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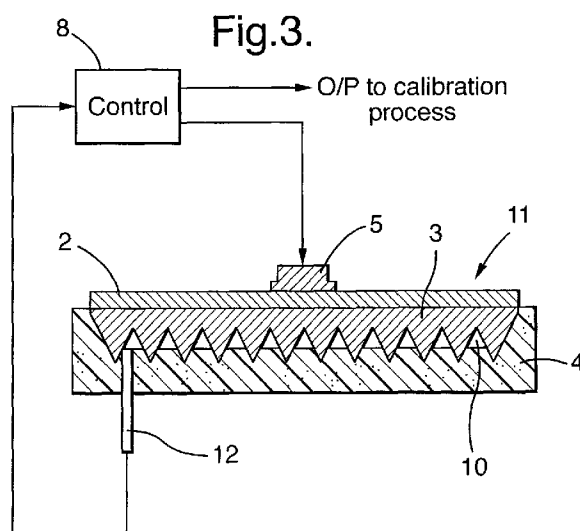
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(54) Title: CALIBRATION LOAD FOR USE AT MICROWAVE, MILLIMETRE OR SUB-MILLIMETRE WAVELENGTHS



(57) Abstract: A calibration load suitable for use with a millimetre wave radiometer comprises a thermal distribution layer, a thermally insulating layer having high transmissivity at the wavelength of interest, and a layer of radiation absorbent material (RAM) sandwiched there between. A means for changing the temperature of the thermal distribution layer, and hence the RAM, is provided, along with a means for directly measuring the temperature of the RAM. The means for directly measuring the temperature of the RAM preferably comprises a non-contact thermometer. An output based upon the measured temperature of the RAM is used to provide an indication of the radiometric temperature of the RAM to the radiometer under calibration. The means for changing the temperature may comprise a heating or cooling element. The means for changing the temperature is preferably controlled using a closed loop controller.

**CALIBRATION LOAD FOR USE AT MICROWAVE , MILLIMETRE
OR SUB-MILLIMETRE WAVELENGTHS**

This invention relates to the field of calibration of receiver systems. More particularly, it relates to calibrators suitable for use from microwave to sub-
5 millimetre wavelengths, collectively referred to herein as millimetre wavelengths.

Receiving equipment, especially when used for measurement or comparison purposes, generally has a requirement that it undergoes periodic calibration.
10 This may be done for example to correct for drift in component parameters such as amplifier gain or component tolerances, or may be to correct for external changes such as outside temperature changes.

Radiometer systems are often particularly sensitive to calibration errors, due
15 to the high levels of amplification required to detect the very small received signal levels. Radiometer systems include imaging systems, such as those described in International Patent publication No. WO2000/14587 and also non-imaging systems such as those described in International patent publication No. WO2004/038453

20 One calibration technique used in such systems is to place a source of radiation having known characteristics in the field of view of the receiver. Highly emissive materials, known as blackbody radiation sources, can be held at a particular, known temperature to provide a calibration source. Radiometer
25 measurements taken from the source can then be used to calibrate that radiometer.

Calibration loads are generally made from materials having a very high emissivity. Such materials are also inherently very absorbent of incident
30 radiation. Highly absorbing materials for use in the millimetre-wave band are frequently known as Radiation Absorbent Materials (RAM). Millimetre-wave radiation levels emitted by these materials are directly related to their physical temperature, and the radiometric temperature (as seen by a millimetre-wave

radiometer) will be substantially the same as the physical temperature of the RAM.

RAM used in calibration loads is often heated or cooled to allow calibrated
5 measurements to be taken at a particular radiometric temperature. Often,
more than one calibration load will be used, the different loads being held at
different temperatures. This allows a more accurate calibration of the
radiometer by providing information on the gain (the gradient) and the offset
(the intercept) of the radiometer output as a function of input radiometric
10 temperature.

A prior art heated RAM calibration load is described in the paper "*Blackbody
calibration targets with ultra-low reflectivity at sub-millimetre wavelengths*", 4th
ESA Workshop on millimetre wave technology and applications, pp359-364,
15 15-17th February 2006.

This discloses a calibration load that relies on multiple reflections from a
moderately low reflectivity RAM to achieve overall a very low reflectivity, and
hence a high degree of accuracy. The form factor of the device is however
20 rather large as a result of the multiple reflection requirement, and is unsuitable
for many applications where a small size is required.

