Aspects of Thermal Noise in Reverberation Chambers

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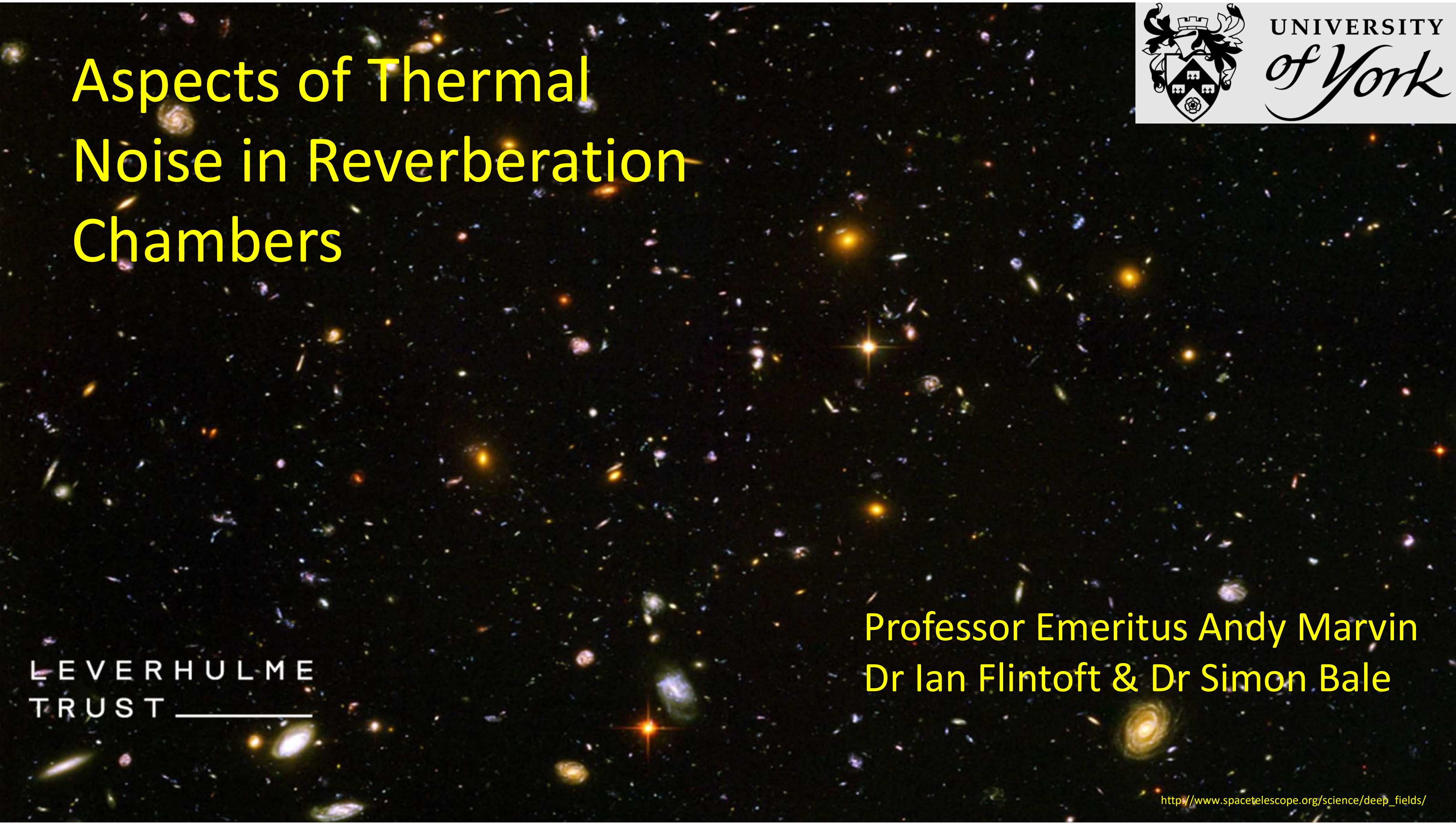

