Signal Plotter

A tool for evaluating APT Antenna Performance

Patrik Tast and Jerry Martes

(Signal Plotter has been a team effort created to evaluate data from the double cross antenna)

It's well over two years since my *APT Decoder* software for capturing weather satellite images was reviewed in GEO Quarterly [1]. In the intervening time, a number of new features have been added, including the *Signal Plotter* which analyses the signal level throughout a satellite pass and creates a graphic illustration of the radiation pattern for the antenna being used. The only restriction on using *Signal Plotter* is that you must utilise either the popular R2FX/ZX [2] or ICOM PCR1000 receiver.

The *Signal Plotter* should be useful to those readers who design and build their own APT antennas. It can be found under the '*Tools*' option of *APTDecoder's* menu. The *Signal Plotter* tool will produce a polar plot of the actual radiation pattern of your APT antenna (figure 1).

The reason for my developing this tool was to produce reliable data to guide my efforts in developing an antenna for use with APT reception. The program plots the actual signal level entering the APT receiver as the satellite passes over. The plots produced by *Signal Plotter* allows me to make direct comparisons between the performances of the various antennas that I build.

Signal Plotter is available, without any cost at all, to anyone who is using *APTDecoder*, which is, as you know, a no-fee APT decoding program [3]. *Signal Plotter* will automatically produce a plot of the antenna radiation pattern when using a *R2FX/ZX* or *ICOM PCR1000 receiver*.

Recording Signal Plots with APTDecoder

To record signal plots you must first enable radio control under **<Settings → General settings → Radio control>**, where you select *Enable auto tuning* and your receiver type (R2FX or ICOM PCR1000). Next, open **<Tools → Radio control>** from the menu bar; you will see a yellow horn icon if you are using the R2FX/ZX and a REC button if you are using the ICOM-PCR1000 receiver. To start recording, click on the icon. The signal file is a text file containing the station information, satellite name, Keplerian elements used and the RSSI (Received Signal Strength Indication) values. The file extension is .rxt and it is saved into *APTDecoder's* date-stamped *audio* folder.

> The *Radio Control* window must be open while recording a signal plot. It will record signals only if the satellite is above the station horizon. The icon colour will change to red when it is in recording mode. To stop recording, click the icon again.

To record signals automatically from horizon to horizon you should press the icon when the satellite is approaching you, but still below your horizon. The program will now enter standby mode until the satellite is above your horizon, when it will automatically start recording. It will stop recording automatically when the satellite recedes below your horizon.

Figures 2 and 3 show the radio control windows while recording with the R2FX/ZX and ICOM PCR1000 receivers.

To view the resulting plot, open **<Tools → Signal plotter>**. Click **<File → Open signal file>** in the *Signal Plotter* window and browse to the recorded .rxt file in the date-stamped audio folder tree. You can adjust the scale of the plot from the **<Settings>** option in the *Signal Plotter* window (figure 4).

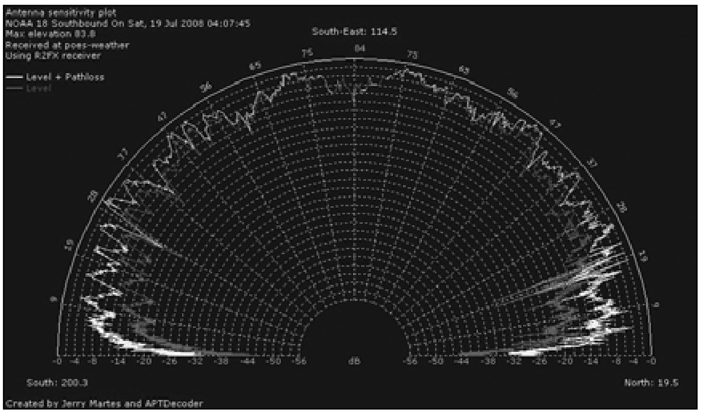


Figure 1 - A typical NOAA-18 Signal Plot

To view the recorded data in detail click **<View → Show data>**. You can also export the CSV data file into Excel for further analysing.

Recording signals using the DATAQ acquisition instrument is under construction and will be supported later this year (2008).

Pass Analyser

Another tool in *APTDecoder* that can be used to analyse your antenna is the *Pass Analyser*. This tool will show you at what azimuth and elevation the signal was weak enough to cause a fade in your APT image. The output is based on how many audio samples were required to show a single line of APT image. The satellite path is rendered in yellow and possible noise in blue, perpendicular to the satellite path.

