N6RO 10/6/80m Tower Upgrade Project Planning

Gary Johnson, NA6O
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"Poor performance is the promise of piss-poor planning!" thundered Jim Bradford, my instructor in a project management class in 1982. He was right of course, and as a young engineer at LLNL taking that to heart is something that helped to make me successful in my career. So how does planning pay off on a ham radio tower project? And what kind of plans are the most useful? This report covers my recent experience on a major tower upgrade at the N6RO super station.

Ham radio towers are high-performance engineered structures. They are expensive, require much labor to install, and demand a certain level of care during design, assembly, outfitting, and maintenance in order to keep them safe and to achieve a long service life. We all have stories of backyard towers thrown together with nary a clue by their owner, sometimes with disastrous or even fatal results. A bit of education and planning can make any project go well.

Background

For many years, station owner Ken, N6RO, had wanted to add a high 80m dipole to his arsenal. One might wonder why that would be appealing, considering his existing 80m antennas: A full-sized four-square plus a pair of two-element bidirectional quads, designed by Dean, N6BV. These antennas have served the station well for decades. The four-square is known to perform very well in contests, with low-angle radiation and a decent pattern that helps reject QRM. The quads, with horizontal polarization, were quieter as receive antennas and had good patterns but didn't always compete quite as well. They were also somewhat difficult to tune.

Now consider the simple dipole. When placed at least a half-wavelength above ground, it will provide good low-angle radiation for DX with the benefit of roughly 5-6 dB of additional gain due to ground reflections that you only get with horizontal polarization. In fact, that gain will be superior to the four-square. It will also likely have lower receive noise compared to the four-square—more like the quads. Predicted patterns are shown in Fig. 1. The one disadvantage of a dipole is its lack of a strong azimuthal pattern. But the overall gain and elevation patterns look very encouraging.

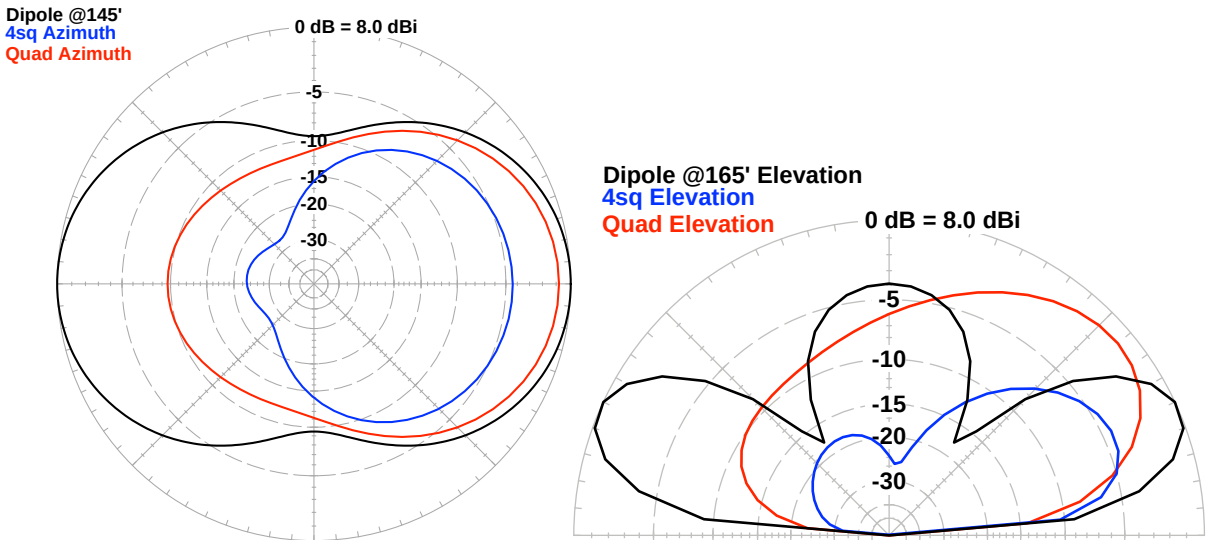

Figure 1. Far-field patterns for the three 80m antennas. Simulated in EZNEC Pro2+ using actual dimensions and specifications of N6RO antennas.

