Cubesat Ground Station Quickstart

Scott Torborg - scott@quadraturecat.com - Good Ancestor Kilakila Project
Last updated 2025-05-09

Overview

This tutorial outlines an approach to building a practical ground station for modern cubesats. There are many different ways to implement a satellite ground station, but this approach places an emphasis on being:

- High-performance for interaction with 433MHz UHF LoRa cubesats
- Capable of basic practice with non-LoRa cubesats (generally amateur radio satellites and the ISS)
- Cost effective
- Simple to operate
- Scalable / flexible to other future goals

At a minimum, a ground station will need a computer, a radio, an antenna, and the mounting and housekeeping to keep it all alive.

The document is divided into sections focused on required sets of components: each section attempts to explain the rationale behind the component choices, and then offers a hardware recommendation in green and sometimes alternatives in yellow. The sections are sequenced such that hardware choices which influence other components are discussed first.

If you want to skip the explanation and jump straight to the full recommended gear list, skip to the end.

Antenna Choice

The first and most important choice is whether the ground station will use a fixed antenna or a motorized elevation/azimuth tracking mount. A fixed antenna is simpler, lighter weight, much less expensive, and more rugged. However, a tracking antenna offers substantially higher RF performance (around a 12-15dB improvement in link margin). For potential future interaction with Good Ancestor Kilakila, a tracking mount is recommended, and may be a requirement for consistent operations.

This is the biggest factor in determining the cost of the entire setup: a fixed antenna station can cost $200-$600 depending on implementation details, whereas a tracking antenna will likely cost a minimum of $2,500.

Some antenna considerations that are common to both fixed and tracking setups:

- Circular polarization is a significant benefit. This is because the relative attitude of the satellite is generally unknown, and attempting to receive a linearly polarized signal with an antenna of the opposite (orthogonal) linear polarization will incur huge losses. That said, it may be possible to make contacts with a linearly polarized ground antenna, especially to satellites which themselves have circularly polarized antennas. Note that Good Ancestor Kilakila has linearly polarized UHF command antennas.
- Antennas should be optimized for usage in the 433-438MHz range, a range of frequencies in the amateur radio 70cm band that is commonly used for LEO cubesats.
- Narrowband antennas will generally be easier to work with. It is tempting to purchase wideband antennas (and other RF equipment) to keep things flexible for future projects. However, a wideband antenna will receive and transmit a lot of undesired signals: using narrowband equipment gets you “free” filtering at every step along the way. Note that the opposite is true when building your own antennas: it is generally easier to build wideband or frequency-independent designs, because they will be less dependent on mechanical precision.

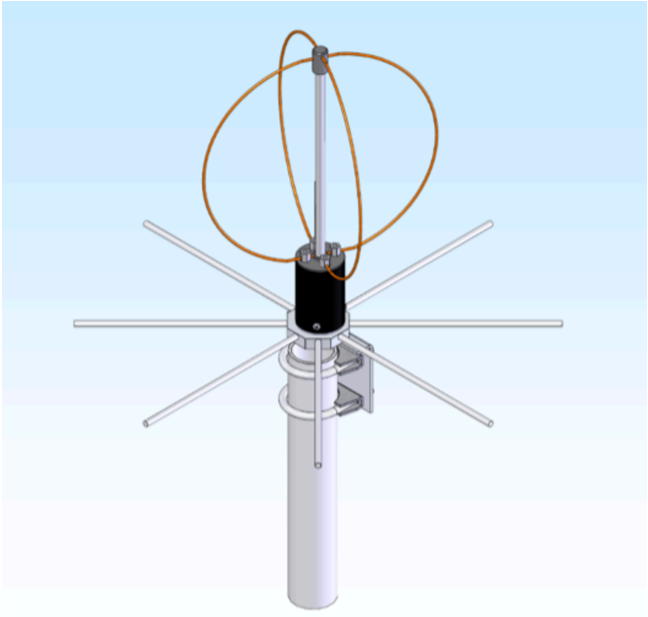
Fixed Antenna

Some suitable antenna types for a fixed mount are eggbeaters, quadrifilar helixes (QFH), or turnstiles (aka “crossed dipoles”). These all offer circular polarization, mostly omnidirectional radiation patterns, easy mounting, and insensitivity to nearby ground planes. Between each other, they vary a small amount in performance and mounting specifics.

