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Deimos Design Report

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Contents

1 Introduction

This report gives a brief description of the design of every component of Deimos. It is intended to give an overview of the design scheme and reasoning behind it, and to provide a summary of the radiometer system. Full details regarding any aspect can be found in the relevant design file. The report is divided into sections, each of which refers to one element of the hardware.

The mechanical designs were drawn up by the D.R.A. Aircraft Department design office, based on sketches supplied by the Met. Office. Full engineering drawings have been provided [see ??]. These were used by the various contractors to machine the hardware. The scientific design which this report was based on was produced by the Met. Office and Met.Office(RS) staff were also responsible for the electrical and electronic designs ,and for populating the components into the hardware.

The calculations involved in this design were iterated in a spread-sheet file and appear in the Appendix.

An assessment of the operational performance and calibration accuracy of Deimos will be presented in a future report.

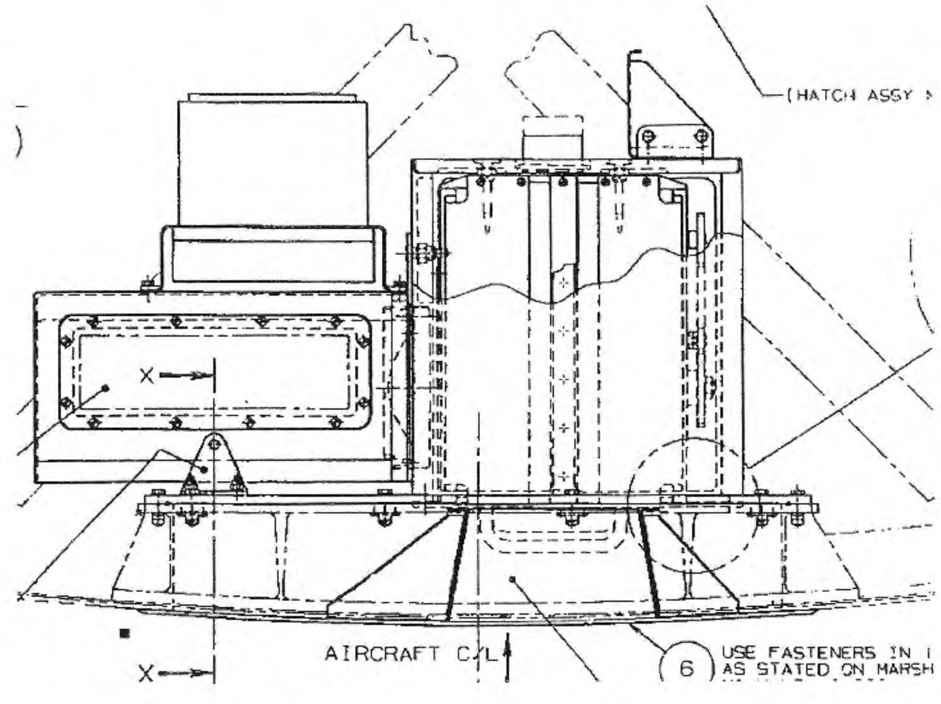

Figure 1: Deimos' Position Within The Aircraft

2 Pressure Plate

The pressure plate is to be the basis on which the whole instrument is mounted. It is designed to replace the blank plate supplied on the downward facing aperture. This general purpose facility was installed by Marshalls as Aircraft MOD5427 during the Hercules' MAJOR service in 1992. The scanning section of the instrument was fixed to its underside in a raised box-section, and the receiver itself was fixed to its top side. The pressure plate ,with the instrument mounted on it, can be seen in Figure 1.

To fit the Deimos pressure plate, first the floor hatch cover has to be removed. Then the blank pressure plate can be removed by the bolts holding it to the aperture flange. Some manoeuvring is necessary to pass the pressure plate through the floor hatch. A cardboard prototype pressure plate was used to ensure there was enough clearance for this fitting. The instrument pressure plate is then mated to the aperture interface by tightening the bolts in its flange.

A section of the pressure plate is to be raised to accommodate the scanning section in the underside. The scanning section includes the drum, its bearings, stepper motor, drive mechanism, position sensor and calibration targets [see 3 for details],and is located when installed by means of precision dowels. It is locked into position by eight "Calfix",quick-release fasteners in its base.

At least 44 electrical channels are required to relay power and signals between the scanning section and the system inside the pressure plate. The required current to be carried being no more than 3 Amps, and the maximum voltage 28Vdc. A hermetic bulkhead is to be fitted in the top of the box section of the pressure plate. A "push-on" type connector mounted on the top of the removable scanning frame will mate with the underside of this bulkhead. Suitable DPX "rack and panel" connectors are made by ITT Cannon, part number DPX-BNE-34P-0001. This is an environmentally sealed

57-way connector.

The receiver baseplate (see 4) must be mounted rigidly to the top side of the pressure plate. A series of fixtures are required to position the baseplate to within the tight tolerances resulting from the quasi-optic considerations described in 4.

2.1 Lens

A lens will be mounted in the side of the box section of the pressure plate. It passes radiation from the scanning section to the receiver, as can be seen in figure 2. The lens re-focusses the projected Gaussian beams from the receiver to form beamwaists located near the drum's mirror, which produce far-field beamwidths of 10° (the angle between the beams' half power points). A focal length, F, of 95.0mm is required for this result (see 5)

The lens must also be large enough so as not to truncate either beam above the 20dB power level. This defines a minimum lens diameter of 90mm, though the lens needs to be larger than this to include a shoulder to mount it.

Its shape may be thought of as that of a planar-convex lens mounted on a slab of dielectric material, although it is ,in fact, machined from a single piece. The backing slab is needed to provide the strength to support the pressure differential without causing distortion. The imaginary interface between the planar-convex lens and this slab is taken as the reference plane of the lens.

The convex surface must follow a hyperbolic curve in projection, with a central thickness of 19.624mm and must be machined to a tolerance of pm0.3mm.The backing slab should be 12.0mm thick, giving a total thickness of 31.624mm.The thickness of the lens, t, at a radial distance, r, from its centre is given by:

$$t(r) = \frac{F}{n+1}\left\{\sqrt{1+\frac{n+1}{n-1}\frac{r}{F}^2}-1\right\} \tag{1}$$

Dielectric materials, such as PTFE, suitable for use as microwave lenses or windows have a significant imaginary component of relative permittivity. The loss, α, [dB/cm] this introduces to transmitted microwave signals of frequency, f [GHz], is related to the loss tangent,$\tan\delta$, the ratio of the imaginary to real components of relative permittivity [2], thus:

$$\alpha = 0.91n\tan\delta \times f \tag{2}$$

The refractive index, n, of most PTFE at microwave frequencies is approximately 1.434 and its loss tangent is 0.8×10^{-3}. So the Deimos lens attenuates transmitted power at 23.8GHz by 0.01dB, which is insignificant with respect to its aperture truncation[see 5], and by 0.03dB at 50.3GHz.

