Differential GPS Azimuth Reference for Microwave Portable Operations

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We describe the use of differential GPS using carrier phase information to provide azimuth bearings for Microwave Terrestrial and EME operations to better than 0.1 degree on a 5 metre baseline. The system uses a u-blox C94-M8P evaluation kit that is available for around $400 US. The u-blox kit is configured to provide relative positions in NED (North, East, Down) coordinates with cm-level accuracy. This position information is converted to an Azimuth bearing using an Arduino microcomputer and displayed for use as an accurate bearing reference. A rifle scope is mounted on the dish – it is aligned to the dish direction based on Sun noise. One GPS antenna is mounted directly above the rifle scope and the other is mounted remotely on a tripod. Once a bearing is determined the dish is rotated so the rifle-scope is aligned on the second GPS unit's antenna and then an azimuth ring on the dish calibrated to this bearing. Other directions can then be determined from the azimuth ring reading.

Requirement for Accurate Azimuth Bearing

The key to long distance or marginal terrestrial operation and EME with small portable stations is to remove as many variables as possible, in particular frequency and pointing. If one is waiting for a tropo-duct to open or for tropo-scatter to peak, or when using aircraft scatter which may last for only a few seconds or beaming at the moon which is not visible it is impractical to make adjustments to compensate for variables. Frequency is readily resolved by using GPS locked systems combined with Doppler correction for EME. Elevation pointing is also readily resolved with an accurate inclinometer. Azimuth can be resolved by using references such as the Moon or Sun or some identifiable feature on Google Earth such as a farm house or radio tower if available. Moderate to larger EME stations can use Moon noise but this is not effective when the Moon is close to the horizon and moon noise is swamped be ground noise. Even at high elevations Moon noise is not useful on dishes of below about 1 meter as while it can be detected it is so small that you need to be able to point accurately before you can find it. In many cases it is not possible to use the Moon or the Sun due them being below the horizon or in cloud or to find an identifiable feature as an azimuth reference. While some claim that corrected magnetic bearings can be used the errors due to metal from cars and equipment and magnetic anomalies rule such methods out for accurate bearings. This differential GPS system has been developed to provide an almost universal method of providing accurate azimuth alignment for portable operations and remove one of the significant variables. We say "almost" because while this differential GPS system is useful in almost all situations, it does require a reasonably clear view of the sky down to 20 degrees elevation and thus it does have limitations when working in a situation such as a forest where the antennas do not have a clear view of the sky.

Required Accuracy

Antenna beam-widths are typically quoted for the 3 dB beam width. For marginal situations one would prefer to be down by no more than 1 dB. Estimated 1 dB beam-widths are set out in Fig 1 below and suggest we should aim for an alignment accuracy of better than 0.2 degrees for a 120 cm dish at 24 GHz.

Dish Size	10 GHz	24 GHz
60 cm	+/- 1.0 degrees	+/- 0.4 degrees
120 cm	+/- 0.5 degrees	+/- 0.2 degrees

Fig 1: Estimated 1 dB beam-widths

System Overview

The core of the system consists of a u-blox C94-M8P evaluation kit. The kit comprises two boards, each with a NEO-M8P-2 GPS module plus an integrated UHF link allowing the units to communicate with each other.

The NEO-M8P-2 is a high precision positioning GPS module. Traditional GPS receivers use the timing of the received signal to determine the distance to a satellite. This gives a result with typically 5 m accuracy. The NEO-M8P-2 also measures the phase of the received signal and uses this to calculate a more accurate position. The GPS signal has a wavelength of about 20 cm so there is an ambiguity regarding the exact number of wavelengths to the satellite. The 5 m uncertainty translates to 25 wavelengths. The module requires good visibility of a minimum of 6 GPS satellites to resolve this ambiguity.

With the evaluation kit, one board, referred to as the Base, is configured to firstly establish its own location accurately. It then, once per second, calculates position from the current GPS signals and sends the difference between its latest calculation and the accurately determined location to the other board over the UHF link. These are referred to as Differential Corrections.

The second board, referred to as the Rover, is configured to find its own GPS location every second and apply the Differential Corrections to the result to increase the accuracy. It then calculates the distance between two units (actually, the distance between the two GPS antennas).

