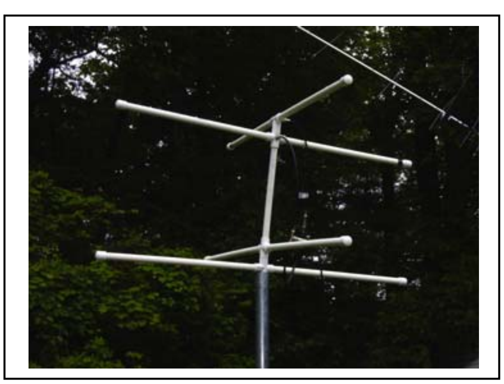
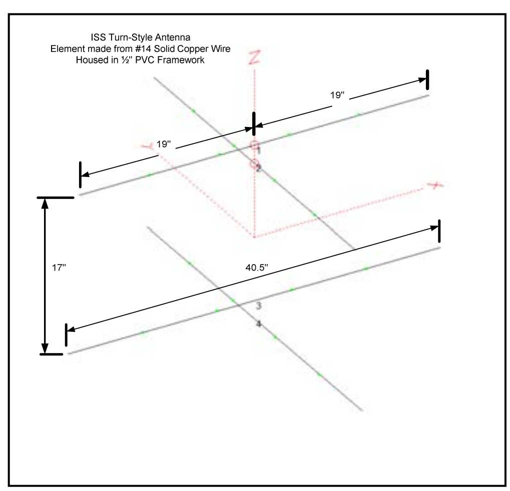
ISS Minimalist Antenna

The purpose of this project was to develop an antenna suggestion that would allow for a simple to duplicate, affordable antenna solution for reasonable access to signals transmitted from the International Space Station (ISS) now and signals from plan CubeSat resources in the near future. The ISS currently transmits Automatic Position Reporting System (APRS) station position reports via VHF packet on frequency 145.825 MHz, and you will sometimes be able to hear random contacts between the astronauts and ham radio operators as well as scheduled school Amateur Radio in the International Space Station (ARISS) contacts on frequency 145.800 FM. Future CubeSats, small amateur radio satellites put into orbit primarily by universities, are tending to use the 2-meter amateur radio band for telemetry downlinks. The signals from the ISS are generally strong and easy to receive with simple radio stations. CubeSat transmitters generally have lower power because of the limited power budge afforded by the small form factor of the 10 cm^3 satellites. To receive signals of quality from both the ISS and CubeSat, directional antennas that are computer controlled in azimuth and elevation to keep the antenna pointing at the orbiting satellite are desirable . These antenna systems are relatively complex and expensive, and in the case of qualifying for an ARISS school contact, are a prerequisite. The antenna described here should be adequate to receive signals from the ISS and the VHF CubeSats to get you started, perhaps whetting your appetite for more reliable receiving capabilities and a further investment in your satellite ground station.

The antenna system needed to receive signals from satellites logically should be optimized for receiving signals from moving objects in orbit above our heads (as opposed to terrestrial signals that are fixed or slow moving and located around our horizon). There are many different fixed antenna systems developed over the years that are optimized to “look up” including tilted verticals, Lindenblad, Quadrifilar Helix, and Eggbeater just to name a few. Each has its advantages and disadvantages. The antenna described here is a Turn-Style antenna that is based on the most basic antenna, the dipole, and a reflector element. The turn-style also has some advantages and disadvantages, but overall it is easy to construct, tune, inexpensive, and a solid performer.

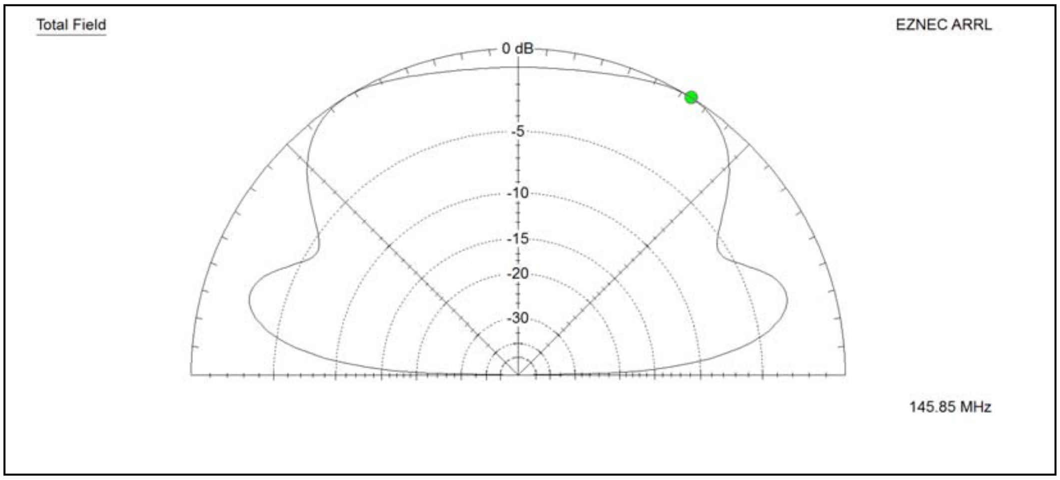
The Basics. The turn-style is basically two, two element yagi antennas that are pointed perpendicular to the ground (pointed up), the two antennas are mounted perpendicular to each other (in a cross configuration) and electrically phased to create a circularly polarized antenna pattern that mitigates signal fading due to polarizations shifts that occur as the signals from space traverse through the ionosphere and reflect off of surfaces surrounding the immediate antenna environment. This is a picture of the turn-style antenna and a diagram with dimensions of the antenna elements.



