Small Antenna Calibration at JPL

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JPL/Caltech (retired) & Space Science Institute

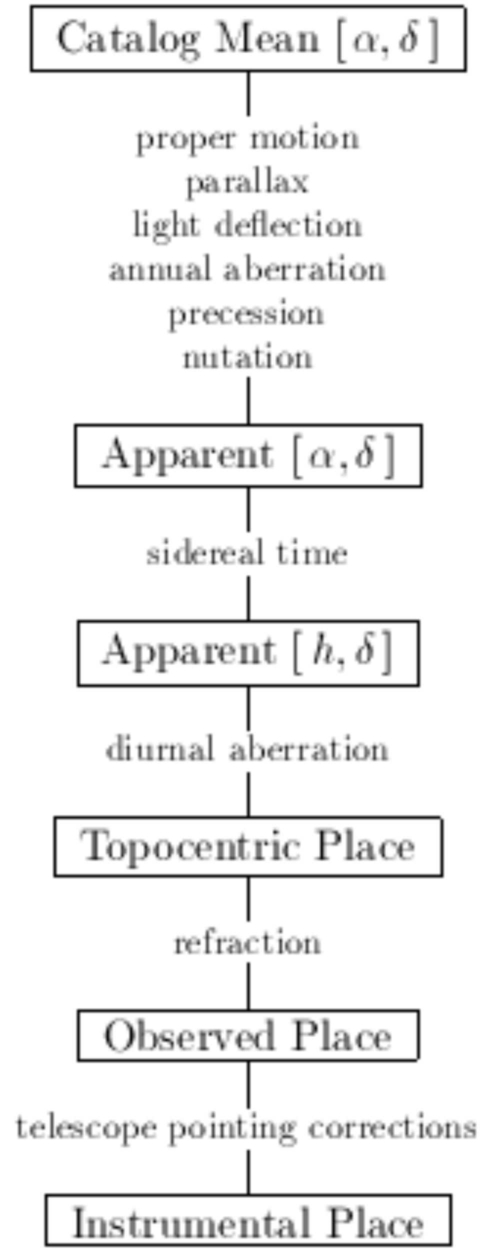
- DSN Array Project: a brief tour
- Pointing models and coefficients
- Receiver temperature
- Aperture efficiency
- Receiver total power stability