Note that the location of the two boards is the reverse to what might be expected to simplify the communication of the Relative Position data from the Rover board to the Arduino system. The Rover antenna is mounted at the dish while the Base antenna is located remotely on another tripod.

The other component of the system is the Display unit. This uses an Arduino Uno with a Touch sensitive 320 x 200 pixel colour LCD shield. The Arduino is connected to the Rover board via an RS-232 receive-only connection.

Block Diagram

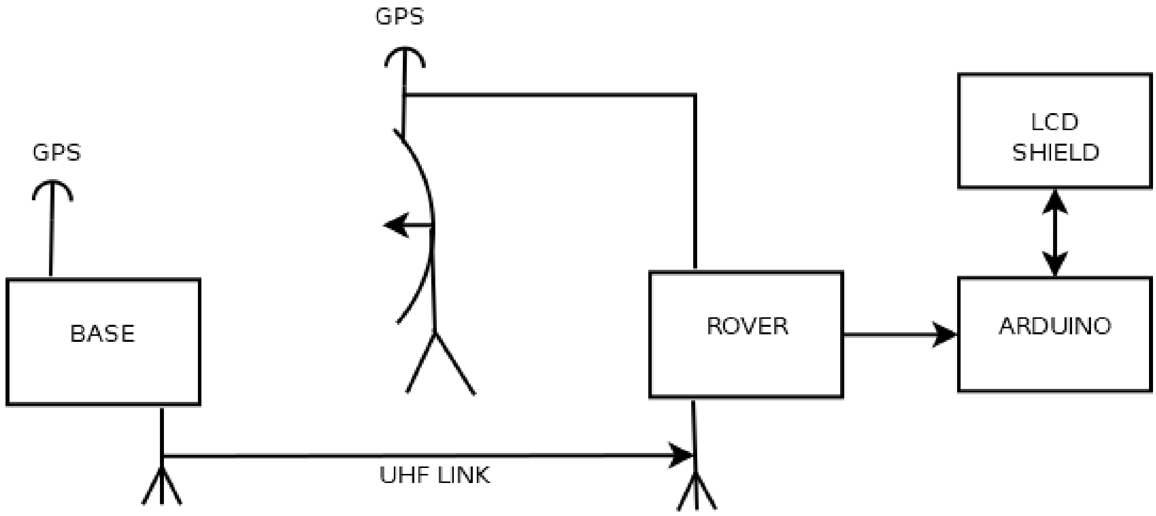

Fig 2: Block diagram of the system showing major components and flow of information.

Display

The display has two modes and one can change between them by tapping the display. The default display mode gives Azimuth, Baseline and Status as show in Figure 3.

