SYNCHRONISED DOME ROTATION

Anyone who has used an observatory class Equatorial, especially either a German or English Cross Axis Equatorial housed within a dome, cannot fail to have noticed that in order to maintain alignment between the dome slit and the telescope it is necessary to turn the dome at regular intervals. Furthermore the frequency with which the dome slit needs to be advanced very much depends on the telescope's polar distance. The telescope also *"looks"* through the dome slit obliquely; how obliquely depends on the distance the tube is offset from the polar axis, and how large the dome is in relation to the length of the tube, and the distance from the slit to the intersection of the declination and optical axes.

When using a large observatory class Equatorial, the observer's task is made less fraught if dome rotation is motorised and can be controlled via a handpaddle or computer. When the Equatorial's drive system is also computer controlled, it helps further if the controller has positional feed back of the dome slit azimuth so that the dome can be turned without observer intervention.

There are several ways of synchronising dome rotation and the motion of the Equatorial in hour angle. If the motor is to be actuated via a software one needs to derive an algorithm based on trigonometric equations that define the geometrical relationship between the telescope's declination and hour angle and the azimuth of the centreline of the dome slit.

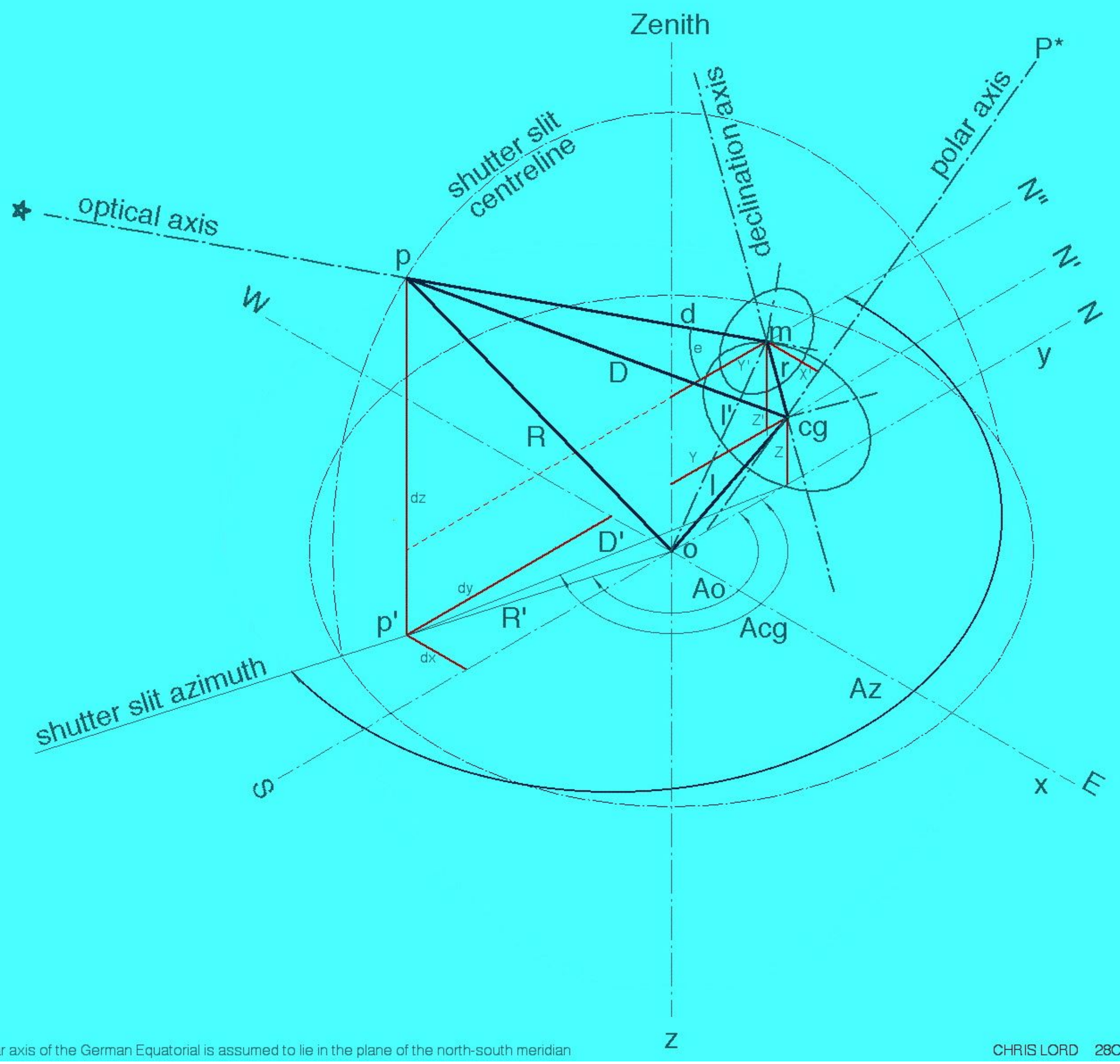
DETERMINATION of DOME AZIMUTH

There are four key elements to this problem. The dome rotation centre, the position of the mounting's centre of gravity (cg) with respect to it, the intersection of the declination axis and the telescope's optical axis (not necessarily coincident with the tube's mechanical axis), and a point on the shutter slit defined by the intersection of the optical axis with the slit's centreline.

The solution which follows makes certain assumptions. These are that the mount is either a German or English Cross Axis Equatorial, and that its cg lies on the dome north-south axis. The solution may be extended to cover cases where the cg is offset from the dome centre not only from the east-west axis but the north-south axis also.