12-m telescope

6-m telescope

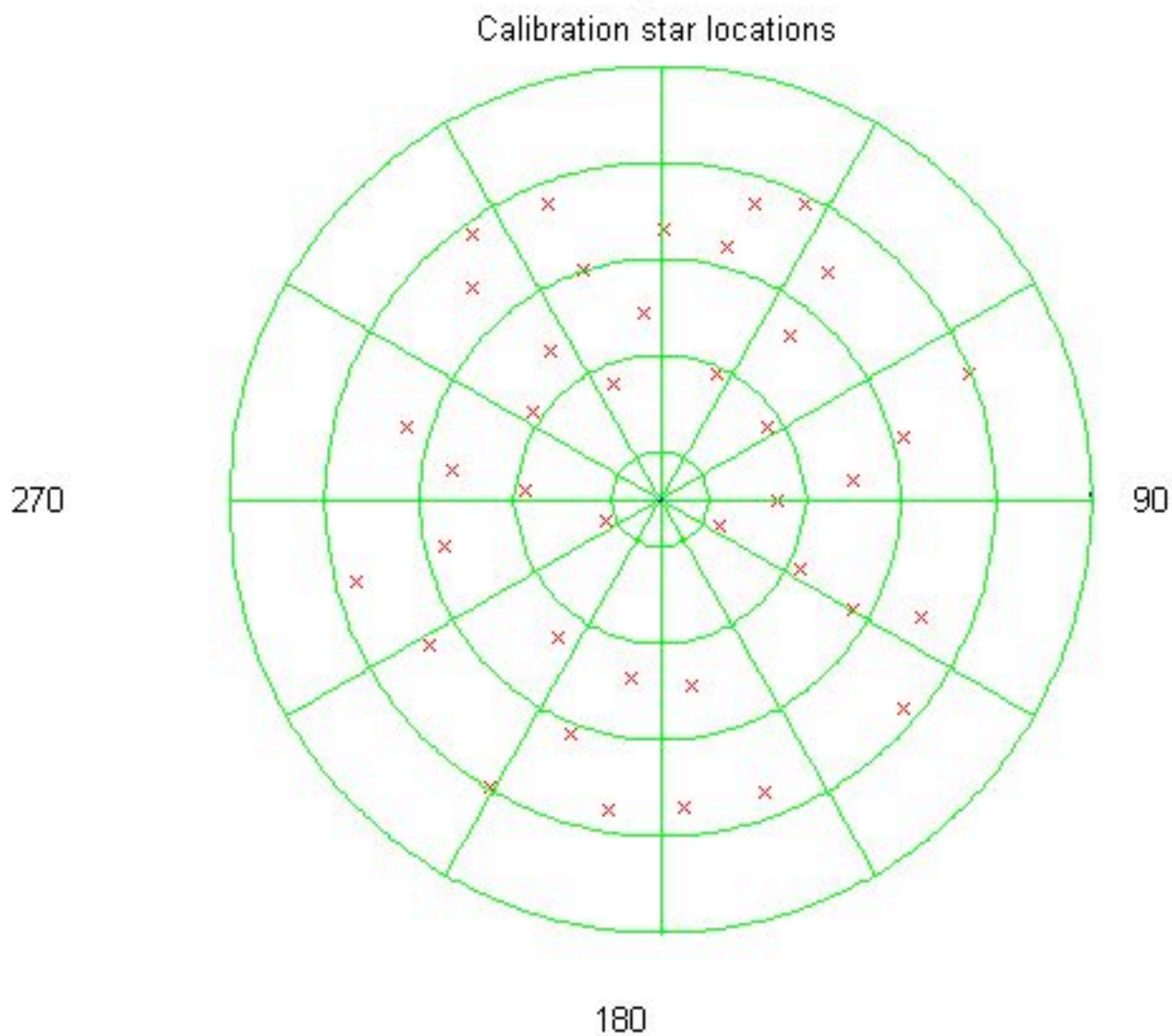
Telescope pointing steps

Most of these effects other than precession, refraction, and telescope-specific pointing corrections should be negligible for the DSES telescope at frequencies < 10 GHz.



Two 6-m telescopes at JPL. Note tiny black optical telescope mounted at the lower edge of each dish.

Even a small optical telescope mounted on the radio telescope allows use of bright stars all over the visible sky.



11-term antenna pointing model

$$\begin{pmatrix} \delta xel \\ \delta el \end{pmatrix} = \begin{pmatrix} P1 \\ P2 \\ \ldots \\ P11 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ \cos(el_t) & 0 \\ \sin(el_t) & 0 \\ \sin(el_t)\cos(az_t) & -\sin(az_t) \\ \sin(el_t)\sin(az_t) & \cos(az_t) \\ 0 & \sin(el_t) \\ 0 & 1 \\ 0 & \cos(el_t) \\ 0 & \cot(el_t) \\ \sin(az_t)\cos(el_t) & 0 \\ \cos(az_t)\cos(el_t) & 0 \end{pmatrix}$$