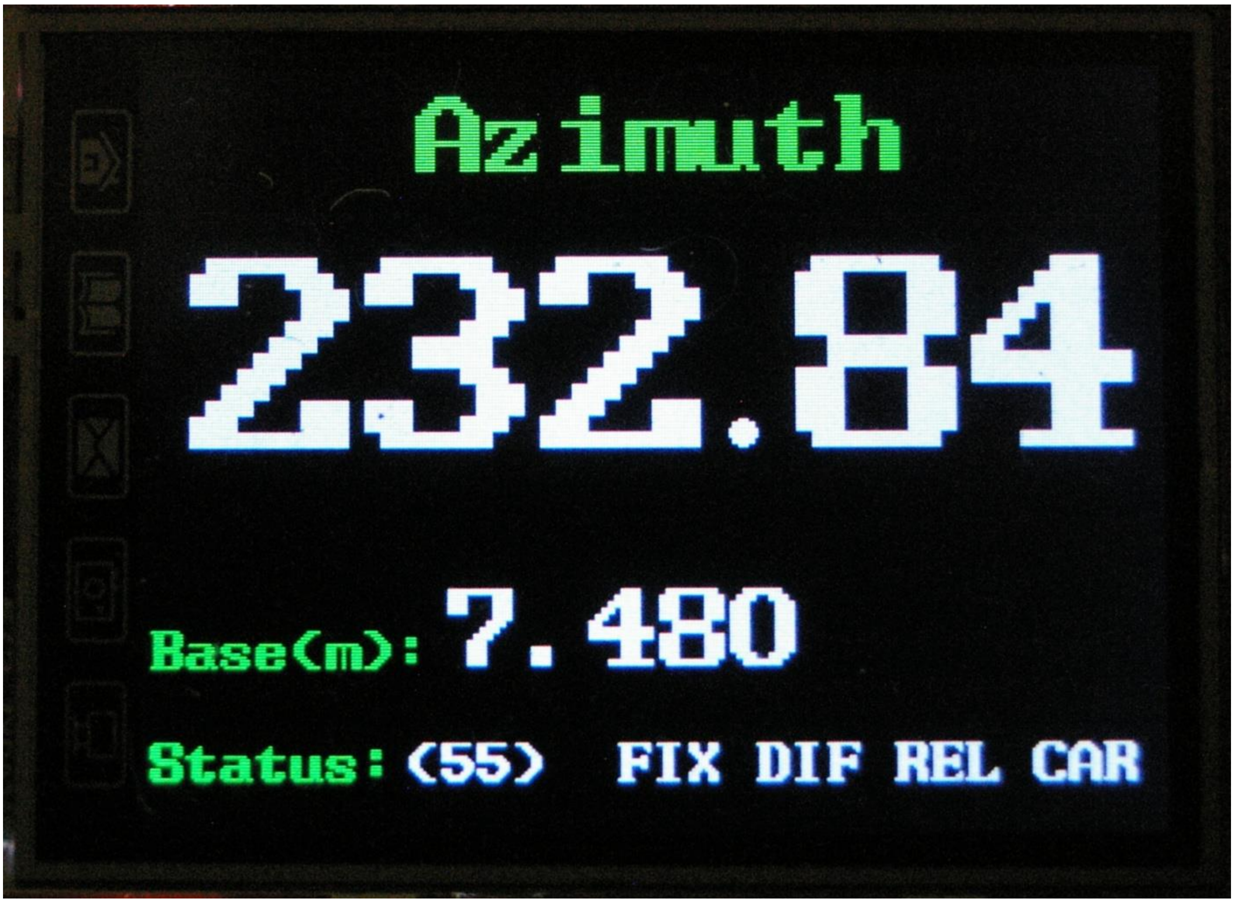

Fig 3: This display mode shows the Azimuth (232.84 Degrees in this case), The length of the base between the two antennas (in this case 7.480 meters) and the Status (in this case 55) in brackets which indicates the bearing derives from a Carrier Phase measurement which gives the accuracy we require.

Also indicated are Status flags:

FIX: the display unit has gained a valid fix

DIF: that the display unit is receiving and using valid differential corrections from the remote unit

REL: that the relative position measurements between antennas are valid

CAR: that the bearing is based on a the relative positions determined from Carrier Phase measurements

The colour of the Status indicators changes to white when they are true.

The alternate display, shown in Figure 4, provides a graph of the Azimuth over the last 20 minutes of operation. The display auto-ranges on the vertical scale to best fit the range of the Azimuth. An average is also displayed, enabling an estimation of precise azimuth to be made.

