THE DESIGN AND BUILDING OF A LARGE DISH ANTENNA ROTOR

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Units of Measure:
This article uses "English" units of measure. They may be easily converted to metric using these factors:

From	To	Multiply by
inches	mm	25.400
feet	m	0.305
yards	m	1.094
lb	kg	0.454
ton	t	0.907
mi/h	km/h	1.609
ft-lb	N-m	0.0847

Introduction

Those of us interested in Radio Astronomy (RA) or Earth-Moon-Earth transmission (EME, or "Moon bounce") usually dream of a bigger antenna at some time in our various quests. Usually this occurs as our Radio Telescope (RT) or EME system gets cleaned up from all the system losses and internally generated noise. Once this is done (which is no small feat) the system and the operator can take full advantage of the increased sensitivity and capabilities of a larger antenna.

The only unique thing about the rotor design described here, compared to any other rotor system that I have run across, is that it uses a slew thrust bearing off a bucket boom truck. These bearings are able to handle almost any dish we can put on them, and they are very compact. If the bearing drive worm gear system is acquired at the same time, it may also be found to be very beefy. The beefy worm drive also solves the braking system problem on the rotor system, because the worm gear drive locks up when not rotating. This setup will handle almost all Mother Nature's forces, except tornadoes and hurricanes.

Prior to my *big dish idea* I had a 10 ft satellite dish (figure 1). With the guidance and help of Dick Flagg (AH6NM) and after several hundred emails, I was able to clean up my system to a point where we were getting some pretty impressive results for my having only a 10 ft dish. When Dick finished with his final suggestion on the system's tune-up, almost a year later, that same system was getting a return echo off the moon, with a 125 watt signal on 1296 MHz!

Fig. 1 – The *old* 10 ft dish antenna mounted on the roof of my radio shack. This is the antenna I planed to replace with a larger antenna. The white dot in the dish center was used to align the TV camera positioned on the end of the feed horn so that it "sees" the horn's shadow when the dish was pointed at the Sun or moon for alignment of antenna and camera.

Keep in mind a 10 ft dish is considered *the absolute minimum* in dish size at 1296 MHz for doing EME. That it happened at all was due to Dick's knowledge and skill. I just followed his directions, and my wife Mary, let me chase my dream without complaint. EME is no small feat as only approximately one trillionth (that is with a "T") of the transmitter output signal power returns to the receiver. It is also a perfect test bed for testing your RT system. You do not need to be a Ham to test your system as long as you do not transmit. You can just listen in on other Hams doing EME. And believe me when I say "listening in" is a whole lot cheaper! If your system can hear a Moon return, you are on your way to meaningful results with your radio telescope system.

Big Dish Idea

With my system all polished up, the calling for a bigger dish became what my wife once referred to politely as *a hormonal imbalance*. I looked at practically every microwave antenna design ever conceived, and came back to the good ole' parabolic dish antenna. Horn antennas appeared to be a real interesting possibility and would produce a very clean antenna pattern. However when I did the math for the horn dimensions at 1450 MHz and a gain of at least 33 dB, (considered the minimum for EME), it was almost 30 ft long!

Elliptical dish antennas appeared to be the best overall design, and had several advantages over the parabolic dish. They were lighter than and not as subject to ground interference as the parabolic dish. With the antenna feed horn offset out of the beam path, it also did not shadow the dish. However from the aspect of design and structural considerations, it is one of the most difficult to make.

I liked the Cassegrain parabolic dish design, which uses a smaller convex dish at the focal point of the parabolic dish to reflect the antenna beam back into a horn mounted back in the center of the parabolic dish, flush with its surface. This design is strong structurally. Horn and preamp adjustments are much more convenient and accessible. The coaxial cable run up to the horn and other equipment is shorter, and less weight is suspended out from the dish's center. It also is less affected by interference from the ground and has a cleaner beam pattern. Finally, just about every really big radio astronomy dish is of this design – a big sales feature.

The down side is that to make up for the loss of gain from the shadow of the convex dish blocking the larger parabolic dish, (about 20%), the big dish must be *at least 60 wavelengths* wide for a Cassegrain antenna to become really cost effective over the simpler parabolic dish. At Water Hole frequencies this is approaching dish diameters of 40+ ft. However, as the frequency goes up, the Cassegrain dish becomes smaller and more practical for the amateur.

I finally returned to the parabolic dish antenna when I weighed the difficulty of making an elliptical antenna, against that of making a parabolic. The antenna gain I would get from all the extra effort involved in making the elliptical, I found that I could make a parabolic dish bigger and compensate for any loses over the elliptical dish. And much easier than I could make an accurately shaped elliptical dish that was as strong as a parabolic. Besides, other than the 350 ft elliptical dish antenna at Green Bank, West Virginia (the Robert C. Byrd Green Bank Telescope described at: http://www.gb.nrao.edu/gbt/), every professional big dish I looked at was a parabolic antenna. I figured there was a reason someone with a lot more brains and money than I had decided on a parabolic.

Size Matters

The original antenna size I contemplated making was 24 ft. This grew to 36 ft at one point, under the RA theory that bigger is better. It is, until I started crunching the numbers on weight and, more importantly, on how was I going to *make* a dish of even 24 ft diameter and *maintain* the accuracy of the dishes curvature during its construction. And that did not even consider the dish having to maintain that accuracy while hanging up in the sky with gravity trying to sag it, the wind blowing on it, and snow falling in it. The more I crunched the numbers, the more reality set in, and the smaller the dish started looking better.

Three things should be paramount in considering the construction of any big dish

1. Dish curvature accuracy – without it, you are wasting your efforts and money. It won't work.
2. Wind loading, and the ability of the dish to not only continue to maintain its proper position, but also to accurately maintain its shape while under stress
3. Dish and its support structure – it does no good to have the biggest dish on the block if it cannot focus that tiny little signal from space into that little can, (feed horn) at the dish's focal point.

And here are some cruel facts on dish design

1. If the dish diameter is doubled, the accuracy of the dish curvature becomes four times more difficult to maintain
2. If the wind velocity is doubled, the force of the wind increases four times
3. Dish accuracy is also directly related to frequency of operation. The higher the frequency of

operation, the finer the tolerance for focusing those wavelengths to the focal point and, consequently, the more difficulty in constructing and maintaining that tolerance under everyday weather conditions

4. A solid 16 ft dish facing into a 60 mi/h wind, mounted on a 20 ft tower exerts approximately 30,000 lb of force at the base of the foundation, trying to blow it over

Green Bank Ideas

On my second pilgrimage to Green Bank for the yearly 3-day SARA Annual Conference and get together, which I might interject is an absolute MUST if you are interested in radio astronomy. For 3 days, NRAO Green Bank opens its grounds to SARA members to wander about, to ask questions, to touch, peer inside, and drool over some of the finest equipment and moveable structures in the world. It is one of the finest programs offered by a government agency to amateur observers that I know of.