Although derived for either a German or English Cross Axis Equatorial it may be simplified and applied to any other style of equatorial or altazimuth. When the mount is alt-az and the intersection of the altitude and optical axes lie at the cg, the same rules apply. When the cg lies on the dome rotation axis the telescope and dome slit azimuth coincide.

GEOMETRY of DOME SLIT AZIMUTH



the polar axis of the German Equatorial is assumed to lie in the plane of the north-south meridian

CHRIS LORD 28OCT2002

SYNCHRONISED DOME ROTATION - DETERMINATION of DOME AZIMUTH

Study the diagram on p2 carefully. Bear in mind it is an isometric projection representing the true 3D geometry. I have set up three rectilinear coordinate systems. The case considered is of a German or English Cross Axis Equatorial, whose polar axis lies on the north-south meridian, and lies in the same north-south plane as the dome rotation centre. This means the cg also lies in the meridian. (In reality polar misalignment will cause it to be slightly offset, but no matter, it will make next to no difference and can be ignored).

The primary coordinate system: X', Y', Z', is that of the telescope, centred on the intersection of the declination and optical axes. I assume that these are perpendicular. (In reality there will be a build error, but again, the small error for the purposes of the calculation does not matter).

The secondary coordinate system: X, Y, Z, is that of the cg, which if the telescope is accurately balanced about all three axes, i.e. mechanical tube axis, declination axis and polar axis, will lie precisely at the intersection of the polar and declination axes. I assume that declination and polar axes are also perpendicular. (In reality there will be a build error, but yet again, the small error for the purposes of the calculation does not matter).

The tertiary coordinate system: x,y,z, is that of the dome; z defines the vertical rotation axis, y the meridian axis and x the east-west axis. The plane defined by x,y lies in the plane of the dome rail.

Before going into the details of how the equations are set up, I shall define the terms used in the diagram:

Ao	is dome azimuth measured from north thru' east
Acg	is mount cg azimuth measured from north thru' east
Az	is telescope azimuth
e	is telescope altitude or elevation above the horizon
o	is the dome coordinate system origin in the plane of the dome rail
p	is the point on the slit centreline where the optical axis intersects
p'	is the vertical projection of p onto the x,y plane
dx,dy,dz,	are the coordinates of p with respect to o
l	is the distance from the dome rotation centre to the cg
l'	is the distance from the dome rotation centre to m
m	is the intersection of the declination and optical axes
r	is the distance along the declination axis from the cg to the optical axis
r'	is the vertical projection of r onto the x,y plane
d	is the distance from m along the optical axis to p
d'	is the vertical projection of d onto the x,y, plane
D	is the shortest distance from cg to p
D'	is the vertical projection of D onto the x,y plane
R	is the dome radius (assumed centred on o)
R'	is the vertical projection of R onto the x,y plane
N	is the zero azimuth direction of the meridian line coincident with o
N'	is the zero azimuth direction of the meridian line coincident with cg
N"	is the zero azimuth direction of the meridian line coincident with m
P*	is the north celestial pole

SYNCHRONISED DOME ROTATION - DETERMINATION of DOME AZIMUTH

Referring to the diagrams on p5:-

The ellipse centred on m is a circle whose centre lies in a plane perpendicular to the declination axis.
The ellipse centred on cg is a circle whose centre lies in a plane perpendicular to the polar axis.

The location of p lies in the plane of the ellipse centred on m and is defined by the declination and hour angle.
The location of m lies in the plane of the ellipse centred on cg and is defined by the hour angle measured westwards from the meridian.

The distance between the intersection of the declination and optical axes, and the intersection of the optical axis and the centreline of the shutter slit, is defined by the directrix, 'd'.

There are certain terms which can be measured physically. These are:

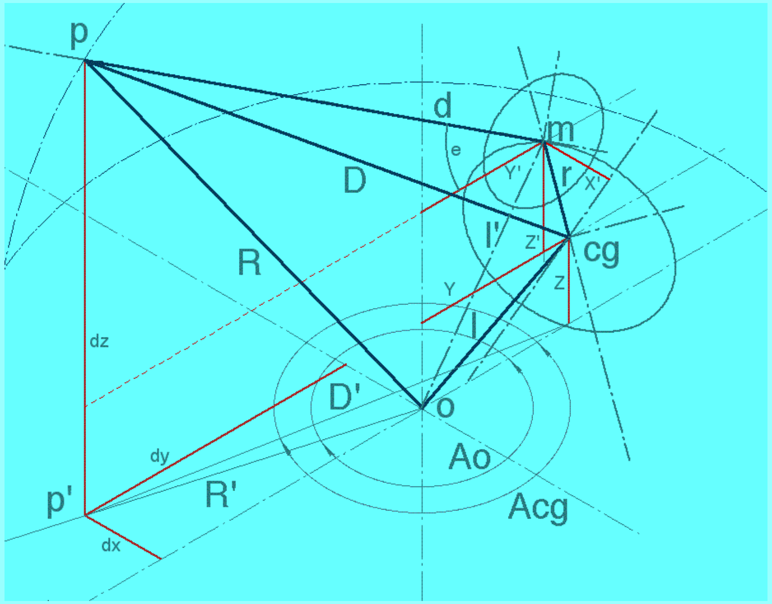
X,Y,Z; R; & r. The elevation of the polar axis is assumed to be the site latitude ϕ .