- A turnstile is simple and common, but will tend to have lower gain at low angles–when the satellite is close to the horizon.
- An eggbeater has better gain at low angles, but will tend to be a bit larger, heavier, and more expensive.
- A QFH will generally offer the best performance, but QFH antennas with suitable tuning are not easily available off the shelf. Some open designs exist which can be handmade or partially 3D printed.

A monopole (sometimes referred to as a "¼ wave omni") is a very cheap and simple option that can be easily handmade, but is very sensitive to grounding and only offers linear polarization.

Recommended:
M2 Antennas EB-432/RK70CM Eggbeater - $355 - Buy at Ham Radio Outlet



Alternate:
Vinnant TUR435/3-S Turnstile - €60.50 - Only available direct

Tracking Antenna

The best antenna for use on a tracking mount will usually be a circularly-polarized Yagi-Uda (aka “Yagi”). Most good choices will be around 7+ft long, offering peak gain of 12dBi or more. They will generally be mounted around the middle of the beam.

Some Yagi antennas are sold as a “cross Yagi”, where the antenna has two independent sets of elements, each linearly polarized and fed by their own connector. These antennas can be converted into a single circularly-polarized antenna by feeding the linear axes 90 degrees out of phase. Usually this is done with a 90 degree hybrid coupler or a phasing line. A convenient aspect of an antenna sold as a cross yagi is that it is easy to swap between right and left handed circular polarization simply by swapping the element feeds.

A circularly polarized Yagi can also be made by combining two independently linearly-polarized Yagis mounted at a 90 degree angle to each other. This will generally be more challenging to set up and keep aligned.

It is possible to use helical antennas in place of a Yagi. Off-the-shelf options are heavier, much more limited, very expensive, and very specialized, but a helical antenna will offer the advantage of a wider bandwidth. This may be useful to support commercially licensed satellite links in the 401MHz or 470MHz range alongside satellites which use amateur frequencies.

It is impractical to use reflectors (dishes), horns, slotted waveguide (Vivaldi) antennas,

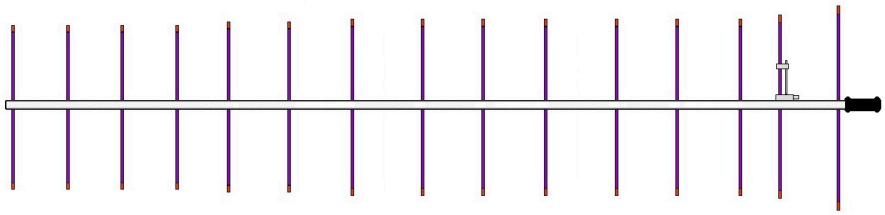
In a tracking setup, it is strongly recommended to have two antennas. This has several advantages:

- The mount is more mechanically balanced, reducing wear and simplifying setup.
- A split transmit/receive allocation can be used, where one antenna is dedicated to transmit via a fixed power amplifier, and the other is dedicated to receive via a bandpass filter and low-noise amplifier.