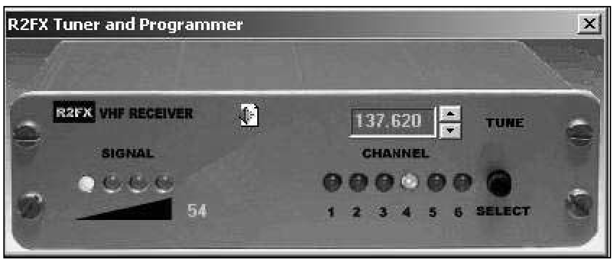


Figure 2 - The R2FX radio control window

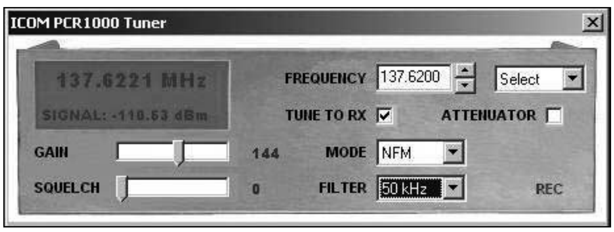


Figure 3 - The ICOM PCR1000 radio control window

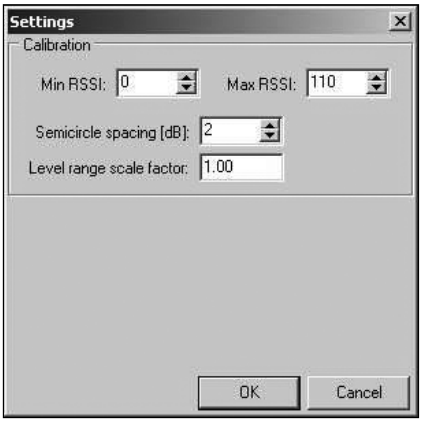
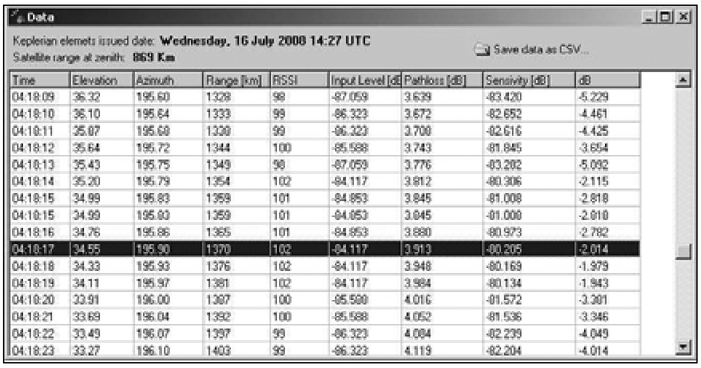


Figure 4

The Settings window



Time	Elevation	Azimuth	Range [km]	RSSI	Input Level [dB]	Pathloss [dB]	Sensivity [dB]	dB
04:18:09	36.32	195.60	1328	98	-87.059	3.639	-83.420	-5.229
04:18:10	36.10	195.64	1333	99	-86.323	3.672	-82.652	-4.461
04:18:11	35.87	195.68	1338	99	-86.323	3.708	-82.616	-4.425
04:18:12	35.64	195.72	1344	100	-85.588	3.743	-81.845	-3.654
04:18:13	35.43	195.75	1349	98	-87.059	3.776	-83.282	-5.092
04:18:14	35.20	195.79	1354	102	-84.117	3.812	-80.306	-2.115
04:18:15	34.99	195.83	1359	101	-84.853	3.845	-81.008	-2.818
04:18:15	34.99	195.83	1359	101	-84.853	3.845	-81.008	-2.818
04:18:16	34.76	195.86	1365	101	-84.853	3.880	-80.973	-2.782
04:18:17	34.55	195.90	1370	102	-84.117	3.913	-80.205	-2.014
04:18:18	34.33	195.93	1376	102	-84.117	3.948	-80.169	-1.979
04:18:19	34.11	195.97	1381	102	-84.117	3.984	-80.134	-1.943
04:18:20	33.91	196.00	1387	100	-85.588	4.016	-81.572	-3.381
04:18:21	33.69	196.04	1392	100	-85.588	4.052	-81.536	-3.346
04:18:22	33.49	196.07	1397	99	-86.323	4.084	-82.239	-4.049
04:18:23	33.27	196.10	1403	99	-86.323	4.119	-82.204	-4.014

Figure 5 - Output from *Pass Analyser*

To view the audio based analyse plot, first decode an audio (WAV) file then click on **<Images → Spacecraft → Pass analyser>** (figure 5). You will get more options if you right-click the mouse on the image. To save the plot select *'Copy to clipboard'* then paste it in your favourite image editor.

The audio analyser plot in figure 6 shows that between azimuth 200° - 205° and less than 2.6° elevation, and azimuth 335° - 340° at less than 2.5° elevation, the recorded signals were weak enough to show noise on the image.

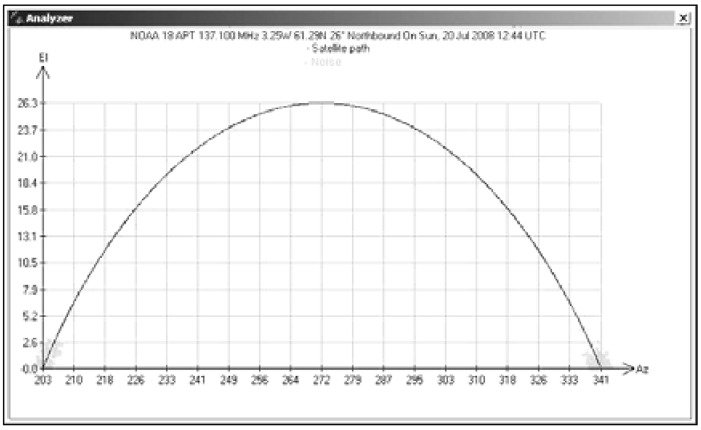


Figure 6 - The Pass Analyser

References

1 APTDecoder - GEOQ 8, page 15
2 R2FX APT Receiver - GEOQ 7, page 19
3 APTDecoder Download - http://www.poes-weather.com/

Development of the Double Cross APT Antenna

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After evaluating several APT antenna designs, it became clear to me that the commonly used APT antenna design concepts perform well enough to produce good images whenever the satellite is above about 10° elevation. For many purposes, a clean image from a satellite down to 10° above the horizon is adequate. But, if the objective is to display a complete satellite image for its entire time at and above zero degrees elevation, some care needs to be taken to build a good APT antenna.