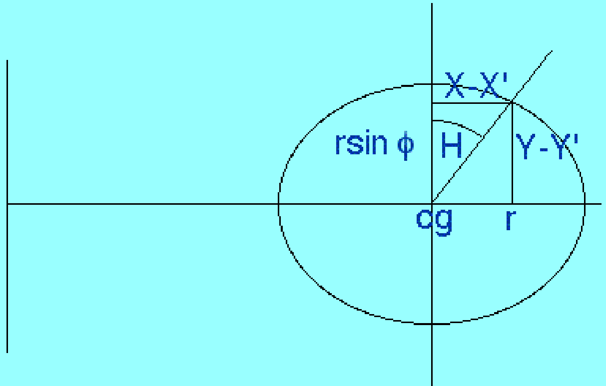
The sign convention for X,Y,Z and also the primary and tertiary coordinates is:-

X (or X' or x) positive East; negative West
Y (or Y' or y) positive North; negative South
Z (or Z' or z) positive above the x,y plane of the dome rail; negative below the x,y plane of the dome rail.

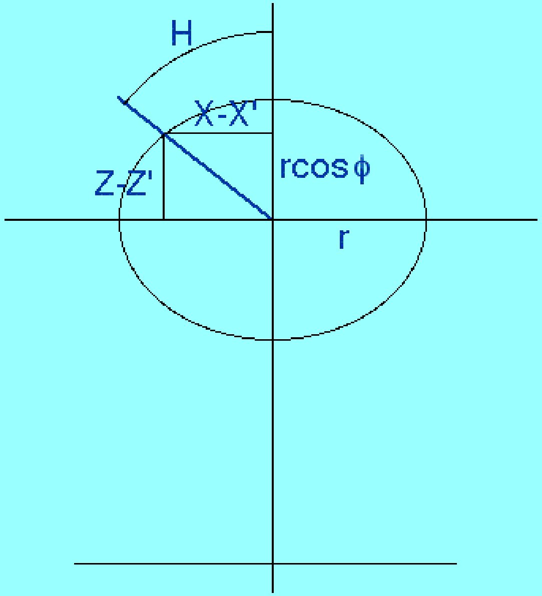
Once you have made these measurements, assigned the correct arithmetic signs and noted your site latitude from an ordance survey map you are ready to begin.

SYNCHRONISED DOME ROTATION - DETERMINATION of DOME AZIMUTH

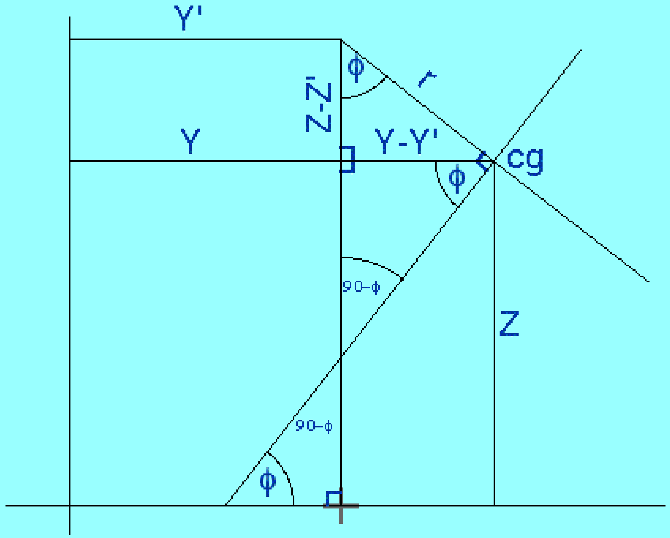




VIEW FROM ZENITH



VIEW FROM SOUTH



ELEVATION on POLAR AXIS

SETTING UP THE EQUATIONS

Referring to VIEW FROM ZENITH. Assume you are looking down on the ellipse centre cg from the zenith. The point of m along the ellipse's circumference can be used to define Y' :-

$$\frac{(X - X')^2}{r^2} + \frac{(Y - Y')^2}{(r\sin\phi)^2} = 1$$

$$\textit{but} \quad X - X' = r\sin H \quad \textit{where} \quad H \quad \textit{is the hour angle}$$

$$\textit{hence} \quad \frac{(r\sin H)^2}{r^2} + \frac{(Y - Y')^2}{(r\sin\phi)^2} = 1$$

$$\textit{from which} \quad Y' = Y - \left(r\sin\phi\sqrt{1 - \sin^2 H}\right)$$

$$\textit{hence} \quad Y' = Y - \left(r\sin\phi\sqrt{\cos^2 H}\right)$$

$$\textit{hence} \quad Y' = Y - r\sin\phi\cos H$$

SETTING UP THE EQUATIONS (cont.)

Referring to VIEW FROM SOUTH. Assume you are looking up the polar axis towards the north celestial pole P*. The point of m along the ellipse's circumference can be used to define Z' :-

$$\frac{(X - X')^2}{r^2} + \frac{(Z' - Z)^2}{(r\cos\phi)^2} = 1$$

$$but \quad X - X' = r\sin H \quad where \quad H \quad is\ the\ hour\ angle$$

$$hence \quad \frac{(r\sin H)^2}{r^2} + \frac{(Z' - Z)^2}{(r\cos\phi)^2} = 1$$

$$from\ which \quad Z' = Z + \left(r\cos\phi\sqrt{1 - \sin^2 H}\right)$$

$$hence \quad Z' = Z + \left(r\cos\phi\sqrt{\cos^2 H}\right)$$

$$hence \quad Z' = Z + r\cos\phi\cos H$$

We now have all the equations needed to establish the primary coordinates X',Y',Z', from the telescope's hour angle.

$$X' = X + r\sin H$$

$$Y' = Y - r\sin\phi\cos H$$

$$Z' = Z + r\cos\phi\cos H$$

when the cg lies on the optical axis

$$X' = X$$

$$Y' = Y$$

$$Z' = Z$$

when the polar axis lies on the dome north-south centreline $X = 0$

SETTING UP THE EQUATIONS (cont.)