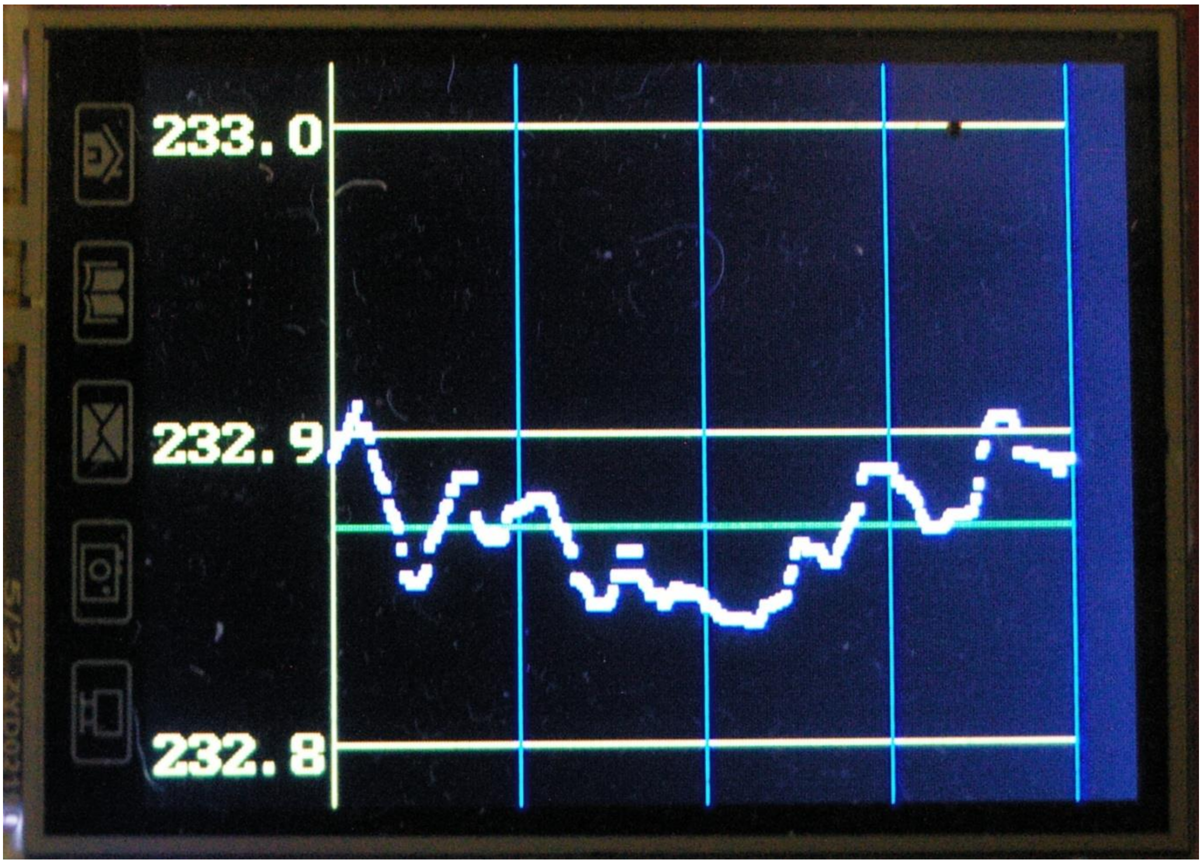

Fig 4: This is a graphical display of the indicated bearing over last 20 minutes. The green line shows the average reading which in this case is around 232.87 degrees with a variation shown by the white graph to be well within +/- 0.1 degrees.

u-blox Evaluation kit

Several variants of the kits are available to meet the frequency requirements of various countries for license-free UHF operation on either 433MHz or 915 MHz.

More information can be found at: https://www.u-blox.com/en/product/c94-m8p

Fig 5: u-blox Evaluation Board - two identical boards come with Evaluation kit as well as cables and both GPS and UHF antennas. GPS unit under blue cover and VHF link under metal cover.

Set-up

Before the evaluation kit can be used, the boards must be configured using the program u-center which is available for download from the u-blox site. The hardware on the two boards is identical but they must be configured differently.

The first step in configuring the boards is to ensure they are running the latest firmware. Refer to the C94-M8P Application Board - Setup Guide document on the u-blox site for more details.

Next, the boards must be configured for Moving Baseline operating mode, and the messages to be sent over the communication link must be selected. Refer to the C94-M8P Application Board - User Guide document on the u-blox site for more details. Follow the steps given in section 4.3 with the following additions for the Rover unit only:

- in section 4.3.4, change Protocol Out to UBX.

- enable transmission of the UBX-NAV-RELPOSNED message as follows:

- in u-center, Message View, select UBX then CFG then MSG
- in the Message drop down list, find "01-3C NAV-RELPOSNED"
- if not already ticked, click the On box next to UART1 to show a tick
- change the 1 that appears in the box next to the tick to 5

Final thing is to save the configuration. Go to UBX CFG CFG and click Save current configuration.

The Rover antenna is mounted at the dish as shown in Figure 6. The Base antenna is located remotely on another tripod, as shown in Figure 7.