A calibration system is disclosed in MSMW 2001, Symposium Proceedings,
Kharkov, Ukraine, June 4-9 2001, "Calibration System of BMSTU Radio
25 Telescope RT 7.5" Efremov et al. There, a calibration load comprises a block
of metal having an aperture in which radiation entering from outside must
undergo multiple bounces before being emitted. The active surface of the
metal block is coated in a conducting ferro-epoxy absorbing paint. The block
is heated, and the temperature of the metal block monitored using a
30 thermistor. The form factor of the device, although smaller than the previous
one, is still rather large.

A further calibration load is described in the paper "Precision Temperature Reference for Microwave Radiometry", Walter N Hardy, IEEE Trans.

Microwave Theory and Techniques, March 1973. This discloses a cooled temperature reference that uses a cryogen soaked porous RAM fitted with an insulator. This uses the assumption that the radiometric temperature of the reference will be equal to the boiling point of the cryogenic liquid used. This is reasonable whilst the RAM remains fully saturated with the cryogen, but will need regular recharging.

10

According to a first aspect of the present invention there is provided a calibration load for use at microwave, millimetre or sub-millimetre wavelengths, the load having a layered structure, and comprising a thermal distribution layer having high thermal conductivity, a thermal insulation layer having high millimetre wave transmissivity, and a material absorptive of millimetre wave radiation located between the thermal distribution layer and the thermal insulation layer, characterised in that it further includes a means for changing the temperature of the thermal distribution layer and a means for measuring the physical temperature of the material absorptive of millimetre wave radiation.

20

The present invention provides a calibration load that is particularly compact in physical design compared to prior art systems. This is because it does not rely on reflections from one broad area of the material absorptive of millimetre wave (MMW) radiation, or RAM, to another, unlike the prior art that has at least two large regions of RAM set up usually in a conic manner to promote reflections between them. This conic form factor can lead to problems with size, as stated above. A preferred embodiment has a generally planar form factor comprising a plurality of layers, each layer having a thickness relatively small compared to its height and width. The present invention also has the advantage that, because the temperature of the RAM is measured directly, the accuracy of a calibration performed using the load is improved.

25

30

The thermal distribution layer may be any material having a sufficiently high thermal conductivity. In practice, this means a material able to distribute thermal energy around its area such that there is minimal temperature variation across it. Thus, any heating or cooling provided by the means for changing its temperature is applied relatively uniformly across it. This helps to provide an even heating or cooling of the of the RAM.

Advantageously the thermal distribution layer comprises a metallic plate. Conveniently the metal plate may be an aluminium plate. The thickness of the plate is preferably chosen to be sufficient to prevent undue steady-state temperature gradients across it when in use. Preferably the maximum temperature gradient when in use is less than 2°C, such as less than 1°C such as less than 0.5°C such as less than 0.2°C such as less than 0.1°C between the centre of the plate and an outside edge, or other reference point, or between any two chosen reference points on the plate.

The temperature gradient may be reduced by adding thermally insulating material to one or more surfaces of the plate.

The size and shape of the plate may be anything suitable, given constraints as to location within the system, range from the radiometer etc. Conveniently the plate may be square, circular, or oblong. Conveniently the plate may be a size of the order of 100mm across.

The plate may be arranged with respect to a radiometer under calibration such that the radiometer receives radiation from a normal direction to the plate. Thus a maximum plate area is presented to the radiometer. The invention allows relatively thin calibration loads to be created however, and so gives a system designer additional flexibility regarding placement of the calibration load.

There are many different types of RAM available. The choice of which to use is dependent upon the calibration accuracy required for the system with which it is used. Some types of RAM are more suited to a particular task than others.

5

The specifications for various types of RAM are usually well documented. These generally give the reflectivity (sometimes expressed in terms of absorbency), at a normal angle of incidence, and sometimes at other angles also. The reflectivity figures can then be used to assess the accuracy of the basic assumption, stated above, that the radiometric temperature seen by the radiometer equals the RAM's physical temperature.

10

No such material will be totally absorbing, and so the apparent radiometric temperature of the RAM will to some extent depend on the radiometric temperature of the surroundings it reflects.

15

The systematic error caused by the non-unity emissivity of the RAM (the radiometric temperature of the RAM as opposed to its physical temperature) is calculable as follows:

20

$$T_{\text{Apparent}} = (R * T_{\text{Surroundings}}) + ((1 - R) * T_{\text{RAM}}) \quad (\text{Eqn .1})$$

where

25

T_{Apparent} is the apparent temperature of the RAM in K (as seen by the radiometer)

R is the reflectivity of the RAM, stated as a ratio, and obtained by $R=10^{(R_{\text{dB}}/10)}$, where R_{dB} is the reflectivity of the RAM in dB

30

$T_{\text{Surroundings}}$ is the radiometric temperature in K of the surroundings that would be reflected in the RAM