http://www.spacetelescope.org/science/deep_fields/

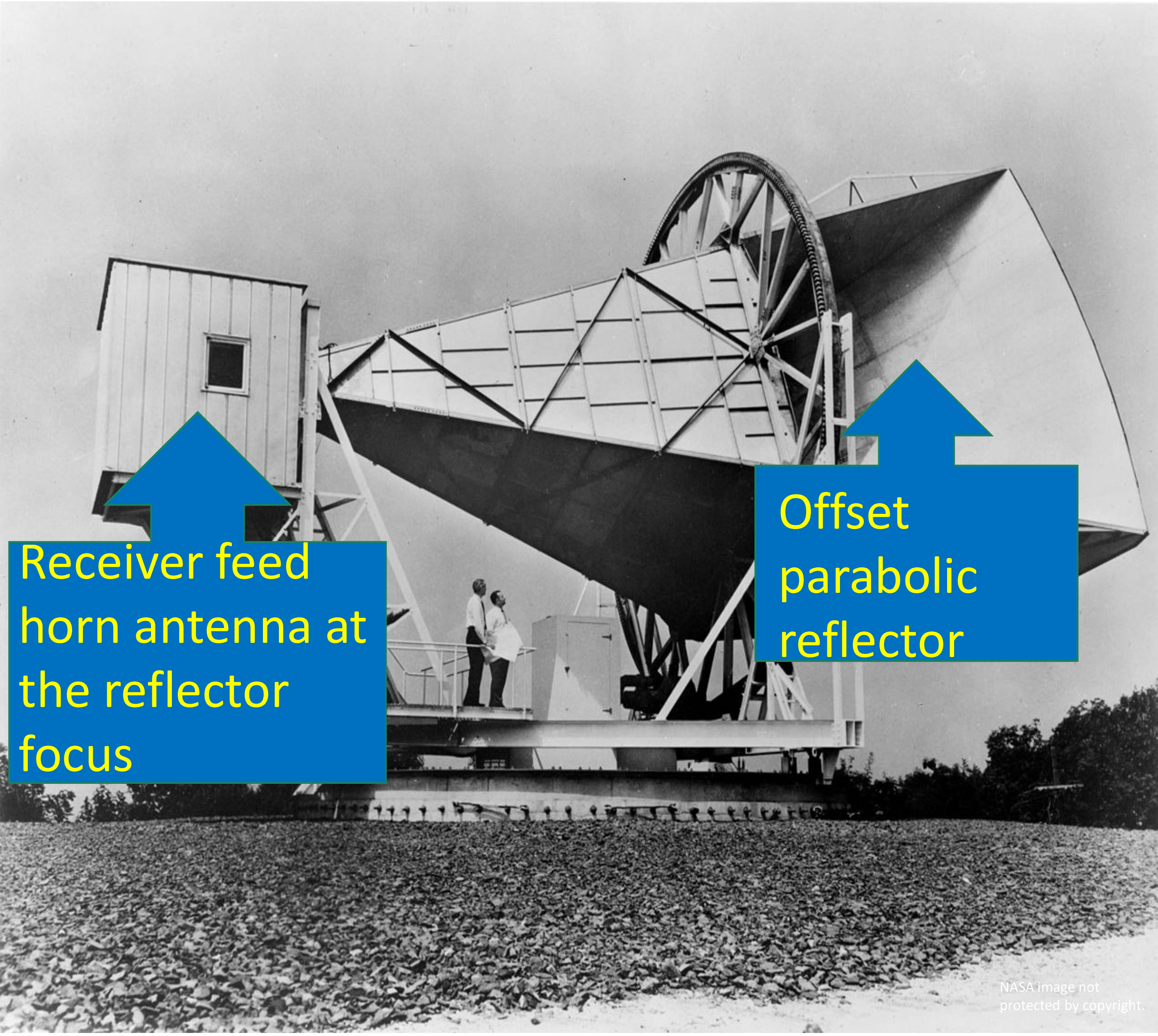
The total noise power measured by a receiver is

$$k(T_{ant} + T_{rx})B$$

where k is Boltzman's constant, B is the receiver bandwidth, T_{rx} is the receiver system input noise temperature and T_{ant} is the antenna noise temperature. The noise power represented by T_{ant} comes from the antenna's surroundings. *In an ideal anechoic chamber it's the ambient temperature of the chamber walls.*

Note that the receiver Noise Figure is defined with a "standard" source noise temperature of 290 K as;

$$N.F. = 10\log_{10}(1 + T_{rx}/290) \text{ dB}$$



Bell Labs Holmdel horn antenna, New Jersey, USA. Wilson and Penzias discover the Cosmic Microwave Background (CMB) in 1964.