I had been having considerable difficulty constructing such an APT antenna till Jerry Martes introduced me to the *Double Cross Antenna* (DCA) design concept. After building my first DCA, it became clear to me that that this design was more tolerant of my crudeness in antenna design and construction.

The DCA may be of interest to GEO readers who have an interest in homebrew APT antennas. Here are some of the design considerations I used.

The quality of an APT image is dependent on there being no loss of adequate signal from the satellite for the entire time it is above the horizon. Also, the satellite signal is about 12 dB weaker when the satellite is at its lowest elevation than when it is overhead. That low-level signal associated with lower elevations places the greatest need for antenna sensitivity on these low elevations.

For antennas located where there are obstacles that shadow the view to the horizon there is less value in sophisticated APT antennas since the satellite signal is obstructed by buildings, trees and mountains.

When it can be assumed that the satellite is 'illuminating' the Earth with an antenna that radiates equal signal strength at all angles in the directions toward the Earth, the ideal APT antenna radiation pattern would be as shown below.

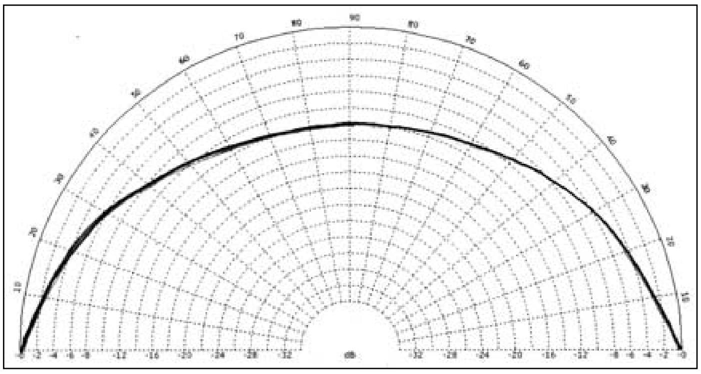

Figure 1 - Radiation pattern for an ideal APT antenna.
The satellite is 4 times closet to the APT receiving antenna when it is overhead than when it is on the horizon. This results in a path loss of close to 12 dB for low elevation satellites as compared with satellites overhead.

It is clear that the satellite signal is about 12 dB weaker when it is at the horizon than when overhead, because the signal travels so much farther when it is at low elevation angles.

If the ground based APT antenna had a pattern as shown in figure 1, the receiver would experience the same signal strength for all elevation angles. As the satellite comes closer while rising, the signal increases, while the APT antenna antenna sensitivity diminishes.

The DCA design concept was developed in an effort to provide a maximum sensitivity to satellite signals from low elevations. An additional benefit of the DCA is its being quite tolerant of being built from nearly any size and shape of materials. It consists of four dipoles, each about 1 metre long as shown in figure 10. The opposing dipoles are spaced about ½ metre apart and tilted about 30° from vertical. These four dipoles in the DCA are fed with a four-way harness so that two dipoles radiate ¼ wave later than the other two.

Development of the DCA for APT

When two dipoles mounted as shown in figure 2 are fed through equal length lines—so that they radiate in phase—spaced ¼ wavelength apart, they produce a free space pattern as shown in figure 3.

This *Cross* array is very sensitive to a circularly polarised (CP) signal perpendicular to the two dipoles (i.e. along the direction of their support arm). The sensitivity degrades to linear when a satellite is overhead but remains quite good since linear sensitivity is only 3 dB less than circular sensitivity.

Such a single *Cross* is a well known, fundamental method of phasing twin dipoles to produce circular polarisation. A problem with the *Cross* configuration, however, results from its high degree of sensitivity to signals reflected from the ground, since ground reflections can seriously degrade the sensitivity to satellite signals. The *Cross* has a total null toward its sides and reflections from the ground at low satellite elevations can null the signal and produce a sharp line on an APT image. Such nulls tend to be decidedly location specific.

The only contribution we have made for the APT community is to show that ***two*** Crosses can be nested together so that one pair fills in the nulls of the other: therefore the term '*Double Cross Antenna*'. With a second pair of crossed dipoles located within the first pair, as shown in figure 5, and fed 90° later than the first pair, the radiation pattern for APT reception is greatly improved (figure 5). This relatively uncomplicated set of two pairs of crossed dipoles can be used for APT with good results since it has good sensitivity to signals from satellites at or near the horizon.

It is expected that the basic DCA concept will be easily understood based on the above explanation. Once the basics are understood, you can refine the design for use with APT reception.