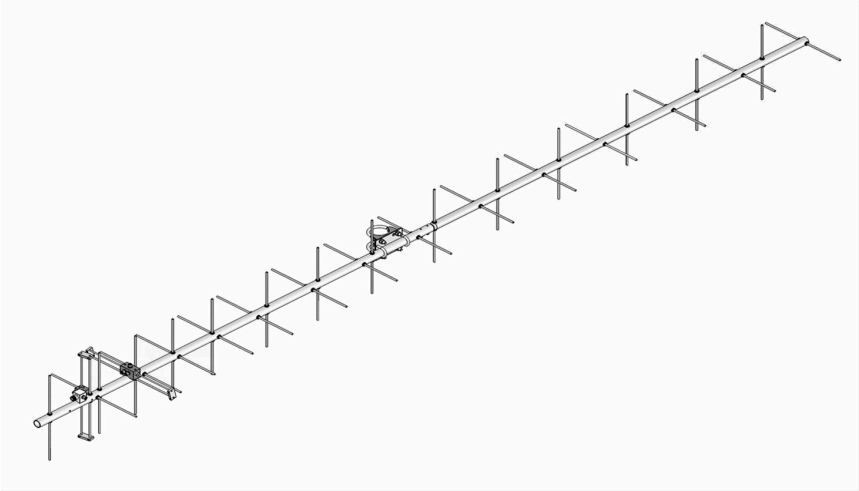
- Alternatively, one antenna can be used for satellite interaction via a hardware radio, and the other antenna can be used to observe/record the interaction via a software-defined radio.

It can also be useful to have an additional fixed antenna nearby. This provides a backup in case of a failure of the tracking mount, and can be used to determine whether an unknown signal is terrestrial in nature.

Recommended:
Arrow Antennas GreenCube Yagi with 2nd element set - $318 ea - Only available direct
Plus Mini-Circuits ZX10Q-2-5-S+ Hybrid Coupler - $42 ea - Buy from Mini-Circuits



Alternate:
M2 Antennas 436CP30 Yagi - $644 - Buy from DX Engineering
Plus M2 Antennas Polarity Switch - $360 - Buy from DX Engineering



Rotator

A tracking mount, also referred to as a “rotator”, generally mounts on top of a circular mast and holds a circular cross-beam. The wind loading of large yagi antennas (and possibly future reflector dishes) can be enormous, so this mount needs to be very robust. The pan/tilt mounts commonly used for cameras or telescope are generally not sufficient.

The mount must also have an active digital controller capable of being calibrated and reliably steered to a particular heading and elevation.

The most popular choices in the amateur / small satellite communication realm are made by Yaesu (the G-5500DC) and Alfa (the SPID line). The latter will tend to be stronger and more versatile, but also more expensive and heavier. The G-5500DC or any of the SPID options will be sufficient to handle a pair of 433MHz yagis, but the SPID will be able to handle additional large antennas or reflectors. If the G-5500DC is used, an aftermarket controller must be bought or built: a popular option is from Green Heron Engineering.

Note that when assembling the system the rotator will need to be lifted onto the top of the mast. If building a system on the top of a tall tower or in a remote area, check the weight of your rotator and consider picking a lighter one. The SPID BIG-RAS weighs over 55lbs: this is challenging to install on top of a tower, and will likely require specialized rigging equipment to do safely! The Yaesu G-5500DC, in contrast, weighs only 20lbs.

Recommended:
Alfa SPID RAS standard Az/El package with MD-03 controller - approx. $1800 - Buy from RF HamDesign

Alternate:
Yaesu G-5500DC rotator - $760 - Buy from DX Engineering
Plus Green Heron Engineering RT-21azel controller - $899 - Only available direct

Antenna Mounting Hardware

Many antennas, particularly fixed omnidirectional ones, will come with all necessary mounting hardware. Some will not, and some minor custom fabrication will be required.

Pay careful attention to corrosion resistance in selecting mounting hardware and fasteners. Stainless steel, galvanized steel, or plastic hardware is strongly recommended. For mounting of vertical fixed antennas, a “double mast clamp” may be useful.

To mount yagi antennas onto a rotator, a cross boom will be required. It’s possible for this to be metal, but a nonmetal material like fiberglass or solid wood will tend to improve RF performance. Avoid the temptation to use PVC pipe: it is too flimsy for even the lightest antennas. Some purpose-built cross booms are available off the shelf, like the M2 Antennas FGCB60, but it’s usually less expensive to just buy a solid wood dowel or fiberglass rod of the correct diameter from the hardware store. Ensure that it is intended for use outdoors, or apply a basic finish to seal it against the elements. A 2” hardwood dowel painted with outdoor primer is a good choice.