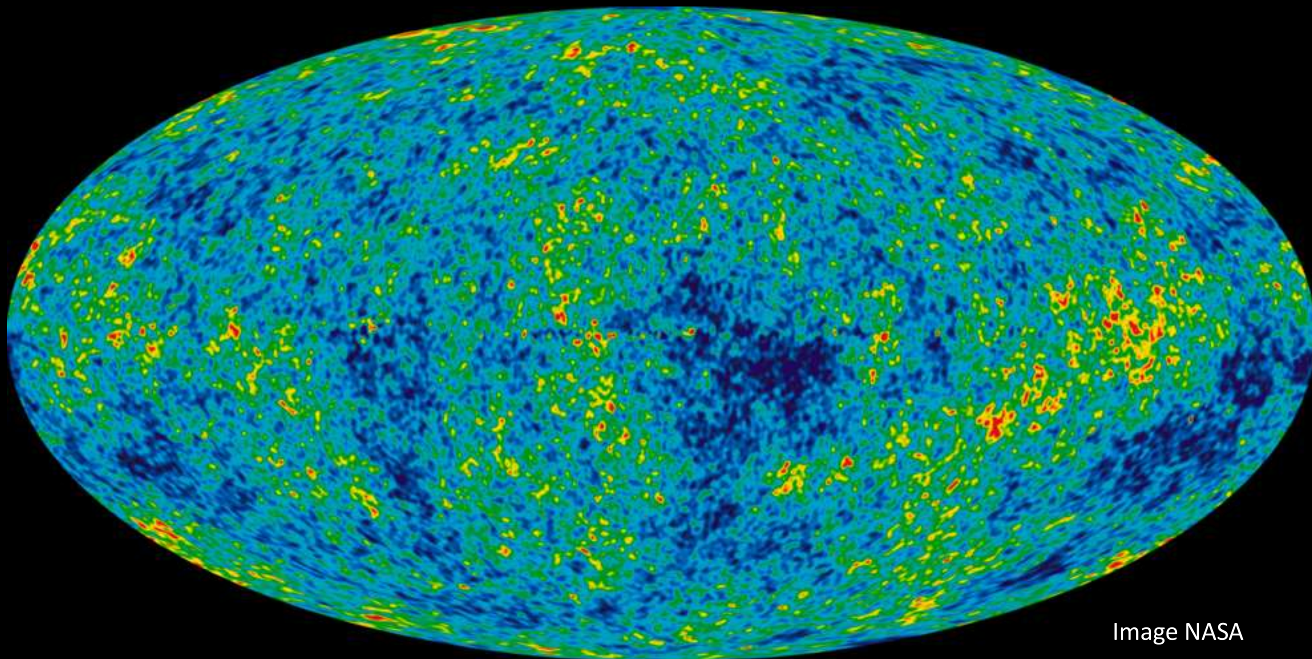
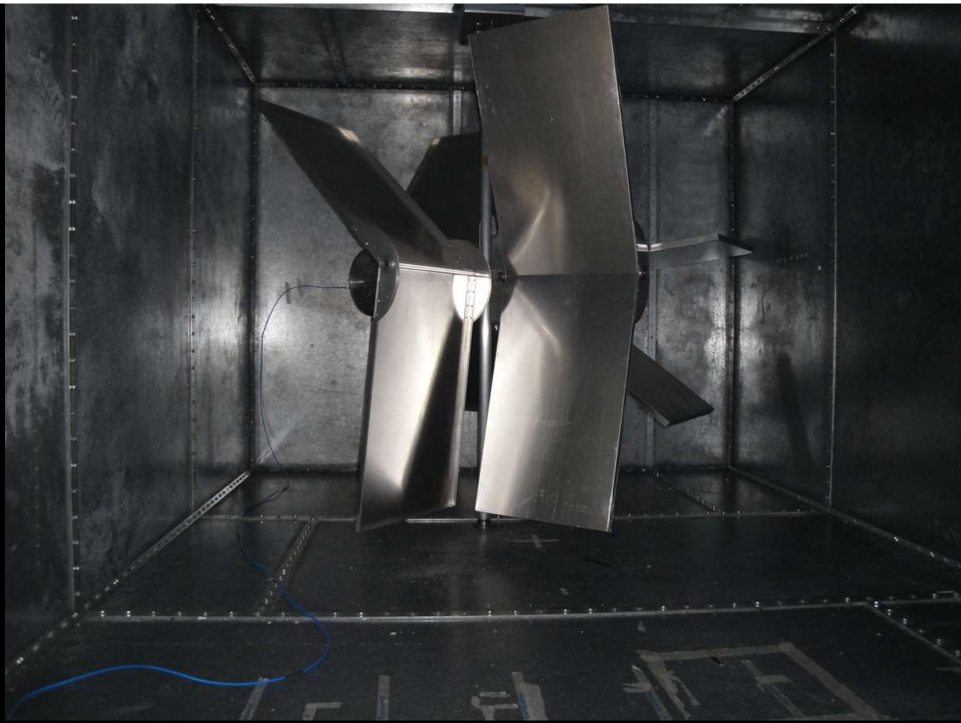


Image NASA

This image is part of a whole sky view of the CMB taken over nine years by the WMAP spacecraft 2.3 Gm from Earth orbiting Lagrange 2 in the Earth's shadow. It shows 200 μK variations in temperature.