Signal Polarisation

The NOAA satellites are transmitting RHCP (Right-Hand Circularly Polarised) signals. It is therefore necessary that the two dipoles must be connected together so their radiation pattern produces Right Hand Circular Polarisation. This means that, when the electric field of the 'north' dipole is pointing upward, the electric field in of the 'south' dipole points downward. Although the 'east' and 'west' dipoles are fed 90° later than the north-south pair, the east-west dipoles must also be connected to one another so the 'west' dipole's electric field points up when the 'east' dipole points down. This is shown in figure 6.

When the dipoles are tilted slightly toward vertical, their terminal impedance becomes very close to 50 ohms. So, for APT, the dipoles are tilted at 30° from vertical. When the terminal impedance of each of the four dipoles in the DCA is close to 50 ohms, a relatively simple connecting harness can be made using 50 ohm coaxial cable, and connected as shown in figure 7.

The *north* dipole is fed in series with the *south* one through equal lengths of 50 ohm coax to provide a 100 ohm load. The *east* and *west* dipoles, fed in phase with each other, produce 100 ohms also. These two 100 ohm loads, when connected in parallel, give a good impedance match with the 50 ohm line to the receiver. The additional 36 cm line length to the *east* and *west* dipoles causes them to radiate ¼ wave later than the north/south pair. The theory is shown in the side panel on page 9. Additional information on the concepts associated with understanding the DCA concept can be found at

http://www.poes-weather.com

Construction of the DCA

If the reader is interested in building a DCA APT antenna and has access to 8 copper or aluminum tubes of approximately 6 mm diameter and each about half a metre in length, a good APT antenna can be constructed by mounting the tubes as shown in

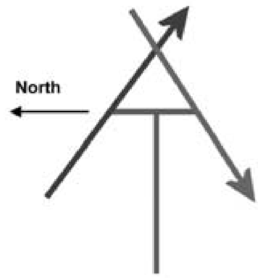

Figure 2
Dipoles, crossed at 90°, a quarter wavelength apart, and fed in phase

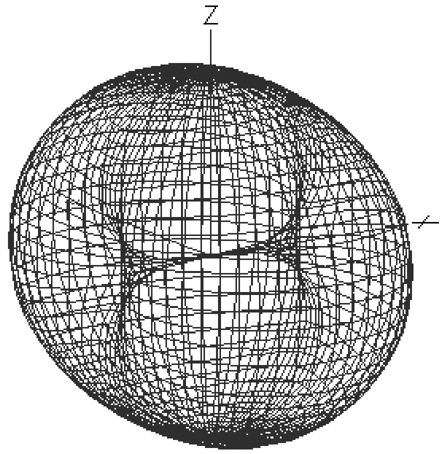

Figure 3
RHCP radiation pattern of two crossed dipoles shown in figure 3

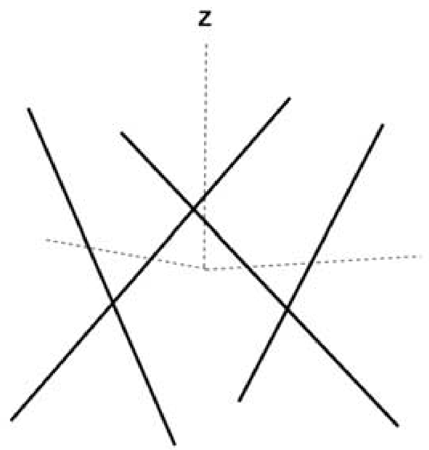

Figure 4
Two pairs of Crossed Dipoles mounted together

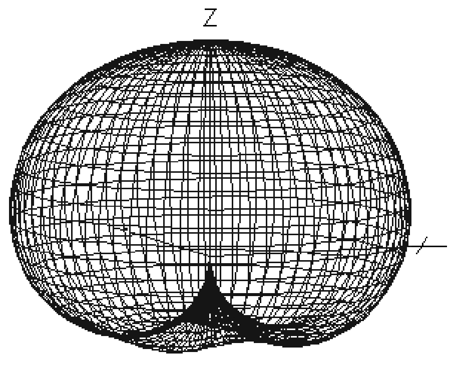

Figure 5
Free space RHCP radiation pattern of the array of four dipoles shown in figure 5

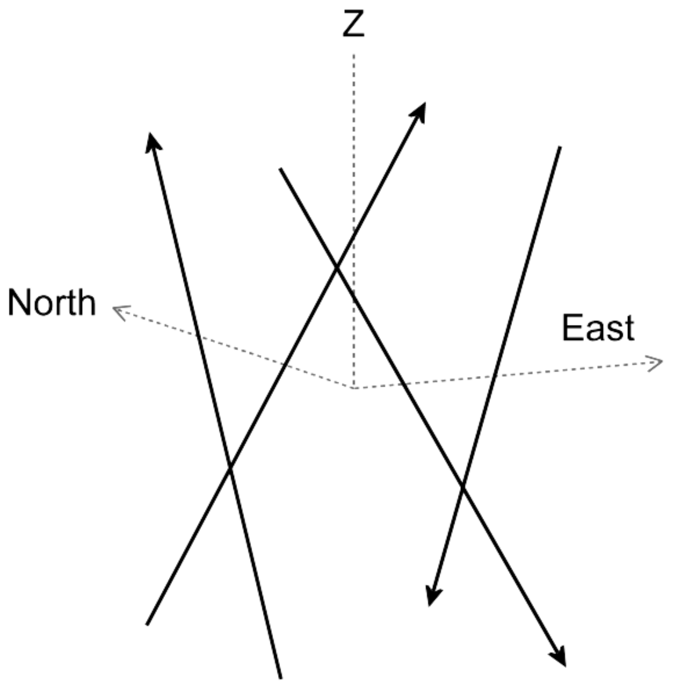

Figure 6
Dipoles with arrows to indicate their connection
to provide appropriate polarity