As I wondered around the grounds looking at all the dishes, each unique in design and the cutting edge of technology when it was built, I noticed that each seemed to be grossly overbuilt. These were not your typical scaled up version of a large home satellite dish antenna on a post! The foundations for these dishes where massive, and so was the backing support structure of the dish surface itself.

One of the technicians happened to be in one of the shops working on a receiver for the new 350 ft dish that was under construction. I asked him why things were so overbuilt. He explained the dishes were designed to survive 100 mi/h winds, lightning, rain and light snow. Though Green Bank very seldom gets a heavy snow, it does get its share of thunder storms that attempt to fill the dishes with water, and lightning tries to weld the rotor and elevation bearings into a solid mass. All the dishes are programmed to automatically stop an observation and point vertically to reduce their wind resistance at a wind speeds above 35 mi/h.

He also pointed out the dish drainage system on a 150 ft dish across the way, and the flexible ground straps around the elevation bearings. But, he said, there are two other reasons for the overbuilding as well: One of the biggest problems at Green Bank is ice storms. Ice can build up in the bowls of the dishes to a point where the weight of the ice can permanently distort the dish if it is not backed up by extra structure.

The second reason is due to the dish attempting to distort from their sheer weight and increased wind resistance when they tilt to track a source during an observation. The weight of the bowl is no longer balanced equally throughout the bowl structure as it was when vertical, and consequently it wants to sag.

We are dealing with trying to receive incredibly weak signal sources. If the dish is damaged by ice buildup, or sags when tilted, the antenna is worthless if it cannot completely focus that incredible tiny bit of energy from a source into that horn antenna. In fact, he said, one of the reasons you see so many dishes is that many of these very capable older dishes cannot be focused closely enough to the higher frequencies researchers are using today.

He went on to say that the way the designers dealt with the structural stiffness and bowl tolerances on the new 350 ft elliptical dish, was to cover the inside of the dish with 2500 individual adjustable panels. These panels are continuously scanned by a laser, and adjusted to always keep the dish focused as it is blown by the wind, changes in size due to temperature, or as it is tilted to track the observation source. Otherwise the 17,000,000 lb. structure of the 350 ft dish would be useless beyond probably 450 MHz simply because of the distortion from its weight alone, let alone all the other Nature variables involved. But with the adjustable panels, research can go well into the gigahertz range, and plans are to do research from 450 MHz to 40 GHz, without limitations from dish sagging.

With this information, and several rolls of film taken of the large dishes at Green Bank, I came back home with a dream of building a larger dish....

Preparing to Design

One of the first orders of business was to find out how to structurally design and build one. One of the first books I bought was ***Satellite Antenna Construction*** (Micromod, Los Angeles, California, 1995). It is a pretty worthwhile soft cover book on actually building dishes from 10.5 to 30 ft diameter. It also includes drawings, parabolic formulas, and other tables for building the dishes.

The second book I recommend is ***Structural Engineering of Microwave Antennas for Electrical, Mechanical and Civil Engineers*** (Roy Levy, IEEE Press, 1996). I borrowed this book from the librarian at Green Bank until I found my own copy. It covers just about everything in dish design you will run into. It is expensive, but worth it if you are serious about building your own dish structure from the ground up.

I live in the center of Washington State. The weather here is variable. That is, it has gone down to –25 °F in the winter and up to +110 °Fin the summer. Winds here are a problem 3 to 4 months of the year. My house is on the hillside of a valley and probably 4 to 5 times a year the winds get to 85+ mi/h The reason I say "+" is because the wind speed indicator only goes to 85 mi/h. This is not a good location for a large dish. Down in the valley this same wind is about 35 mi/h.

Snows here can get pretty bad, but with global warming the snow seems to be moderating as the polar ice caps depart. The reason I mention this is you should consider what kind of weather you live in before you build a large dish. In short, can your pocket book and the resulting dish, stand up to the elements? Do not just design for the average weather conditions, *design for the worst*! Eventually Mother Nature will attempt to destroy your dish, usually when you are at work, asleep, or on vacation. If you go to all the trouble to build it, protect that substantial investment in time, labor and money with something designed to meet the weather in your area.

Obviously you cannot design against hurricanes, or tornadoes. That is a risk you will have to live with. However you can design against a thunderstorm, which is the single most dangerous threat your dish may have to contend with. High winds, heavy rain, lightning, hail all balled up in one big event.

The Moving Mount

The next thing I decided to look into was how to move the dish. I considered at one point putting the dish in the ground, like Arecibo (Puerto Rico), but decided against it because the tracking ability was too limiting for my latitude, as well as the other things I wanted to do with it.

I also decided against a dish with no azimuth control. At Green Bank the 40 footer is made available to SARA members at the yearly gathering if it is not being used for research. It is a *very fine top of the line* instrument, recently updated with new equipment. However it has no azimuth (horizontal) movement capability, only elevation (declination). This solves many structural and movement problems involved in building the dish, but it also imposes some severe restrictions on the freedom to point the dish about the heavens at will. A mount with no azimuth control only allows the drift-scanning technique.

While at Green Bank I quickly found out that if I had not anticipated everything I had to do in recording an observation with the 40 footer, I had to wait until the next night for another attempt. Or, if something really interesting caught my attention, I could not continue to track it. So I figured that if I was going to go to all the trouble of building a bigger dish, then it should not be limited in what it could do by its movement.

How to mount the dish came next. In searching the web there were many photographs of various large amateur dishes, some to up 45 ft diameter, and others mounted on 5 in gun mounts! It is absolutely amazing what people can come up with to solve a problem when the need arises and they are determined.

I liked the circular track idea for azimuth control. I still like it. A dish mounted between two A-frames on trucks (wheels) riding on a circular track is a very strong structure. It has the advantage of being able to handle the wind loading better. Plus, it is easier to work on and maintain than a pole structure with the rotor set on top. Access to the feed horn, preamplifier, receiver, waveguides, and position indicators or encoders is easier and safer. Weight is carried by the trucks and not on a thrust bearing. Also, the falling distance to the ground of the person working on it usually is less, which is nice benefit.

On the negative side, the track area takes up a considerable amount of ground space. In areas with snow considerations, keeping the tracks cleared of snow and free of ice can be a problem. An absolute must is a level circular track, and this can be the most serious problem to overcome.

Cabling up waveguides and power to follow the structure as it rotates can lead to some interesting problems as well. Yet building the observation shack inside the support structure for the dish, and having everything go around with it would be an interesting solution to several problems.

The pole-mounted rotor seems to be the most popular, even though it has many disadvantages compared to the A-frame on a track. A pole mount's most practical advantage is its space savings. Its second advantage is simplicity of the structure. A large heavy-wall pipe for the pole mount is much easier to place and build than a *very level* circular track carrying an A-frame structure.

On the negative side, the pole-mounted rotor has several disadvantages. It has an advantage over an A-frame up to a certain size of dish. Beyond that certain size, determined by the dish's weight and area, support pole diameter, weather factors, rotor weight, access convenience for maintenance, etc., the pole mount's advantages of simplicity begins to rapidly disappear.