How can they measure tiny variations in the 3 K CMB (T_{ant})when the reflector is at an ambient temperature of ~ 300 K?

*And if so, what happens to the antenna noise if the antenna is **surrounded** by a reflecting surface, a reverberation chamber?*



Thermal radiation is emitted by any physical body with a temperature above absolute zero. Plank’s Law determines the radiated noise power in a given frequency interval as a function of frequency and temperature for a “black body” having a surface emissivity of unity.

For a *partially reflective body*, the radiated noise power is reduced by the surface emissivity which is less than unity. At radio frequencies, and for surface temperatures in the region of 300 K, the Rayleigh-Jeans approximation to Plank’s Law can be used indicating that the radiated power in a frequency interval is directly proportional to the absolute temperature of the body.

In "Aperture excitation of electrically large lossy cavities" TEMC 1994, David Hill & Mark Ma demonstrated that there is a number of loss mechanisms in a reverberation chamber which include the small ohmic losses in the chamber walls and stirrer and any antennas and other objects in the chamber.

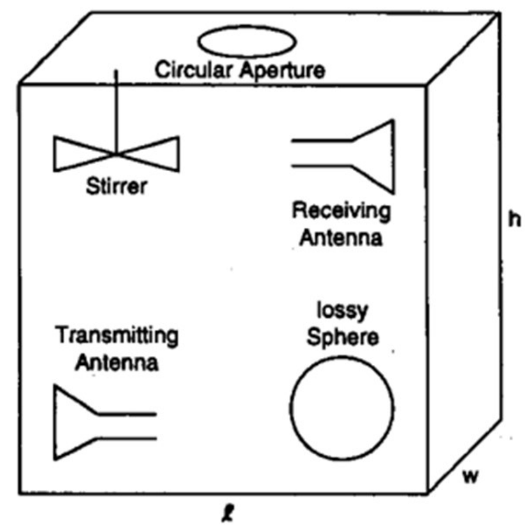


Fig. 4. Rectangular cavity with a circular aperture, a mode stirrer, receiving and transmitting antennas, and lossy sphere(s).

Hill, Ma et al
IEEE Trans EMC 1994
Issue 3

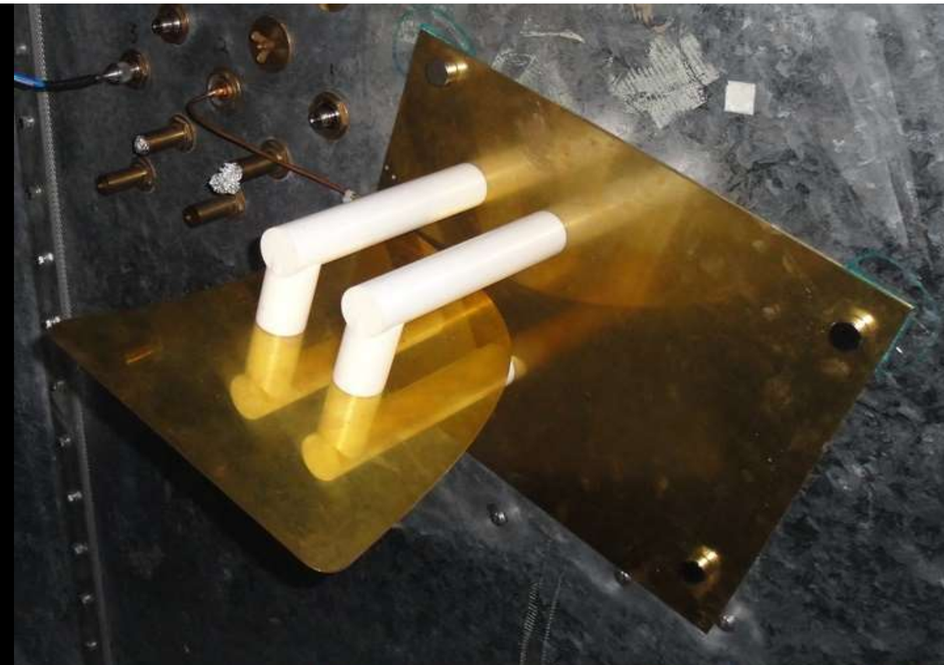
These ohmic losses all radiate thermal noise determined by their absolute temperature. This noise is received by the installed antenna.