Notionally, the new dipole, a JK Antennas JK-801 (Fig. 2), was to be installed on the existing 10m/6m tower which stood 83 ft tall and was built from Rohn 45G in 2011. It was outfitted with a stack of three 10m Yagis plus a 6m LFA and a 6m loop antenna. All of those antennas were to be reinstalled after extending the tower to a height more suitable for the dipole: 133 ft, plus a mast extending another 13 ft. As a bonus, that tower is located on a small hill, effectively placing the new dipole an additional 20 ft above average terrain... Nearly 165 ft up. That is definitely a good working height.

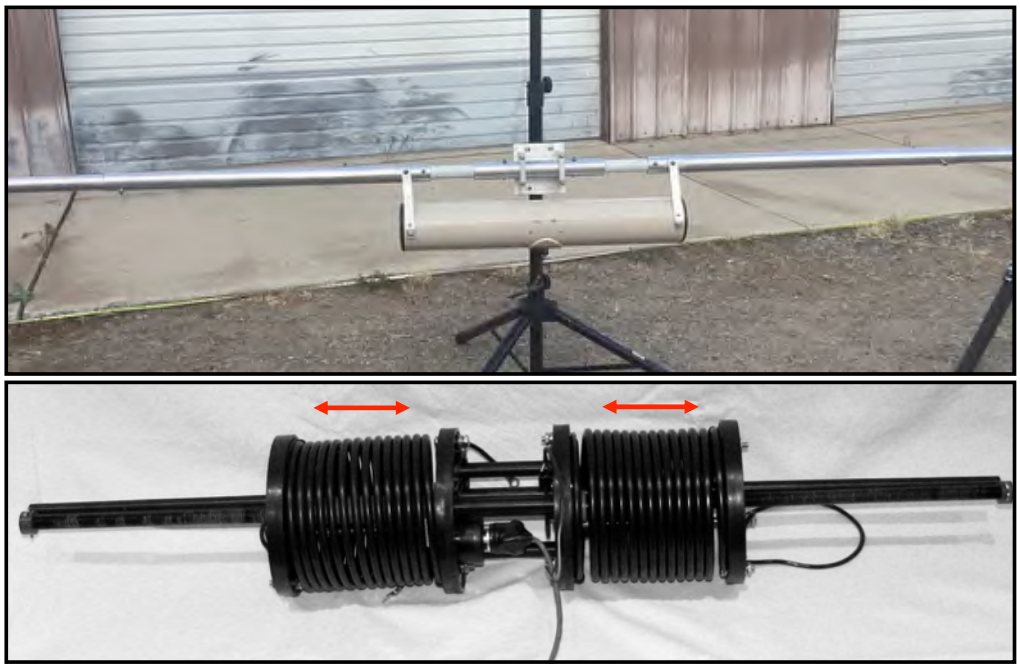

Figure 2. The JK-801 80m dipole (top) uses a Tornado Tuner (bottom) to cover the entire band. A small DC motor compresses the loading coils to vary inductance.

Let the Planning Begin

We started by discussing the objectives and various tradeoffs, focusing on antenna types and heights. The dipole was the primary new antenna and drove the specification for ultimate tower height. Existing antennas were all to be reused, with the addition of one more small 6m Yagi. Exact heights are influenced by the location of guy wires, but there is some flexibility. Next, we looked at various options for coaxial feedlines, switching, and control cabling. There is a single 7/8-inch heliax cable feeding the entire tower (200 ft from the shack), with a remote-operated antenna switch. An additional run of coax was needed for 80m. We use a stack match for 10m, and the various 6m antennas are individually selectable. While there are many ways it could have been done, this simple architecture leveraged existing equipment, cabling, and controls, and considered station operating style. Experience with failures of stack match relays drove us to install that device at the bottom of the tower. Predicting maintenance problems is worthwhile at this stage of planning.

Simulation should be part of your initial planning. Radiation patterns as shown above are produced by electromagnetic simulators such as NEC and are indispensable for comparisons and when developing homebrew antennas and special arrays. Another tool is High-Frequency Terrain Assessment (HFTA), available free through ARRL and included with their Antenna Handbook. HFTA generates the vertical radiation pattern of horizontally polarized antennas taking into account the profile of the surrounding terrain. It's useful for optimizing antenna height. Note that it does not work with vertically polarized antennas.