A fraction of radiation incident on the surface of the lens will be reflected back due to the change in refractive index at the interface between the two media (ie air-PTFE). Such reflection will occur at both surfaces of the lens. These reflected waves will interfere to some extent, and so the total reflective loss will vary across the area of the lens, depending on local thickness and surface angles. So it is not simple task to estimate the exact total loss. However an average figure for power loss, $\bar{\Gamma}^2$, may be derived thus:

$$\bar{\Gamma}^2 = 2r^2(1+2r^2)^{-2}, where\, r = (n-1)/(n+1). \quad (3)$$

This reflection loss may be reduced by "blooming" the lens with a layer of dielectric material with an intermediate refractive index ,($n \simeq \sqrt{n}$) . The thickness,$t = (2i+1)\lambda/(4\sqrt{n})$, of such a layer must be carefully chosen to produce two interfaces whose reflections mutually cancel out. It is, however, difficult to find a material with a suitable refractive index, and the strong frequency dependence makes it unsuitable, as a coating to match both Deimos' frequencies would be 12mm thick, which is obviously impractical. Matching can be similarly achieved by "blazing" the surface of the lens with precisely machined grooves. However, this technique is highly frequency and polarisation sensitive. As a result neither technique was used.

The lens used in pressure surface of the MARSS radiometer system has very similar dimensions to that of Deimos. This lens has been pressure tested and thermally cycled to check for "cold creep", by Quality Assurance Services, RAE Farnborough in May 1988 [5]. The thickness of the sample was found to vary by less than 0.20mm over the temperature range -55° to +40°C and the pressure range -7PSI to +61PSI. This suggests the surface of the lens will not distort by more than a small fraction, (<3%) of a wavelength under operational conditions.

The lens was subsequently certified for use in MARSS' pressure surface. Deimos' lens is made from the same material, polytetrafluorethylene (PTFE), and its performance in use could be inferred from the results of the tests done on MARSS's lens, making its certification as air-worthy much simpler.

The lens is mounted within the wall of the pressure plate's box section, by clamping its shoulder section. Its centre must be aligned radially to within ±0.5mm of the datum defined by the receiver's antenna optical axis. The axial alignment is less critical, though the lens must not be allowed to foul the 20dB power contour of the 23.8GHz feedhorn. This implies the outer (flat) surface of the lens must be be mounted further than 2.0mm inboard of the pressure plate's outer surface.

2.2 Certification

The pressure plate is constructed of several pieces of aluminium alloy plate, a half-inch thick. The joints between these pieces must be capable of supporting the maximum pressure differential likely to be experienced operationally (approx. 750mb, or 10.8PSI).

A pressurisation test is necessary every time this pressure plate is installed or replaced by the blanking plate. An additional pressure box should be made up for laboratory when resources are available to eliminate this inconvenience.

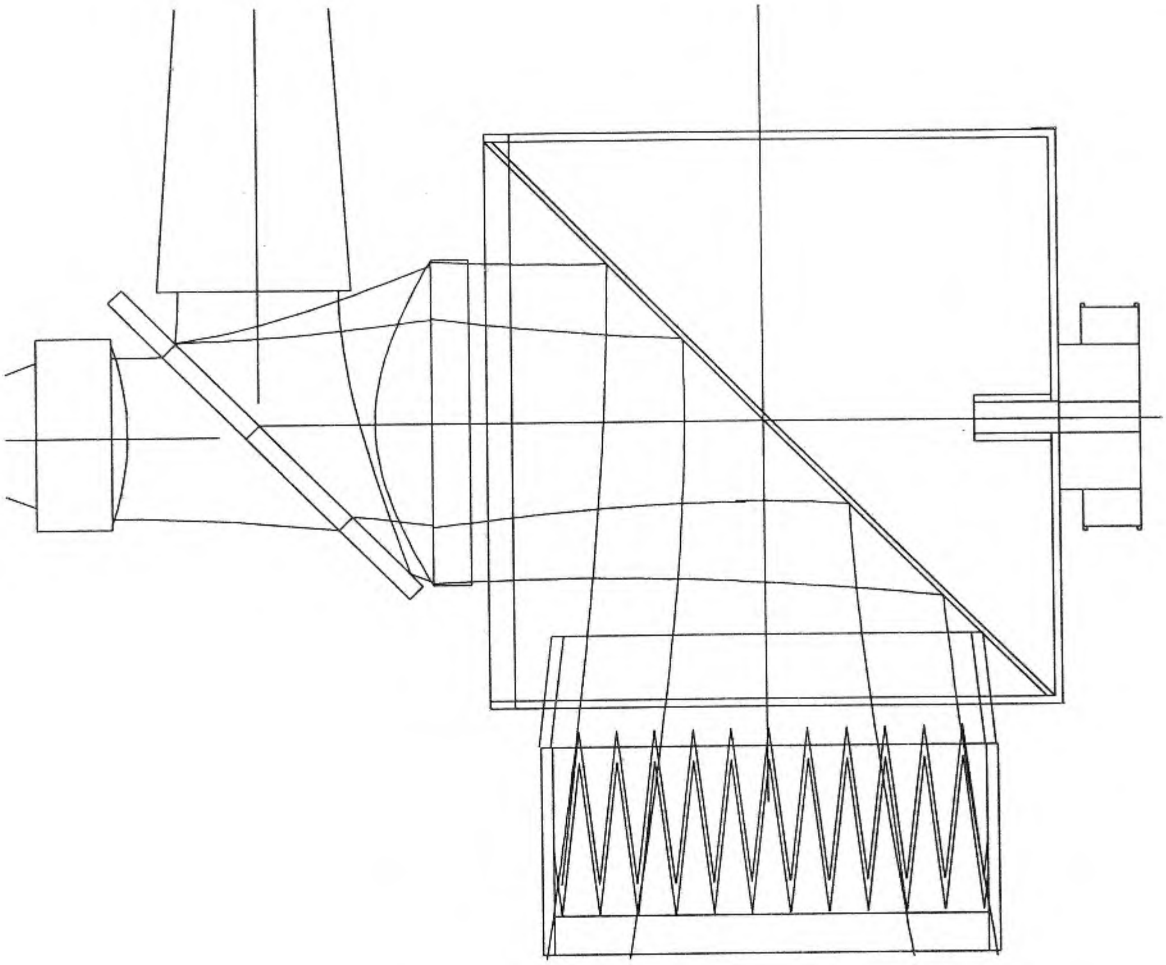

Figure 2: Schematic Of Deimos scanner

3 Scanner

The scanning section is centred around a rotating right cylindrical drum. A flat mirror mounted at 45° within this drum directs incoming radiation along its axis, through the lens in the pressure plate and into the receiver section. A schematic of this is shown in figure 2. The drum is driven by a stepper motor via a pulley and drive belt mechanism. Mounted above and aft of the drum are two black body targets which are maintained at different temperatures(see 3.2.1). As the drum rotates, the receiver is exposed to views of five downward scenes, separated by 10°, and the two internal targets, which provide calibration points.

The scanning section is housed in a frame, which is removable from the underside of the pressure plate, this is shown in Figure 3 where the view is along the axis of the lens. The mirror, drum and calibration targets can be clearly seen.