Not to be forgotten is the foundation block to hold the pole up. This MUST be at least equal to the force of the designed wind loading or, like the old sailing ships, the dish will roll over. Also the lack of stiffness in the pole can be felt not only when you are up working on the system in a mild breeze, but also in the recorded observations on the chart. A larger diameter pole equals a stiffer pole and better observations.

After completing my dish and testing it with a Sun shot. I thought I had an electrical short in something. The wind was blowing about 10 mi/h, and the chart was showing a wavering in the signal that should not have been there. I finally noticed that the TV camera I had mounted at the back of the horn, to track the Sun, was weaving around about one-half of the Sun's disk instead of staying centered during the test. Consequently the signal was wavering as the dish was moved around by the wind.

I finally decided on a pole-mounted rotor. The choice of a pole over an A-frame was made mostly due to space considerations. I built the large dish next to my original setup for the 10 ft dish and 10' by 10' shack. It was located down in the valley in a friend's apple orchard. My friend requested that the new dish lip be at least 7 ft off the ground when the dish was lowered down so he could move his orchard equipment under it without hitting the dish. Also, a cleared area for a circular track for an A-frame structure, he politely hinted, would have cost too many apple trees that were more income producing than a radio astronomy dish.

Wind Loading
Where I worked was an old civil engineer who was also interested in my endeavor. He offered some engineering suggestions on the pole size and base mounting. One of his suggestions was to use fiberglass concrete for the base to resist cracking. Another was to weld five 2-1/2 in x 5/16 in x 5 ft long fins on the pipe that was to go in the concrete to ensure that the pole did not loosen in the concrete and rotate because of heat expansion and contraction. The fins would also distribute the forces out into the concrete better than just the plain round surface area of the pipe.

As a result of this discussion, I used a 17 ft long, 10 in pipe with 3/8 in wall thickness to survive the wind loading. This had a flange welded on each end. The flange at the top end was bolted to the rotor support disk. The other end was bolted to another 7 ft length of the same size pipe with a welded flange. To prevent rotation of the pipe, fins were welded on the piping that was to be cemented into 35,000 lb of poured concrete.

At the base of the pole that connected to the pipe foundation the civil engineer suggested putting another five tapered fins 1/4 in thick and 10 in long, tapered from 1 in to 2 in at the flange end. These would be welded to the pipe and flange surface to again spread the forces on the pole out along the pole pipe, rather than concentrating it at the joint where the pole flange connected to the one in the concrete. He also suggested not to taper the hole for the concrete but to keep the hole sides straight (vertical) to resist the toppling forces on the pole. As he said, shallow rooted trees topple easier than trees with tap roots.

Here are a few cost considerations on the pole and foundation (unfortunately in 2002 US dollars): Three 10 in pipe flanges, $150 each; 25 ft of 10 in dia. x 3/8 in thick pipe, $225; twenty-four 3/4 in bolts, $1 each; flat washers, both sides, 50 cents each; nuts for same, $1 each; 7 cu. yd of fiberglass concrete, $500; and backhoe to dig hole, $65.

Choosing Dish Size

The dish size and what it was to be made from kind of solved itself. After looking on the web for dishes, I found one 24 ft satellite dish made of perforated sheet metal. I called and received a quote of approximately $6,000. This included the post, stand, and the horn, none of which I would use, and I could not buy the dish by itself. I also looked at some 16 ft fiberglass dishes that were nicely made and broke down into three pieces for shipping. These turned out to be $15,000 plus shipping.

I decided to see what the local satellite dish dealer had, but found it was the same stuff at the same price. However, as I was walking out, the dealer asked what in the world I wanted that big dish for? I told him and he said, “I think I have just what you are looking for in a 15 ft dish I have had in storage for 20 years, and never could sell”.

Out in the storage yard was what appeared to be an AFC (Antennas For Communications, http://www.afcsat.com) 15 ft, C- and K-band, fixed mount, fiberglass dish. It broke down into 3 pieces and had a very accurate surface. It also looked like it was built to withstand a nuclear blast. It weighed in at 850 lb without the mount! He said, “It’s yours for $300". I said, “I’ll give you $400 for it, the $100 extra is for a year’s storage fee until I get the rotor mount made”. We both rushed to the cash register before the other guy could change his mind!

The dish was smaller than I really wanted and weighed more than a metal 24 footer by far, but its design solved several problems, one of which was mounting it to the rotor system. This thing had no metal bracing in the back to get in the way. Its strength came from the large oval fiberglass backing ring that served as dish stiffener and mounting ring (as seen in previous picture). Plus the large lips where the two wing pieces bolted together to form the dish helped strengthen the dish, and a 10 in curved lip around the edge of the dish made it extremely stiff. AFC does not make cheap stuff! To top it off, the dish was about 5/16 in thick across the surface, and the backing ring was another 3/8 in thick and about 4 in high x 6 in across. It was an incredibly strong design. It also had a very accurate surface – much better than I could ever hope to match with metal screening.

One thing I could not figure out was how the dish reflected the signal. Fiberglass is not a great reflector of electromagnetic waves – at least not at the water hole frequencies. The answer did not become clear until I finished the rotor and had to cut a 1 in cable access hole in the dish with a core drill. I found that about 1/16 in below the surface of the dish there was about 1/32 in layer of very fine powdered metal embedded in the fiberglass.

Azimuth Control Thrust Bearing and Gear Box

With the dish problem solved, the next problem I faced was a thrust bearing that could handle the weight of the dish, an equal amount of counterweights, the feed horn and preamplifier, power cables and waveguides, the rotor-to-dish support arms, drive motors, gear boxes, junction boxes, etc. The cost of a thrust bearing able to handle all that kind of weight and stress was something I was afraid was going to sink the whole project.

At the time, I was working for a utility company at a large dam. One day I was talking to one of the mechanics during a break and the talk finally came around to the dish, (actually it is surprising how many people were interested in it). I explained the thrust bearing problem to him. About an hour later he called me up and said to meet him out at the company scrap pile at lunch time. When I got there he pointed to a bucket truck which had been used to raise line crews up to work on the power lines. It had been hit by a drunk driver in the side, and the truck was totaled. I said something to the effect of, so what? He pointed to the boom hoist and its thrust bearing. It was *absolutely perfect* for a large dish rotor.

The company had a policy that its employees could buy scrap out of the yard for scrap iron prices. The next weekend was spent tearing the boom off the truck and getting the bearing out. It weighed 175 lb. It was only 3 in thick, and 32 in diameter including the large bull gear teeth machined into the outer race to turn it around. Also included was a very large 23:1 worm drive gear box weighing 240 lb that drove the bull gear/thrust bearing and rotated the boom. The thrust bearing was in perfect shape. The worm drive shaft bearings were damaged from the impact but could be replaced, and the gear case was not cracked.