az_t is the true azimuth

el_t is the true elevation

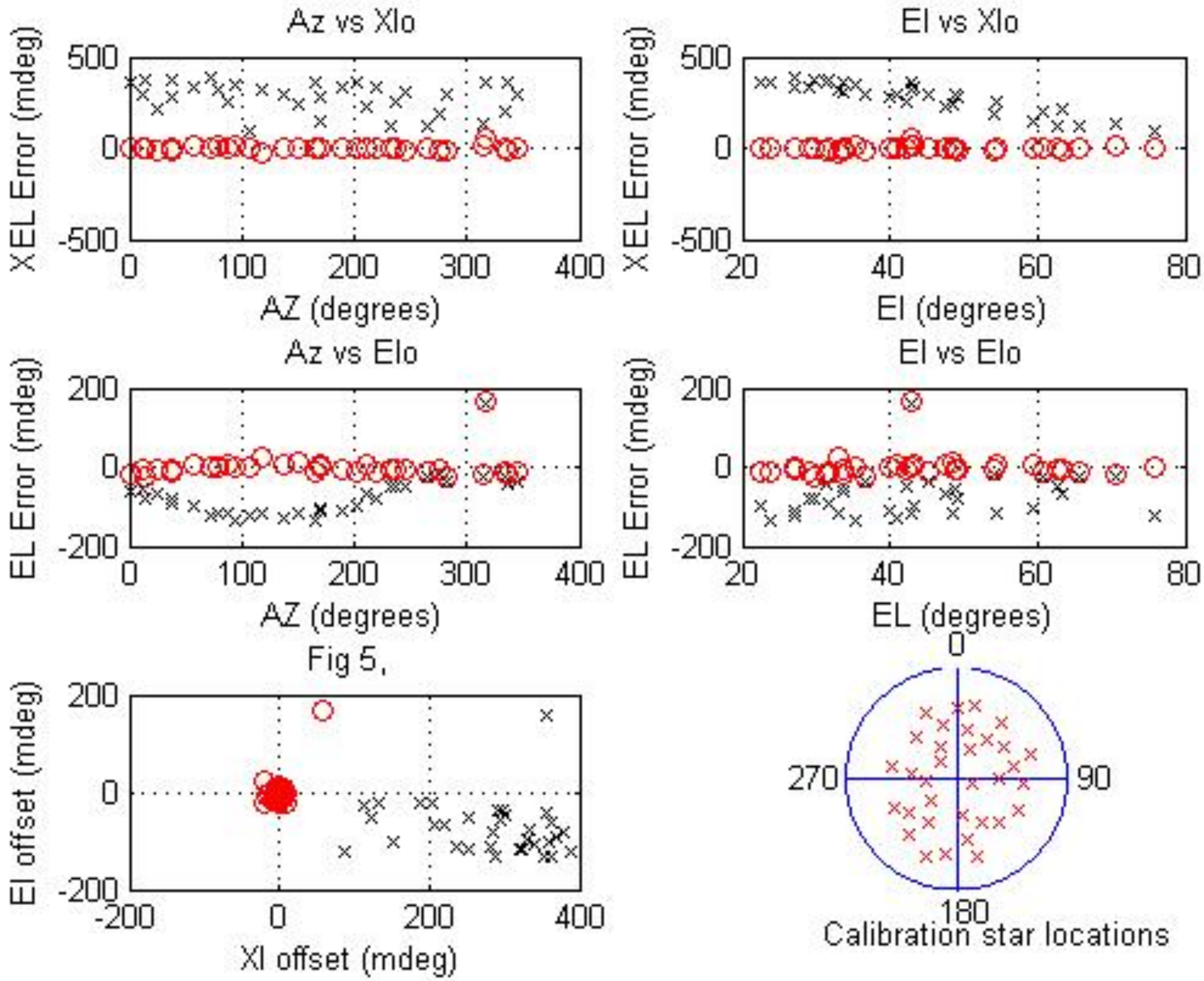
$$az_a = az_t + \arcsin(\sin(\delta xel)/\cos(el_t))$$

$$el_a = al_t + \delta el$$

Mechanical misalignment terms

- **P1:** Feed offset in cross-elevation (collimation error)
- **P2:** Azimuth encoder zero offset (after any large fixed azimuth offsets removed)
- **P3:** Axis skew (non-orthogonality)
- **P4:** Azimuth axis tilt in north-south direction
- **P5:** Azimuth axis tilt in east-west direction
- **P6:** Elevation encoder zero offset
- **P7:** Elevation axis flexure (sag) in plane perpendicular to elevation axis (gravity)
- **P8:** Elevation axis flexure in plane perpendicular to azimuth axis (mass asymmetry)
- **P9:** Residual refraction (probably negligible)
- **P10:** Azimuth encoder coupling alignment error in north-south direction
- **P11:** Azimuth encoder coupling alignment error in east-west direction