3.1 Drum

The drum must be large enough to allow the targets' shrouds to contain the beams to beyond the 20dB level. The angle this contour projects onto the wall of the drum was calculated, and a check was made that this was less than 45°. This is the maximum

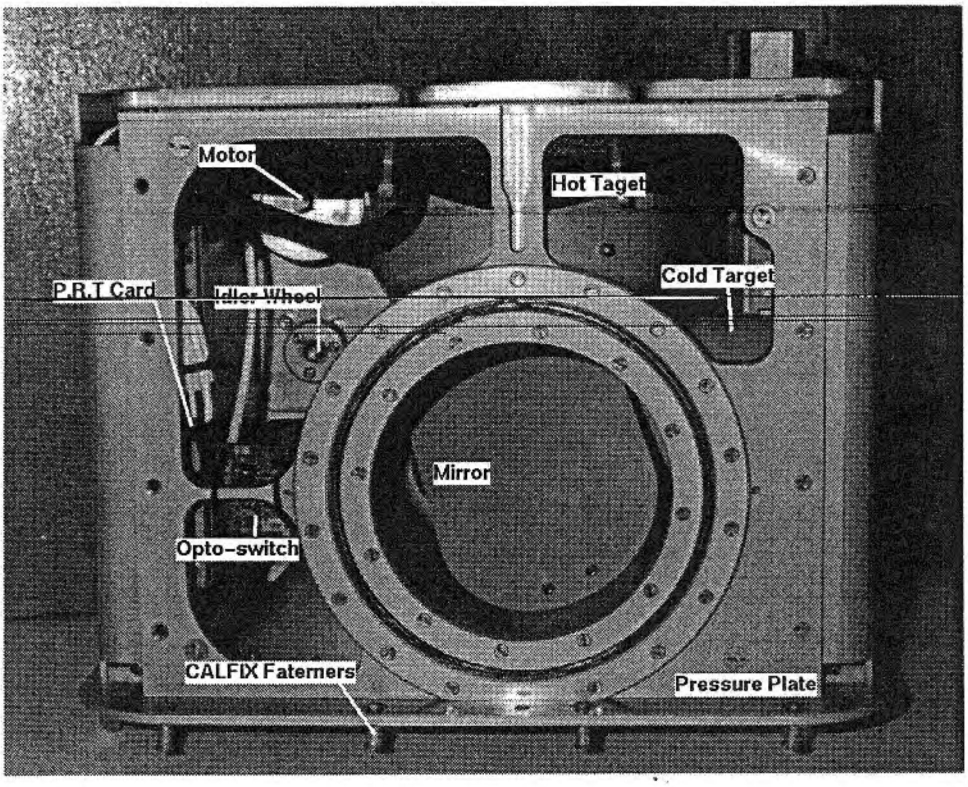

Figure 3: Deimos scanner

angle that the target shrouds may subtend at the drum wall if the targets are mounted 90° apart (i.e. above and aft of the drum). A diameter (and length) of 150mm was chosen as a convenient dimension, meeting this requirement that it exceeds 130mm.

The wall of the drum was given a metallic finish. This causes all incident microwave radiation to be reflected, so radiative losses from the targets are minimised, and no stray radiation is allowed to enter the receiver.

It is also important to keep the mass of the drum as low as possible, whilst still maintaining rigidity. Since the higher the mass of the drum, the higher its moment of inertia which increases the torque requirements of the driving mechanism.

The outer surface of the drum must be circular to within a tolerance of ± 0.5mm. This allows the targets' shrouds [see 3.2.2] to close couple to the drum to reduce the amount of stray radiation entering the receiver during calibration views.

One end of the drum is closed, and has a shaft mounted in it, to which a pulley is fixed to drive the drum. This shaft is 1/8" in diameter, in order to match the pulley's bore.

The drum includes shoulders at either end to allow it to be mounted within two thin section bearings, which are attached to the frame housing the scanning assembly.

3.1.1 Mirror

The mirror is made of a 2mm plate of Aluminium. It's surface must be flat to within a small fraction of a wavelength, ie $< \pm 0.1$ mm, although it is not necessary that the surface be polished or optically reflective. The angle of the mirror must be within $\pm 0.5°$ of 45°, to provide views within 1° of the specified positions.

The mirror must be large enough to contain the 20dB power contour of both beams as projected from the receiver. This requires it to be an ellipse, with an axial ratio of ,$\sqrt{2}$:1, and a minor axis diameter of at least 90mm.

3.1.2 Mirror Heater

It is important that condensation and frost are not allowed to form on the surface of the mirror. This would reduce the gain of the system, and its effect may well be variable of over the scan period, introducing an error not removed by the calibration. To prevent this condensation it is necessary to heat the mirror from behind. A "Thermofoil" heater was chosen for this purpose because of it's low mass and hence small contribution to the drum's moment of inertia.

To minimise conduction losses through the edge of the mirror, it is mounted on SRBF blocks to insulate it from the drum. The power required from this heater has been estimated at 15W. This figure was arrived at by considering the necessity of warming-up the mirror from a minimum ambient temperature to its operating temperature of +5°C within ten minutes, and then maintaining this temperature against convective, conductive and radiative losses. These were estimated assuming an initial ambient temperature of -45°C. The heater draws its power from a +50Vac supply, hence a current of 1 Amps is anticipated.

Two PRT's are mounted on the rear of the mirror to monitor its temperature in flight and any condensation forming on the mirror will produce a discontinuity in its temperature. One of the PRT's is also be used to control a proportional-integral-differential (PID) circuit governing the voltage supplied to the heater.

3.1.3 Slip-ring

To pass power to the mirror heater and retrieve the resistance of the PRT, a slip-ring mechanism must be included in the end of the drum. Six channels are needed for this purpose, with a maximum current rating of 2 Amps (for the heater). Airflyte Electronics' hollow slip ring and wire brush block, part numbers BSR-228 and BBK-284 respectively, were chosen for this purpose. Although this mechanism is gold plated, regular inspection will be required to ensure there is no surface degradation or build-up leading to bad contacts.

3.1.4 Drum Window

A window is required in the drum wall through which microwave radiation can be transmitted into the receiver. One was centred in the wall of the drum, on the axis of the mirror's alignment and its size was such that its edge subtended a cone of half-angle 45° ,in order to match the target snouts [see 3.2.2].

The window should not protrude beyond the edge of the drum. It was ensured that its radial thickness did not vary by more than 0.2mm,and that its neither profile did not depart from a circular sector by more than this amount. It was then mounted within the drum by machining a shoulder around its edge.

This window could have been constructed from any of a number of polymer materials. High-density polyethylene (HDPE) or polytetrafluorethylene (PTFE) are just two alternatives. It is important that the window material be of low loss at the microwave frequencies in question. Any temperature variations of a lossy window during one scan period will produce changes in system noise which will not be removed by the calibration process. But the window is only a few millimetres thick, the power loss of the HDPE or PTFE will be so low that this effect is negligible.

Nylon could also have been used for this window as this is readily available as an aircraft quality material. The power loss of the window could be measured in laboratory tests, by comparing the system noise temperature with and without the window in position. If it was found to be unacceptably high, an alternative material would be required.

TPX (Polymethylpentene) was finally chosen because, it has the advantage that it is optically transparent, so the status of the mirror's surface could be observed during servicing. It is available in 150mm^2 sheets, 0.5mm thick.