I looked up the specifications on the bull gear/thrust bearing and found it was rated for 25 tons! The gear box was rated at 18,000 ft-lb of torque with a 40 hp hydraulic drive motor. A side benefit of using this setup was that the worm drive reduction gear box also acted as a positive rotor brake, saving another design headache. With the worm drive torque rating there was no chance of damaging it when holding the antenna in position during very high winds.

I paid the utility company $110 for 415 lb of scrap and rebuilt the gear box for another $275. Another $17 went for a fifth of Wild Turkey to the mechanic who came up with the idea (surprising what a bottle of booze can do in these kinds of projects). A new gear box would have cost $4,300 and a new bull gear/thrust bearing $9,000. Unfortunately this was the last of the gifts from heaven. From then on the merchants in town always rubbed their hands together in wild anticipation when they saw me walk in.

For an azimuth drive motor on the rotor I had a very fine military surplus, weatherproof, 1/4 hp, 115 Vac motor, with 100:1 gear ratio in a very compact setup (figure 2). I had this motor rewired to run in either direction.

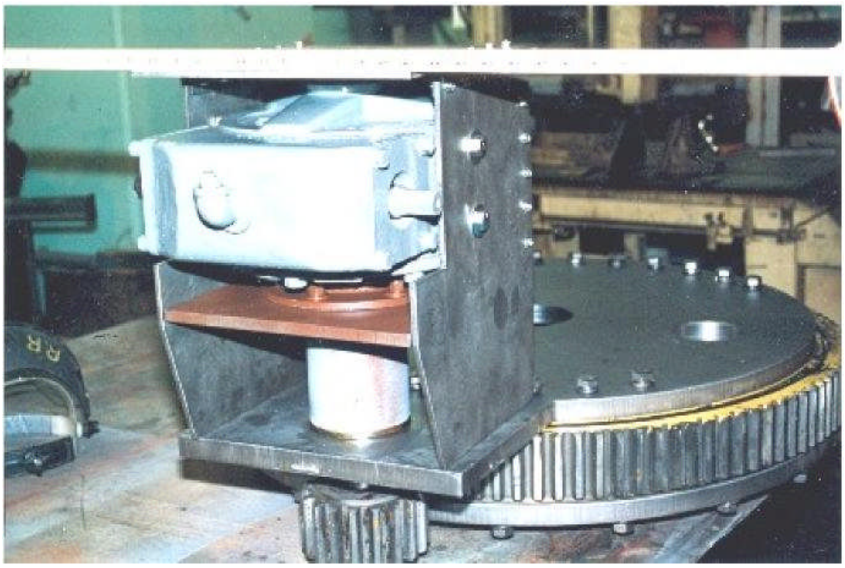


Fig. 2 – Worm drive gear torque box (on left) cased on three sides with 1/4 in steel plate to support and hold the gear box and bull gear/thrust bearing. The pinion gear shaft housing (approx 4 in diameter) is pressed into an approximately 4 in hole bored in the 1 in thick upper plate over the thrust bearing to handle the gear box thrust. The back of the gear torque box housing is open for adding oil and inspecting. A yardstick is placed on the top of the gear torque box to indicate scale.

I attached a 2:1 sprocket and chain drive to the azimuth motor output shaft. This drove the input shaft on the worm drive reduction box for another 23:1 reduction. The output shaft pinion of the worm drive then drove the bull gear on the thrust bearing at a further reduction of 7:1, giving a total reduction ratio of 230:1. The 1/4 hp motor had no problem turning the rotor under any condition. It also worked out coincidentally to rotate the rotor at 1r/min, which worked perfectly – it was fast enough to move the antenna around in a reasonable time, but not too fast to allow for fine adjustments. The modification costs were $45 for the motor rewire and $40 for the sprockets and chain. The motor had been gathering dust for 15 years waiting for a worthy project.

The thrust bearing had been attached to the original bucket truck bed with sixteen high-grade, 5/8 in diameter bolts on each side of the bearing. Measuring and drilling the holes for the bolts in the plate was no small project. I did this after hours by using the utility company's equipment that was made for doing such things.

Each plate weighed 170 lb. The center of both plates was bored out with a 4 in hole for the cabling and wave guides to run up through the pole to the rotor system and antenna (figure 3). At the time I thought a 4 in hole would be more than adequate. By the end of the project these holes were *just* big enough to squeeze everything through with sleeving, which I used to protect the cabling from chaffing on the plates as the rotor turned.

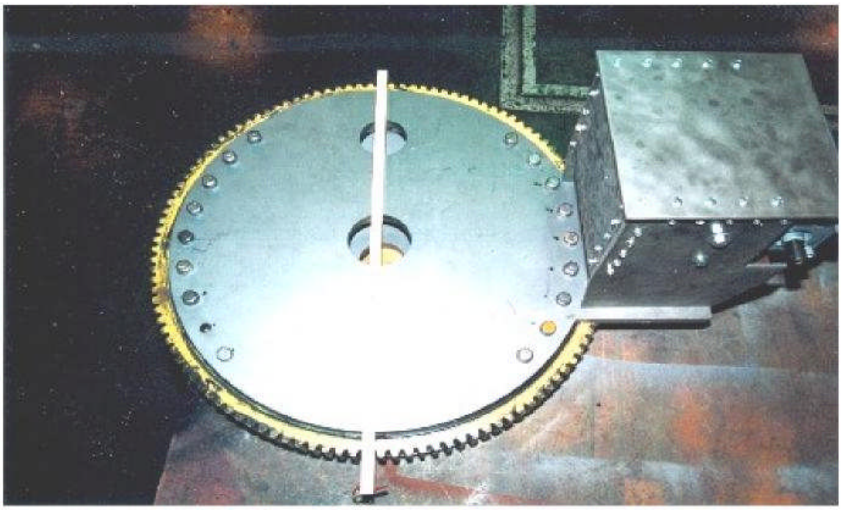


Fig. 3 – Top view of bull gear/thrust bearing and worm drive torque box. A 4 in hole in the center of the 1 in thick upper thrust bearing cover plate allows the control cables and waveguide to pass through. The upper 4 in hole is to access the bearing grease fittings. The thrust bearing is a ball bearing ring design. Measuring in from the gear teeth it is only approximately 6 in wide. It is a beautiful design for an antenna rotor. A yard stick is placed across the center of bearing for scale. To attach the bottom of the bull gear/thrust bearing to the pole, and then attach the bull gear/thrust bearing to the upper part of the rotor, I had two 1 in thick x 30 in diameter steel disks flame cut out at the local steel supplier.

The lower plate attached to the support pole, so I also had to bore out twelve holes for bolting the pole flange to the center of the plate. These were placed around the 4 in hole that the cabling passed through. I made all the bolt holes in the plates slightly oversize to allow for measurement errors, temperature changes, bolts not being exactly the same diameter, etc. This had an unexpected benefit. When these plates were being lowered by the crane onto the pole in a slight wind, while trying to control and bolt up a swinging 170 lb plate next to your head, it is nice when the bolts slip in perfectly.