When mounting yagis to the cross boom, try to mount them such that the elements are at a 45 degree angle to the ground. This ensures that both polarizations are equally affected by ground reflections.

Mast Setup

Regardless of the choice of antenna and rotator, the whole apparatus will generally be mounted on top of a steel pole that is around 2-3” in diameter. There are many, many different ways of accomplishing this, each with tradeoffs that are specific to the setup and structure. This document will not go into detail, but instead just provide a basic overview. Lacking other constraints, a good default option is a non-penetrating mount.

In all cases, it's a good idea to connect the mast to ground with a large wire or copper strap, unless it is already grounded naturally.

Already Existing Structures

There may be a suitable unused mast already on your facility. Ensure that it is **very sturdy**. Aside from the weight of the equipment, it will have intense wind loads on it, particularly for a tracking setup. A rotator with a large reflector dish will have **extreme** lateral loads on it.

Side Attached Mast

For small setups, particularly fixed antennas, it can be practical to secure a mast to the side of a building or deck. Two good approaches for doing this are:

1. Find a suitable kit designed exactly for the purpose.
2. Install two strut channels mounted horizontally and spaced 2-4' vertically, then use a pipe clamp on each one to hold the mast.

If you are not familiar with some degree of construction or electrical work, consider hiring an electrician or contractor before drilling into the side of your building.

Guyed or Self-Supporting Tower

For a larger setup or one that is independent of a building, use a guyed or self-supporting tower kit. On the smaller side, this could be a telescoping mast like an EZ TM-50 and a guy wire kit. On the larger side, a very nice system is the Rohn 25G tower catalog.

Either of these is a significant undertaking with a lot of opportunity for injury or property damage: look for specific books and websites on ham radio tower construction.

Non-Penetrating Mount

For a flat roof, the simplest approach is a "non-penetrating mount". This consists of a vertical pipe, appropriate brackets, and a large tray intended to hold concrete slabs or blocks as ballast. In the USA, the vast majority of these are designed for 8x8x16" cinder blocks (internationally, this varies).

Good vendors for such mounts are Rohn and Easy Up (aka EZ). For a satellite ground station, it is advisable to pick a mast that is on the shorter side (e.g. 5ft) and as large of a diameter as is compatible with the rest of your equipment.

Most mounts have a roof pad set that is included or available as an additional accessory. It is **strongly recommended** to use this pad to protect the roof from wear and even out the ballast load. Many commercial properties and government facilities have legal requirements for the use of such pads. Depending on the roof material and access, it may be wise to buy additional pad material to make a walkway to the station (e.g. from a ladder or access hatch).

Once the mount is assembled, ballast it with cinder blocks. There is generally no reason to not completely fill the tray with the “designed” number of cinder blocks. Orient them with the openings facing horizontally: this will keep them from getting filled with debris, and provide a convenient work surface when doing setup and maintenance.

In a geographical area with the chance for extreme winds (or tornados/hurricanes), consider adding a safety cable to secure the non-penetrating mount to other permanent structures.

Recommended:
Rohn FRM238SP5 Non-Penetrating Roof Mount with FRMMAT pads - $275 - Buy from Amazon

Radios

Software Defined Radios

The best place to start the practice of tracking and making contacts with satellites is through an SDR. It is exceedingly valuable to be able to see a spectrogram of signals, and provides direct feedback to aid in setting up the station.

There are many excellent SDR choices, but any receiver based on the RTL-SDR chipset (specifically, the RTL2832U and the R820T2 or R860) will have the best software compatibility and the easiest setup. The RTL-SDR Blog V4 dongle is a well-made variant.

For future transmit capabilities, consider a LimeSDR Mini 2.0.

