Low-budget satellite tracking system for highly elliptical orbits

12/17/09; Thomas.Rode@gmx.de

The background:

Back in 2003 I was a member of the club station DL0AMD. In those days AO-40 was still active. So the idea came up to upgrade DL0AMD by adding equipment for satellite communication. Donators were found for almost everything (transceiver, Yagi, dish, …) but the tracking system, namely the elevation/azimuth rotor. The only hardware available was a simple, one axis rotor. After looking a little deeper into the "rotor-issue", I came up with an idea on how to make use of the available hardware for our special purposes. After installation that system was used for many month (and QSOs) and it actually worked quite well. Unfortunately our experiment was ended by the failure of AO-40. But who knows, maybe there will be a successor in the near future. If that happens and if you are not one of those who can already call a full-size satellite tracking system their own, you might be interested in just getting started by taking our approach.

The idea:

In order to aim a TV-satellite dish to its target, a method called "polar mounting" is often used. That method requires only one degree of freedom (i.e. rotation axis / drive). The axis is aligned (parallel) to the axis of Earth rather that perpendicular. By turning that axis, an imaginary circle around the equator (geostationary orbit) will be described by the beam of the antenna. Mathematically, of course, that circle is only correctly drawn, if your location is at one of the poles of the planet. But since the distance between the two axis (Earth / rotor) is small in comparison to the orbital

height (36000km), the error created by it can often be neglected (unless your dish is the size of a radio telescope).

But how can "polar mounting" be used for satellites in elliptical orbit that do not circle the equator? Interestingly the principle is not limited to equatorial circles but can be applied to "scan" any orbit, as long as it is circular and parallel to the equatorial plane (as for example used for the aiming of astronomical instruments). Such imaginary circles can also be drawn simply by connecting all apogees of an elliptical orbit, as they are shifting over time. Knowing in addition that at highly elliptical orbits the satellite remains near the apogee for most of the time (a phenomenon referred to as "apogee dwell"), the aiming of the antenna will be accurate enough over a long time period as well. For a more detailed illustration please see diagram 1.
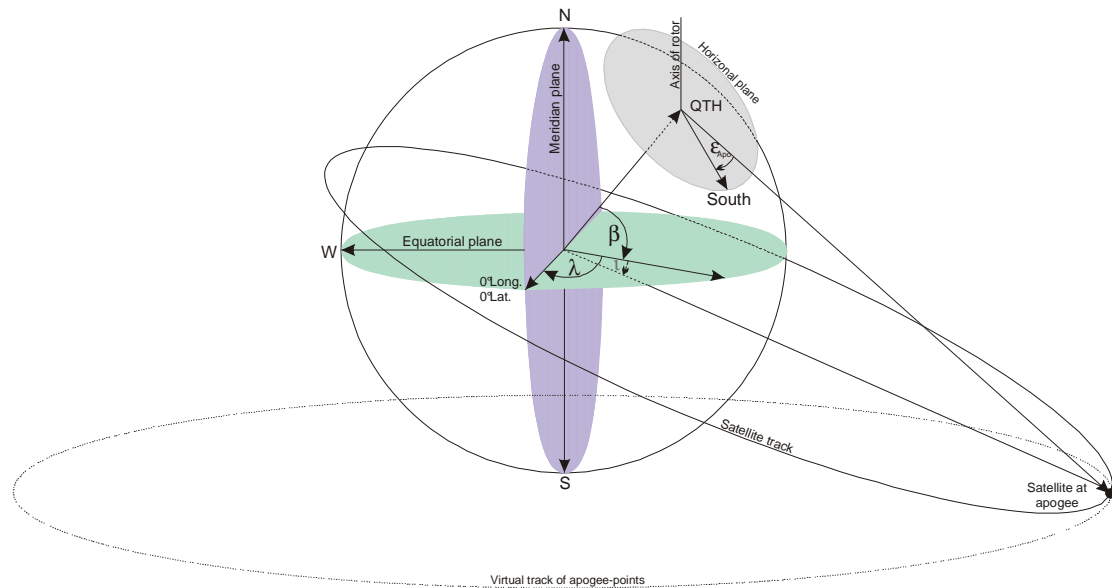

Diagram 1: Principle of polar mounting

Here a sectioned illustration of the Earth is given, showing the equatorial plane as well as the plane of the prime meridian (longitude 0). The QTH is defined by its longitude (λ) and latitude (β). According to the principle of polar mounting, the rotor is aligned in parallel to the Earth-axis. When pointed to the south, the antenna(-system) mounted to it has an elevation (from the plane of horizon) of ε_{Apo}. Let us assume that in this position the antenna is pointed to the (exemplary) apogee of a satellite in elliptical orbit. Since for most orbits the apogee will shift over time (relative to the observers location), it will create a virtual track of apogees, which is circular, parallel to the equatorial plane and can be tracked by the (polar mounted) antenna. The angular distance between that virtual track (plane) and the equatorial plane is called inclination (ι).

