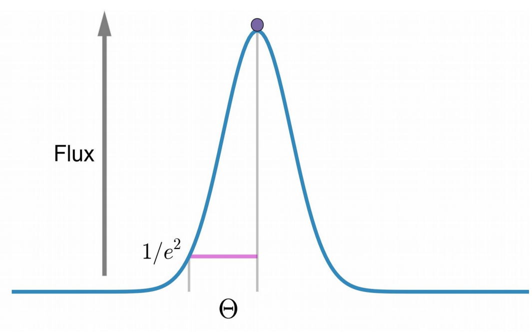
Procedure for taking azimuth and elevation scan data on a satellite for estimating transmit beam divergence

Context

It is increasingly necessary for SLR stations to know their laser beam intensities at satellite heights. This can inform satellite mission operators of the potential hazard to sensitive on-board equipment. This note describes a method to estimate the laser beam divergence of SLR stations from satellite scans. Further details on this technique are found in *Burris et al*, 2013.

What is needed for the beam divergence estimation?

The goal of the technique is to determine the $1/e^2$ divergence half angle. A scan of a single satellite gives the angular offset from the beam centre to the edge of the beam profile, θ_s. The reduction factor, F, required to extinguish the signal, is determined either by a reduction in laser power or the insertion of ND filters. These two quantities are used to compute the divergence, θ_t, at which the intensity falls to $1/e^2$ of the beam centre:



$$\theta_t = [-2\theta_s^2/\ln(F)]^{1/2}$$

where: $\boldsymbol{\theta_s}$ is the scan half-angle (microradians or arc-seconds)
F is the signal reduction factor required to extinguish the signal. This is obtained from either: a) $\mathbf{E_{MIN}/E_{MAX}}$, where $\mathbf{E_{MAX}}$ is the full laser energy and $\mathbf{E_{MIN}}$ is the reduced laser energy; b) alternatively, F is the applied ND transmission value, $\mathbf{T_{ND}}$.

Procedure

Measuremes are best performed at night in a cloudless part of the sky. For a strong signal, remove any daytime filters, open the iris and choose a satellite with fairly strong returns. Turn off any automatic attenuation. It is important to minimise the time taken to perform each measurement so that variables are approximately constant.

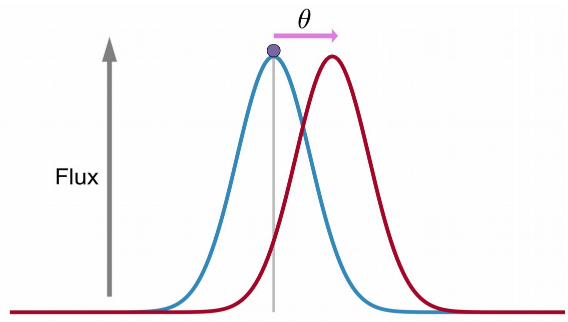
Step 1: Find the beam centre

i. Find satellite and optimise return rate to get initial estimate of centre position
ii. Scan in azimuth to find signal boundaries (offsets required to extinguish signal)
iii. Centre azimuth and repeat for elevation.
iv. Centre beam.

Step 2: Scan for the beam half-angle

From the centre position determined above:

i. Scan in azimuth to signal boundaries and record angular offsets
ii. Repeat for elevation.
iii. Record satellite slant range and elevation



Step 3: Measure the signal intensity reduction factor

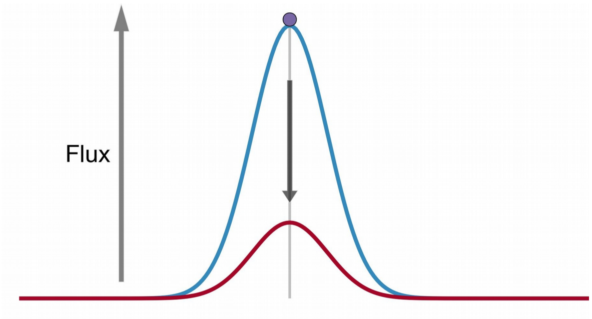
From centre position determined in step 1.

If laser energy can be modified:

i. Measure full transmit power, record E_{MAX}
ii. Reduce laser transmit power until signal is extinguished, record E_{MIN}.

If using neutral density filters in receiver optics:

i. Insert ND filters until signal is extinguished, record ND.



Some practical factors to consider

- Real world conditions will introduce variations in the measurements. Pressure, humidity, local seeing, the proximity of the Sun, human error, target cross section, thermal gradients and laser performance will all impact on the result. It is advisable to perform the experiment swiftly and take an average value of several measurements at about the same elevation.

- When reducing transmit power on a flashlamp pumped system, do not reduce power by decreasing the capacitor bank charge voltage since this will reduce the lamp pump energy. A decrease in lamp pump energy will reduce the thermal loading of the laser medium and change the divergence. The transmit power can be reduced by changing the timing of the laser pulse transit with respect to the flashlamp pulse timing so that the laser pulse experiences less gain.

- There is a degree of subjectivity in estimating the angular offsets at which the signal is extinguished. This has no effect on the final result provided the measurements are consistent.

Further measurements

Once the scan procedure has been used to determine the divergence at a given setting, θ_1, the beam divergence can be changed and the transmit power (or ND filter value) adjusted again to obtain Npe ~ 0 while the beam is still centred on the satellite. This allows determination of θ_2 from θ_1 from the following equation:

$$\theta_2 = [(T_{ND,2}/T_{ND,1})\theta_1^2]^{1/2} \quad \text{or} \quad [(E_{MIN,2}/E_{MIN,1})\theta_1^2]^{1/2}$$

This should only be used after θ_1 is well characterized since errors in θ_1 propagate to θ_2. This allows for the quick determination of large divergence values, θ_2. See *Burris et al, 2013* for more details.

Data Recording

Stations should maintain their own records of divergence measurements and send the data in the format suggested below to Jose Rodriguez at josrod@nerc.ac.uk . The data will be used by the NEWG and distributed to the other working groups of the ILRS as appropriate.

DATE/TIME (UTC)	SATELLITE	STEP SIZE	AZ CENTER	EL CENTER	FULL AZ WIDTH	FULL EL WIDTH	RANGE	ELEVATION	FULL POWER	LOW POWER OR ND FILTER

References

Burris R. et al., *Proposed beam divergence estimation procedure for the ILRS.* 18th ILRS Workshop, Tokyo, Japan, 2013. (http://cddis.gsfc.nasa.gov/lw18/docs/papers/Session8/13-03-06-Burris.pdf)

Davis M. et al., *Beam Divergence: Introduction, results of measurements. 17th ILRS Workshop, Bad Kötzting, Germany, 2011.(http://cddis.gsfc.nasa.gov/lw18/docs/papers/Session8/13-03-06-Burris.pdf)*