An underappreciated factor in preliminary design is **equipment availability**. At the time of this project, there were global supply chain problems and prices were rising fast. You can't assume that your favorite selection will be delivered on time (or at all), let alone at a fair price. We teamed up on the online shopping and phone calls to locate all the hardware. Friends in NCCC and local clubs also helped out. Our tower climber, Hector, XE2K/AD6D, had some tower sections and other hardware for sale as well. Coordinating with his schedule was also a very important factor. Hector is about the only fully-qualified ham tower worker in our region and only makes a couple of trips up here each year. So it was even more important that all items arrived on time.

This leads us to the **Parts List** (Fig. 3), one of the easiest planning tools. Use a spreadsheet to list every item in the project, even the smallest. Show the quantity, manufacturer, part number, supplier, cost, and delivery status. You'll start with the big, obvious things like tower sections, antennas, rotators and so forth. But don't skip those tiny parts like nuts and bolts that can bring you to a (very expensive) halt with the climber up the tower. Keep your list constantly updated and shared with others on the project. *Google Sheets* is one way to do live sharing.

Description	Mfg	P/N	Source	Quan.	Cost ea	Cost ext.	Status
80m dipole	JK	JK80I	JK Antennas	1	$ 2,639.00	$ 2,639.00	
Rotator controller, for Tornado	Green Herron	RT-21DC	JK Antennas	1	$ 449.00	$ 449.00	
Rotator	AlphaRadio	Big-RAK	DX Shop (UK)	1	$ 1,000.00	$ 1,000.00	
Rotator controller	Green Herron	RT-21	Green Herron	1	$ 599.00	$ 599.00	

Figure 3. The parts list keeps track of every item.

When all those parts start arriving, do a careful **inspection** of each package. Count all the parts! We were caught short once simply because the supplier didn't quite fill the order. Here's an old saying: "You don't get what you EXpect, you get what you INspect."

Drawings and Mechanical Design

A **scaled drawing** of the tower and antenna design is very useful.

- It clearly identifies each component and its location.
- Your tower contractor and all team members will understand exactly what is planned.
- You can look for interference with the guy wires or other elements of your plan.
- It helps you inventory the required hardware.
- You can obtain cable lengths with good accuracy, allowing you to prefabricate them.

Even a pencil sketch on grid paper is helpful, but in our modern age it's reasonable to use a CAD or other drawing program on a computer. Fig. 4 shows the elevation drawing for the N6RO project. All drawings are stored in a folder on Dropbox for ready access at the station and other locations.