On the upper plate I made a 1/4 in thick steel box to protect the worm drive from the elements and to hold it so it did not rotate from the worm gear torque. The problem was made worse by the fact that I might need to pull the gear drive someday for repair. As a result I could not just weld up the entire box. On the other hand, the box had to be strong enough to resist the tremendous torque and not be torn off. I got around the problem by first making all the sides of the box fit together very tightly. I left the back end open for access and oil addition. I spot welded a 1 in angle piece along the entire length of the inside of each side plate where it would bolt up to the end plate. This was done with the box end piece clamped in place to ensure an accurate fit before spot welding the 1 in angle iron on one side.

Holes in the top and back plates of the torque box had already been drilled for hex head sheet metal screws. Next, the holes in the angle iron were drilled using the holes in the end and top plates as a template and drill guide. The box was then bolted-up to the gearbox mounts, the end and top of the box bolted up, and then the two sides of the box were welded to the upper 1 in angle.

The reason for all this care was a 1/4 in thick plate that was being welded to a large mass of 1 in thick plate. Unless the box was well fitted together and rigid, the individual 1/4 in side plates would have been warped totally out of shape as they expanded from the heat of the weld bead while the heavy plate warped very little. If the welding of the unit had not been done this way it probably would have been impossible to get the box sides to match again after welding and to bolt up accurately with the rest of the box.

Elevation Control
Moving the dish vertically presented major problems. To simplify things I decided to use a motor operated screw-driven ram. This choice was based on the fact that it is simple, rugged, powerful, and very low maintenance. Plus, it could be designed to reduce the strain on the dish support arms by applying the dish's lifting and lowering forces at a point directly behind the dish rather than through the dish support arms. This created a 3-point support system for the dish rather than the 2-point system using just the dish support arms. It also made the dish much more stable and resistant to the wind and other forces acting on it.

In designing a rotor system there is a tendency to focus all the design considerations on the weight of the dish and forget about the relatively light objects to be hung way out beyond the dish surface; for example, the feed horn and other equipment at the dish's focal point. Obviously, in comparison to the weight of other major items, the microwave feed horn, waveguides, and preamplifiers seem like nothing. However they have a surprising effect on the rotor performance because of the distance of this equipment from the dish's pivot point on the rotor bearings. These little items can exert a surprising amount of leverage, not only from their weight hung way out there, but also from their inertia when being started or stopped.

As an example of this force, a weight of 1 lb at a distance of 1 ft equals a moment of 1 ft-lb. The dish focus is 11 ft. from the rotors bearing supports. The feed horn I used was a very good one. It was almost 2 ft long and had a scalar ring almost 16 in diameter. Added to this was the weight of the preamplifier, a junction box, TV camera, waveguide, power cabling, mounting ring, and transmit/receive switching relays. I ended up with 22 lb of equipment hanging out in space beyond the focal point. This translates into a minimum of 222 ft-lb of leverage alone, excluding any inertial forces generated when the dish was moved up or down or horizontally!

To handle moving the dish vertically, I used a ram powered by 115 Vac that exerted 1600 lb of force and had a 36 in stroke. The 1600 lb of lifting force may sound excessive, but it was not. It allowed for the weight of the dish and dish support structure and any wind acting on the dish while it was being moved. It also held the dish in position during windy conditions with the same amount of force.

Normally the dish and support arms are balanced with counterweights of equal weight, resulting in a lightly loaded elevation drive system. During movement of the dish, the drive system is only overcoming any weather effects on the dish. However, when the dish and rotor are being assembled, the dish will have to be moved to attach the counterweights. To do this, the ram (or any other type of lifting mechanism) *must be able to move the entire weight of the dish, or its counterweights, and its support structure, unbalanced*!

The only problem I had with the screw drive setup was that it was slightly too fast in moving the dish up and down. This sometimes made fine elevation adjustments difficult. It was not the fault of the screw drive; it was my fault in ordering the wrong drive speed. Sometimes slower is better, especially when only driving through a 90 deg. arc.

No matter what method is used to elevate the dish, I would *strongly* suggest that it lock in position when the movement stops, power is removed or during a power failure, so the dish will not move. Do not rely on applying a manual stop or brake!

Also I would recommend a couple of other features be included. In the event either of the drive motors failed, I wanted to be able to move the dish manually. Consequently, I had an option included in the ram so that it could be operated manually if necessary. This was inconvenient to do with a wrench, but as a last resort, it allows you to get the dish and your investment out of trouble when nothing else works. The azimuth rotor worm gear box also had a manual (wrench) option already built into it.

Another must is a *reliable* over-travel limit or cutout. In the case of screw drives it is possible to unscrew the ram out the end of the support tube if there is no limiting device to stop its extension. Needless to say, it is not good for the shape of the dish if it is dropped down into the support post because the elevation drive ram over extended and dropped out.

More than once the elevation cutout saved my dish because I had become too focused on following the source I was tracking and not paying attention to the dish position. This same logic applies to azimuth rotor limit movements. There is nothing like shearing off the waveguide or power cables because you hit the wrong direction button accidentally, or you were not paying attention to the dish position and started the dish around a second time!

I found several of the designs that were powered by hydraulics. In my case I liked the idea very much but because of the heat and cold where I live, I felt it would cause too many problems. Of course, using a screw-driven ram is not the only way to move the dish up and down. Looking on the web at what others have come up with for moving their dishes shows what can be done especially when driven by the need to accomplish something.

Fig. 4 – A-frame dish support shown in vertical position with the vertical actuator ram fully extended. Also shown is the I-beam coupling of the A-frame to support shaft. The counterweight arms are attached to back side of the I-beam. The work platform shown at lower-right behind the azimuth drive was awfully small when the rotor was mounted on the pole and the wind was blowing.

Some of the aspects of using hydraulic systems were very attractive, such as almost unlimited ram power. Also, the costs of hydraulic rams are considerably lower than electric screw drives. However, hydraulic systems require a pump and motor, an oil reservoir and the associated plumbing. Also, an interface is needed for the dish position control circuit to change the electrical signals into hydraulic movement. That was beyond my monetary means, so I decided it would be cheaper and easier to use a electric screw driven ram. However your experience, needs and luck in finding something else to do the job could lead down a whole different path.

The cost of a new 36 in electric screw driven ram, with a manual emergency operator, a ram travel position limiter and position locking brake was $1800. I would not recommend buying these screw drives USED unless you really know what to look for. A lot is riding on it.

Dish A-Frame Support

To support the dish, an A-frame design was used with the large end legs attached to the dish mounting ring with eight 3/8 in bolts (figure 4 and 5). The support arms were 2 in x 4 in x 1/8 in wall thickness rectangular steel tubing. For extra stiffening and to dampen any side-to-side forces acting on the dish, each leg on each A-frame was cross-tied to the other with the same stock. The lower cross-tie was cut and rewelded to allow the screw driven ram shaft to pass through without interference.