Phasing the DCA Dipoles

Radio waves travel at the speed of light, 3×10^8 m/s. In order to create the desired circular polarisation, the *east* and *west* dipoles must react 90° later than the *north* and *south* dipoles; this means delaying the signal from the satellite by one quarter of a wavelength.

To establish the extra length of coax needed, we make use of the frequency (137.5 MHz) and the velocity factor of the coax (which is 0.66 for RG58U). One quarter wavelength (which equates to a 90° phase change) for RG58 coax at 137.5 MHz is given by

$$\Delta L = \frac{\text{speed of light} \times 0.66}{4 \times 137.5\ \text{MHz}}\ \text{m}$$

$$= \frac{3 \times 10^8 \times 0.66}{4 \times 137.5 \times 10^6}\ \text{m}$$

$$= \underline{0.36\ \text{m}}$$

The coax for the *east* and *west* dipoles are thus each 36 cm longer than the coax for the *north* and *south* dipoles. If the N/S coax is 1 m long, then the E/W coax must be 1.36 m in length.

Note: The centre conductor of each length of co-ax connects to the *upper element* of each dipole

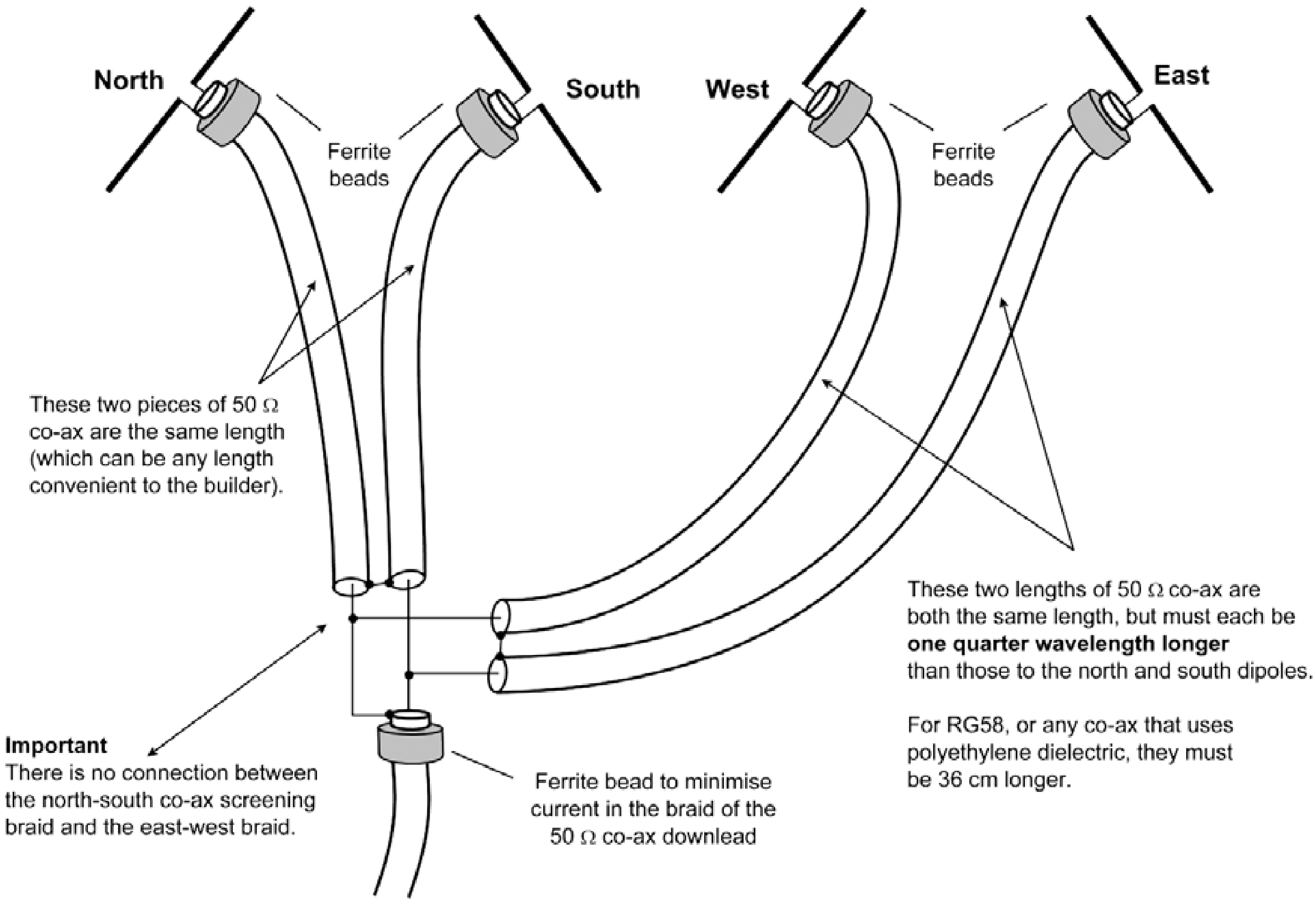

Figure 7 - The DCA harness made from RG 58, 50 ohm coax and ferrite rings.

