AN EXPERIMENTAL MILLIMETRE-WAVE RADIOMETRIC TRACKER

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ABSTRACT

Recent improvements in mixer design and device technology have made possible the realisation of high performance millimetric receivers. This paper describes a 4 channel amplitude comparison radiometric receiver for target tracking which has been developed within certain specified constraints.

Introduction

Measurements of sky temperature as a function of frequency show that distinct minima occur in the region of 30 GHz, 90 GHz and 140 GHz [1] . The radiometer was designed to resolve the sky temperature reflected from a metal object against an emissive background at ambient temperature. Therefore, it was necessary to work within one of these minima which gave the largest change in antenna temperature for a specified target size and maximum antenna aperture size. Bearing in mind the system constraints the receiver was designed to operate in the 80-90 GHz frequency band.

The system comprises a 4 beam antenna with squinted beams and separate waveguide feeds for each beam. Associated with each feed is a mixer and with each pair of feeds a sampling switch, i.f. amplifier with detector and subsequent signal processing. The sampling is performed at i.f. where it is possible to realise lower insertion losses than with r.f. switching. A signal injection technique [2] is used to zero the system and compensate for any drift in the mixers as well as to allow a BITE circuit to test the complete system. This type of radiometer has the advantage of no moving parts and offers a greater range potential than that of the conical scan receiver assuming all other parts of the system are identical. This is because the energy in all four quadrants can be received continuously rather than sampled as in the conical scan technique.

Components and Radiometer

The antenna was required to provide 4 beams squinted away from boresight. When such an arrangement is examined in detail it becomes apparent that the optimum feeds are too large to fit close together at the focus and give the required crossover levels. Therefore it is necessary to consider the space allowed by the beam spacing constraints and fit in the largest feed possible. The feeds are then smaller which gives higher edge illumination, higher sidelobes and larger spillover. The tradeoffs between efficiency and crossover level for such an antenna have been examined in detail in [3] and [4] . Bearing in mind the above-mentioned tradeoffs a crossover level of -8dB was chosen.

The mixers were made using 'E' plane circuits mounted in the centre of standard rectangular waveguide WG26 [5, 6, 7] . The circuits use combinations of finline, microstrip and coplanar transmission lines which are processed on a thin metallised dielectric sheet with a permittivity of 2.22. The diodes used were Mott devices which were specially developed in our laboratories for use in the frequency range 60-90 GHz [8] and these devices were also designed to be compatible with the dimensions of finline and coplanar lines used in the mixer. The mixers have a d.s.b. noise figure of 5.5 dB at 5 mW local oscillator power over the frequency range 80-90 GHz.

A 4 way power splitter was made in WG26 to distribute the local oscillator power to the 4 mixers. The splitter consisted of 1 'H' plane and 2 'E' plane tees and showed an input reflection loss of 11 dB and an insertion loss to each output arm of ≈ 6.5 dB.

The i.f. amplifiers were developed using hybrid i.c. amplifier modules developed within Philips to yield a high performance amplifier at low cost. The overall noise figure was less than 3.5 dB over the bandwidth of 30 MHz to 1.5 GHz with an associated gain of ≈ 65 dB. A detector circuit was also integrated into each i.f. amplifier module.

The assembled unit is shown in figure 1 together with the housing tube and radome.

A separate control box enabled the zero reference level of each pair of channels to be set and post detection integration times to be selected between 10 ms and 1s.

The Range Equation

The maximum range of a single radiometric receiver can be found by equating the minimum resolvable temperature difference of the receiver to the change in apparent antenna temperature when a target comes on boresight. Hence we find :

$$R = \left(\frac{A_t G' \Delta T}{4\pi \Delta T_{min}} \right)^{\frac{1}{2}} \quad \ldots \quad (1)$$

where

R = range (m)

A_t = target area (m^2)

G' = mean gain over target area A_t

ΔT = target/background contrast temperature (K)

ΔT_{min} = minimum resolvable temperature difference (MRTD) of receiver (K)

and $$\Delta T_{min} = cT_{sys} \sqrt{\frac{A}{B\tau}} \quad \ldots \quad (2)$$

where

c = radiometer constant e.g. 2 for alternate sampling system.

T_{sys} = system temperature (K)

A = signal to noise ratio for detection

B = noise bandwidth (Hz)

τ = post detection integration time (s)

If we assume a typical antenna aperture efficiency of 66% and an identical beam shape in both the principle planes equation (1) becomes :

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$$R = 0.73\ (A_t \Delta T)^{\frac{1}{2}}\ \frac{D}{\lambda}\ (\frac{1}{cT_{sys}})^{\frac{1}{2}}\ (\frac{B\tau}{A})^{\frac{1}{4}} \quad (3)$$

where D = antenna aperture diameter (m)

λ = wavelength (m)

This equation clearly shows the range restriction for a specified maximum aperture size together with the diminishing returns of increasing the bandwidth and integration time due to the fourth root dependency. The noise bandwidth will, for a given system, generally be fixed and hence it will be the integration time τ which will determine the range. The maximum permissible value of τ depends on the application and will determine the system response time.