We now need to set up some equations known as equations of state, because they define the relationship between terms we know, and terms we wish to find. These are:

$$R^2 = dx^2 + dy^2 + dz^2$$

$$R'^2 = dx^2 + dy^2$$

$$l^2 = X^2 + Y^2 + Z^2$$

$$l'^2 = X'^2 + Y'^2 + Z'^2$$

$$D^2 = (dx - X)^2 + (dy + Y)^2 + (dz - Z)^2$$

$$D'^2 = (dx - X)^2 + (dy + Y)^2$$

$$d^2 = (dx - X')^2 + (dy + Y')^2 + (dz - Z')^2$$

$$d' = (dx - X')^2 + (dy + Y')^2$$

$$D^2 = r^2 + d^2 \quad [\Delta\ Drd\ rt\angle]$$

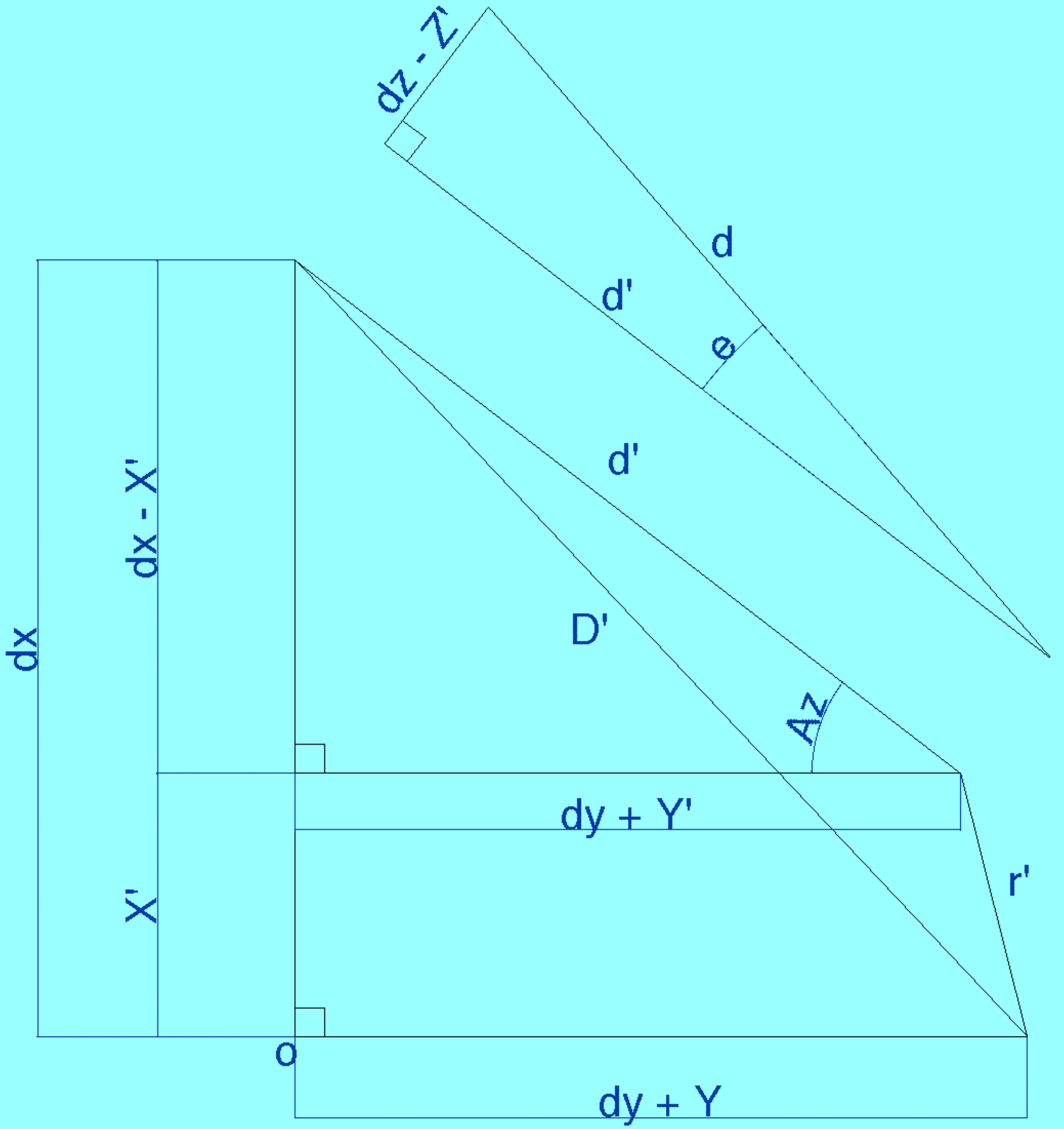
Now look at the dashed red line from m, tangent to ellipse cg, perpendicular to dz. The angle between this line, and the line m,p directrix d, is the elevation of the telescope e.

The elevation (or altitude) can be calculated from the standard spherical trig formula: $\cos z = \sin\phi \sin\delta + \cos\phi \cos\delta \cos H$ where z is zenith distance. Altitude is $90^0 - z$.

The azimuth of the telescope can be calculated from the standard spherical trig formula: $\sin z \cos A = \cos\delta \sin H$

δ & H are declination and hour angle respectively, A is telescope azimuth, Az on the diagram on p2.