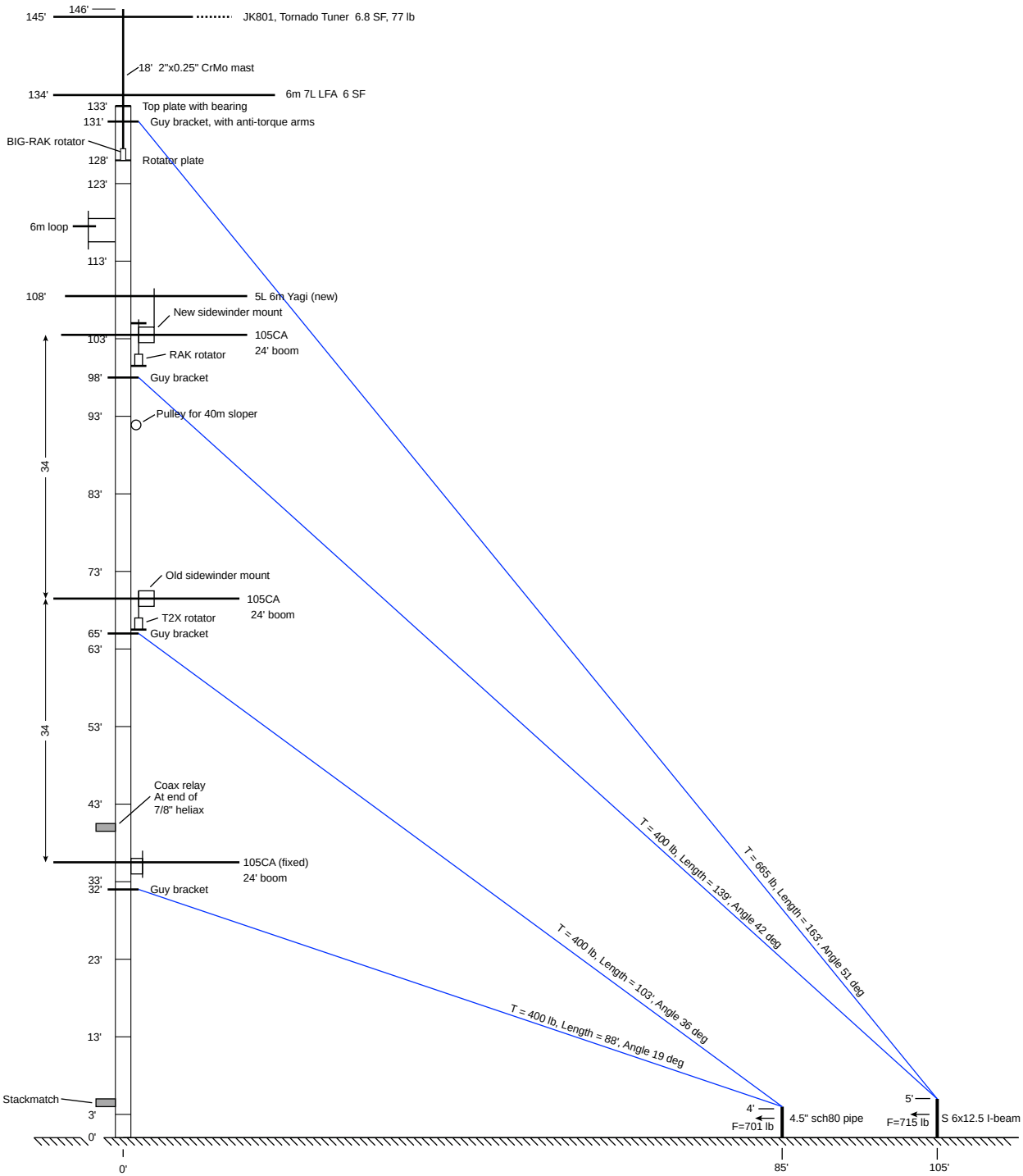

Figure 4. Tower elevation. This scaled drawing is the foundation of the entire project.

As I mentioned, towers are high-performance mechanical structures. Manufacturers supply clear instructions on how their tower products must be installed and how much load they will support. You must understand and follow these specifications. Before you do anything, be sure to get up to speed on recommended practices in tower work. I can recommend two books: *Up the Tower* by K7LXC [ref 1] and *Antenna Towers for Radio Amateurs* by K4ZA [ref 2]. We used the Rohn 45G guying specifications for heights and tensile strengths of the guys. To reduce interaction

with antennas, upper parts of each guy are Phillystran, a Kevlar-based material, while the lower parts are the usual extra-high strength (EHS) steel wire for fire and abuse resistance.

One challenge on the N6RO property is that it's covered by a working vineyard, and tractors are driven around regularly. For that reason, the guy anchors are elevated. A couple of new anchors were needed, so I did a structural analysis to determine the size of an I-beam that would support the full tension of a set of guys, and also chose a conservative reinforced concrete base design (Fig. 5). Most hams should consult a qualified engineer to come up with a safe design for such anchors, if not using the manufacturer's standard design.

Figure 5. New guy anchors have a substantial rebar cage in the base and use galvanized I-beams that are designed to handle the full load with a large safety factor.

Another critical element of any tower design is the **mast**. Hams are famous for overloading their masts, and there are plenty of photos of masts that failed in high winds. The DX Engineering website has a simple Mast Load Estimator [Ref. 3] where you enter the heights and projected wind areas of each antenna, and it estimates the maximum safe wind speed. It's a real eye-opener. Luckily, this station is in a pretty benign area in terms of wind speed, but we still designed for 90 MPH.

To mount an antenna anywhere but at the top, you'll need special hardware. We use swing-arm or so-called *sidewinder* mounts, which are like a swinging gate with the antenna mounted on top

(Fig. 6). While it doesn't cover the full 360 degrees of rotation, it's affordable and easy to install. Arms for fixed-direction Yagis are also popular and we used one of those as well. Another option is a *ring rotator* such as the ones from TIC General. These are fairly heavy and expensive contraptions but are able to handle large arrays. You definitely need to work with your tower contractor on these special mounts.

Figure 6. A swing-arm mount supporting two antennas. This one is fabricated from aluminum by Robin, K4IDC.

Cable Design and Fabrication

Decades of experience as an R&D engineer showed me just how important the cable system is on any project. The more "stuff" you have on your tower, the more cables and connectors you will need, and with complexity comes additional risk of failure. Here are some rules for success.