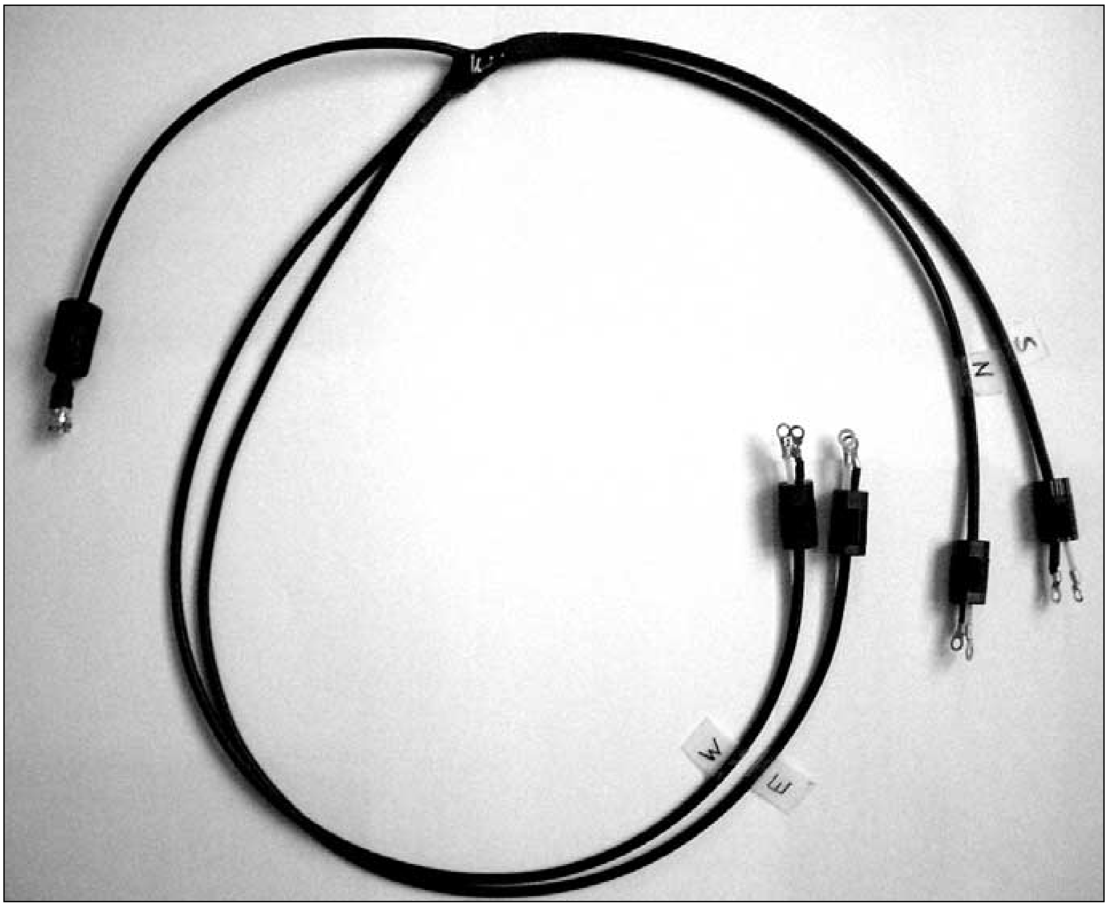

Figure 8 - Photograph of the completed harness, with each length of coax labelled

figure 6. A construction diagram for the harness which connects the four half wave dipoles with the downlead coax to the receiver is shown in figure 7. A photograph of the completed harness appears above in figure 8.

The ferrite beads can be of any ferrite material developed for reducing high frequency RFI. The beads used on computer cables will work OK. Any ferrite bead with relatively high permeability will probably work. The objective of the ferrite beads is to produce a high impedance to currents conducted from the inside of the coax to its the outer shielding braid. Any current conducted along the outside of the coax shield will interfere with the desired radiation pattern of the dipole.

Figure 9
Detailed view of one of the ferrite beads

It is important to pay close attention to the connection of the harness to the dipoles. Notice that *either* of the short lengths of coax can be connected to *either* of the longer lengths (opposite dipoles). The other short coax is connected to that opposite dipole. It is perhaps worth labelling the *north* and *south* two dipoles so that they can be easily identified.

After the coax has been connected to the *north* and *south* dipoles, adjust the dipoles so the upper half of each is connected to the centre conductor of the coax. Then connect the *west* dipole to the long length of coax that has DC continuity to the upper half of the *north* dipole. The remaining coax in the harness is connected to the *east* dipole.

As a double check, be sure that the rear dipole of each pair is tilted to the right (as viewed along the length of the supporting strut) as shown in figure 11. Additionally, check that the upper half of each dipole connects to the centre conductor of its coax.