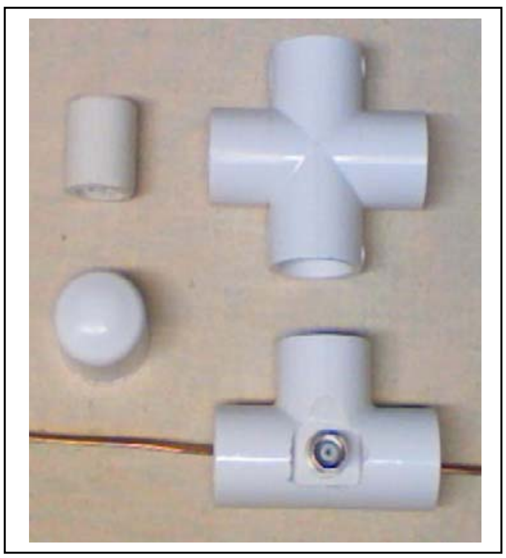


The actual antenna elements are made from common #14 electrical wire available at home improvement stores (insulated or non-insulated). The simple wires are not rigid enough to maintain their shape as an antenna; therefore, the antenna elements are inserted into an exoskeleton made of common ½ inch PVC pipe. The PVC exoskeleton is connected together with simple PVC fittings.

Performance. This is an elevation plot of the turn-style antenna developed by the EZNEC antenna analysis program. The distance the line plot is away from the origin of the polar graph (where the antenna is located), the greater the signal strength is at that location. The gain of this antenna (the outer ring of the plot) is approximately 5.6 dB. There is a peak gain at 58^{o} above the horizon, the small null is actually 0 dB (no gain) at 32^{o}, and the small peak of 3 dB is at 16^{o} above the horizon. Logically, this antenna is optimized for signals originating from about 10^{o} above the horizon to directly overhead. In looking at the typical satellite orbit, satellites pass predominately between 25^{o} to 75^{o} above the horizon; the turn-style performance is in that ball park.



Construction details. The PVC exoskeleton is made of ½ inch PVC pipe and fittings.



You will need 8- ½ inch PVC end caps, 3- ½ inch PVC cross “T” connectors, and 1- ½ inch PVC “T” connector as illustrated above. You will need to purchase 2- 10 foot lengths of ½ inch PVC pipe. Cut 8- 20 inch lengths of pipe to make up the element arms of the antenna, 1- 13 inch length of PVC pipe to be the center support between the dipole elements and the reflector elements, and 2- 1 inch lengths of pipe to serve as connectors between the “T” connectors. File or sand smooth the burs that are left when sawing the PVC sections (inside to allow free passage of the wire elements through the PVC, and outside to facilitate smooth attachment of the fittings).

In the center junction of the “T” fitting, and in the center of one cross “T” fitting, drill a 3/8 inch hole that will accept the BNC bulkhead connector. You will probably have to use a file to remove some of the PVC pipe thickness where the bulkhead connector passes through to facilitate attaching the nut on the inside of the “T”, just use care not to remove too much material and defeat the mechanical strength of the attachment area. The illustration shows the modified “T” fitting with the BNC bulkhead connector in place.

You will have to use some patience when mounting the BNC bulkhead connectors to the “T” connectors-it is a tight fit. Just looking ahead for a moment, you will solder one driven element to the BNC solder lug first and cut that element to length (to include the length of the solder lug). You then mount the BNC connector with the solder lug under the mounting nut, tighten it down. Then solder the other driven element to the BNC center post from one of the side holes as shown above. If anyone can come up with a better way of doing this, I am all ears.