Of course communication is not limited to the time when the satellite is exactly at apogee. How long the usable time-window actually is, depends on the orbit itself as well as the beamwidth of the antenna. To give an example, in case of DL0AMD we used a 16 element x-Yagi for the 70cm uplink (-3dB beamwidth = 30°) and a 60cm offset-dish for reception at 13cm (-3dB beamwidth = 15°). In practise it turned out that good communication was possible basically throughout the whole DX-time window.

Setting up the rotor:

When mounting the rotor it is important that it remains adjustable in both vertical as well as horizontal direction. In case of DL0AMD we used scaffolding poles and clamps to insure that necessary flexibility. The next task is now to give the rotor an orientation that is in parallel to the Earth axis. As a first step, the rotor has to be turned until the tip of the axis points to the north. Looking quite trivial on first glance, that part requires some accuracy and is actually a bit tricky. If you have access to a good map, you could use landmarks to bear the direction. Or you could use the polar star (of course only if you live in the northern hemisphere). In case of DL0AMD, we calculated the time for the transit of the sun (when the sun is exactly in the south at our location) on a certain date. After that time had arrived we took the bearing by turning the rotor/axis towards the sun. **Do not stare into the sun but use some aids or, as we did, drop a perpendicular from the axis and align to the axis shadow.** Instead of doing the calculation by yourself, you can use some astronomical software (e.g. the freeware "Home Planet" from www.fourmilab.ch) to determine when the sun is in transit at your location. The second step is to set the necessary vertical tilt of the axis, which is identical to the latitude (β) of the QTH. One possible way of doing that adjustment is to use a plumb line. The angle between the axis and the line then has to be **$90° \div \beta$**.

Setting up the antenna system:

After the antenna system has been hooked up to the rotor, it should be pointed to the south. Its elevation (angular distance to the plane of horizon) can now be set to ε_{Apo}. The angle ε_{Apo} has to be calculated from the Kepler elements, using the parameter „Mean Motion" **(MM)**, Eccentricity (**EX**), Arg of perigee (δ) as well as Inclination ι. Additionally the latitude (β) of the QTH will be needed again. Kepler elements are available in two different formats, the so-called NASA-2-line format and the AMSAT format. For both an exemplary data set from AO-40 is listed below. The parameters of interest are highlighted.

<u>Set of Kepler elements in AMSAT – format:</u>

Satellite:	AO-40	
Catalog number:	26609	
Epoch time:	03014.42373129	
Element set:	304	
Inclination:	**7.9543 deg**	*Inclination of orbit in Degree*
RA of node:	70.5875 deg	
Eccentricity:	**0.7935115**	*Eccentricity of orbit*
Arg of perigee:	**133.0894 deg**	*Argument of perigee in Degree*
Mean anomaly:	327.3710 deg	
Mean motion:	**1.25596681 rev/day**	*Mean motion in revolutions per day*
Decay rate:	2.5e-07 rev/day^2	
Epoch rev:	1014	
Checksum:	282	

<u>Same set of Kepler elements in NASA-2-line format:</u>

```
AO-40
1 26609U  00072B   03014.42373129  .00000025  00000-0  10000-3 0  3042
2 26609    7.9543  70.5875  7935115 133.0894  327.3710  1.25596681 10146
```

Note that eccentricity in NASA-2-line format is given in positions after decimal point only. So 7935115 stands for 0.7935115. With sufficient accuracy $\varepsilon_{\mathbf{Apo}}$ can be calculated using equation 1.

$$\varepsilon_{Apo} = 90° - \alpha - \arctan \frac{\sqrt[3]{MM^2} * \sin \alpha}{6.636 * (1 + EX) - \cos \alpha} \qquad \textit{Equation} \quad 1$$

The angle α must be entered in degree and is calculated as follows (equation 2):

$$\alpha = \beta + \iota * \sin(\delta) \qquad \textit{Equation} \quad 2$$

For DL0AMD the latitude is β = 51.133°. Entering that as well as the exemplary Kepler data into the two equations, the result is:

$$\alpha(DL0AMD) = 51.133° + 7.9543° * \sin(133.0894°) = \underline{56.942°}$$

$$\varepsilon_{Apo}(DL0AMD) = 90° - 56.942°$$

$$- \arctan \frac{\sqrt[3]{1.25596681^2} * \sin(56.942°)}{6.636 * (1 + 0.7935115) - \cos(56.942°)}$$

So for DL0AMD we get $\varepsilon_{\mathbf{Apo}}$ = 28.15°. Finally it should be mentioned that for satellites without active orbit control (e.g. by onboard thrusters) the value of $\varepsilon_{\mathbf{Apo}}$ will change over time. Fortunately that change happens very slowly, making corrections of the antennas elevation a rare event, necessary only if the value has changed by some degree. At DL0AMD we had a protractor mounted to the antenna system, making adjustments of $\varepsilon_{\mathbf{Apo}}$ a quick and easy job.