To support the dish, its supports and an equal amount of weight in counterweights, a 2 in diameter stainless steel shaft was used (stainless steel was used to eliminate rusting). The shaft rides at each end in two 2 in tapered roller pillow block bearings. Each bearing was rated for 2 tons of rotating load.

To attach the dish support shaft to each of the dish and counterweight arms, I used a 6 in I-beam, 12 in long, as a mating surface between the two opposite support arms of the counterweights and the dish.

These were bolted together with sixteen 5/16 in bolts. The center of the 6 in I-beam was bored out to receive a 2 in collet-type shaft coupling. This was then bolted to the I-beam with the six high tensile strength bolts that came with it. This method of attachment allowed the I-beam to be slipped on the shaft and aligned with the support arms from the dish without having to be concerned with aligning key ways, or pinning the shaft.

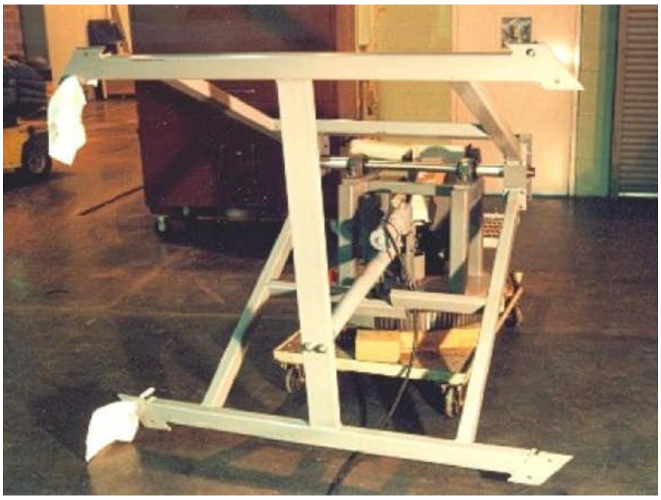


Fig. 5 – Rotor and dish support arms in the shop. The dish attaches to angled points on the dish support A-frame with eight 3/8 in bolts. The rags hanging on ends were head and ankle reminders to compensate for my mind thinking of other things. Rags were finally installed after several bloody encounters

Once the shaft coupling was aligned to the support arms, the coupling bolts were tightened down (figure 6). This clinched the coupling collet down on the shaft with a tremendous locking force and without weakening the strength of the shaft with key ways or holes for shear pins. This design also had the advantage of being *relatively* easy to remove without scoring the shaft. However, if in your design the lifting torque for the dish arms is applied through the support shaft, key-ways will be needed to prevent slippage. The torque required will be too high to rely on friction alone between the shaft and the coupling.

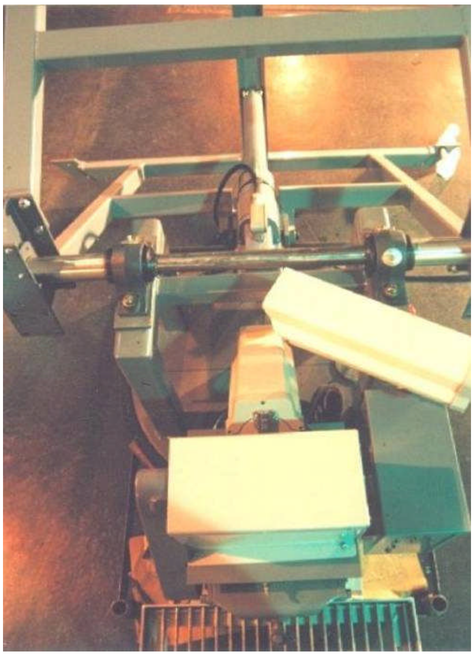


Fig. 6 – Looking down on the rotor. This view shows the two long rectangular TV camera (right and middle) explained later. One camera is looking down directly at a large drafting protractor ring around the center cable hole for the waveguide and power cable. The other is mounted about 45° to the support shaft looking at another large protractor to be mounted on the support shaft. The gray box to the right of the azimuth motor cover (lower-right) is a junction box for the control, power, and TV camera connections.

The support shaft was kept aligned between the two pillow block bearings with two shaft keepers on either side of each pillow block bearing. These were held in place with two large setscrews per keeper and seated into small dimple holes drilled in the shaft after everything was aligned.

To connect the support structure to the upper rotor mounting plate, two bearing support structures were cut and welded into an inverted U-frame out of 2 in x 2 in heavy walled square tubing (figures 7 and 8). The legs of each U-frame were welded to the rotor mounting plate, and then two 1/2 in holes were drilled in a cross piece on each of the U-frames for mounting of the shaft bearing pillow blocks with high tensile strength bolts. As an afterthought, the two U-frames were cross-tied under the shaft with another piece of tubing to prevent any side-to-side forces on the supports from being transferred onto the dish support shaft. This is a good idea when dealing with a lot of rotating inertia.

Counterweights

The counterweight arms were made of the same stock as the dish supports. Two cross-braced arms each carried a 450 lb. piece of 10 in diameter shafting cut from a small scrapped out hydro generator shaft. The length of each counterweight support arm was the same length as the dish arms. Each counterweight support arm weighed 50 lb without the counterweight attached.

The counterweight arms had two minor design flaws, both of which did not show up until the project was completed. The total weight of the counterweights and arms added up to the same weight as the dish, 850 lb, but I had forgotten to allow for the weight of the equipment at the focal point. The feed horn supports, quite a bit of cabling and the waveguides run from the pivot point of the dish support shaft out to the focal point. Surprisingly, I had to add another 200 lb of bagged lead shot to the counterweights to overcome the leverage and balance everything out (figure 9).

Fig. 7 – The U-frame shaft supports are welded to the 1 in upper support plate. On top of the U-frames is the support shaft for the 2 in diameter dish arms. The vertical actuator ram (vertical shaft on left) is mounted on two 1/2 in x 3 in plates welded to the upper 1 in support plate. The ram pivots are mounted in 1 in sealed needle bearings. Needle bearings can carry a high load for their size.

It would not appear that a 200 lb of unbalanced load would be noticeable but it is when a ton of equipment is mounted up on a 17 ft pole. Small deflections become evident in the setup as the dish changes position from vertical, where all loading is straight down the support pole, and horizontal, where the imbalance due to the leverage I discussed earlier shows up and tries to topple that balanced ton of weight off the top of the pole. The deflection of the support pole was hardly detectable and was a lot less than normal wind loading, but it was enough to let you know things were not quite as they should be.

Fig. 8 – Rotor set up for testing. A sheet metal dust cover at bottom of the assembly is covering the thrust bearing gear teeth to lessen dust getting into the heavy grease that coats the gear teeth and to keep snow and ice out of the teeth. The coil of cable on the worm gear torque box is for testing and not used in the finished rotor. The dish supports and counterweight arms bolt to short I-beam sections on either side of the horizontal shaft. A 1/4 hp azimuth drive motor is mounted on top of the worm gear torque box and drives it through a chain drive. The worm gear drive and bull gear can handle 18,000 ft-lb of torque.

