Synthesis Imaging Workshop Practical Session

Measuring temperatures using a single antenna

The aim of this experiment is to firstly determine a calibration factor so that an antenna output can be converted to a temperature scale, and secondly then to measure the receiver noise temperature, the temperature of the Moon, and brightness temperatures of the Galactic Centre and the radio galaxy Centaurus A.

Some background

The power at the output of a receiver system is the sum of several components:

- The power from the astronomical source (including the cosmic microwave background).
- Noise originating from the Earth's atmosphere.
- Black body radiation from the ground spilling into the system ('ground pickup' or 'ground spillover').
- Noise originating from ohmic losses in the antenna structure, feed horn, waveguide components etc.
- Noise originating in the receiver itself.

The power produced by a blackbody radiator is given by the Planck equation, which relates power to temperature and observing frequency. The Rayleigh-Jeans approximation to the Planck equation is valid for most radio astronomy experiments. In this case, power is proportional to temperature, and it is usually convenient to talk in temperature units. The power measured at the receiver output has an equivalent noise temperature, called the system temperature. The cosmic microwave background contributes 2.7K to this system temperature. If the receiver horn is covered with a piece of absorber at a temperature of 300K, it will contribute 300K to the system temperature. Similarly, if we look at a blackbody, with physical temperature T, which fills the antenna field of view, it will contribute T K to the system temperature.

Basic operation

As other groups will be using the array as an interferometer, we will have access to one or two antennas. After setting up the observing frequency, we will drive the antenna by giving commands to the Antenna Control Computer (ACC), and taking readings from an output port near the front end of the antenna.

The output port that we have access to is the so-called "gated total power" (GTP). To first order, this gives a voltage that is proportional to the output power or system temperature of the receiver. This can be thought of as the output of a detector connected to the receiver.

Because of non-linearities in the detector, and because the gain of the receiver can change somewhat, the ATCA uses a calibration system which continuously calibrates this total power output. This works using a noise source which is taken as having a constant signal - it is our reference. This noise signal is injected into the system before the front-end amplifier, and so goes through the same electronics as the astronomical signal. By modulating (switching) this noise source on and off comparatively rapidly (128 Hz), and by measuring the change in the detector output, we can correct for any change in the gain of the system. The noise signal is equivalent to about 5% of the system temperature resulting from the blank sky, and is sufficiently small that the detectors are linear over the range of fluctuations that it produces. If the noise source has a equivalent noise temperature of $T_{\rm cal}$, and if the gain of the system is k (in Kelvin/volt), then the outputs during when the noise source is on and off are

$$\begin{aligned} T_{\rm sys} + T_{\rm cal} &= k\,V_{\rm on} \\ T_{\rm sys} &= k\,V_{\rm off} \end{aligned}$$

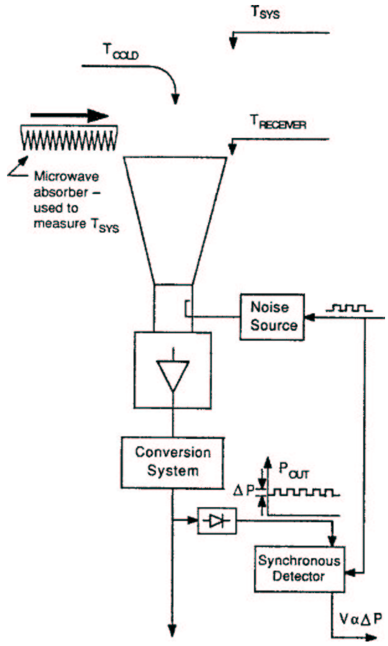

Figure 1: Measuring system temperatures

and so (with a little manipulation)

$$
\begin{aligned}
T_{\rm sys} &= T_{\rm cal}\frac{V_{\rm off}}{V_{\rm on}-V_{\rm off}} \\
T_{\rm sys} &= T_{\rm cal}\frac{V_{\rm off}}{\Delta V}
\end{aligned}
$$

There is an output port which gives ΔV scaled by 20. As ΔV is demodulated at the on/off switching rate of the noise source, this output is called the "synchronous detector output" (SDO). The "total gated power" (GTP) port provides us with $V_{\rm off}$. So to summarise, to measure the system temperature, we compute

$$T_{\rm sys} = 20\,T_{\rm cal}\frac{GTP}{SDO}$$

$T_{\rm cal}$ is a calibration factor that we will need to measure.

Determining $T_{\rm cal}$

Both $T_{\rm cal}$ and $T_{\rm rec}$ (the contribution to system temperature of noise originating within the receiver and horn system) can be determined by placing two loads of known temperature over the antenna horn. For this experiment, we will use a ambient absorber as one 'hot' load ($T = 300$K) and the cold sky as another load (equivalent temperature of about 10K at 3cm - this includes ground spillover and antenna ohmic loss terms). So

$$
\begin{aligned}
T_{\rm rec} + T_{\rm hot} &= 20T_{\rm cal}\frac{GTP_{\rm hot}}{SDO_{\rm hot}} \\
T_{\rm rec} + T_{\rm sky} &= 20T_{\rm cal}\frac{GTP_{\rm sky}}{SDO_{\rm sky}}.
\end{aligned}
$$

Knowing $T_{\rm hot}$, $T_{\rm sky}$, and measuring the GTP and SDO, we can compute $T_{\rm rec}$ and $T_{\rm cal}$.