Performance

Analysis of the antenna [4] has yielded the results given in fig. 2 for effective to true contrast ratio $\Delta T_{eff}/\Delta T$ as a function of angle of centre of target off boresight, for different ranges, assuming a circular target falls within the antenna beam.

From these curves the field of view (FOV) at a given range can be calculated. e.g. to find the FOV using a receiver with a minimum resolvable temperature change ΔT_{min} of 0.15 K and a target to background contrast ΔT of 120K (typical for fog at 100 m visibility assuming a reflective metal target against an emissive vegetative background) at a particular range we normalise the minimum resolvable temperature change to the background contrast,

$$\frac{\Delta T_{min}}{\Delta T} = \frac{0.15}{120} = 1.25 \times 10^{-3} = \frac{\Delta T_{eff}}{\Delta T}$$

and use figure 2 to determine the angle from boresight at which such a change can be detected. For this example, this corresponds to an off boresight angle of 2.1^o. The 8dB crossover points for each beam correspond to an off boresight angle of 1.8^o. Hence the overall field of view is :

$$FOV \simeq 2(2.1 + 1.8) = 7.8^o$$

The rms tracking error θ_{er} for the radiometer can be calculated from the general expression :

$$\theta_{er} = 1020\ \frac{R^2}{A_t}\ \frac{\Delta T_{min}}{\Delta T}\ \frac{d\theta}{dG'},\ \text{degrees} \quad (4)$$

where $d\theta/dG'$ is calculated at the mutual crossover angle between opposite beams. For the radiometer described here, this is given approximately by the equation :

$$\theta_{er} = 8.8 \times 10^{-3}\ \frac{R^2}{A_t}\ \frac{\Delta T_{min}}{\Delta T}\ \text{degrees} \quad (5)$$

The tracking error measurements were made in the controlled environment of an anechoic chamber. A series of cooled scaled targets, simulating a larger target at greater ranges, were made by cooling emissive material in liquid nitrogen in an expanded polystyrene dewar. Measurements made on the dewar with and without the material enabled the effect of the target alone to be determined. The dewar and simulated target could be moved horizontally by means of a railway. A typical error voltage curve from one channel pair is shown in fig. 3 together with a theoretical result. This curve was measured by aligning the radiometer in the vertical plane and then passing the target through the 2 beams in the horizontal plane. The error curve clearly shows when the target is on system boresight and on the boresight of each individual beam. From these measured results the rms tracking error could be determined. Similar results were obtained from the vertical channel pair which were made in the horizontal plane for ease of measurement.

The theoretical and measured results for tracking error are shown in fig. 4. The 2 theoretical curves were determined from a) the general equation (4) involving a numerical evaluation of the mean gain G' and b) equation (5) which was derived using an approximation for G' assuming a gain distribution of the form $(\sin \phi/\phi)^2$. In general, the agreement between measured and theoretical results was good thus confirming the validity of equations (4) and (5).

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References

1. Report 5/287 (Doc 5/1026) of the XIVth Plenary Assembly of the CCIR (Kyoto Japan 1978) ITU Geneva 1978.

2. Guildford, L.H. and Nightingale, S.J., "Gain Stabilisation in Radiometers" British Patent Application No. 8115490 filed 20th May 1981.

3. Nightingale, S.J., "A 4 Channel Amplitude Comparison Millimetre-Wave Radiometer" Proceedings of 11th European Microwave Conference, Amsterdam, 7th - 11th September 1981 pp 365-370.

4. Dewey, R.J. "Reflector and Lens Antennas for Millimetre-Wave Radiometers" Proceedings of 11th European Microwave Conference, Amsterdam, 7th - 11th September 1981 pp 573-578.

5. Bates, R.N. and Coleman, M.D. "Millimetre Wave 'E' Plane MICs for use up to 100 GHz" Proceedings of 2nd Military Microwave Conference, London, 22nd - 24th October 1980 pp 88-94.

6. Bates, R.N., Coleman, M.D. Nightingale, S.J. and Davies, R., "E-Planes Drop Millimeter Costs" Microwave System News, December 1980 pp 74-80

7. Nightingale, S.J., Bates, R.N. and Coleman, M.D. "E-Plane Circuits and Components for Frequencies up to 140 GHz" IERE Colloquium on Waveguides and Components for the 80-300 GHz Frequency Range, London, 23rd April 1981.

8. Summers, J.G., Surridge, R. and Woodcock, J. "Planar GaAs Mott Low Noise mm-wave (35 and 85 GHz) Mixer Diodes" Proceedings of 11th European Microwave Conference, Amsterdam, 7th - 11th September 1981. pp 871-875.