Hour angle is derived from $H = LST - \alpha$ where LST is local sidereal time & α is right ascension, and must be converted to arc.



VIEW FROM ZENITH in PLANE of D' & d'

SETTING UP THE EQUATIONS (cont.)

Now consider the diagram on p9. This shows the geometry of the directrix ‘d’ & ‘D’, projected onto the x,y plane, and the elevation of the directrix ‘d’ from the x,y plane.

from this:

$$d' = d\cos e$$

$$dx = d'\sin Az + X' = d\cos e.\sin Az + X'$$

$$dy = d'\cos Az - Y' = d\cos e.\cos Az - Y'$$

$$dz = d\sin e + Z'$$

but:

$$\begin{aligned}R^2 &= dx^2 + dy^2 + dz^2 \\ &= (d\cos e.\sin Az + X')^2 + (d\cos e.\cos Az - Y')^2 + (d\sin e + Z')^2 \\ &= d^2\cos^2 e.\sin^2 Az + 2dX'\cos e.\sin Az + X'^2 \\ &\quad + d^2\cos^2 e.\cos^2 Az - 2dY'\cos e.\cos Az + Y'^2 \\ &\quad + d^2\sin^2 e + 2dZ'\sin e + Z'^2\end{aligned}$$

& rearranging we obtain:

$$\begin{aligned}R^2 &= d^2(\cos^2 e.\sin^2 Az + \cos^2 e.\cos^2 Az + \sin^2 e) \\ &\quad + 2d(X'\cos e.\sin Az - Y'\cos e.\cos Az + Z'\sin e) \\ &\quad + X'^2 + Y'^2 + Z'^2\end{aligned}$$

SETTING UP THE EQUATIONS (cont.)

which is a quadratic of the form:

$$\left(\cos^2 e.\sin^2 Az + \cos^2 e.\cos^2 Az + \sin^2 e\right) d^2$$
$$+ 2\left(X'\cos e.\sin Az - Y'\cos e.\cos Az + Z'\sin e\right) d$$
$$+ \left(X'^2 + Y'^2 + Z'^2 - R^2\right) = 0$$

but: $$l'^2 = X'^2 + Y'^2 + Z'^2$$

& simplifying $\cos^2 e.\sin^2 Az + \cos^2 e.\cos^2 Az + \sin^2 e$

since $\sin^2 Az = 1 - \cos^2 Az$

and $\sin^2 e = 1 - \cos^2 e$

by substitution:

$$\cos^2 e.\sin^2 Az + \cos^2 e.\cos^2 Az + \sin^2 e = \cos^2 e\left(1 - \cos^2 Az\right) + \cos^2 e.\cos^2 Az + \left(1 - \cos^2 e\right)$$
$$= \cos^2 e - \cos^2 e.\cos^2 Az + \cos^2 e.\cos^2 Az + 1 - \cos^2 e$$
$$= 1$$

and putting:

$$L = X'\cos e.\sin Az - Y'\cos e.\cos Az + Z'\sin e$$
$$M = l'^2 - R^2$$
$$d^2 + 2Ld + M = 0$$
$$\textit{from which} \quad d = -L \pm \sqrt{L^2 - M}$$

but d is always positive: $\therefore$ $$d = \left(\sqrt{L^2 - M}\right) - L$$

SETTING UP THE EQUATIONS (cont.)

Once the length of directrix 'd' has been determined it becomes possible to derive dx; dy; dz,

and hence dome azimuth:

$$Ao = \arctan \frac{dx}{dy}$$

There is one caveat in determining Ao, and that is the sign of X'.

When the telescope is east of the pier (circle following) X' is positive.

When the telescope is west of the pier (circle preceding) X' is negative.

A meridian reversal will consequently change the sign of X'.

SYNCHRONISED DOME ROTATION - RATE of CHANGE of DOME SLIT AZIMUTH

rate of rotation of dome is derived from:

$$\frac{dAo}{dH} = -15\left(\sin\phi - \cot z.\cos Ao.\cos\phi\right)$$

where Ao & H are expressed in arcsecs and seconds of time respectively

NOTE:

$$0 \le A \le 180^{o} \Leftrightarrow 0 \le H \le 12^{h}$$

$$0 \ge A \ge -180^{o} \Leftrightarrow 12^{h} \le 24^{h}$$

SYNCHRONISED DOME ROTATION - USING THE EQUATIONS TO DEVELOPE AN ALGORITHM

Your algorithm needs measured constant distances to be input: X; Y; Z; R & r, together with your site latitude, ϕ , and a continuous real time or periodic update of Az & e, and H.
ϕ ; r; Y; Z & H are used to calculate X'; Y'; Z'

The algorithm must procede as follows:-

line	*operation*
10	enter ϕ (constant)
20	enter δ & H (H variable with local sidereal time) & convert to e & Az
30	enter $\mathrm{r, X, Y, Z, \ \& \ R}$
40	determine $X' = X + r\sin H$
50	determine $Y' = Y - r\sin\phi.\cos H$
60	determine $Z' = Z + r\cos\phi.\cos H$
70	determine $l' = \sqrt{X'^2 + Y'^2 + Z'^2}$
80	determine coefficient $L = X'\cos e.\sin Az - Y'\cos e.\cos Az + Z'\sin e$
90	determine coefficient $M = l'^2 - R^2$
100	determine $d = \left(\sqrt{L^2 - M}\right) - L$
110	determine $dx = d\cos e.\sin Az + X'$
120	determine $dy = d\cos e.\cos Az - Y'$
130	determine $dz = d\sin e + Z'$
140	determine $Ao = \arctan\dfrac{dx}{dy}$
150	determine $\dfrac{dAo}{dH} = -15(\sin\phi - \cot z.\cos Ao.\cos\phi)$