Measuring the brightness temperature of other objects

Having a calibration for $T_{\rm cal}$, we can measure the system temperature when looking at a variety of objects. The system temperature that we measure will equal the brightness temperature of the object plus the system temperature that would be measured without the object present. For a blackbody radiator that fills the beam of the antenna (e.g. the Moon), this temperature change will equal the physical temperature.

Object	RA (degrees)	DEC (degrees)
Galactic Centre (Sagittarius A*)	266.4168	-29.00780
Centaurus A	201.3651	-43.01911
Mars	281.4530	-26.01047
Moon	(see appendix)	

Table 1: Positions of some sources. The coordinates needed by the antenna control computer are rather unusual – degrees of RA and DEC. The position of Mars is as seen from Narrabri at 4pm, 27 September

Other possible experiments

- Humans emit as blackbody radiators. Attempt to measure your body temperature. You will need lots of hands and arms to attempt to fill the view of the feedhorn for this.
- Do a 'sky dip', and measure the change in system temperature with elevation. What are the causes of the changes with elevation.
- Move the antenna, in az and el, to be ahead of the Moon, stop the drives and then watch the Moon drift through the beam. Determine the angular velocity of the Moon relative to us. Can you detect that its not purely sidereal motion?

Appendix A – Brief antenna operating instructions

The antenna will be driven by giving commands directly to the Antenna Control Computer (ACC) in the 'pedestal' room. First switch the ACC terminal selector to the pedestal room, and then use the terminal located to the left of the door as you enter. Commands that are relevant are

`loca` Put the ACC into local mode (i.e. not controlled from the control building).

`dron` Switch on the drive motors.

`stop` Stop drives and switch them off.

`goto 0,6,`*x,y* Goto celestial coordinate *x,y*, where *x* and *y* are in degrees of right ascension and declination respectively.

`goto 0,0,`*x,y* Goto coordinate *x,y*, where *x* and *y* are in degrees of azimuth and elevation respectively.

`show sv` Show screen giving antenna position, etc.

`stow` Stow the antenna.

`remo` Put the ACC back into remote mode (i.e. back to being controlled from the control building).

Appendix B – Position of the Moon

By astronomical standards, the Moon's proper motion is extreme (it moves by about 13° per day), and parallax effects are very significant (e.g. eclipse and occultation events depend very much on where on the Earth you are). Below are the coordinates of the Moon, as a function of time, for 27th September.

Time (AEST)	RA (deg)	DEC (deg)	Az (deg)	El (deg)
14:20	308.9749	-21.2728	107.72	12.12
14:30	309.0603	-21.2704	106.65	14.12
14:40	309.1442	-21.2679	105.60	16.14
14:50	309.2265	-21.2653	104.55	18.16
15:00	309.3073	-21.2625	103.51	20.20
15:10	309.3867	-21.2596	102.48	22.25
15:20	309.4645	-21.2566	101.45	24.30
15:30	309.5408	-21.2533	100.42	26.37
15:40	309.6157	-21.2498	99.39	28.44
15:50	309.6892	-21.2461	98.35	30.52
16:00	309.7612	-21.2421	97.31	32.61
16:10	309.8318	-21.2378	96.25	34.70
16:20	309.9011	-21.2333	95.18	36.80
16:30	309.9690	-21.2284	94.08	38.90
16:40	310.0356	-21.2232	92.97	41.01
16:50	310.1010	-21.2177	91.82	43.12
17:00	310.1652	-21.2117	90.63	45.24
17:10	310.2281	-21.2054	89.40	47.35
17:20	310.2899	-21.1987	88.12	49.46
17:30	310.3507	-21.1915	86.77	51.58
17:40	310.4103	-21.1839	85.34	53.69
17:50	310.4690	-21.1759	83.82	55.80
18:00	310.5267	-21.1674	82.19	57.90
18:10	310.5835	-21.1584	80.41	59.99
18:20	310.6395	-21.1489	78.47	62.07
18:30	310.6947	-21.1390	76.31	64.14
18:40	310.7493	-21.1285	73.88	66.19
18:50	310.8031	-21.1175	71.11	68.21
19:00	310.8563	-21.1059	67.89	70.20
19:10	310.9090	-21.0939	64.10	72.13
19:20	310.9612	-21.0813	59.54	74.00
19:30	311.0130	-21.0681	53.95	75.77
19:40	311.0644	-21.0544	47.00	77.40
19:50	311.1156	-21.0401	38.29	78.84
20:00	311.1665	-21.0253	27.46	79.98