The driven elements of the antenna (the dipole elements that are connected to the coax) are cut to a length of 19 inches. The end of one element is soldered to the center post of a BNC bulkhead connector. The end of the other element of the dipole is connected to the soldering lug that is held in place by the bulkhead connector mounting lug. The length of the element connected to the center post can be cut to 19 inches and it will probably end up the right length. The length of the element connected to the BNC solder lug will have to be trimmed a bit to compensate for the length of the solder lug; just measure from the center of the solder lug mounting hole to the end of the element and cut to 19 inches.

Slide two 20 inch PVC pipe sections over the exposed element wires. I would not suggest gluing the exoskeleton together until you have everything tested and working. Mark the element that is connected to the BNC center pin with some electrical tape. It will become important which element is which when doing the phasing of the antenna.

Cut the two reflector elements to 40 ½ inches. The reflectors are single lengths of wire and are not cut in the center or connected to anything; these elements just lay inside the reflector exoskeleton. Construct the reflector element exoskeleton with 2- 20 inch lengths of PVC and a cross "T" in the middle. Slide the reflector element in this assembly and cap off the ends.

Using the above photo illustration of the completed antenna as a guide, put the antenna together by starting with one reflector, a 1 inch PVC pipe section, the other reflector, the 13 inch spacing section of PVC, the driven element with the cross "T" midsection, a 1 inch PVC pipe section, and finally the driven element with the "T" midsection. You can use the left over length of PVC at the bottom for a mast, but you might find that that length of PVC too flimsy for the final installation.

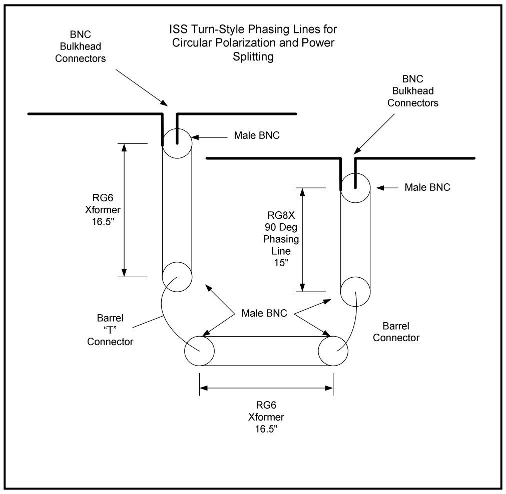
Rotate the elements sets so that they are perpendicular to each other and the driven element/reflector element pairs are parallel. A pair is made of elements that are 17 inches apart, again refer to the illustration.

Phasing Lines. There are a couple of things to consider when connecting your radio to this antenna to get a proper match and also the desired polarization.

First, the turn-style antenna is actually made up of two independent 50 ohm impedance antennas. If you were to connect these antennas in parallel to your 50 ohm impedance radio, there would be a mismatch between the 25 ohm equivalent impedance of the 50 ohm impedance antennas connected in parallel (remember Ohms law: when you connect two 50 ohm resistors in parallel, the resulting resistance is 25 ohms) and the radio input impedance. The mismatch will result is some signal strength degradation (something we want to avoid when working with low strength signals from space). Consequently we need to transform the impedance of the 50 ohm antennas to 100 ohm impedance antennas so that when connected in parallel, the equivalent impedance of the combined antennas is returned to 50 ohms.

Second, by convention, satellite antennas tend to be right hand circularly polarized (RHCP) which means the antennas are optimized to receive signals that are rotating clockwise when looking into the direction from which the signals are coming (looking from the back of the antenna toward the front of the antenna). Some satellites will transmit signals from circularly polarized antennas and send rotating signals, other satellites will send either vertically or horizontally polarized signals. In either case, during the transit from space, through the ionosphere, and bouncing around all the reflective surfaces in the vicinity of the ground station antenna, these signals rarely match the polarization as originally transmitted. To mitigate this situation, an antenna that is circularly polarized will tend to receive signals with less polarization shift fading.

So to complete our turn-style antenna, we need to construct a phase line harness that will act as a transformer to take care of the impedance mismatch of connecting the antennas in parallel and also to cause a phase shift of 90 degrees between the antennas to create a RHCP antenna. The construction of the phase line harness is illustrated below.



The transformer sections are made from ¼ wavelength 70 ohm impedance RG6 coax, and the phasing section is made from ¼ wavelength 50 ohm impedance RG8X coax. The dimensions of the coax sections that should work from common coax cable are in the illustration. (1/4 wavelength of RG6 at 146 MHz is 16.5 inches, ¼ wavelength of RG8X at 146 MHz is 15 inches. The difference is due to the differences in the coax velocity factor as described below.) The coax sections are terminated with BNC connectors, and the connections between sections are made with BNC barrel connectors or a BNC “T” connector.