Could start by setting P6, P9, P10, and P11 to zero


Az vs Xlo
XEL Error (mdeg)
AZ (degrees)
El vs Xlo
XEL Error (mdeg)
El (degrees)
Az vs Elo
EL Error (mdeg)
AZ (degrees)
El vs Elo
EL Error (mdeg)
EL (degrees)
Fig 5,
El offset (mdeg)
Xl offset (mdeg)
0
90
180
270
Calibration star locations

1 mdeg =

3.6 arcsec

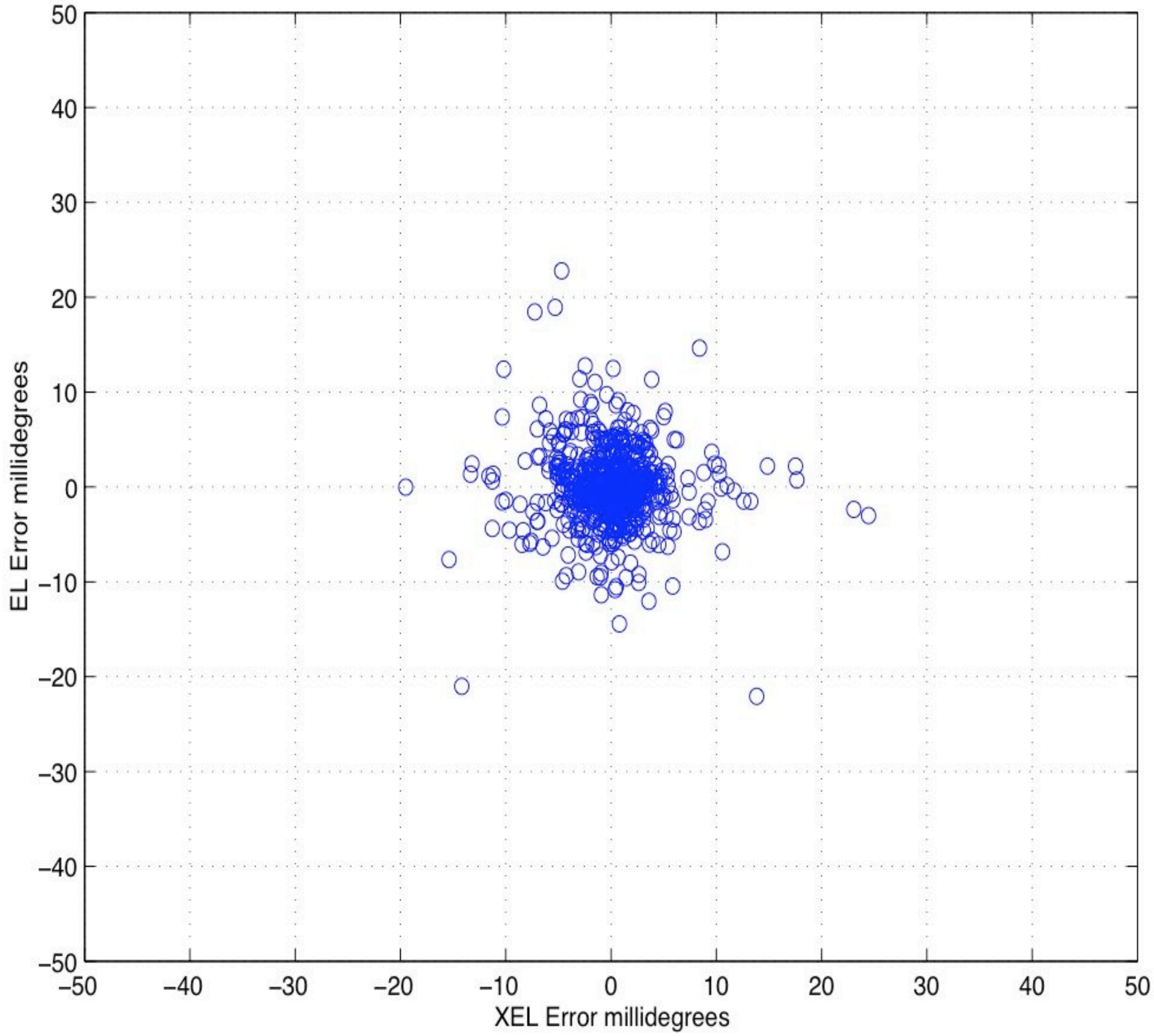


Figure 28. Measured pointing accuracy of 12-meter breadboard antenna

Receiver temperature

Hot and cold loads needed for absolute calibration.