We have shown that the Antenna Noise Temperature of an antenna in a Reverberation Chamber is the ambient temperature modified by the mis-match correction ratio of the antenna – receiver combination *C*.

$$T_{ant} = [\frac{P_{Noise-ant}}{P_{Noise-50\Omega}} \cdot (T_{50\Omega} + T_{rx}) - T_{rx}]$$

The antenna noise temperature is calculated from measurements of the noise received from the antenna compared to that from a 50Ω load at a known temperature. *T_{ant} depends on the stirrer position.*

The impedance mis-match correction ratio *C* is derived from *$S11_{ant}$* and *$S11_{rx}$* measured at the plane of the external chamber wall. *C depends on the stirrer position.*



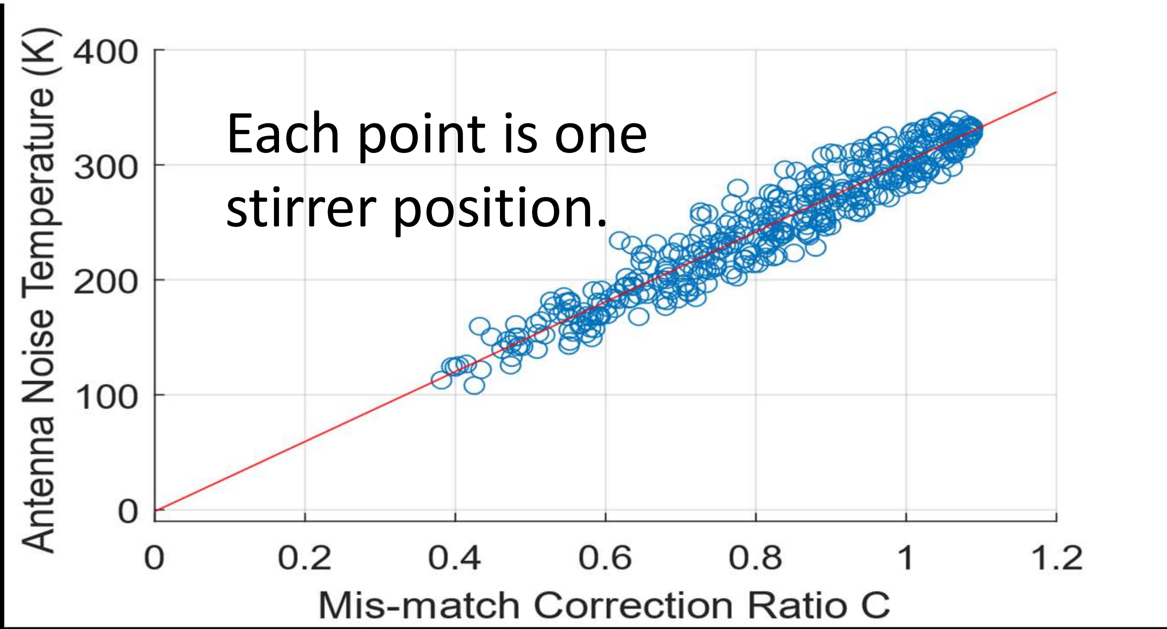
$$\frac{(1-|S11_{ant}|^2)(1-\ |S11_{rx}|^2)}{|1-S11_{ant}S11_{rx}|^2}$$

Antenna mis-match factor

Best fit straight line goes through *C* = 1 at the ambient temperature of the chamber.