As with the lens, reflection can be a serious source of loss, with reflected waves from both surfaces of the window interfering with each other. This is important not only because it results in a loss of signal from the scene,but because it also allows signals which may have leaked from the local oscillator(L.O) to be reflected back into the antenna. Two means by which this can be reduced are "Blazing" and "Blooming". Neither technique was used for similar reasons as with the lens. A much simpler method involves altering the thickness of the window to minimize reflection. The formula by which the optimum thickness can be calculated is shown below [2].

$$|\bar{\Gamma^2}| = \frac{(r_1 + r_2)^2 - 4r_1r_2\sin^2 x}{(1 + r_1r_2)^2 - 4r_1r_2\sin^2 x} \quad (4)$$

,where ,r_1, and ,r_2, are the reflectivities of the two surfaces of the dielectric slab. The factor ,x, is a function of the thickness of the window,its refractive index, the wavelength of radiation and the angle of incidence that varies as d/λ. The reflectivity of the window has a minimum give by : [2]

$$|\bar{\Gamma^2}| = \frac{4r^2}{(1 + r^2)^2} \quad (5)$$

This formula was implemented on a spread-sheet (shown in the Appendix) during the design.

3.2 Calibration Mechanism

Two black body calibration targets are to be mounted above and aft of the drum. The upper one of these targets is maintained at a constant +65°C by heating from behind. The other is left to float at ambient temperature. Knowledge of the temperature of these targets allows continuous calibration of the system's gain and receiver noise.

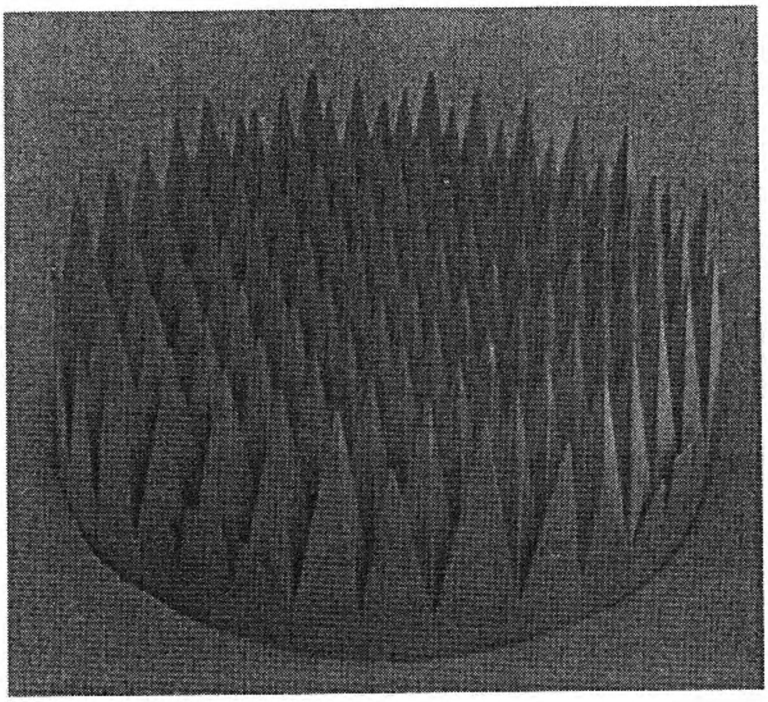

Figure 4: Deimos Calibration Target

3.2.1 Blackbody Targets

Initially the present MARSS targets were to be used in Deimos. Each target consists of an array of aluminium pyramids, 40mm high, with 10mm sided square base, coated with 1mm of absorber material, Eccosorb CR114. Their pyramidal structure causes multiple reflection of incident radiation of any polarisation. This results in a reflectivity of less than -40dB at 88, 156 and 182GHz and sufficient (less than -35dB) down to 8GHz [6].

At lower frequencies the targets are not as good, due to a gradual degradation of the absorption coefficient of Eccosorb. A larger thickness of absorber would be required to compensate, but this would result in larger thermal gradients through the absorber coating producing a bias in the calibration [7].

The targets are mounted on a 10mm thick circular base of 114mm diameter. It is important that the 20dB power contour of the beams projected from the receiver do not extend beyond this area. For this reason, the targets must be mounted near the drum. This also helps to reduce the overall dimensions of the scanning section.

Duplicates of the new MARSS targets have been manufactured in house to the same dimensions as above. The coating material is Ferroflow in this case, which has been found to perform as well as Eccosorb from 2-20GHz. One of these targets is shown in figure 4.

3.2.2 Target Shrouds

A hollow aluminium alloy cylinder surrounds each target. The surface of these cylinders are anodised, but left uncoated to reflect any stray radiation back onto the target. Three lobes are riveted onto the base of each cylinder to enable to the targets to be mounted with a degree of thermal isolation. Both cylinders are approximately 50mm long, so they house the target's base and surround the pyramids to their tips.

The targets are close-coupled to the drum by tapered "snouts" attached to the top of the target cylinders. The inside surface of the snouts is also annodised, but uncoated to allow reflection of the targets' surface, so they need not be heated. They are coupled to within 1mm of the drum to protect against stray radiation. The snouts are shaped to subtend a cone of approx. 45° half-angle, centred on the mirror's axes, on the drum wall.

A layer of insulation around the hot target's base and cylinder is required to minimise heat losses from the target and hence reduce thermal gradients across it surface and through its base. It also serves to protect the cold target from any radiated heat.

The required thickness of insulation, Δx, can be estimated by assuming it supports a maximum temperature difference, ΔT, of 100K with conductive losses,P, less than 20W. The surface area, A, of the insulation is approximately 0.04m^2. The thermal conductivity, λ, of polyurethane foam is 0.038W/m/K. The required thickness of insulation is thus estimated as 8mm, by this equation:

$$\Delta x = \frac{\lambda \Delta T A}{P} \tag{6}$$

Emmerson & Cummings' ECCOFOAM FPH-12-8H-FR was chosen as a suitable insulation material because of its good machinability, low thermal conductivity, high temperature capability and fire-retardant properties. This is a polyurethane foam-in-place resin. Once this has been mixed with its foaming catalyst, it is poured into the mould formed by the hot target, its shroud and the top of the scanning frame. Once cured it is trimmed to shape.

The contractor, AVCO, encountered difficulties when attempting to use ECCO-FOAM in conjunction with a release agent to form a slab between the base of the target and the top of the scanning frame, accommodating the wiring. A sheet of GEC Marconi's P10 polyurethane foam was acquired as an alternative, which was machined to fit. It meets similar specifications, without the flame-retardant properties. Clearance was granted on the grounds that there is a very small mass of this foam and it will be outside the pressure surface of the aircraft.

3.2.3 Target Heaters

Fixed onto the base of the hot target is an aluminium backed foil heater element from Minco. This is capable of delivering 20W to the target to maintain it at +65°C throughout operation, after an initial 20 minute warm-up period from +20°C ambient. This heater is powered by two wires, carrying 1 Amp from a +50V ac supply.

Surrounding the hot target's shroud are two foil heater elements. This enables the shroud's temperature to be controlled in order that it follows that of the hot target ;to improve its thermal stability. These heaters will draw less than 1Amp form a 50V ac supply.

A thermal strap is needed to couple the base of the cold target to a metallic surface exposed to the environment. This allows the target to cool more rapidly during ascents, and maintain a larger temperature difference between the targets, improving the accuracy of the calibration. The strap was made as wide as possible and of a high thermal conductivity metal (eg copper or brass). One end is clamped to the base of the cold target, the other fixed to the base of the scanner. There are eight M3 bolts mounting the target through the thermal strap onto the end plate of the scanning frame. However, due to an inaccuracy in the drawings, only 6 of these are accessible. The design office have cleared this as providing sufficient strength, although additional bolts would improve the rate of heatsinking.