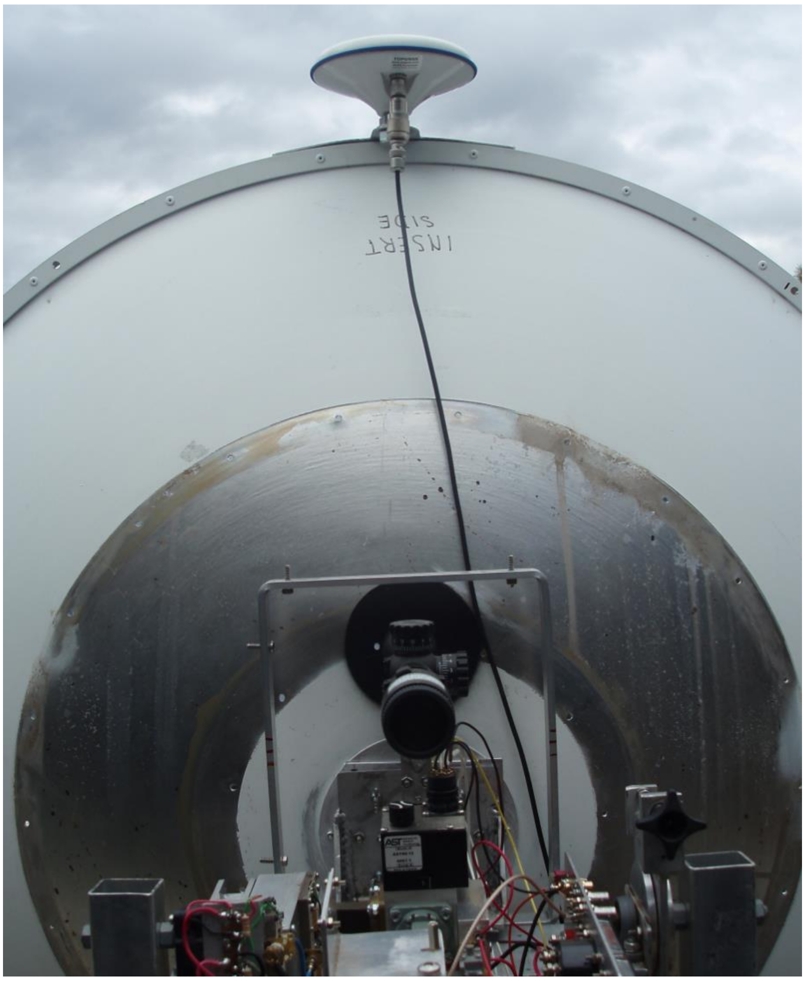

Fig 6: Rover antenna mounted on dish directly above rifle scope

Fig 7: Base antenna with u-blox evaluation board in weather proof box and separate battery

Antennas

The u-blox kit comes with two consumer grade antennas with ground planes as shown in figure 8. U-blox recommend using a better quality antenna in difficult conditions to get faster lock. While the Survey Grade antenna shown in figure 8 does give slightly improved performance, the consumer grade antennas are more than adequate.

Fig 8: The u-blox kit comes with two consumer grade antennas and a ground plane as shown on the left. On the right is a survey grade antenna which we have used for our testing.

Programming of System

The software is written in C. It runs on an Arduino Uno board.

The display is a 320 x 200 pixel colour touchscreen TFT LCD shield. Unfortunately, the display used by the authors is now obsolete. Similar displays may be found online at sites like Adafruit. Some minor changes to the software may be needed to accommodate a different display.

The software source code may be obtained by contacting David Smith VK3HZ.

Results

The graph in Figure 9 shows the results over a 5 meter baseline with a clear view of the sky above 20 degrees elevation. The graph is based on a running median value from 13 readings to reduce the impact of outliers. The peak variation is less than +/- 0.1 degrees and the Standard Deviation is only 2 hundredths of a degree. It is difficult to provide an independent check of the absolute accuracy to the level that is available by this method - but as close as we can tell using Google Earth and a 15 km baseline it is within +/- 0.1 degrees.