50Ω load mis-match factor

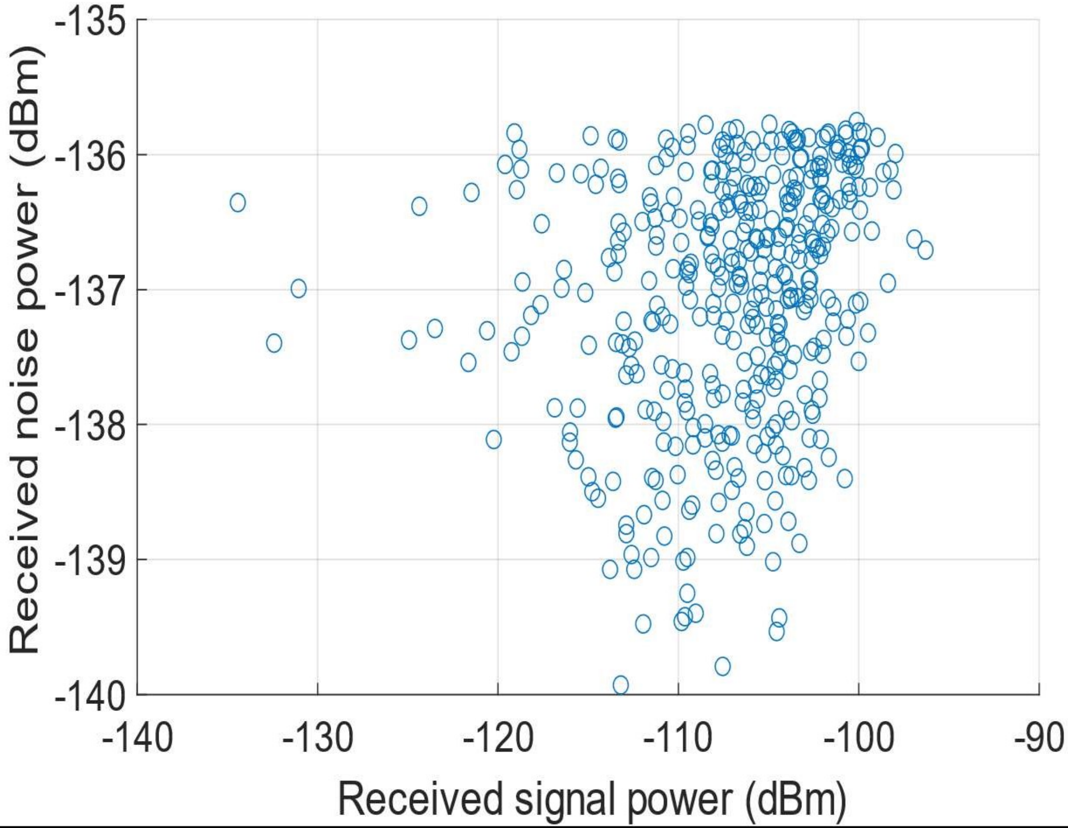
$$(1-|S11_{rx}|^2)$$



Mis-match Correction ratio C

$$C = \frac{(1-|S11_{ant}|^2)}{|1-S11_{ant}S11_{rx}|^2}$$

Simulated EUT (470 mm x 430 mm x 180 mm) showing the simulated contents and the signal excitation dipole.