We have recorded many weather satellite images and signal plots, using designs of the DCA constructed from various shapes and sizes of materials. All have produced excellent images even though their dimensions are not precisely the same as each other. Perhaps there is yet another design configuration of the DCA that can be considered 'ideal'. But to date, the performance of the basic configuration has been good, and additional refinement of the design may not be needed. We will be delighted to receive comments from readers who undertake the construction of a *Double Cross Antenna*.

Mounting the DCA

The final mounting of the DCA dipoles is left to the ingenuity of each individual constructor. Jerry has used a wooden framework to support his metal dipole pairs while figures 10 and 11 illustrate two designs based on plastic tubing and connectors.

Jerry has produced a PDF document detailing many of the stages in the construction of his double cross antennas.

http://shop.poes-weather.com/pub/137-DCA-Kit.pdf

Fred Piering has produced an even more detailed assembly manual which also includes a parts list.

http://www.poes-weather.com/media/DCA-Assembly-Hints.pdf

A DCA Constructor's Comment

From Mike in North Carolina: '*I had tried many times to build a QFH, with no luck. I just could not get it to work properly. The DCA worked the first time, with great pictures. Easy and cheap to build.*'

Imaging

The false colour NOAA-18 image (figure 8) was recorded by Jerry on January 9, 2008 at Los Alamitos, CA. The minute markers included on the image show that 15 minutes of imaging were possible. Bearing in mind the fact that Jerry

Figure 10
This Double Cross Antenna constructed by Tom Baldwin (W6MDX)

This antenna consists of four ½-wave dipoles
with ¼-wave spacing between opposing dipoles

Figure11 - The Double Cross Antenna

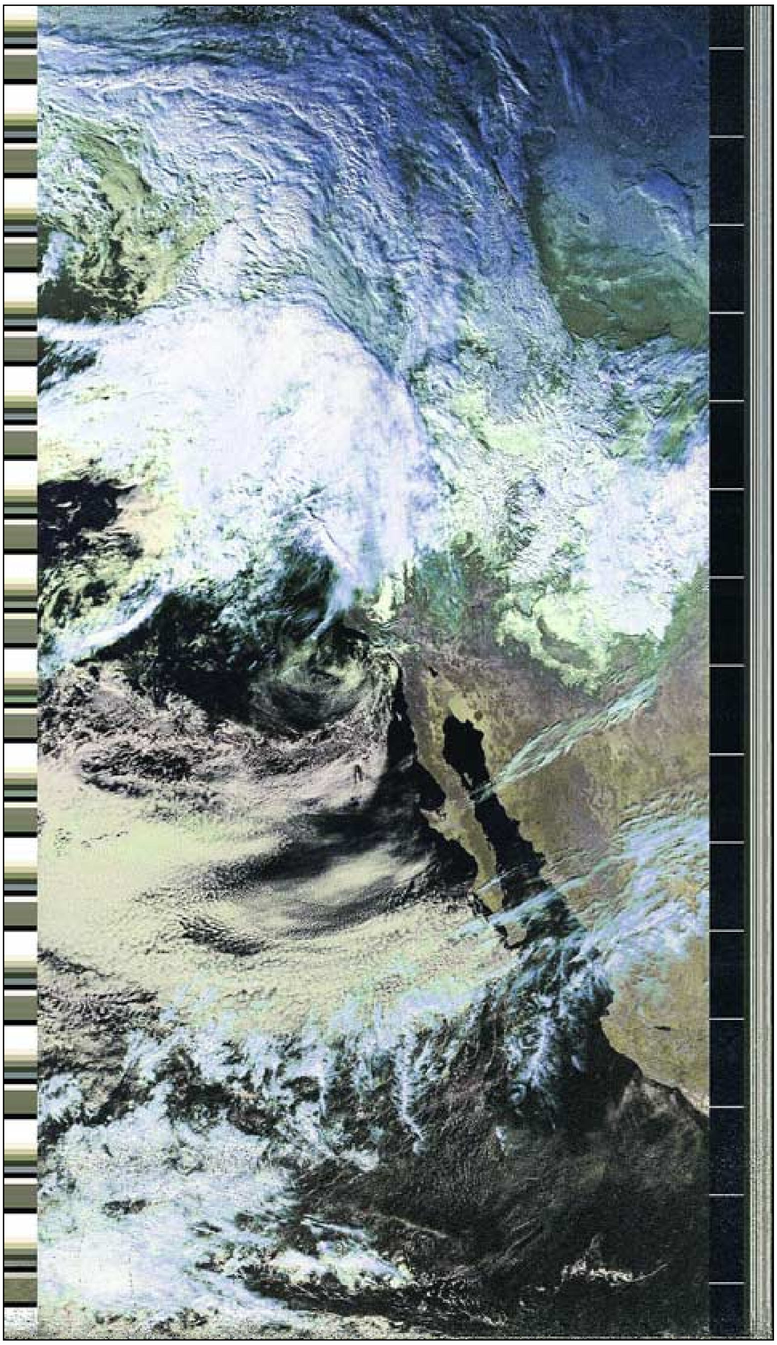

Figure 12
A 15-minute NOAA18 pass received by Jerry Martes
using his DCA antenna at 21:08 UT on January 9, 2008

Figure 13

Jerry Martes' location, showing the power lines directly behind his property

has overhead power lines just 10 metres from his location, this image is testimony to the effectiveness of the Double Cross Antenna.