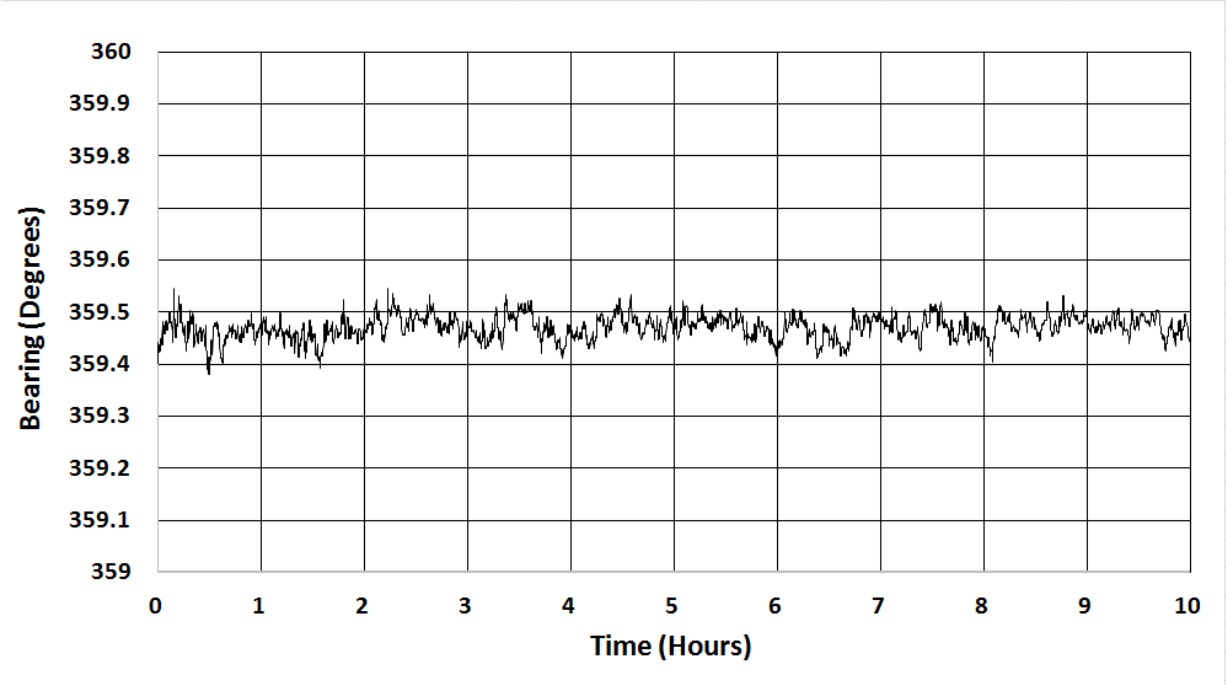

Fig 9: Results with Survey Grade antennas over a 5 metre baseline with a clear view of the sky.

In a situation where the sky is clear down to 20 degrees elevation the unit typically takes no more than a few minutes from a cold start to give an accurate bearing. The system does take somewhat longer to resolve the Carrier Phase ambiguities as the baseline is increased but works well with baselines from 5 to 15 metres. The accuracy of the bearing increases with longer baselines. We have not done sufficient testing to recommend the use of baselines beyond 15 metres, but we have no reason to believe it should not work at longer distances given time to resolve Carrier Phase ambiguities.

Impact of an obstructed sky

In situations where the sky is obstructed above about 20 degrees the system may suffer degraded performance. This occurs in two ways.

- Firstly it takes longer to gain lock and provide a bearing. For example in a situation with a clear view overhead down to around +/- 70 degrees elevation the unit did not provide a bearing at all. Under somewhat less obstruction the system may take up to 30 minutes to achieve a bearing. These impacts do vary depending on the position of the Satellites.
- Secondly, the accuracy of the bearing reduces even when it does indicate a bearing. This occurs in part because the unit tends to drop back to the 47 status message and give a bearing based on the relative position data from both units rather than the more accurate Carrier Phase as indicated by a 55 status message. Even when the unit is giving a 55 status message its accuracy can be reduced by obstruction by a factor of possibly two.

If you find yourself in a situation where you cannot gain a clear view of the sky but still have an indicated bearing we suggest you look for bearings with a 55 status message and also watch the graphical display to gain an indication of the variability.

Conclusions

Providing one has a relatively clear view of the sky this system can provide azimuth bearing references that are more than adequate for portable EME and Terrestrial microwave operations.