- Design your cables early, before buying materials or starting fabrication.
- Whenever possible, preassemble and test all cables in the shop rather than the field. A clean bench, proper tools, good lighting, and test equipment are needed.
- Choose the best materials. That means high-quality connectors such as Amphenol, and outdoor-rated cable which preferably will have a polyethylene jacket.
- When reusing old cable, thoroughly inspect and test it. Replace degraded connectors.
- Label each end with To/From. I use a Brother labeler with their Flexible PZ tape, which sticks to itself and stays in place even on small cables. It lasts many years in the sun.

- Cover all connectors before hauling them outside. Cables get dragged in the dirt during installation, a disaster for electrical connectors. I use protective caps from ABR Industries on coaxial connectors (taped on), and electrical tape on everything else.

Drawings are important for multiconductor control cables, such as the ones for rotators, switches, and stack matches. Again, any kind of sketch is helpful, or use a drawing program. Show the color codes, pin numbers on each connector, connector type and sex, and cable type. I prefer to draw the entire end-to-end connectivity on a single page, all the way from the shack to the top of the tower. That way, I can troubleshoot anywhere along the line with just one drawing. Figure 7 shows part of a typical control cable drawing.

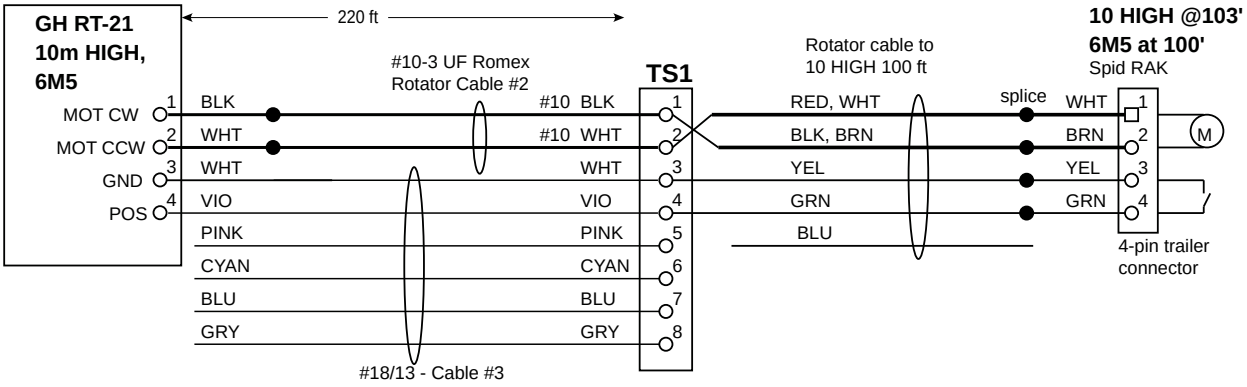

Figure 7. Typical cable diagram for a rotator. This makes construction and troubleshooting easy.

For RF coaxial cables and switches, I generally make a block diagram that shows all the interconnected elements and identifies the connector and cable types.

In order to make preassembly possible, you need a detailed **cable list**. Since you already have a scaled drawing of your tower, lengths are fairly easy to determine. Make a spreadsheet that looks something like Fig. 8. Keep this list forever. If a cable needs to be replaced or an antenna moved, you'll know exactly what's on your tower. Figure 9 shows our bin full of fabricated cables, organized and ready to go. I'm now known as *Gary the Cable Guy*.

Antenna	FROM	TO	Length	Cable Type	New?	Loss	@MHz	Notes
80 Dipole @145'	Ant feed	Tower top	28	400MAX	Y	0.08	4	Ant pigtail, rotator loop
	Tower top	shack	350	LMR400	Y	0.9	4	
	Tornado	Tower top	28	4/c rotator	Y			Tornado pigtail, rotator loop
	Tower top	Term box @3'	132	4/c rotator	Y			
	BIG-RAK @129'	Term box @3'	130	4/c rotator	Y			
6m LFA @134'	Ant feed	Tower top	8	BuryFlex	N	0.07	50	Ant pigtail, rotator loop
	Tower top	Coax relay @36'	105	LMR600UF	Y	0.9	50	Cable is 125 ft. N conn

Figure 8. Cable list. Necessary for preassembly and tracking of many cables.

Figure 9. Nearly all the cables ready to go, in one bin. Protected, labelled, and organized.