1. LN_2 absorber + ambient temp absorber (best)
2. Ambient temp absorber + sky:

$$\frac{P_{vane}}{P_{sky}} = \frac{T_{receiver} + T_{vane}}{T_{receiver} + T_{spillover} + T_{sky}}$$

HOT-COLD noise power ratio gives receiver temperature:

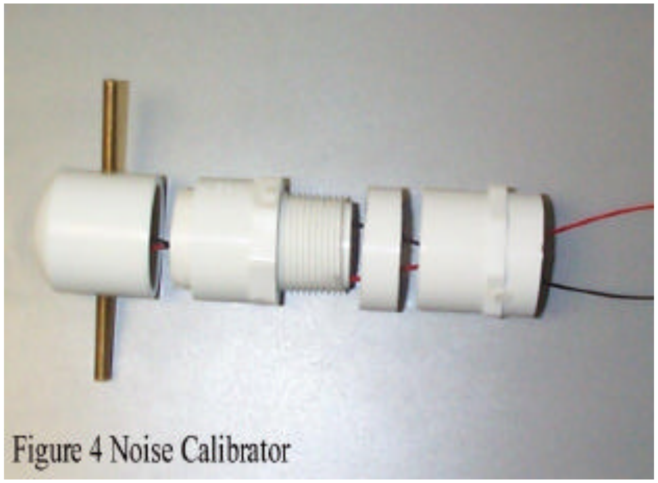
$$Y = \frac{N_{on}}{N_{off}} \qquad T = \frac{T_{source}^{ON} - Y \cdot T_{source}^{OFF}}{Y - 1}$$

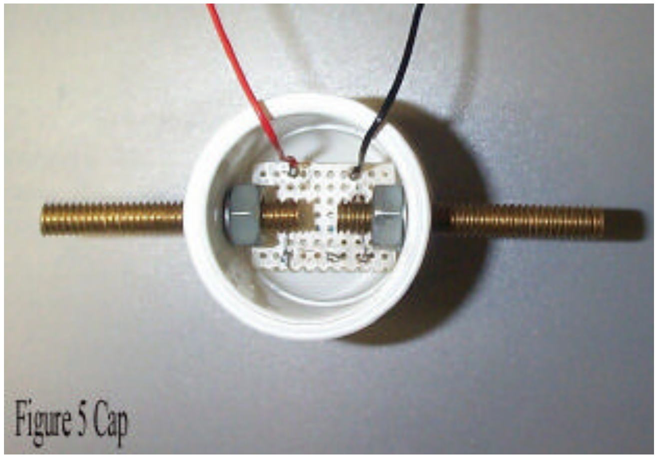
Receiver temperature

Hot and cold loads needed for absolute calibration.