3.2.4 Target Thermometers

There are 12 thermometers mounted in various positions within the base of each target, and one on the hot target's shroud. Minco S201PD and Labfacility 0815 wire-wound ceramic PRTs are used in the targets, each connected via 0.6m of screened 4 core cable, each of 2.5mm external diameter, to the PRT multiplexer card. These PRTs have a temperature coefficient of 0.00385Ω/°C and meet IEC751 and DIN43760, Class B specifications, so should be capable of measuring temperatures to an accuracy of 0.1°C over the required operating temperature range.

3.2.5 Target Thermometry

The resistances of the target PRTs are read locally and transmitted to the CPU by serial link. There are two "PRT Multiplexer" PCB's mounted in a card rack on the end wall of the scanner, one dedicated to the hot target and its shroud, the other to the cold target and mirror PRTs. They send a 1mA current to each of the PRTs and measure the voltage developed across them. These values are digitised and then transmitted over a common RS422 link as a 12 bit value, preceeded by a 4 bit identifier when interrogated by the CPU, once per scan.

The remaining three channels on each card are dedicated to reference loads of precision resistors, selected to represent the minimum, mid-range and maximum temperature of each card. The measurements of these references can then be used to calibrate the 13 PRTs from the same card. The cold target multiplexer card has a range of -60°C to +65°C, the hot one runs from -35° C to +90°C, with a resolution of 0.03°C.

An identical card is used in the receiver to record various temperatures and scaled voltages. This shares the same range as the hot target multiplexer.

3.3 Drive Mechanism

It was originally required that the scanning drum be rotated to allow the receiver to dwell in five downward views (0° – 40° forward of nadir) and two internal calibration views (180° and 270°). The period of rotation must match that of MARSS, ie. 3 seconds. Each view must be held within an angular tolerance of ±1° for 100ms, whilst two radiometric integrations are taken (one in each of two orthogonal polarisations). This leaves (3.0s-7x0.1s) 2.3s for the drum to rotate through 360° in various sized steps.

It has since proved to be impossible to achieve an unobstructed 40° forward view, using the design featuring a removable scanning section. The practical advantages of this design were felt to be more important than the scientific benefit of larger viewing angles. Views are unobstructed from 5° back from nadir through to 35° forward of the aircraft's z-axis. Taking account of an average aircraft pitch of +5° on a level run, these views correspond approximately to nadir to 40° forward. Greater incidence angles may be achieved in practice by banking the aircraft.

In order to reduce the overall width of the system, a belt drive mechanism was chosen to rotate the drum. In this configuration, the motor is mounted in the space above the cold target and aft of the hot one. This also allows the use of gearing by selection of motor and load pulley sizes to reduce the inertial load on the motor and hence its torque requirements. An adjustable idler wheel is needed to take up the slack when fitting the drive belt. The tension in this belt is an important variable in reducing the mechanism's overshoot.

3.3.1 Stepper Motor

A stepper motor was chosen because of its ability to move in finite steps with non-cumulative errors. It has the advantage over servo motors that the relative position of the motor's shaft, and hence the receiver's relative viewing angle, is always known, without the need for an encoder mechanism.

A large-angle "instrument"-type stepper should have provided sufficient torque within the available size. Astrosyn's model 20PM-A015-1 is a four-phase variable reluctance motor with a step angle of 15° and it is specified to operate over the required temperature range of -45°C to +55°C . It operates from +28Vdc and with its winding resistance of 20Ω, implies it draws a current of 1.4 Amps from its six 24 AWG gauge Teflon coated wires.

This motor was mounted to the frame of the scanning section by three standard "Synchro clamps". These allow for the motor to be rotated manually before clamping to align its step positions with the radiometer views. A suitable synchro clamp, known as a "Mount Cleat" is available from Reliance Gear Company, part number SM-3.

In trials the above motor was found to be incapable of delivering sufficient torque. A size 23 bipolar hybrid type stepper motor was sourced from Astrosyn, model E231. This has a much smaller step angle of 1.8° and is driven in half-stepping mode. It draws 2 Amps through four 22 AWG gauge wires from a +28Vdc supply.

This motor's square mounting face has been factory modified to remove one corner, allowing it to be mounted through the remaining three bolt holes to the side wall of the scanning frame.

3.3.2 Drive Belt And Pulleys

The motor is connected to the drum's axle by a drive belt and pulleys. This mechanism has the advantage of positive drive, minimum backlash and no requirement for lubrication. A pulley is fixed to the drum's shaft, and another to the shaft of the stepper motor. An additional, movable pulley is used as an "idler wheel" to tension the drive belt. The two small bearings housing this idler wheel add a negligible friction load to the system.

The drive belt must be capable of operating over the temperature range of -45°C to +55°C and be capable of working with a tensile load of 5N. The belt's length and number of teeth were chosen to suit the separation and size of the pulleys. A suitable drive belt was the Reliance Gear Company's model 32GBF-189-E. This has 2.49mm pitch, polyurethane coated stainless steel teeth, and is 18.55" long.

By selecting of the ratio of the number of teeth on the motor's and drum's pulleys, a 1.8° motor full step size can be geared down to a 1° step size of the drum. This is an integer fraction of the required separation between adjacent views, so reducing the need for micro-stepping. This also reduces the torque loading on the motor by a ratio of 1.8^2:1.

Pulleys with 40 and 72 teeth were selected as appropriate sizes. Suitable items are anodised aluminium alloy drive pulleys made by Reliance Gear Co., part numbers 32DP28A-40 and 32DF5A-72 respectively. These meet the requirement that a pitch diameter larger than 0.750" is used with the 32GBF series belts.

A pulley with 24 teeth is adequate for use as an idler wheel. The corresponding part number is 32DP28A-24.

3.3.3 Torque Requirement

The estimated dynamic torque required from the stepper motor is calculated as the product of the moment of inertia of its load and the maximum angular acceleration required plus any frictional torque experienced.

The moment of inertia of the load is calculated by summing the moments of the drum, mirror, shaft, pulley, half the drive belt and inner races of the bearings about their axis of rotation.

The load's moment of inertia presented to the motor is reduced by a ratio of 1.5^2:1, due to the effect of the reduction gearing. This must then be added to the moment of inertia of the rotor, pulley and half the drive belt to estimate the total moment around the motor's axis of rotation. The result being approx. 0.001 kg.m^2.

A certain angular acceleration is required to rotate the load between the views within the three second scan period (allowing a 100ms dwell time in each view). This is calculated assuming a linear rate of acceleration (a good assumption if the torque is uniform up to the maximum step rate). The resulting angular acceleration is 12 radians/sec^2 for the drum and 23 radians/sec^2 for the motor.

The torques required to start the bearings against frictional forces are 0.059Nm and 0.018Nm [see 3.4.1]. The small bearings on the idler wheel present negligible friction. To predict the torque this presents to the motor, this figure must be scaled by the reduction ratio squared i.e. $1/1.8^2$. When this frictional load is added to the product of the total moment of inertia and the angular acceleration, a total torque requirement of 0.039Nm is obtained. This requirement is met with some margin by Astrosyn's model E231 stepper motor, mentioned in 3.3.1, when driven by a bipolar drive with dual phase excitation.