SYNCHRONISED DOME ROTATION

Angles must obey the four quadrant rules:

quadrant 1

$$Az = a\cos\left\{\frac{(\cos\delta.\sin H)}{\sin z}\right\} - \frac{\pi}{2}$$

$$X'\_east = X + r\sin\left(H + \frac{3}{2}\pi\right)$$

$$X'\_west = X + r\sin\left(H + \frac{\pi}{2}\right)$$

quadrant 4

$$Az = \frac{3}{2}\pi + a\cos\left\{\frac{(\cos\delta.\sin H)}{\sin z}\right\}$$

$$X'\_east = X + r\sin\left(H + \frac{3}{2}\pi\right)$$

$$X'\_west = X + r\sin\left(H + \frac{\pi}{2}\right)$$

quadrant 2

$$Az = \frac{3}{2}\pi - a\cos\left\{\frac{(\cos\delta.\sin H)}{\sin z}\right\}$$

$$X'\_east = X + r\sin\left(H + \frac{\pi}{2}\right)$$

$$X'\_west = X + r\sin\left(H + \frac{3}{2}\pi\right)$$

quadrant 3

$$Az = \frac{3}{2}\pi - a\cos\left\{\frac{(\cos\delta.\sin H)}{\sin z}\right\}$$

$$X'\_east = X + r\sin\left(H + \frac{\pi}{2}\right)$$

$$X'\_west = X + r\sin\left(H + \frac{3}{2}\pi\right)$$

SYNCHRONISED DOME ROTATION

DOME DRIVING RATIONALES

It might be reasonably thought that having derived an algorithm defining the azimuth of the dome slit in an absolute relation to telescope's declination and hour angle, and the rate at which the dome needs to be turned so the slit keeps up with the telescope as it tracks an object, that it would simply be a matter of writing a programme to turn the dome drive motor at the calculated rate. However driving a dome continuously, as far as the ATMer is concerned presents certain problems.

If you choose to drive the dome continuously (which for reasons I will explain in the conclusion is not recommended), you will need to run your programme derived from your algorithm in real time, which calls for a real time operating system. The popular IBM clone operating system WinXP & its predecessors including DOS6.2, & Apple's Mac OS Classic are not real time or even soft real time OS's. You will need to port your programme to either a Linux distribution such as RedHat or MacOS X. Either of these operating systems are able to control command processing in real time because of the way they handle interrupt requests to the CPU.

You will also need some feedback mechanism to close the drive loop. It is insufficient to put an encoder on the dome gearmotor output spindle and expect dome slit synchronisation to be maintained. Proximity sensors and pickups should be placed around the dome and dome rail to provide azimuth information at a resolution of at least one third the angular width of the slit.

There are also mechanical disadvantages in choosing to drive your dome continuously. The motor will be continuously energized and will run hot and create dome seeing problems. You will have to damp out motor vibration. Also slit azimuth synchronisation may be lost during a meridian reversal ("walking the dog") and will have to be re-established. However there is a more immediate difficulty, inadequate dynamic range. For example, at my site latitude (+52º), the average dome tracking rate is approximaltely 12º per hour, except near the zenith where the rate increases considerably. Let us assume it is envisaged that either a capacitor start AC induction or shunt wound DC gearmotor is to be selected. In order to continuously drive the dome at such a slow speed, the gearhead ratio will need to be enormous. But when we wish to point the telescope to a different object, we need the dome to rotate much faster than 12º per hour. My dome for instance turns through 360º in 3 minutes, or 2º per second. This is 7200 times faster than the average tracking rate. No AC induction motor or shunt wound DC motor can accommodate such a vast dynamic range. There are only three practical alternatives. Either a custom engineered differential or electromagnetic clutch and two motors, or a DC Torque motor or a DC Servo motor. None of these practical solutions are economic.

It is feasible to step turn the dome using software by modifying the algorithm to take into account the difference between the telescope and dome slit azimuth. Suppose for instance the angular width of the slit from the dome centre is 15º, and suppose the slit width is three times the telescope aperture. The maximum azimuth difference permissible before the slit begins to cut off light to the objective will be 10º. The dome will have to be turned to an azimuth such that the following side of the slit just clears the objective. The telescope's azimuth may then advance 10º until the dome is given a catch-up command. The difficulty lies in calculating the catch-up azimuth angle because it will not be equal to the change in telescope azimuth. If the catch-up azimuth is assumed to be equal to the change in telescope azimuth, synchronisation will inevitably be lost.

The alternative software approach is to run the programme at preset intervals, and issue turning commands until synchronisation or a predetermined offset is re-established.

I have written an AppleWorks v6 and an Xcel2000 spreadsheet which can be downloaded and run on either an AppleMac on MacOS9.1 or an IBM compatible PC on WinME or XP. It is an interesting and illustrative exercise to see how the dome drive rate changes by setting the telescope's declination and hour angle such that the telescope is pointing northeast, and then to systematically increase hour angle to simulate tracking an object as it rises, culminates at the zenith and then sets in the northwest.

As the telescope is tracked across the zenith, westwards, the dome drive rate steadily increases from approximately 12^o per hour to infinity. At least it does in theory. In practice, the dome has to be turned through a large angle in a very short time, say 90^o in 2 minutes. Producing a workable software solution to this problem involves knowledge of the maximum dome drive rate and the angular width of the dome slit.