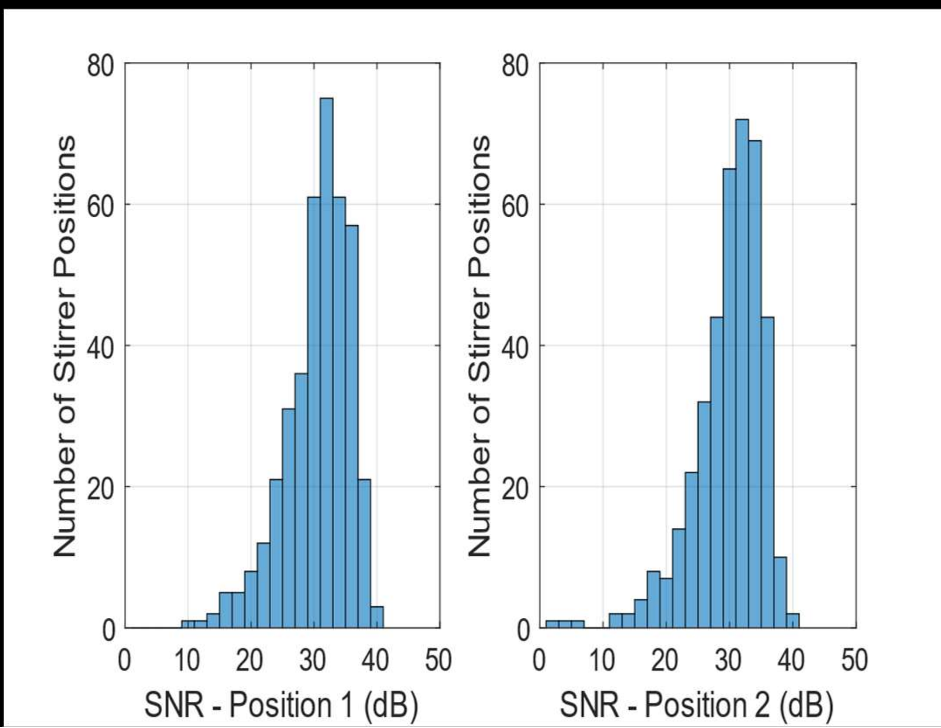


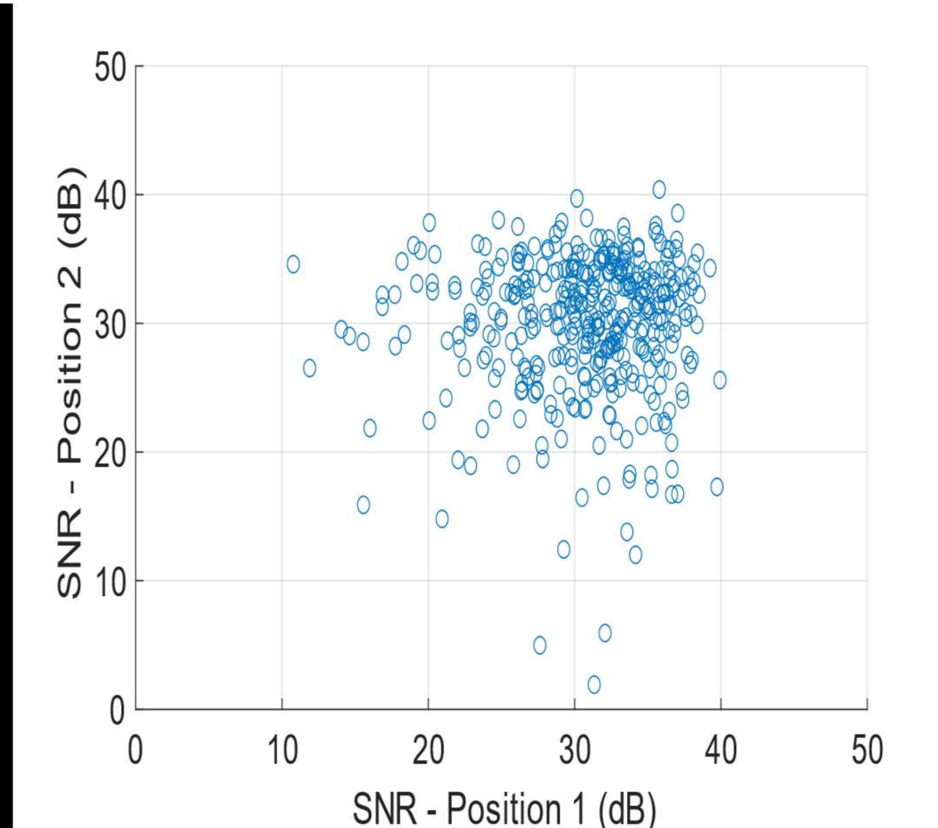
Typical received signal power and received noise power in the chamber at 800 MHz with an input power of -90 dBm.

Each point is an individual stirrer position.

There is no correlation between the signal power and noise power.

Typical histograms of the signal to noise ratio for two different simulated EUT positions.





There is no correlation between the signal-to-noise ratios for the two simulated EUT positions.

If a resistive absorbing body is put into the chamber then the overall *Q* factor of the chamber is reduced by the resistive properties of the absorbing body.

The absorbing body also emits thermal energy. It can be shown that (code for lots of algebra!) the measured antenna Noise Temperature in the chamber T_{ant} is the weighted sum of the chamber ambient temperature T_{RC} and the temperature of the absorbing body T_{AB} through the measured average absorption cross sections of the empty chamber and the absorbing body.