3.3.4 Opto-switch Sensor

A sensor is needed to establish an absolute datum for the position of the drum. It is used to initialise the motor control and processing software, so the starting position of the drum can be measured. Operationally, it is also used to keep a check that the motor is responding correctly and not losing synchronisation and that the drive belt has not been damaged.

A simple approach to this problem, is to mount an opto-switch sensor adjacent to the outer surface of the drum wall. Such devices contain a GaAs infra-red emitting diode and a silicon photo-transistor. The sensor responds to the emitted radiation from the infra-red source only when a reflective object is within its field of view. In the case of Deimos a thin groove, painted black, on the outside surface of the drum wall is used to trigger the sensor. If a precision better than 1° is desired, this strip should be no wider than 1.3mm on a 145mm diameter drum.

A Mil-Spec switch meets the operating temperature requirements of (-45°C to +55°C) and provides suitable sensitivity, when positioned 4-5mm from the surface of the drum.

An alternative approach is to mount an absolute encoder on the shaft of either the motor or the drum. However, no encoder could be found that would operate over the required temperature range.

Another alternative, or additional, sensor may be provided by mounting a slotted opto-switch on the strut of the scanning frame, immediately above the slip rings, and extend a spoke through the back of the drum from the mirror mounting block.

3.4 Scanning Frame

The whole scanning system (drum, targets and drive mechanism) is to be mounted on a common frame, which will be housed in the box section of the pressure plate (see figures 1 and 3). This modular approach allows for easy fitting and removal of this section from the underside of the aircraft without the need to remove the pressure plate. Handles have been included on the base of the frame for ease of installation. 8 Quick release "Calfix" fasteners secure the unit in position, but these require a special tool to remove them (available in the aircraft tool-kit).

3.4.1 Bearings

Bearings are needed at both ends of the scanning drum. A bore diameter of 5.5" is required at the lens end, and 22.2mm on the pulley end. The radial load on the bearings due to the stepping motion of the drum is minimal (approx 1.3N). In addition, the bearings must support the weight of the drum (approx 0.5kg) in high-g turns and vibration (max. $60m/s^2$), representing a vibrational load of 30N. Thrust loading will depend on the mechanism by which the drum is mounted within the bearing.

Shields ,also, are necessary to protect the bearings from particles above $50\mu m$, which could damage them. Sealing the bearings is not a practical solution, because this would increase the start-up frictional torque to 0.70Nm.

Angular contact thin section bearings are ideal for this application and Kaydon's model KA060CPO and KA009XP0 are suitable. These have bore diameters of 5.5" and 0.875" respectively, outside diameters of 6.0" and 1.875", and are only 0.25" wide. The torque required to overcome friction in starting these bearings is 0.059Nm and 0.026Nm when lubricated with light oil. They are specified to operate over the required temperature range of -45°C to +55°C, with this lubricant.

Circular apertures were machined into the sides of the frame to accommodate these bearings. Shoulders were included around these apertures to fix their positions. The manufacturers' recommended lubricant for this application (Khïbers, ISOFLEX LDS Special A low temp. grease) is applied to the bearings by a foam tipped bud during regular servicing of the instrument.

3.4.2 Electrical Interface

At least 44 electrical channels are required to relay power and signals between the scanning section and the system inside the pressure plate, a required current to be carried being no more than 3 Amps, with a maximum voltage of 28Vdc. A sealed bulkhead is fitted in the top of the box section of the pressure plate and a "push-on" type connector mounted on the top of the removable scanning frame mates with a similar piece on the underside of this bulkhead.

DPX connectors made by ITT Cannon are suitable "rack and panel" type connectors for this application, and are available in a 57-way, environmentally sealed version.

3.5 Internal Fairing

A internal "fairing" is included to the bottom of the scanning section to reduce the air flow through it. The components in this section will then be more stable thermally than if they were unshielded.

The surface of this fairing is not simple. It couples closely to the scanning drum (within 1mm), whilst not truncating any of the radiometer's nadir views above their projected 20dB power level. This means it must be tapered to meet to meet the scanning drum at approx. 45° aft and 85° forward of nadir. It must be thick enough to support itself rigidly with no risk of contacting the surface of the scanning drum.

3.6 External Fairing

A separate external fairing can be used to further couple the base of the scanner to the outer skin of the aircraft. This was originally designed in fibreglass, but the production cost proved prohibitive, so aluminium alloy was chosen for a new design. The use of this item is optional, as the installation is cleared to fly without it in place, however, its inclusion should further reduce air flow within the scanner.

The 50.3GHz feedhorn was supplied by Flann Microwave. It has a beamwidth of 10° and feeds 0.165" diameter waveguide. It has an integral planar-convex Rexolite lens in its mouth to reduce the radius of curvature of the wave fronts and thus improve the side-lobe levels, whilst maintaining small overall dimensions.

4.1.3 Polarisation Switches

The polarisation switches are ferrite waveguide devices. The polarisation angle of the radiation output from the switch is controlled by the current used to energise the ferrite material. Thus the output polarisation angle may be rotated from the input polarisation to that at the input of the feedhorn [8]. Alpha Industries parts 145-396 and 145-165 were chosen . These are driven by a constant current supply housed in the electronics box. These supplies can deliver between 0 and 250mA through the 12Ω coil and are switched between values stored on an EFPROM under the CPU's logic control. In this way, two polarisations will be integrated for 50ms each, in all seven views.

It was necessary to add a clamping mechanism to rigidly fix the polarisation switches to the feedhorn, as there was no access the the rear of their waveguide flanges to allow the usual bolt/dowel fixing.

4.1.4 Waveguide Transitions

Two tapered waveguide transitions are used to transmit the linear polarised TE_{11} mode from the circular waveguide of the polarisation switches to the TE_{10} mode in the rectangular waveguide of the mixer.

4.1.5 Mixers

Harmonic mixers are used in the receiver to convert microwave frequencies to intermediate frequencies, by mixing them with a constant frequency source. There are two products of this mixing, equal to the sum and the difference between the frequencies. The sum is strongly attenuated when transmitted through the mixer's co-axial output, whereas the difference is passed as a range of output frequencies.

The mixing frequency is supplied by a GUNN oscillator fixed to the relevant waveguide port on the base of the mixer. The mixers are specified to operate with +7dBm local oscillator (LO) power and offer more than 20dB isolation between the LO and RF ports. In practice, it may be found that additional isolation is required to reduce the levels of LO signal emitted from the feedhorns. Such leakages may be reflected from an obstacle or mis-match and subsequently produce interference as standing waves.

Alpha's balanced harmonic mixers 9600-KHRL and 9600-UHRL were selected. These GaAs beam lead diodes are rugged enough to withstand the vibration expected in their operating environment, whilst offering low noise figures and conversion losses. These draw 1.5mA from a +15V bias and this is supplied to the connections on the mixer block whilst the instrument is in operation.

4.1.6 Oscillators

The local oscillators supply a reference frequency to the mixers. GUNN diodes are used as LO's because of their good stability, spectral purity and reliability. Alpha's CMF610 and CMF810 each draw approx. 500mA from bias voltages of +3.5V and +5.0Vdc, and output +8dBm ($\simeq$6mW) at 23.8GHz and 50.3GHz, respectively. A regulated power supply must be used to produce an accurately defined bias voltage for each LO, which is gradually applied by ramping up from 0V at turn-on.