The second flaw to show up was not cross-tying the two counterweight arms together. This was because the counterweight arms were located on either side of the support pole when the dish was in the vertically stored position. This problem did not show up when the dish was moved up or down. However when the dish was rotated around, even at 1r/min, and came to a stop, the momentum of 1000 lb of counterweights deflected the counterweight support arms from side to side about 2 in. Again, it was nothing serious, but it was just one of those things that needed to be improved upon.

I had included a local control station at the bottom of the support pole in addition to the main control station in the shack. When rotating the antenna from down at the local station at the base of the pole and with the counterweights passing overhead, there was cause for one to contemplate how well the counterweight arm welded joints were handling the slight side-to-side swinging stress. If I had it to do over, I would have cross-tied the arms together with a bowed cross piece that passed around the support pole. In comparison, the dish was as solid as a rock because of its support cross-bracing.

In Control

For controlling the dish movement and position I looked into several methods and ended up with probably the simplest. Though the design was not the best for accurate positioning, it was reliable and used a minimum of hardware. It was also very low maintenance and allowed for future improvement using the existing cabling.

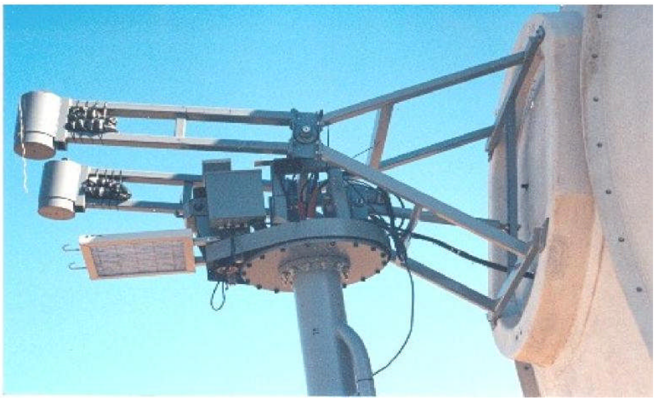


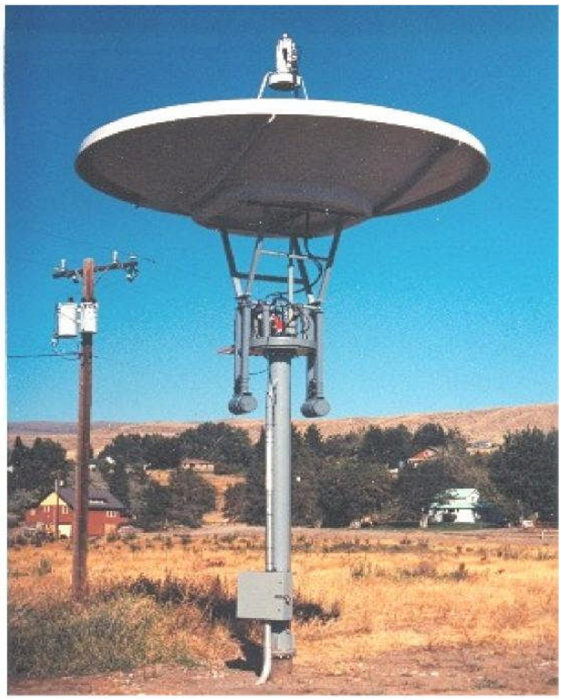
Fig. 9 – Rotor assembly showing the large fiberglass mounting ring built into the dish antenna on the right. Dish support arms, finished rotor and cabling. Also seen are counterweight arms and 450 lb counter weights on left. Objects to right of each counterweight are 100 lb packages of lead shot to balance *additions* to the feed horn. The platform directly below the counterweight arms provides access to the rotor and has hooks to catch and hold the ladder rungs. The white ribbon on nearest counterweight is a wind indicator. Although the counterweights balance the dish, the horn and extras have almost a 2:1 leverage ratio hanging out in front of the dish. Little additions really add up fast!

Designing electrical circuits is not my cup of tea. I would rather vacuum the house or pull weeds, and I am not very fond of doing either one. This has always made me wonder why I ever got interested in radio astronomy and amateur radio. Probably two of the longest running hobbies I have ever enjoyed.

I wanted a positioning system that would take advantage of the rotor's power and positioning capabilities. I took a very serious look at using encoders for rotor position feedback. Unfortunately, at the time, I had to downgrade. Setting up an encoder system was too complicated, especially combined with an automated computer control for tracking. This, of course, is the way to go, but was beyond my circuit skills and budget at the time. Many of you will have no problem in this area, but I have this genetic defect when it comes to these kinds of things.

Until I could not only afford but also could come up with an encoder system, I decided to use TV cameras for looking at large degree indicating wheels positioned on the rotor. Today's small TV cameras are relatively inexpensive, very reliable, rugged and have very good resolution for the cost. To get the desired position pointing capability I bought two of the biggest protractors I could find at the drafting supply store. To sharpen the focus and thus the position accuracy, I bought two macro lenses for the azimuth and elevation position TV cameras. These lenses worked great and allowed the pointing accuracy of the rotor to be compatible with the dish's beamwidth capability. A third weatherproof camera was mounted on the end of the feed horn looking along the antenna beam. All the cameras were low light, auto-iris, black-and-white cameras with 420 lines of resolution. These cameras are fed into a multiplexer so I could display all three images on one 21 in black and white TV monitor screen.

To control the rotor motors, each of which operated from 115 Vac, I decided that, if I had to do the positioning manually, I would keep it simple and use push-button switches. These were not Radio Shack switches but were industrial grade control push-button switches that could handle the motor's starting current. The switches only operated the motors when they were depressed, thereby giving fine positioning



control. They worked fine, eliminated relays, and the contacts never welded. I used eight of them, four in each of the two control stations, for up, down, clockwise, and counter-clockwise rotor movement. Although the positioning system worked great, and never caused any problems, it was labor intensive, more so than I thought when I was building it. The main problem, disregarding the almost constant adjusting for the Earth's rotation, was due to the dish's narrow beamwidth.

Fig. 10. – IT IS DONE! The 24 ft dish antenna on its support poles with the rotor system and associated structure

As the dish size becomes larger or the frequency is increased, the beamwidth of the dish becomes smaller, and the sensitivity and resolution increases. The rate of adjustments needed to keep the dish beam on the source also increases proportionally. A manually adjusted system eventually becomes impractical, and I would say a 16 ft dish approaches that limit. Though my TV setup worked fine for drift scanning, it left a lot to be desired when it came to tracking a source. It should be kept in mind, that *across the antenna's beamwidth* is a bell curve of sensitivity, and the center portion of the hump of that curve is the goal of the tracking device. You are losing the reason for having a larger antenna if you cannot track to the dish's full maximum beam sensitivity capabilities. Today it is possible, and it will be well worth it.

Fig. 11 – Completed dish in vertical storage position. Cabling ran underground from the shack in a 4 in pipe to a junction box, then up the side of the pole to just below the rotor, where it went into the pole and up through rotor support plates and thrust bearing to another junction box for motor controls. The waveguide continued out to the antenna horn.