Once T_{rcvr} is known, we can calibrate a noise diode for near-continuous monitoring of receiver temperature.

With fast switching, noise diode can also be used to correct for receiver gain fluctuations.

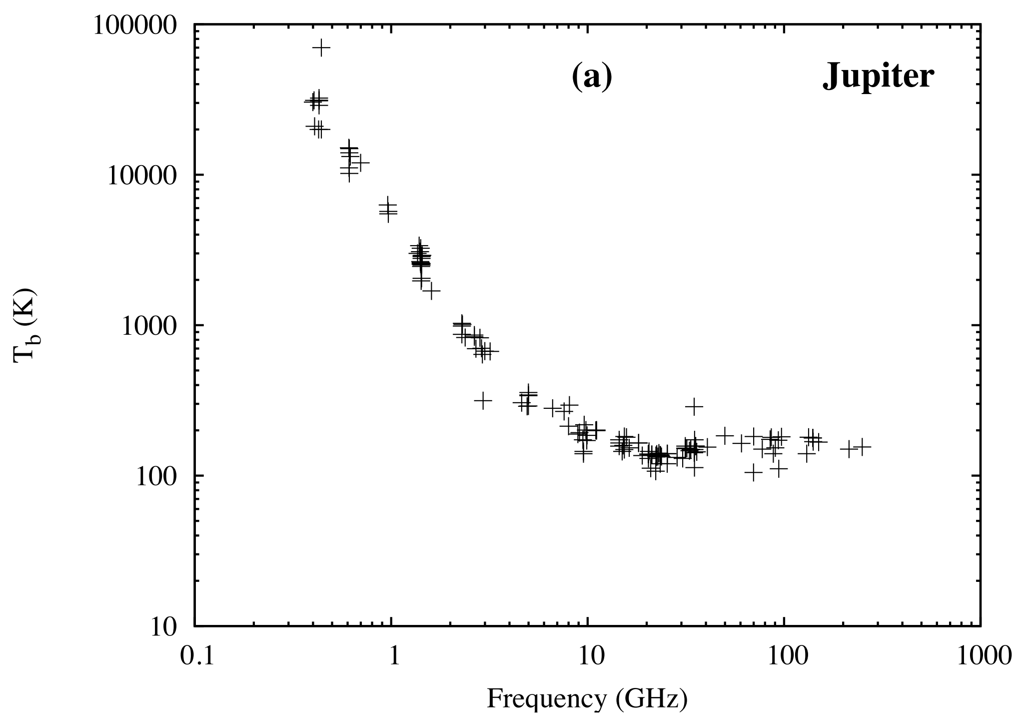


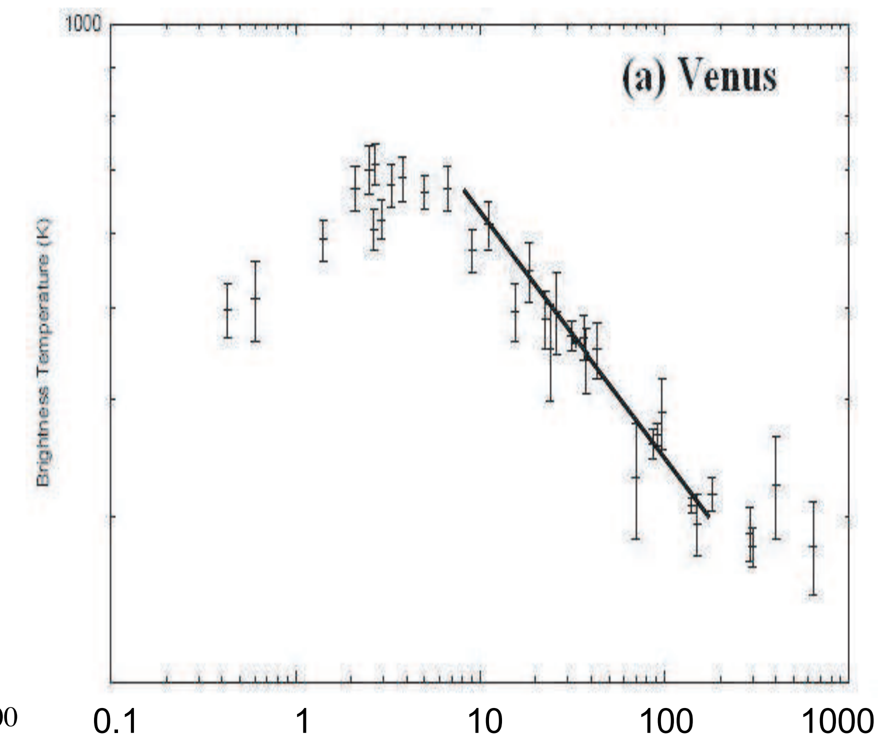


Aperture Efficiency

Need calibrated noise source (hot/cold loads or lunar observations) so T_{ant} can be measured.

Need a radio source with known flux density S in Jy. Could use Cas A, Tau A, Cyg A, and possibly Jupiter or Venus near inferior conjunction.





Aperture Efficiency

