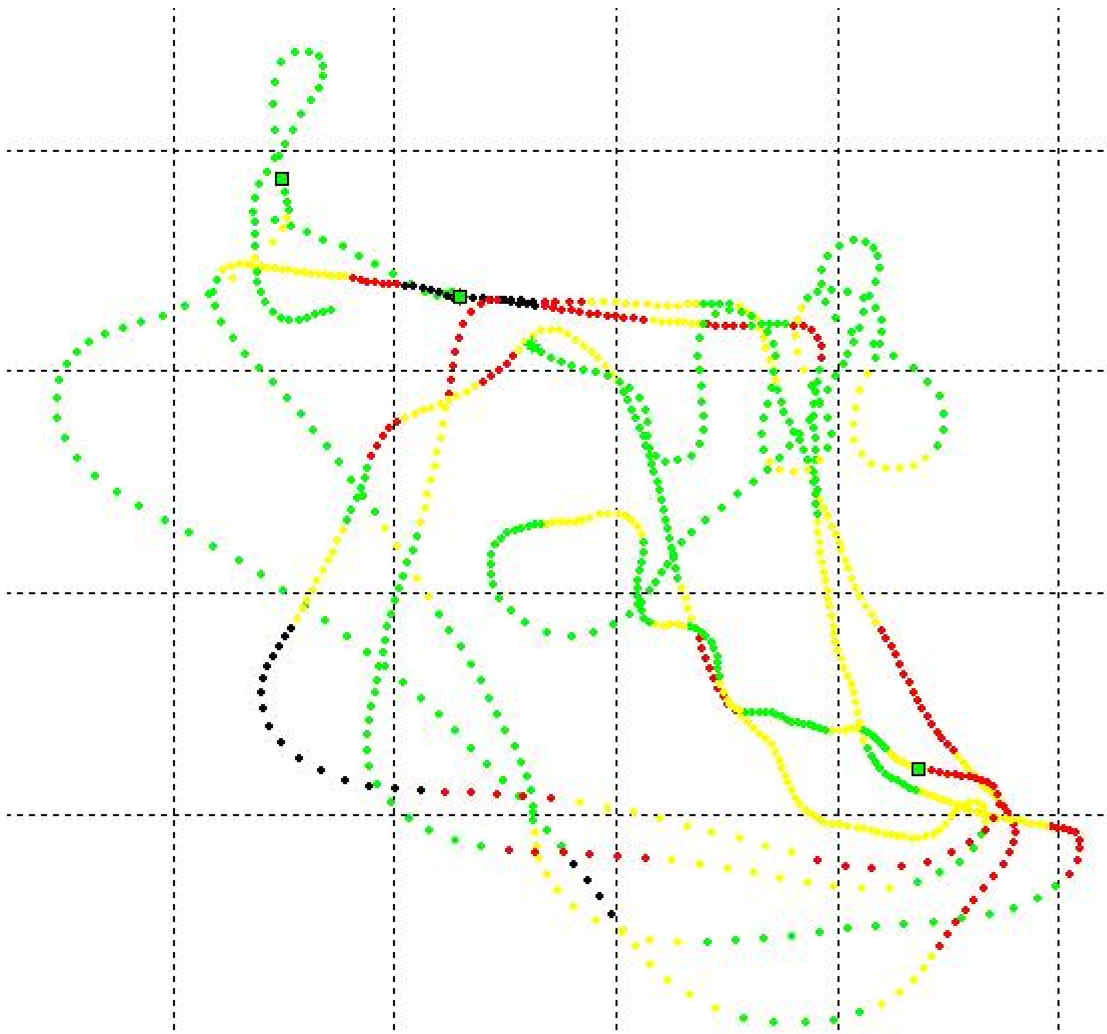

Figure 6 - Flight Data Link Plot Example

Color Code

Color	AckRatio (Link)
Green	>=90
Yellow	>=80
Red	>=55
Black	<55

In this example, the plot shows that communications were poor during some turns and when the aircraft was flying directly overhead.