Most dome slits do not extend across the entire hemisphere of the dome, but truncate just beyond the zenith. I have written the equations to derive only one value for A_0 to reflect this. In theory there are two values, 180^o apart.

Because dy can equal zero, A_0 becomes indeterminate at the East & West Cardinal compass points:

from $$A_0 = \arctan\frac{dx}{dy}$$

when $$dy = 0 \quad A_0 = 90^o \ or \ 270^o \quad (E \ or \ W)$$

no trig solution for A_o is possible when dy is zero, because you cannot divide by zero.

Furthermore the reduced telescope azimuth angle from $Az = \arccos\left\{\frac{(\cos\delta . \sin H)}{\sin z}\right\}$

has a pair of possible solutions, only one of which is relevant and the equation becomes indeterminate when $z = 0^o$.

The final difficulty you are going to encounter in using software to synchronize dome rotation is during a meridian reversal. Suppose for instance that the difference in dome slit and telescope azimuth is 10^o. When the telescope is reversed across the meridian, dome azimuth must change by twice this difference, or 20^o. Also do not forget that the sign of X' will change. You will have to add code to account for these changes.

DOME DRIVING RATIONALES (cont.)

SUMMARY

Whilst it is possible to synchronize dome rotation and dome slit azimuth with telescope declination and hour angle using a software solution there are inherant difficulties in doing so.

These are:

i) When the dome is driven continuously the motor will need a huge dynamic range, or two motors must be used.
ii) Difficulties in dealing with heat.
iii) Difficulties in damping vibration.
iv) Additional sub-routines needed to deal with:
   - indeterminate conditions
   - meridian reversals
   - zenith passage
   - quadrant rules

That is why I recommend designing a dome rotation system that does not wholely rely on a software, and one that advances the dome in steps.

COMMERCIAL SOLUTIONS

Various dome manufacturers offer domes with motorised shutter and rotation options, for example see <http://www.company7.com/techin/>. None so far as I am aware offer hardware dome synchronisation. There are several observatory control software suites that include dome synchronisation, although it is embedded in either complete automation or remote operation.

The precursor to these total software solutions was OCAAS, “Observatory Control and Astronomical Analysis System” written by Elwood Downey at the Clear Sky Institute <http://www.clearskyinstitute.com>.
The copywrite and source code was sold to Torus Technologies in 1999, who in turn sold it to Optical Mechanics in 2001 <http://www.opticalmechanics.com/> who renamed it TALON <http://phobos.physics.uiowa.edu/tech/software.html>.
It has been developed into a complete observatory, telescope and ccd camera control and data processing suite, even including Patrick Wallace’s telescope pointing analysis programme, TPoint <http://www.tpsoft.demon.co.uk/>.

DFM Engineering <http://www.dfmengineering.com/> offer total solutions to telescope and observatory control which includes dome synchronisation, as do Astronomical Consultants & Equipment <http://www.astronomical.com/RCS.htm>,
Optical Guidance Systems <http://www.opticalguidancesystems.com/computer.htm>
and Astralnomicon Observatory Systems <http://home.earthlink.net/~astralnomicon/PremSvc.htm>.

However these companies do not offer economical single end user site licences for their software making them unattractive for the lone ATMer. Their softwares are however ported to professional Unix platforms with the distinct advantage brought by a soft real time operating system. It is of course feasible to install Linux on either a PC or an AppleMac, and MacOSX is a Unix based OS in any case.

COMMERCIAL SOLUTIONS (cont.)

The following are PC software solutions:-

Technical Innovations' Digital Dome Works <http://www.homedome.com/info2a.htm#4> a PC automation system supplied with ROBO-DOME.

Software Bisque's AutomaDome <http://www.bisque.com/Products/AutomaDome/automadome.asp> a PC application that integrates with TheSky Astronomy Sotware <http://www.bisque.com/Products/TheSky/TheSky.asp> to control robotic domes.

AstroDigitals' Meridian Dome Automation System <http://www.astrodigitals.com/domeauto.html> supplied with ObservaDome, or Meridian Controls Corporation <http://www.meridiancontrols.com/DA/da.html> intended for use with a closed loop DC servo azimuth drive.

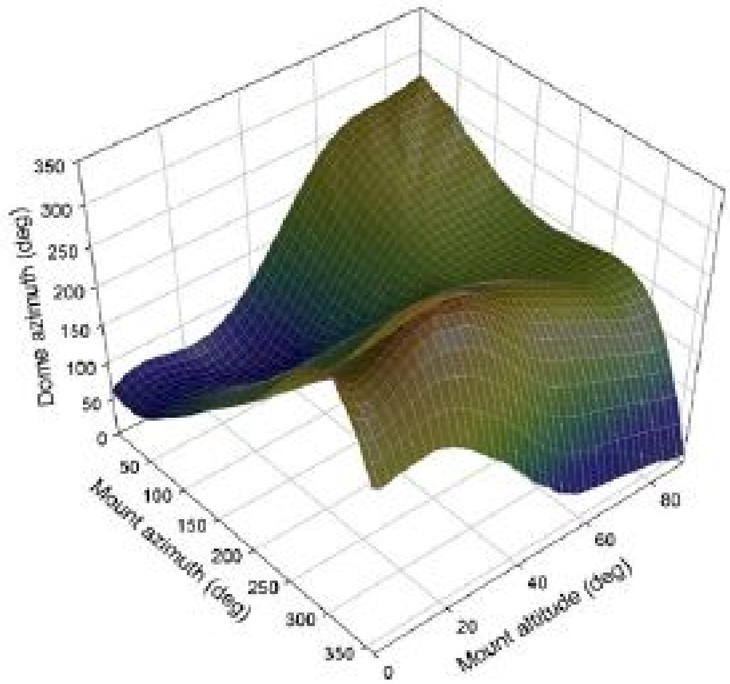
DOME DRIVING RATIONALES (cont.)