For a uniformly bright disk (moon or planet) and a gaussian telescope beam, the measured antenna temperature is reduced by:

$$x^{-2}\,[1 - \exp(-x^2)]\ ,\quad \text{where } x = \mathrm{sqrt}(\ln 2)\,[\Phi_{DISK} / \Phi_{HPBW}\,]$$

Calculate expected antenna temperature:

$$T_{ant} = A_{physical}\ S_{Jy}\ 10^{-26}\ /\ 2\,k$$

Efficiency is just measured T_{ant} divided by predicted T_{ant}

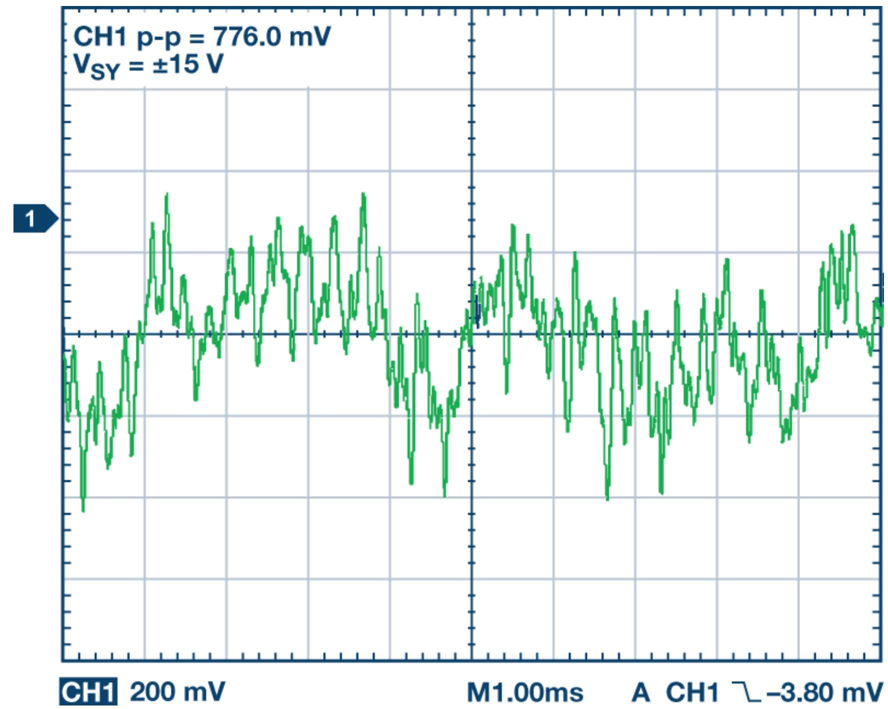
Cas A and Tau A are supernova remnants that are fading with time as they expand

Table 2. Cassiopeia A flux density for epochs 1965 and 2000.