The LO's define the centre frequency of each channel and can be manually tuned over a range of 100MHz using a back-short screw. Their frequency varies with operating temperature at a rate of -2.50MHz/°C. To achieve the required centre frequency stability, the LO's operating temperature must be kept constant to within ±4°C. This can only be obtained if the LO's are maintained at a temperature higher than that of any operating environment, eg. +35°C. It is therefore important that the temperature of the LO's be monitored by attaching a PRT to each.

The LO's must not generate more than -100dBc/Hz in sideband noise, 10MHz away from the carrier (peak) as such sideband noise will leak through the mixer and may cause interference in the IF circuitry. If this is found to be the case in practice, insertion of an isolator in the IF circuitry should reduce the problem.

It may also be found that an isolator needs to be inserted between the oscillator and mixer, if mismatches produce a poor conversion efficiency.

4.1.7 IF Amplifiers

Amplification of the IF signal from the mixers is required to raise the signal to a level detectable by the square-law diodes within the detector circuitry (See 4.1.9). The exact amount of amplification depends on the 1dB compression point of the detectors with the maximum level at least 10dB below this. Extra attenuation may be required if the system is found to be non-linear in practice.

The power output level from the mixers is given by:

$$P = kT_{sys}B \tag{7}$$

Where, k is boltzmann's constant,T_{sys} is the system noise temperature, and B is the pre-detection (IF) bandwidth. In the case where T_{sys}=1000K and B=100MHz, P=-90dBm. A power level of -15dBm is required by the detectors, so +75dB amplification is needed.

This can be supplied by one 3-stage and one 2-stage bipolar IF amplifier. Such an amplifier must cover the required frequency range (10-135MHz) and offer a low noise figure, so as to have a minimal effect on system noise, e.g. MITEQ's models AU-3A-0150 and AU-3A-0150, provide +46dB and +30dB gain over a range of 1-500MHz.

If the amplifier's gain changes by a small fraction, dG/G, the radiometer's output will increase by the same fraction. This would be misinterpreted as a change in system noise and could dominate any change in antenna noise temperature. If such gain variations plane of the lens. Beyond this external beamwaist, the beam will begin to diverge at a different rate. The focal length, F, of the lens required to produce such a beam is approximated by the "thin" lens equation:

$$F^{-1} = \{z_i[1 + (\frac{\pi w_i^2}{\lambda z_i})^2]\}^{-1} + \{z_0[1 + (\frac{\pi w_0^2}{\lambda z_0})^2]\}^{-1} \quad (17)$$

See 2.1 for more details of the lens design.

The above formulas were implemented in a spreadsheet file (see Appendix), to calculate iteratively the positions and dimensions of all quasi-optic components. This was also used to quantify the effects of optical misalignments, and losses.

References

[1] J. S. Foot, "Scientific Specification for Deimos", Met Office(RS) Branch File M/RSI/32/6/2

[2] J. C. G. Lesurf, "Millimetre-wave Optics, Devices & Systems," IOP: Adam Hilger, Bristol, New York, 1990, pp 18-23.

[3] C. Letrou & M. Gheudin, "Conception de diplexeurs dichroïques dans le domaine millimétrique," *Ann. Télécommun.*, (French), vol. 45, no. 5-6, 1990, pp. 278-287.

[4] F. T. Ulaby et al., "Microwave Remote Sensing - Active and Passive, Volume I: Microwave Remote Sensing Fundamentals and Radiometry," Reading, MA: Addison-Wesley, 1981, p352.

[5] "Approval No.IBQR01," Met Office File D/Met.O.19/11/20/3/3.

[6] T. J. Hewison, "Target Reflectivity Tests," Met Office(RS) Branch Working Paper, 1991

[7] T. J. Hewison, "Target Model of Black Body Targets," Met Office(RS) Branch Working Paper, 1991

[8] A. J. Baden Fuller, "An introduction to microwave theory and techniques," Pergamon, 1979, p179-184.

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Quasi-Optic analysis

AMSU-A	Channel	1	3		Notes	
Frequency	NU	23.8	50.3	GHz		
Wavelength	l	12.6	6.0	mm		
Beam aperture-radius ratio	r	1.5	1.5		-20.0 dB	
Horn diameter	Øh	53.8	50.0	mm		
Horn mouth radius	Z1	22.2	23.5	mm		
Horn length	Yh	135.0	45.0	mm		
Horn Lens thickness at centre	Y1	0.0	4.0	mm		
Far field 3dB beamwidth	FWHM	19.0	9.1	°		
Assymptotic divergence angle	Thetae	15.9	7.7	°		
Internal beamwaist radius	Wi	14.1	14.0	mm		
Beamwaist-aperture distance	z	280.0	280.0	mm		
Beamwaist radius at aperture	W(z)	80.8	40.4	mm		
Horn-dichroic plate distance	Yhp	39.0	35.0	mm	OK	OK
Beam radius at DCP near end	Wpn	22.6	21.5	mm		
Beam radius at DCP far end	Wpf	40.4	24.6	mm		
Dichroic plate diameter	Øp	89.1	89.1	mm		
Dichroic plate-2° lens dist.	Yp2	50.0	50.0	mm	OK	OK
Horn-2° lens distance	Yh2	89.0	85.0	mm	-ve root only	
2° Lens focal length	F	95.0	95.0	mm		
External 3dB beamwidth	BW3dB	10.1	10.0	°		
External beamwaist radius	Wo	26.8	12.8	mm		
	Check:	26.8	12.8	mm		
2° Lens-beamwaist distance	Y2o	73.4	86.7	mm	-ve root only	
Beam radius at 2° lens	Wo2	44.0	27.5	mm		
2° Lens radius	Zo2	45.0	45.0	mm		
2° Lens diameter	Øo2	90.0	90.0	mm	OK	OK
2° Lens thickness at edge	Y2min	10.0	10.0	mm		
2° Lens thickness at centre	Y2max	29.6	29.6	mm		
2° Lens refractive index PTFE	n	1.434	1.434			
2° Lens aperture blockage	To2	-0.035	-0.000	dB		
2° Lens-Drum seperation	Y2d	10.0	10.0	mm		
Near beam radius at mirror	Wmn	40.9	19.6	mm		
Far beam radius at mirror	Wmf	43.3	20.5	mm		
Max drum diameter required	Ød	150.0	150.0	mm		
Chord-perimeter radial dist.	x	14.8	4.8	mm		
Beam radius at drum wall	Wdw	44.7	26.3	mm		
Beam half angle at drum	Thetaw	36.6	20.5	°	OK	
Drum-target distance	Xdt	10.0	10.0	mm		
Beam radius at target	Wt	47.4	28.6	mm		
Required Target diameter	Øt	94.7	57.2	mm	<MARSS	
MARSS target internal diameter	Ømi	114.0	114.0	mm		
Truncation of beam at target	Tt	-29.0	-79.4	dB		
View angle from nadir	Theta	35	35	°		
Skin-optical axis distance	Zos	276.0	276.0	mm		
Skin aperture-beamwaist dist.	XZmsa	276.0	276.0	mm		
Beam radius at aperture	Wsa	49.3	42.9	mm		
Square base of LN2 target	Øln2	163	163	mm		
Truncation of beam at LN2 targ	Tln2	-23.8	-31.4	dB		
Skin aperture-opt axis dist	Xba	284.5	272.7	mm	-5°to +35°only	
Skin aperture-opt axis dist	Yba	74.8	65.1	mm		