ATM SOLUTIONS

Brent Boshart has written a PC shareware pcdome.exe <http://www.heavenscape.com/software/pcdome.exe> for the now defunct Boyd commercial domed observatory. See <http://userwww.service.emory.edu/~twichma/dome_rot.htm> for an example of its use by Thomas Wichmann. Brent Boshart's shareware programme has unfortunately been pulled because Boyd Observatories Inc. has folded. However its use in the system implemented by Thomas Wichmann is ingenious as he describes:-.

The basic idea is to incorporate a microcontroller into the controller box. The microcontroller "speaks" via serial lines to both the mount and the motor controller board. In the "regular" mode, the system simply permits to manually move the dome in clockwise or counterclockwise direction, and, of course, to stop its motion. In the "slave" mode, the dome is linked to the mount so that the dome's slit is always pointing in the direction of the telescope. For this, the mount is polled for azimuth (in the case of fork-mounted scopes), or azimuth and altitude (in the case of GEMs or other mounts); the information is used to calculate the target dome azimuth, and the dome is moved to that target azimuth. The target calculation and movement is updated regularly so that the dome keeps up with the telescope. For fork-mounted telescopes which are positioned so that the declination axis is the center of the dome (which means having an eccentric pier!), the dome azimuth always conincides with the scope azimuth. In GEMs, the translation between scope pointing and dome azimuth is not as simple, because the relationship between scope azimuth and dome azimuth varies with the scope altitude. The math behind this is complicated, and I finally settled (with the help of Brent Boshart) on a more empiric approach, i.e., the program uses an input table that links scope pointing information to a certain dome azimuth.

This image shows the (empiric) relationship between azimuth and altitude readout from my mount and the dome azimuth required to place the dome shutter in line with the optic axis.



Linking the dome to the scope could be accomplished most elegantly through direct calculation of the dome azimuth from the telescope pointing information. This is complicated math. I have tried to develop the respective algorithms for a while, and have, thus far, failed to come up with a viable algorithm for this - the problem is not so much the translation of the hour angle/declination into dome azimuth, but the fact that the mount is not exactly in the center of the dome (see image above). As mentioned above, Brent Boshart came up with an alternative approach that actually works well, and is based on a lookup table. Scope azimuth/altitude and East/West information are then used to find the two closest dome azimuth values in the lookup table. The actual target azimuth is then determined via a simple interpolation routine. The BX-24 microcontroller is able to run through this calculation intensive routine about once every second, so that reasonable 'slaving' accuracy can be achieved. Each iteration of this routine ends in transformation of the dome azimuth (in degrees) into the equivalent encoder counts, and a GoToTarget step, during which the IPM card receives the current target, and initiates driving the motor towards that target.

This approach, although telescope / dome specific, circumvents the programming complications referred to on p17.

DOME DRIVING RATIONALES (cont.)

ATM SOLUTIONS (cont.)

Jack Patterson, Nubbin Ridge Observatory, Hot Springs, Arkansas, USA, has written a PC freeware called JPDome, see <http://www.nubbin.darkhorizons.org/dome_automation.htm>

HARDWARE SOLUTIONS

There are two hardware solutions to this problem, both of which are affordable, completely reliable under all possible circumstances, and more importantly, simple to set-up.

The first assumes you have no computer control. All that is needed is a coil and oscillator fitted to the mouth of the telescope tube, and a bell wire circuit to both sides of the slit, and connected to an op-amp and Schmidt trigger. The coil and oscillator sets up a toroidal electromagnetic field around the end of the tube. As the tube moves towards the preceding side of the slit, it induces a weak current in the bell wire. This current is amplified and at a predetermined level causes the trigger cct. to close the preceding dome drive relay. This in turn causes the dome to turn and as the separation of the bell wire and the field grows again, the induced current collapses, the trigger flips back and causes the relay to open and the dome to stop turning.

If the dome motor and drive speed are designed to turn the dome at an angular rate which matches the slew rate of the telescope then this system will also maintain synchronisation when the telescope is either repointed eastwards or westwards, slewed across the zenith or reversed across the meridian.

The alternative hardware solution assumes you have a computer controlled telescope drive that enables data inputs for dome azimuth and shutter open / closed conditions, such as the AWR Intelligent Drive System <http://dspace.dial.pipex.com/awr.tech/ih/index.htm>.

All you need are proximity sensors to provide this information. I strongly suggest you use Hall effect Reed switches for this purpose. Directional optical / IR or Ferro-magnetic proximity sensors are very expensive in comparison.

A pair of Reed proximity switches @ $22^{\circ}.5$ and 24 magnetic pickups spaced at 15° intervals around the dome rail will provide $7^{\circ}.5$ resolution. Add a third Reed switch @ $3^{\circ}.75$ from the second, and the resolution will be increased to $3^{\circ}.75$. The azimuth information from the dome is fed to the controller and when the telescope azimuth exceeds the dome azimuth by the resolution limit the controller initiates a stepwise dome rotation until it receives a signal from the next pickup.

Information of shutter open or closed can also be provided to the controller via proximity switches and sensors at the limits of travel. Contact me if you want more specific design and construction details. I can provide circuit diagrams and component lists at a modest cost, tailored to your specific needs.