When I started the project I fully expected to have it up and running in 6 months. It actually took a year-and-a-half. I had some advantages that some of you may not have. For example, I had access to equipment at my employer and used the workshop to do most of the work. I have a pretty good shop at home but I needed more space. Plus, when you are moving some of the counterweights described here, a big hoist is a must, along with a place to attach the hoist that will not bring the roof down, thus helping to keep peace in the family.

Willpower Makes a Way

This is not to say you cannot build your own dish if you do not have these things. WHERE THERE IS A WILL, THERE IS A WAY. If your will to build one is strong enough and you want one bad enough, you will do it (figures 10 and 11). As I said, look on the web at all the amateur dish antennas. Then keep in mind that Noah built the Ark without a power saw! If you can believe that! And historians are still trying to figure out how the Egyptians moved all those blocks of stone around to build the Pyramids. It is a shame the Egyptians were not into parabolic dishes back then.

I would gladly have included some prints and drawings of the rotor design in this article but there are not any – just these photographs. The project came together as the pieces appeared and as the problems were solved. Ideally I should have made drawings, bought the needed items, and built it. Normally I do that. However on this project I started with a dish and a thrust bearing, and things were just adapted to fill in the need between the two. I do not believe this is necessarily a bad way to go, at least for building this kind of project, where you are adapting things as they become available to meet the need.

Tips

1. Get or build the dish, or know the size and the exact weight of the dish you are going to use. Figure wind loading, etc.
2. Get the thrust bearing. This is the key piece **-** *it makes or breaks the entire project*, literally! Mine is called a slew bearing. They come in all different sizes
3. Cranes are expensive, so over design everything for reliability that will need a crane to service or repair. Besides, Mother Nature will do her best to try and tear down everything
4. Always look ahead on the project. I have mentioned some examples of where I blinked
5. Build your dish where it will never have to be moved during its lifetime. It is kind of like planting a tree. Once located, it is a real problem to move, especially with a 35,000 lb. block of concrete attached to the end of it.

The fifth suggestion on antenna placement is interesting. You might have noticed that this large dish project is often referred to in this paper in the *past tense*. The day before the dish installation was completed I was notified that the property I had put it on was going to be sold. The apple market had gone in the bucket, and the profits from the apple crop would not even pay the property taxes on the orchard and the spraying. However, I was told that it would probably be 2 or 3 years before the property actually did sell because it was riverfront acreage and, consequently, it was very expensively priced.

To everyone's surprise the property sold in 3 months. The new owner was nice enough to give me until the following spring to remove the antenna. I have not put it back up and it has been stored in a shipping container for the last 7 years. It awaits a computer tracking setup.

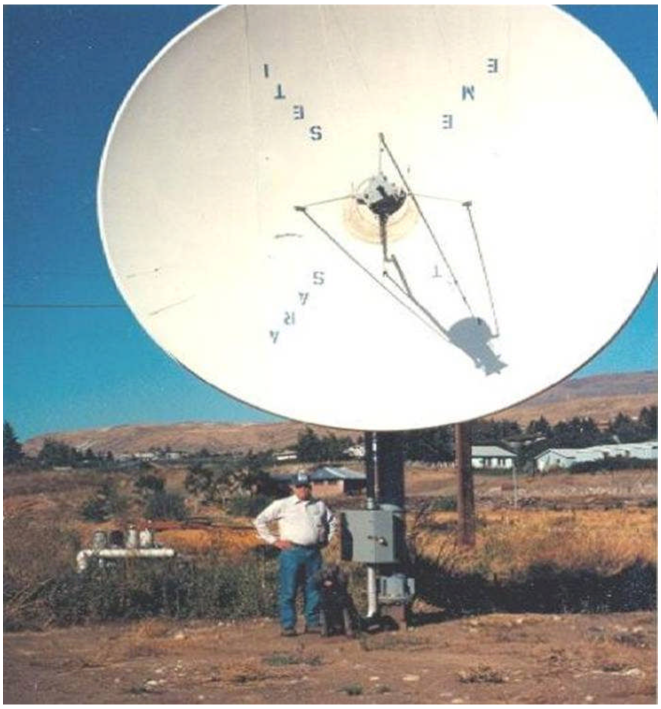


Fig. 12 – The *new* 16 ft antenna, author, and his wonder dog Boab, an 80 lb Poodle, in 2002. Compare to the old 10 foot antenna in figure 1.

Let the Fun Begin

Building a large dish antenna is not only a challenge. There is a lot of fun and self-satisfaction in doing it. Much to my total surprise, the neighbors around the area actually loved it! It was something different that people found interesting and were very curious about. Several times when the moon was up, I would turn on the transmitter and let them listen to an echo ping off the moon. You could see for the first time in their lives they could suddenly relate to the speed of light. As they looked at the far off moon and I pressed the transmitter key, they then heard the ping return 2-1/2 seconds later. The same wonder applied if they were just listening to the sounds of the stars, or the Sun for that matter, if the moon or stars were not up.

It was interesting for me to watch their faces change to an expression of fascination, and yet know I was seeing a reflection of myself in their faces. Letting them experience what radio astronomy was all about also apparently had an unexpected side benefit in that there was never any vandalism done to the antenna. I had fully expected some with it sitting out there in a field all by itself.

I would find footprints, bicycle, and motorcycle tracks in the dirt around it, but there was never any painting, shooting or attempts to climb it. The neighborhood around the area watched out for it because they liked it. It was also used as a direction finder to their houses and was quite the conversation piece of guests visiting them. The dish's picture even made the front page of the local newspaper.

If I were to build another one, I do not think I would change much of anything except for the items I mentioned that needed to be improved. It was a good, strong design that worked very well (figure 12). Give one a try.

About the author: Cliff Bates became a Ham in 1992 as a Tech Class because of an interest in chasing Ham satellites. This led to his meeting Richard Flagg, A6HNM, on a ham satellite AO-13. Dick created a further interest in SETI, RA and EME. Cliff retired in 2002 as a Chief Hydro Operator, (controlling the electrical power generation of several of the dams on the Columbia River) after a 35 year career in just about all aspects of electrical generation. However, Cliff is not electronically inclined in the least with smaller voltages. He likes to design and work with large mechanical things, not electronic circuits. However his interest in RA and EME forced him into the uncharted waters of electronics, where Dick Flagg, Chuck Osborne, Jeff Litchman, Tom Crowley, (all SARA members or founders) were "ALWAYS" there to answer his questions. This has caused him to write several "how to" articles about RA in gratitude for their help. Their knowledge was absolutely stunning in their fields, and yet with all their knowledge, they all have the capability to relate their answers to the knowledge level of the individual asking the question – a very rare gift of great teachers. What you read here is about Cliff's experiences in RA, but it is THEIR time and effort in showing him *The Way*, that *truly* made the projects happen. Otherwise they would have remained a dream.