<u>How this works is as follows:</u> the 90 degree phase shift is developed by the ¼ wavelength section of 50 ohm RG8X coax. The impedance of the output end of this phasing section is also 50 ohms (because of the odd ¼ wavelength increment). The 90 degree phase shift means that the radio signal coming out of the end of the phasing line when compared to the input end (antenna side) of the phasing line will be delayed or shifted in phase by ¼ wavelength. Remember marking the element connected to the center post of the BNC connector? This is where that becomes important. To achieve RHCP, we want the signal received from one of the turn-style dipoles to be shifted or rotated clock-wise or delayed by ¼ wavelength from the other dipole element (which makes it appear that the rotating wave front is preferred or optimized). So looking up from the back of the antenna, find one marked element (#1) and think of it being in the 12 o’clock position, and the second marked element (#2) is at the 3 o’clock position. To achieve RHCP, we need the signal received by element #2 to arrive at the receiver ¼ wavelength later than the signal received by element #1. To get this ¼ wavelength delay at element #2, attach the ¼ wavelength phasing line to element #2. This sounds more complicated than it should be. A picture (just look at the antenna) is worth a thousand words.

The development of the transformer sections will take a little mathematics as follows:

Equation 1 can be used to determine required impedance of a ¼ wavelength of coax needed to transform the input impedance into the output impedance of the transformer.

$Z_0 = \sqrt{Z_i Z_L}$ equation 1

Where Z_0 is the phasing line impedance, Z_i is the antenna impedance (input to the transformer), Z_L is the load impendence (output of the transformer)

If we assume that the dipole has an approximate impedance of 50 ohm, when we connect the two dipole antennas in parallel, Ohms law tells us that the resulting impedance is 25 ohms (equation 2), and this is an unacceptable mismatch .

$R_T = \frac{R_1 R_2}{R_1 + R_2}$ equation 2

To achieve the desired 50 ohm impedance of the two antennas connected in parallel, the impedance of each antenna needs to be transformed to 100 ohms.

Plugging the antenna impedance of 50 ohms in for Z_i and the desired transformed impedance of 100 ohms in for Z_L and solving equation 1, we have a transformer line impedance of approximately 70 ohm. RG6 coax is a good match for this impedance.

The next challenge is to determine the electrical length of ¼ wavelength. Using the standard formula for determining antenna wavelength will get you into the ballpark, however, the antenna formula is for waves traveling in free space, at the speed of light. Whenever a wave is traveling through a media, such as a conducting wire, the wave slows down and this affects the wavelength. This magnitude of this slowing down of waves in coax transmission lines is quantified as the velocity factor of coax. There are manufacturer supplied velocity factor specifications for coax, and the velocity factors typically run from .6 to .9.In other words, the electrical wavelength as calculated for free space needs to be reduced (or multiplied) by the velocity factor. The electrical wavelength of a coax line can also be determined by using SWR or antenna analyzer meters to measure the electrical wavelength. The later method is preferred, particularly if the manufacturer's velocity factor specifications are in doubt.

<u>Putting it all together</u>. Once you have the antenna constructed, it is time to get it airborne. The general rule of antenna placement is the higher the better, but that is not always the case. In this instance, since we are looking up, not toward the horizon, higher does not necessarily mean better, however, clear of obstructions (buildings and tress) would be preferable over height. In fact, the nice smooth antenna pattern depicted in the opening illustration is produced from the antenna at about 6 feet above the ground. If the antenna is elevated higher, like from a tower or high mast, the antenna pattern becomes ragged with a number of deep nulls that may degrade the antenna's performance. (Mounting the antenna on a roof might be a good alternative; just mount the antenna approximately 6 feet above the roof surface.) Of course, antenna mounting is always a compromise between what is optimum and what you can get. The bottom line is to try the antenna in various locations and choose the final "spot" that works best.

Because you will be working with low level signals from space, signal loss in the coax feed line can be significant, so part of your installation thought process must include the tradeoff between access to the horizon and the added signal loss from a long length of feed line. In any event, you will find that the inclusion of an antenna mounted pre-amplifier will improve your receiving station remarkably. A pre-amplifier project for this, and other antennas, is in the works and will be published when completed.

For the time being, set up your antenna, connect the receiver, tune to 145.825 MHz, watch for when the ISS is within range, and listen for the packet transmissions from the ISS. Once you hear these signals, you will want to display the position reports relayed from the ISS, which is itself a separate article. A suggestion is to explore the UISS software by ON6MU available at: http://users.belgacom.net/hamradio/uiss.htm. This software is free software for map display of position reports and also uses free sound card based TNC software that turns your computer sound card into a packet Terminal Node Controller needed to decode packet radio transmissions.