Frequency GHz	S_{1965} Jy	S_{2000} Jy	Secular decrease % per year
1.405	2439±50	1970±50	0.67
1.415	2470±50	1885±40	0.67
1.44	2328±50	1793±40	0.66
1.44	2367±20	1813±55	0.66
3.15	1258±38	1030±30	0.62
3.2	1279±58	1008±45	0.61
4.08	1084±26	860±20	0.59
6.66	684±20	548±16	0.57
8.25	615±22	497±18	0.55
10.7	468±0	388±0	0.54
13.49	394±13	323±11	0.53
14.5	367±10	310±9	0.52
15.5	376±18	309±15	0.51
16	354±11	292±9	0.51
22.28	285±10	236±9	0.49
32	224±6	192±5	0.47
33	211±5	183±5	0.47
86	115±4	100±4	0.41
87	109.4±0	95.4±0	0.41
140	78.3±7	69.1±6.2	0.38
250	51.8±5.6	47.2±5.3	0.36

Receiver stability

For total power measurements, sensitivity is almost always limited by receiver stability (1/f noise) and not by thermal noise!



Receiver stability

$$\sigma^2_{\rm total} = \sigma^2_{\rm noise} + \sigma^2_{\rm G}$$

$$\sigma^2_{\rm total} = T^2_{\rm sys}\left[\frac{1}{\Delta\nu_{\rm RF}\tau} + \left(\frac{\Delta G}{G}\right)^2\right]$$

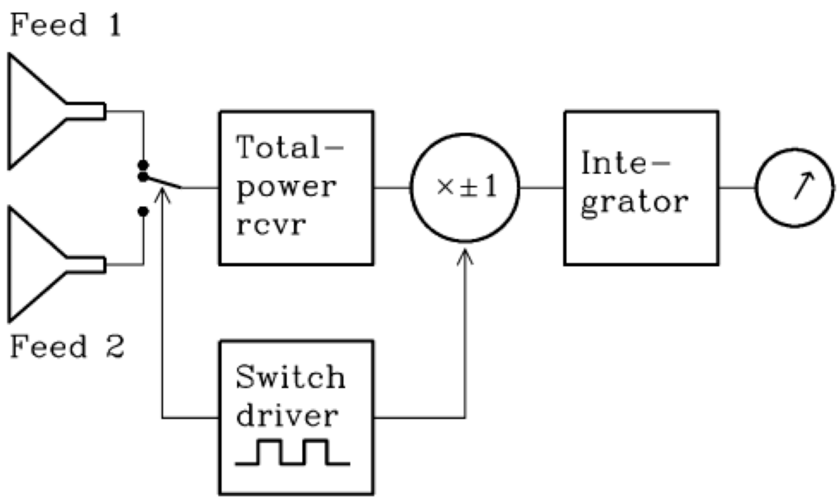
The ***practical total-power radiometer equation*** is thus:

$$\boxed{\sigma_{\rm T} \approx T_{\rm sys}\left[\frac{1}{\Delta\nu_{\rm RF}\tau} + \left(\frac{\Delta G}{G}\right)^2\right]^{1/2}}$$

Clearly, gain fluctuations will significantly degrade the sensitivity unless

$$\left(\frac{\Delta G}{G}\right) \ll \frac{1}{\sqrt{\Delta\nu_{\rm RF}\tau}}$$

Receiver stability



If the system temperatures are T_1 and T_2 in the two positions of the switch, then the receiver output is proportional to $T_1 - T_2 \ll T_1$ and the effect of gain fluctuations is only

$$\Delta T_{\mathrm{G}} \approx (T_1 - T_2)\frac{\Delta G}{G} \ll T_1 \frac{\Delta G}{G} \, .$$