Recommended:
RTL-SDR Blog V4 Dongle - $40 - Buy from Amazon
LimeSDR Mini 2.0 - $440 - Buy from Crowd Supply

Ham Radios

For traditional contact with amateur satellites or the ARISS repeater aboard the International Space Station, the best choice is a traditional “analog” ham radio transceiver. Virtually any transceiver capable of VHF or UHF operation can be used, but the best choice is a transceiver with two VFOs, to allow for receive on one band and transmit on a different band. Many ham satellites have split transponders with the uplink on VHF and downlink on UHF, or vice versa.

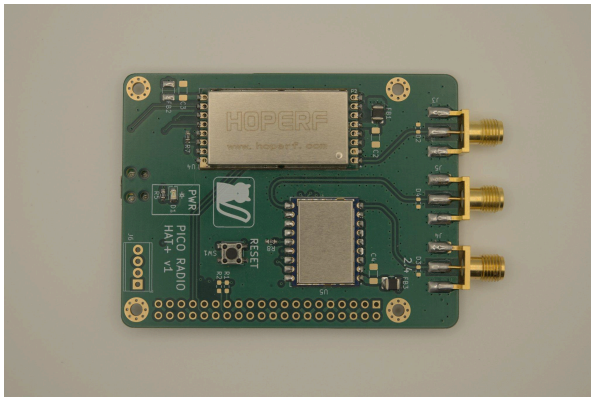
Some amateur satellites have APRS and packet functionality: for particular interest in those operations, consider a higher end transceiver with built-in digital mode support.

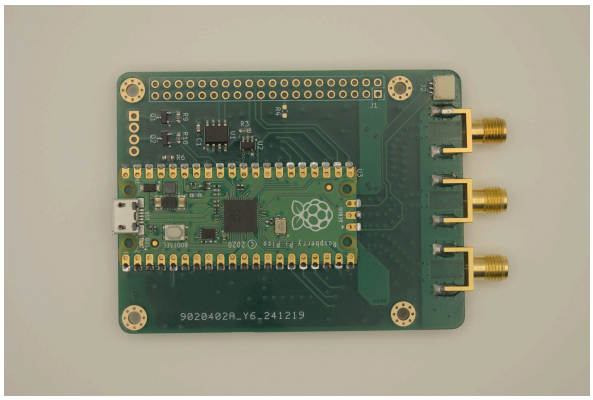
Hardware LoRa/GFSK Radios

Interaction with most digital LEO cubesats will benefit from a hardware radio capable of receiving and transmitting LoRa packets natively. It is possible to use an SDR for this application, but the tight timing requirements for rapid half-duplex LoRa interaction will make a native hardware radio much, much easier to use.

A good way to get started is with the TinyGS project firmware running on an off-the-shelf LoRa development board such as the Heltec WiFi LoRa 32.

To interact with Good Ancestor Kilakila, a special custom Raspberry Pi HAT+ board will be required, the Pico Radio HAT+:





To get one of these boards, keep in touch with the author, scott@quadraturecat.com.

Single-Board Computer

The ground station should have at least one computer that is dedicated to ground station operations, so that it can be continuously available to record telemetry or interact with a satellite. It may be desirable to add additional computers for either redundancy or more sophisticated operations, but the simplest approach is to start with just one first. A single-board computer immediately adjacent to the antenna will make the rest of the hardware setup easier, but requires the users to be fairly experienced with command-line usage and remote administration over a network: for more GUI-oriented users, consider a laptop or desktop in a room as close as possible to the antenna.

The Raspberry Pi 4B 8GB is the most suitable option as of mid-2025. UHF satcom operations do not have particularly high demands for compute performance, even when an SDR is used, because the RF bandwidths involved are small. The additional performance offered by something like a Pi 5 or an Intel NUC is generally unnecessary, and may make cooling more difficult in the summer. It can be desirable to have more onboard RAM for IQ recording.