Planning for Build Day

Get your tower contractor involved very early in the process. They will have to implement all your grand ideas, and you must have their 100% buy-in well before they show up. Having drawings and a parts list will make it clear what you are planning. Hector had a lot of useful suggestions especially on guying and also provided some of the materials. Figure out how much additional help you will need. We tried to have three people as ground crew at all times through the four long, hot days of construction. That means you need to coordinate schedules with everyone. And don't forget the food and water!

Hector had a clear plan in mind for the construction sequence:

1. Remove everything from the existing tower, right down to the last scrap of old tape.
2. Refurbish and test old antennas and mounts. Assemble new ones.
3. Replace old guys, then add sections, installing new guys as it grows.
4. Install antennas etc. generally from the top down, aligning as we go.
5. Install cables and connect to shack.

Remember that the person up the tower is the boss. The ground crew needs to be in constant communication, whether it's by yelling or radio, and following directions at all times.

Figure 10. Left, hoisting a tower section. Lower guys are already tensioned. Upper right, the winch operator (KK6PXT) has a lot of responsibility. Lower right, preparing to *tram* a 10m Yagi.

The business of refurbishing and testing is really important. Antennas that have been aloft for many years can have lots of issues, such as corroded and outright failed hardware, damaged elements, and more. The ground crew was very busy on this task and there is no way to do it in advance. I fabricated new K9YC-approved feedpoint chokes for our 10m Yagis. Every antenna was checked for SWR on the ground to verify basic function. Speaking of chokes, when you are upgrading antennas and cables it's a perfect time to install modern common-mode chokes to help reduce receive noise [Ref. 4].

Heavily-used rotators should not be reinstalled without a rebuild (Fig. 11). Rusted bolts should be discarded. I suggest getting your nuts and bolts from a proper supplier, such as Fastenal or McMaster-Carr instead of the unknown junk from the Big Box store. Of course, you can't order such things on the day you are building the tower, so do try to plan ahead. Old coax can deteriorate and connectors are always suspect. I use a vector network analyzer (VNA) or two-port antenna analyzer to measure loss and a high-voltage insulation tester to verify dielectric

integrity. Your tower project is a big investment and the newer and better the hardware, the longer it will provide reliable service.

Figure 11. This Alfa-Spid RAK rotator definitely needed servicing.

What Went Wrong

Thankfully, nothing horrible... A shipment of guy grips came up one short, requiring an emergency order and overnight shipping. A connector didn't mate up properly with the switch due to the way the receptacle was mounted. A replacement jumper was located for that. We ran out of time connecting everything to the shack, so testing of the Tornado tuner on the 80m dipole could not be performed until Hector had headed home. It appeared to be stuck (disaster!) but with some advice and a nudge from a DC power supply, we got it working. Also, we later found that the antennas on the swing-arm mounts weren't at quite the right angles, limiting their motion somewhat. That's why it's a good idea to allocate time to test everything before your climber leaves, even if it means quickly hay-wiring a controller just to be sure a rotator turns properly.

Conclusion

Everyone, especially Ken, was pleased with the pace and quality of work. We had few construction difficulties and learned a lot from the process thanks to the guidance from Hector. The new 80m dipole is playing very well so far, though we're waiting for winter to really exercise it. It's a magnificent sight, and looks brand-new shining in the sun (Fig. 12). I'd say the planning paid off.

Figure 12. The completed tower shining in the California sun.

Acknowledgements
Thanks for the support of the entire N6RO team and especially the construction crew: Ken, N6RO; Hector, XE2K/AD6D; Nahum Ruiz and sons Luis & Ricardo; Greg, KK6PXT; Kevin Reasoner; Roberto, K6KM; David, W6DMW; Chris, N6WM; and John, WX6G.

References

1. *Up the Tower* by Steve Morris, K7LXC, available from Champion Radio.
https://www.championradio.com/

2. *Antenna Towers for Radio Amateurs* by Don Daso, K4ZA, published by ARRL.

3. *Mast Load Estimator* online calculator from DX Engineering.
https://www.dxengineering.com/mastloadestimator

4. *A Ham's Guide to RFI, Ferrites, Baluns, and Audio Interfacing.* Jim Brown, K9YC.
http://k9yc.com/RFI-Ham.pdf

Additional photos are available at:
https://www.flickr.com/photos/wb9jps/albums/72177720299680084

The June, 2022 Northern California Contest Club monthly club meeting includes a presentation on this project. Video is available at:
https://www.youtube.com/watch?v=SUoBo88ttwE&t=3045s