Patrik took another DCA, constructed from plastic and aluminum tubing, to a remote site in Vasa, Finland, where there are clear horizons and therefore minimal shadowing of satellite signals. The NOAA-18 opposite, with a maximum elevation of just 51°, was received on July 6, 2008, using the DCA, R2FX and laptop computer. Excellent imagery is displayed, stretching all the way from the far northwest of Greenland to Turkey.

Figure14
APT imaging from a remote location at Vasa, Finland. The DoubleCross Antenna is mounted prominently on the roof of the vehicle at left.

Figure15
Patrik's R2FX and laptop APT station in the rear of the vehicle:

The colour image of Greenland and the Arctic on our front cover comes from the 09:42 UT NOAA-15 pass acquired earlier the same day, which had a maximum elevation of just 11° from Vasa.

There are many other images available to the readers, which can be found in the *Portable APT Blog* section at

http://www.poes-weather.com

These images and their associated *Signal Plotter* patterns indicate that the DCA is a good antenna design concept for APT reception.

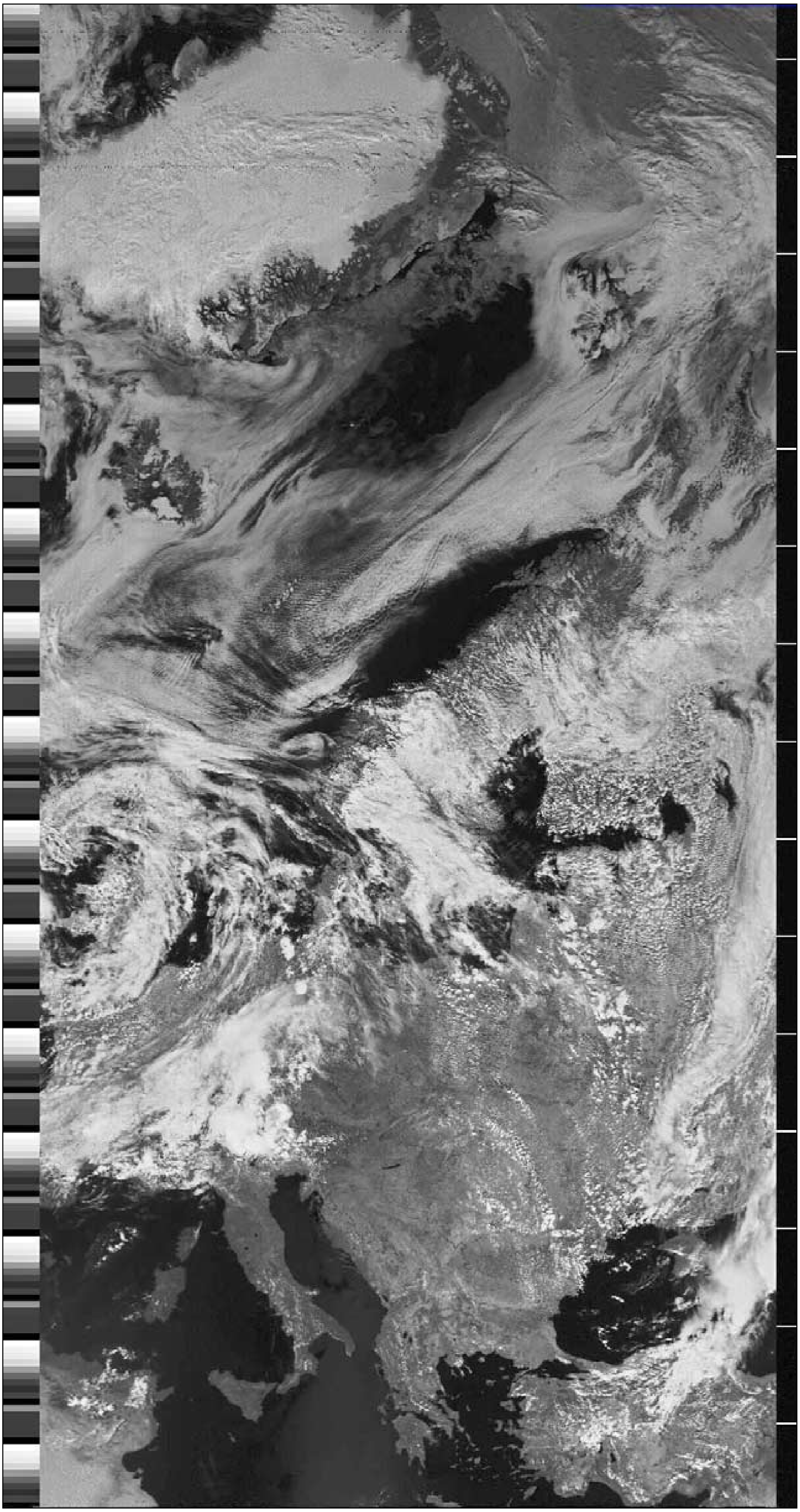

Figure16 - A 15 minute 51° elevation NOAA-18 pass acquired from Vasa, Finland at 11:41 UT on July 6, 2008