It should run Linux: either Raspberry Pi OS (in the case of a Pi) or Ubuntu LTS (in the case of an Intel laptop or desktop) is strongly recommended.

Some additional setup recommendations:

- Power the Pi via power-over-ethernet (PoE) so that it's easier to remotely power cycle it.
- Use a high-endurance SD card (such as one intended for a security camera) for better resilience if the onboard software is doing a lot of logging or IQ recording.
- Alternatively, use a Compute Module 4 with onboard eMMC in a suitable carrier board.
- Label the Pi with the hostname that you have assigned to it.

Enclosure

All of the electronics equipment will need to be mounted fairly near the antenna. You can get creative about mounting things just inside a skylight or underneath a roof eave, but the most straightforward approach is to buy a large weatherproof "NEMA enclosure". This genre of part generally has flexible mounting (usually designed for walls or poles), a modular backplate or DIN rail inside, and a door with a latch and padlock hasp.

The most important characteristic of a suitable enclosure is just that it actually provides protection against the elements: it is generally not necessary to be completely watertight (and sometimes even not desirable), but to the extent that it has openings, they should be designed with weather protection in mind.

Consider getting a box that is much larger than initially needed: it will likely gain more upgrades later, with additional interface boxes, cabling, power supplies, etc.

There are many vendors of high quality enclosures: two are Bud Industries and L-Com.
Recommended:
L-Com 12x10x5 inch NEMA 4X rated enclosure with DIN rails - $268 - Buy from L-Com

RF Cabling

The setup will have a significant number of RF cables and connectors involved, all of which must be secure and good quality for the system to function. When used at 433MHz and lower, RF cabling is fairly forgiving, and it isn't as important to use high-end low-loss cabling. However, it is important to ensure that the materials used for jacketing and connectors will survive outdoor weather. It is generally wise to use UV-resistant cables and stainless steel connectors.

For long runs, a good cable choice is LMR240, LMR400, or manufacturer-specific variants of either.

For shorter runs or for use with GNSS only, RG58 can be a cheaper alternative with more connector variety.

Amazon offers a huge range of RF cables in various lengths and connector choices, and the quality of well-reviewed products is generally acceptable. However, for more dependable sourcing, look to vendors like L-Com, Mouser, or Digi-Key.

Once the configuration is fully dialed in and working, consider wrapping all outdoor RF connections in silicone “F4” tape for additional weather protection.

Full Equipment List

Note that there are **two custom parts** in this list: a set of antenna mounting blocks only needed for use with a tracking setup, and a PCB assembly for interaction with LoRa setups. Contact scott@quadraturecat.com about acquiring these.

Description	Mfr	MPN	Supplier	Price	Qty
NEMA enclosure with predrilled N(f) openings, power cable gland, and DIN rail mounts, 12x10x5"	L-Com	NB121005-000DR	L-Com	$ 235.99	1
DIN rail for enclosure	L-Com	DIN-35-NB12	L-Com	$ 4.09	1
Pole mounting kit for enclosure, 1.25-2" diameter	L-Com	HGX-PMT16	L-Com	$ 68.99	1
Raspberry Pi 4B, 8GB RAM	Raspberry Pi	SC0195(9)	Mouser	$ 75.00	1
Micro SD card, high endurance V30, 256GB	SanDisk	SDSQQNR-256G-GN6IA	Amazon	$ 22.99	1
Pico Radio HAT+ assembled PCB	Quadrature Cat	picoradiohat-v1.0	Quadrature Cat		1
DIN rail mount for Raspberry Pi	HCDC	B08JQ389FJ	Amazon	$ 18.99	1
Waveshare PoE 802.3af/at HAT for Pi	Waveshare	B0928ZD7QQ	Amazon	$ 24.99	1
Standoff, M2.5 x 16mm + 6mm male-female, brass	uxcell	B08F28SLW6	Amazon	$ 0.24	4
Standoff, M2.5 x 12mm female-female, brass	uxcell	B08F2BRXPN	Amazon	$ 0.20	4
Standoff, M2.5 x 6mm + 6mm male-female, brass	uxcell	B08F2F96HM	Amazon	$ 0.10	4
Pan head screw, M2.5 x 4mm long, Torx T8, 18-8 stainless	McMaster-Carr	90362A143	McMaster-Carr	$ 0.08	8
Waterproof bulkhead coupler, RJ-45 male to female with cable	Penglin	B0DHJRS56D	Amazon	$ 7.00	1
Outdoor rated cat-6 cable	Hardware store	-	Hardware store	*$ 25.00*	1