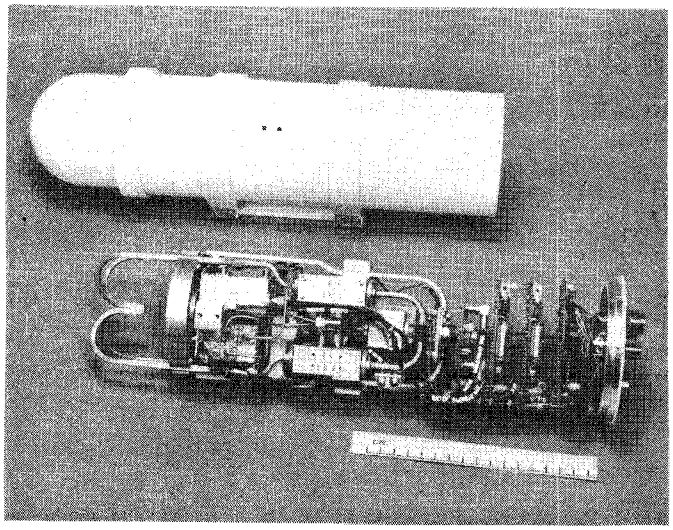

Fig.1. A 4 channel W-band radiometer.

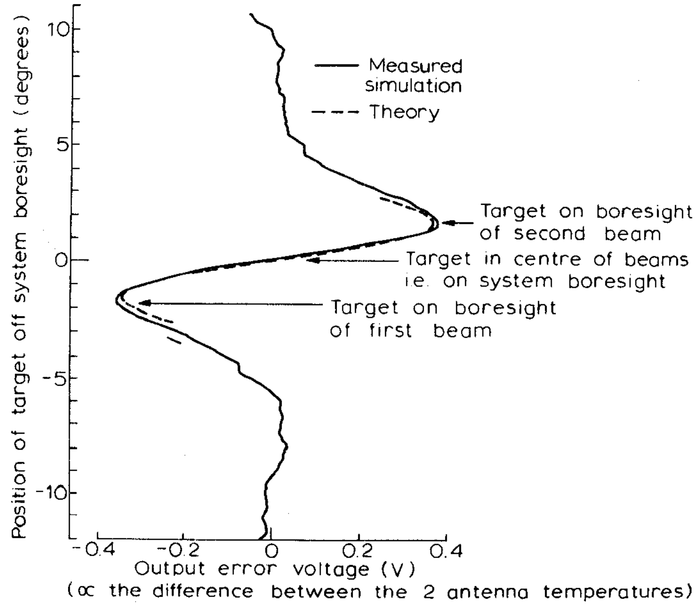

Fig. 3. Output error voltage v. target position.

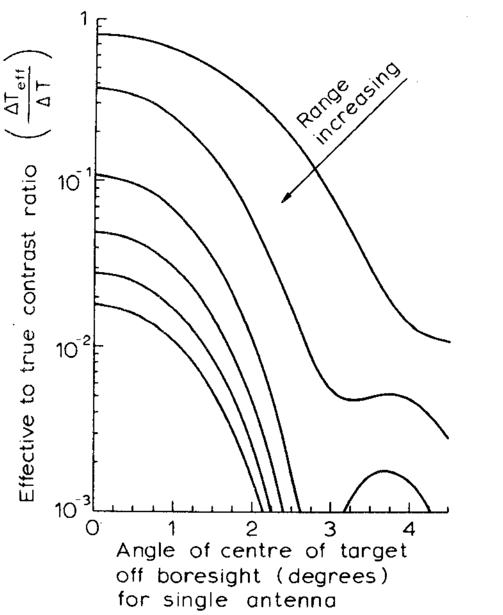

Fig. 2. Normalised contrast v. target position for W-band radiometer.

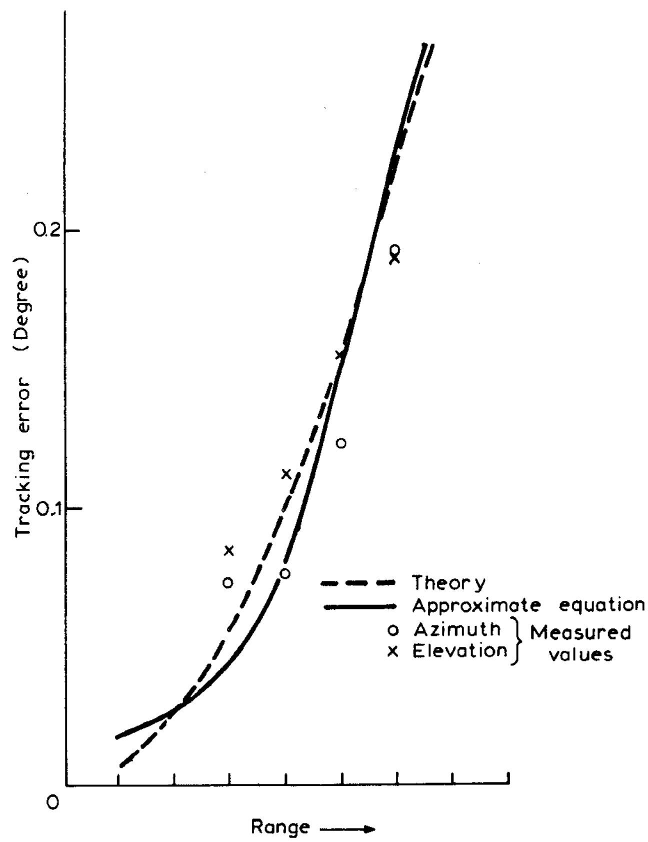

Fig. 4. Tracking error v. range for a simulated target.