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Drive Mechanism

Item	Material		Density kg/m^3	x/Øo mm	y/Øi mm	z/l mm	Mass kg	Moment kg.mm^2
Drum wall	Al alloy		2700	145	141	164	0.398	1046
Drum base	Al alloy		2700	145		4	0.178	937
Big bearing	Stainless		8000	149	140	10	0.165	458
Retainers	Al alloy		2700	149	125	3	0.042	117
Mirror	Al alloy		2700	140	99	2	0.059	210
Mirror mount	PTFE		2100	20	15	60	0.038	74
Mirror mount	PTFE		2100	20	15	60	0.038	74
Drum Shaft	Stainless		8000	26	24	75	0.047	4
Sliprings	Nylon		2000	50	26	15	0.043	13
Small bearing	Stainless		8000	35	22	8	0.036	5
Spacer	Al alloy		2700	27		9	0.013	1
Drum Pulley	Al alloy	72	2700	57	10	5	0.035	14
Drive belt	PUE/Steel		2000	59		471	0.058	50
Drum Total							1.148	2954
Motor pulley	Al alloy	40	2700	32	6	5	0.011	1
Drive belt	PUE/Steel		2000	33		266	0.033	9
Motor shaft	Al alloy		2700	6		26	0.002	0
Motor - Astrosyn	23-E231			56		57	0.550	16
Motor Total							0.595	26

		Drum	Motor		
Transmission ratio	i	1.80	0.56		
Transmission efficiency	ZETA	1.00	1.00		
Drive net moment of inertia	Jdrive	2954	26	kg.mm^2	
Total load moment of inertia	Jtot		938	kg.mm^2	

		Drum	Motor		
Scan period	P	3.00	3.00	s	
Number of dwells	Nd	7	7		
Dwell time	Td	0.10	0.10	s	
Time for movement/scan	Ts	2.30	2.30	s	
Acceleration	ALPHA	12.43	22.37	rad/s^2	
Bearings' frictional torque	TAUb	0.059	0.018	N.m	
Torque required	TAU		0.039	N.m	OK
Maximum angular velocity	Omega	3.97	7.14	rad/s	
Maximum step rate	SPS	227	227	/s	
Step size	dTheta	1	1.8	°	Astrosyn
Max. torque supplied	TAUsm		0.300	N.m	E231

Radiometer Performance

AMSU-A	Channel	1	3	
Frequency	NU	23.8	50.3	GHz
Temperature of front end	To	313	313	K
Antenna radiation Gain	Ga	-1.5	-1.5	dB
Antenna radiation Noise Fig.	Fa	1.5	1.5	dB
Polaristion switch Gain	Gps	-0.5	-0.6	dB
Polaristion switch Noise Fig.	Fps	0.5	0.6	dB
Mixer Conversion Gain (DSB)	Gm	-1.0	-2.0	dB
Mixer Noise Figure (DSB)	Fm	1.7	3.4	dB
Mixer LO-RF Isolation	Ilorf	22.8	32.0	dB
IF Amplifier Gain	Gif	45.0	45.0	dB
IF Amplifier Noise Figure	Fif	1.1	1.2	dB
2nd IF Amplifier Gain	G2if	30.0	30.0	dB
2nd IF Amplifier Noise Figure	F2if	1.1	1.1	dB
IF Amplifier Gain stability	dG/GdT	-0.013	-0.013	dB/K
IF Amplifier Temp stability	dTif	0.04	0.03	K/3s
Bandpass filter Gain	Gbpf	-0.6	-0.6	dB
Bandpass filter Noise Figure	Fbfp	0.6	0.6	dB
Front End Gain	Gfe	72.9	71.8	dB
Power from IF amplifier	Pif	-15.8	-16.9	dBm

		Hot scene			Cold scene	
Receiver noise temperature	Trec	595	919	K	595	919
Antenna radiation temperature	Ta	295	295	K	80	80
Antenna noise temperature	Ta'	300	300	K	313	313
System noise temperature	Tsys	890	1214	K	675	999
Bandwidth	B	110	80	MHz	110	80
Integration time	tint	0.05	0.05	s	0.05	0.05
Noise Equivalent Delta T	NEdT	0.38	0.61	K	0.29	0.50
Predetection attenuation	Gdet	0.0	0.0	dB	0.0	0.0
Detector IF input power	Pif	-15.8	-16.9	dBm	-17.0	-17.8
Detector sensitivity	dV/dW	170	170	V/W	170	170
Detector output	Vdet	4.5	3.4	mV	3.4	2.8
Max Video amp gain required	Gvid	1675	2175			
RX system gain	Gsys	8.43	6.18	mV/K		
ADC Input voltage range	Vadc	10	10	V	0	0
ADC voltage resolution (16bit)	dVadc	0.15	0.15	mV		
ADC antenna temp resolution	dTadc	0.02	0.02	K		

15.9 7.7

Lens surface tolerance estimate

				========Ch 1=======			========Ch 3======		
		t' /mm	F(t') /mm	Y2o' /mm	Wo' /mm	3dB BW' /°	Y2o' /mm	Wo' /mm	3dB BW /°
F	95.0	17.8	95.0	73.4	26.8	10.1	86.7	12.8	10.0
n	1.434								
Ro	42.5								
thyp	17.8	17.8	95.0	73.4	26.8	10.1	86.7	12.8	10.0
tpar	21.9	17.8	116.7	0.0	29.0	9.3	80.1	15.1	8.5
tsph	ERR	17.8	137.2	-52.3	28.0	9.7	-24.6	16.6	7.7

2° Lens loss tangent of HDPE	tand	0.000	0.000		
2° Lens power attenuation	Lo2	-0.01	-0.03	dB	
2° Lens E-field reflectivity	Ar	0.18	0.18		Planar slab
2° Lens phase difference	Chi	7.15	15.11		Normal
2° Lens power reflectivity	Ro2	-0.24	-0.38	dB	incidence
2° Lens power reflectivity	Ro2	-0.27	-0.27	dB	Average

View	View angle /°	Dwell time /s	Step angle /rads	SQRT(step)
Nadir	-5			
10° FWD	5	0.1	0.175	0.418
20° FWD	15	0.1	0.175	0.418
30° FWD	25	0.1	0.175	0.418
40° FWD	35	0.1	0.175	0.418
Hot cal	180	0.1	2.531	1.591
Cold	270	0.1	1.571	1.253
Nadir	355	0.1	1.484	1.218
	Total	0.700	6.283	5.733

R-type Mixer Specifications

	Ch. 1 Max	Ch. 3 Max	Ch. 1 Typ	Ch. 3 Typ	
Conv. gain	-2.0	-3.0	-1.0	-2.0	dB
IF Amp NF	1.5	1.5	1.5	1.5	dB
Mixer+amp NF	3.5	5.0	3.0	4.5	dB
Mixer NF	2.0	3.7	1.7	3.4	dB

K
K
K
K
MHz
s
K
dB
dBm
V/W
mV

V