RF adapter, N(f) to SMA(f), IP rated	TE Connectivity	ADP-SMAF-NF-B-W	Mouser	$ 7.75	2
RF cable, internal, SMA(m) to SMA(m), RG-316DS, 18"	Cinch Connectivity	415-0033-018	Mouser	$ 15.13	1
Filter, 410-470MHz lumped LC, SMA inline	Mini-Circuits	ZX75BP-440-S+	Mini-Circuits	$ 69.51	0
Cinder block, 8x8x16"	Hardware store	-	Hardware store	*$ 3.00*	8
Fixed Antenna					
Non-penetrating roof mount, 2" x 72" mast, with roof mats	EZ	NP-72-200	Amazon	$ 180.00	1
RF cable, external, N(m) to N(m), LMR240, 1m	L-Com	LCCA30173-FT4	L-Com	$ 43.79	1
Antenna, 400-470MHz rugged eggbeater, RHCP, 500W power handling, N(f)	M2 Inc	EB-432/RK70CM	DX Engineering	$ 358.99	1
Tracking Antenna					
Non-penetrating roof mount, 2.38" x 72" mast, with bundled FRMMAT roof mats	Rohn	FRM238SP5	Amazon	$ 275.00	1
Hose clamp for L-Com mounting, 3.25 to 4.125" clamp ID, 304 stainless, 2pk	McMaster-Carr	5661K15	McMaster-Carr	$ 13.51	1
Custom mounting block for Arrow Yagi, CNC milled ABS	Quadrature Cat	arrow-mounting-block-v1	JLC CNC	$ 19.23	4
Hex head screw, 1/4-20 x 1.5" long, partially threaded, 18-8 stainless	McMaster-Carr	92198A546	McMaster-Carr	$ 0.16	8
Washer, 1/4" nom, 0.281" ID, 0.625" OD, 18-8 stainless	McMaster-Carr	92141A029	McMaster-Carr	$ 0.06	16
Hex nut, 1/4-20, 7/32" height, 18-8 stainless	McMaster-Carr	91845A029	McMaster-Carr	$ 0.05	8
U-bolt, 1/4-20 threaded, 2.25" center to center, 304 stainless	McMaster-Carr	8896T107	McMaster-Carr	$ 4.87	4
Antenna, 15-element yagi, 433MHz, BNC ("Greencube" antenna)	Arrow Antennas	435-15BP	Arrow Antennas	$ 219.00	2
Extra element set for above, to make a cross yagi	Arrow Antennas	-	Arrow Antennas	$ 99.00	2

Alfa SPID RAS alt/az rotator with MD-03 controller	RF HamStore	SPID RAS package	RF HamStore	$ 1,176.23	1
Power supply for MD-03	RF HamStore	PS-03	RF HamStore	$ 413.90	1
Dowel rod, wood, 48" x 2"	Waddell	6456U	Home Depot	$ 10.98	1
Hybrid coupler, 330-580MHz, 20W power handling	Mini-Circuits	ZX10Q-2-5-S+	Mini-Circuits	$ 42.28	2
Cable, BNC plug to SMA(m) 20", RG58	TUOLNK	B09GVQTFBP	Amazon	$ 5.00	4
Cable, SMA(m) plug to N(m) plug, KMR240, 12’ length	MOOKEERF	B0CS36NDT3	Amazon	$ 19.99	2