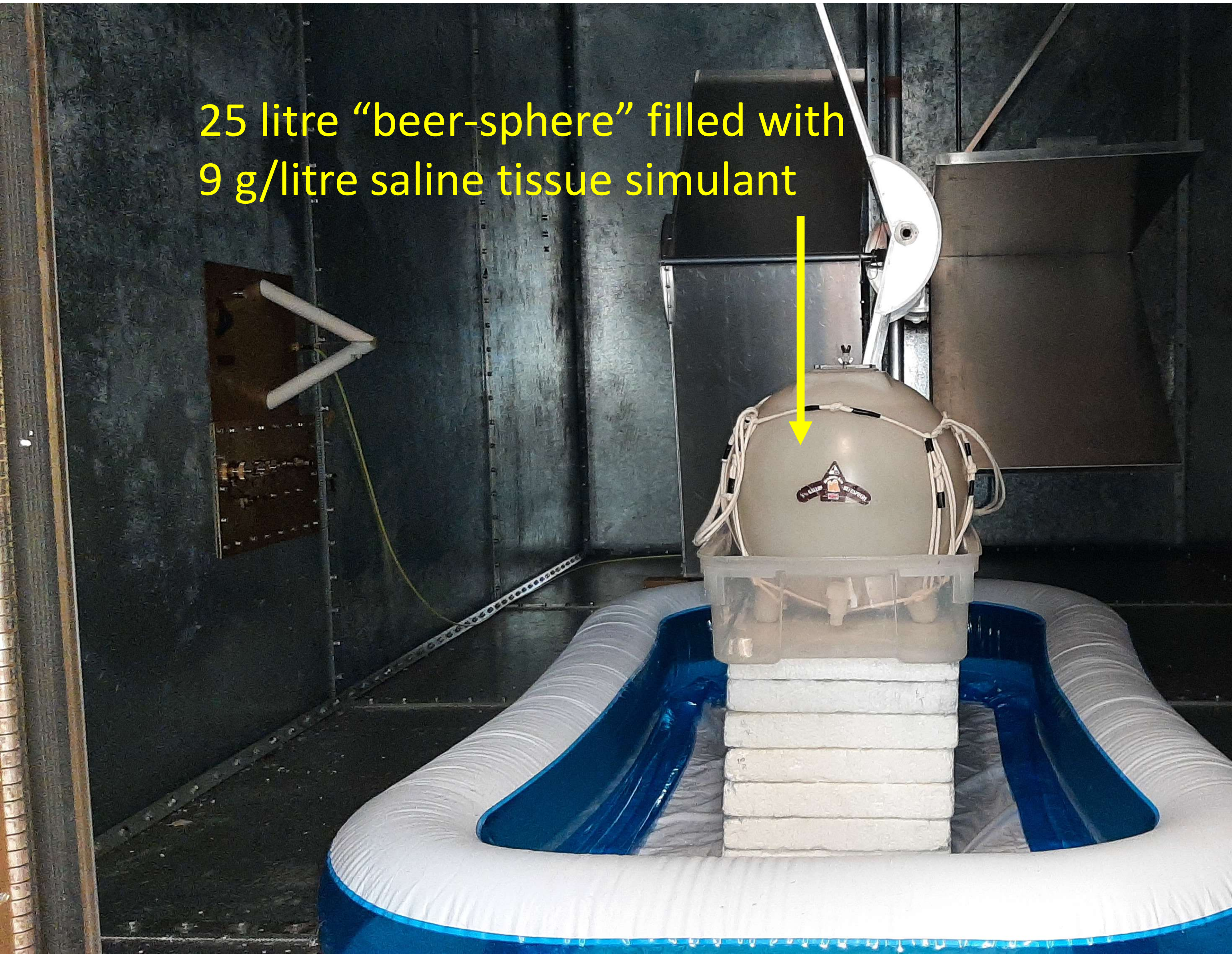
$$T_{ant} = \frac{\langle\sigma_{RC}\rangle T_{RC} + \langle\sigma_{AB}\rangle T_{AB}}{\langle\sigma_{RC}\rangle + \langle\sigma_{AB}\rangle + \langle\sigma_{ant}\rangle}$$

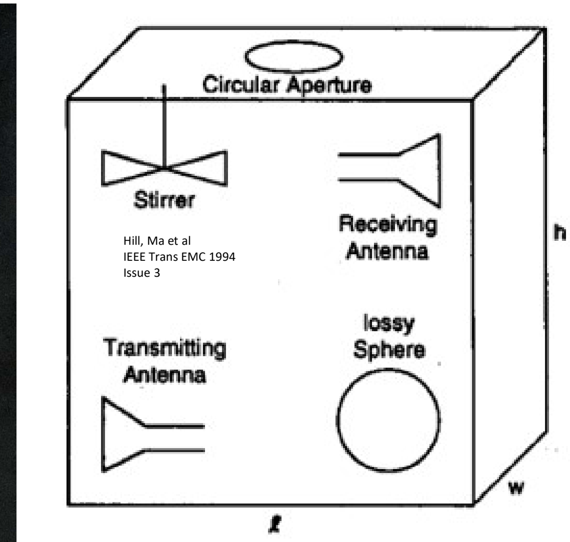
By measuring T_{ant} we can get T_{AB}

$$\langle \sigma_{AB} \rangle = \frac{\lambda^2}{8\pi} \left(\frac{1}{G_{AB}} - \frac{1}{G_{empty}} \right)$$

$$G = \frac{\langle |S_{21}|^2 \rangle}{(1 - |\langle S_{11} \rangle|^2)(1 - |\langle S_{22} \rangle|^2)}$$

The absorption cross section of a body σ (m^2) is the ratio between the power density in the chamber (W/m^2) and the power absorbed by the body (W). It is calculated by measuring the scattering parameters between two antennas in the chamber.


25 litre “beer-sphere” filled with
9 g/litre saline tissue simulant


Circular Aperture
Stirrer
Receiving Antenna
Hill, Ma et al
IEEE Trans EMC 1994
Issue 3
Transmitting Antenna
lossy Sphere
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- The technique allows for the thermodynamic temperature of the absorbing body to be measured. The low frequency, 800 MHz, means it’s not just the surface temperature.
- It is independent of the emissivity of the body.
- It can measure absorbing body temperatures above and below the ambient, demonstrated so far -5 C to 40 C with ~ $\pm$0.75 % accuracy.
- Target application is biological measurements hence the tissue simulant. Non-absorbing coverings (clothes) have no effect.
- Body movements should just help the chamber stirring!