T_{RAM} is the physical temperature of the RAM, in K

Assuming $T_{\text{Surroundings}} = 290\text{K}$, and $T_{\text{RAM}} = 310\text{K}$, Equation 1 gives the following results:

Reflectivity R_{dB}	Apparent temperature [K]	Temperature error [K]
-10 dB	308	-2
-20 dB	309.8	-0.2
-30 dB	309.98	-0.02
-40 dB	309.998	-0.002
-50 dB	309.9998	-0.0002

5

The typical temperature sensitivity of a good quality radiometric millimetre wave receiver is of the order 0.1K. The error produced by RAM reflectivity can be arranged to be significantly below this, as seen in the above table, such that the most significant errors in the calibration system lie elsewhere, even when a calibration load according to an embodiment of the invention is arranged such that radiation entering the load only undergoes a single reflection before exiting. A RAM reflectivity of the order -30dB or less will be sufficient for this. Higher reflectivities (i.e. greater errors) may be acceptable for some radiometer systems, depending upon the application to which they are being applied.

15

The RAM may conveniently be in the physical form of a rubberised sheet, or may be a hard solid material. Some forms of RAM comprise an open-cell sponge-like material, but this is not preferred in the current invention due to the difficulty of regulating the physical temperature of such materials, and obtaining a sufficiently uniform temperature spread across it.

20

The thermal insulation layer may have a low thermal conductivity. Conveniently the thermal insulation layer of the layered calibration load

comprises of expanded polystyrene. Expanded polystyrene has a high transmission coefficient at millimetre wavelengths, and is a good thermal insulator, in terms of preventing or reducing conduction and convection losses. It is also relatively straightforward to cut and shape as required. The

5 expanded polystyrene insulates the RAM from the surrounding air, whilst allowing the millimetre-wave radiation emitted from the RAM to be emitted practically unhindered. Other thermally insulating materials that are substantially transparent to millimetre-wave radiation may be used as required, particularly if good performance is required at temperatures where

10 polystyrene may be less suitable. Examples of such materials are polythene, expanded polythene and quartz. The thinner materials tend to be less good at preventing conductive heat loss, but still provide valuable insulation in terms of reducing or preventing convective losses.

15 The thermal insulation layer may be located such that it is in close contact with the RAM. Alternatively, it may be located in partial contact with the RAM, such that air gaps exist between parts of the RAM and the insulation layer. Alternatively, it may be located such that an air gap exists across substantially the whole face of the RAM. A typical air gap may be of the order 10mm, but

20 may vary depending upon the degree of thermal insulation required, convenience of mechanical attachment of the insulation layer to its support, or other factors.

The thermal insulation layer may be located in front of the RAM so that it only

25 insulates the RAM itself. Alternatively, additional insulation may be added so as to surround both the RAM and the thermal distribution layer (e.g. a metal plate) if space permits. Clearly the latter is preferable if it is required to prevent or reduce heat losses due to convection.

30 The means for measuring the physical temperature of the RAM may conveniently comprise a thermocouple. Alternatively, the means for measuring the physical temperature may comprise a non-contact temperature measurement device, such as an infra-red temperature sensor. Other means

for determining the temperature may be suitable, such as a temperature dependent resistor (i.e. a thermistor), or a semiconductor device adapted to carry out this function. The non-contact temperature measurement device may be positioned so that it receives IR radiation without the IR radiation
5 passing through the insulating layer. For example, the temperature measurement device may be small enough to lie inside the insulation layer, or may arranged to protrude through a hole in the insulation layer. Alternatively, should the insulation layer be transmissive to IR radiation (as well as millimetre wave radiation), then the temperature measurement device may lie
10 outside the insulating layer

The means for changing the temperature may conveniently comprise a heating element. Such a heating element may be a power resistor of suitable value, driven from an electrical supply.

15 Alternatively, or as well, the means for changing the temperature may comprise a cooling means. The cooling means may comprise a heat pump. The heat pump may be, for example, a Peltier cell which may conveniently be attached to a heat sink. The heat pump may alternatively be of a type that
20 uses a circulating refrigerant, such as in a refrigerator.

The cooling means may alternatively use a coolant such as liquid nitrogen, or solid carbon dioxide.

25 The means for changing the temperature of the RAM may have an associated temperature controller. The controller may be open-loop or closed-loop. An open-loop system has the advantage in that it may be simpler to implement, whereas a closed loop system may be used to achieve a particular RAM temperature with greater accuracy. A closed-loop system may use any
30 suitable form of control. For example, a means of control may comprise a separate processor unit adapted to monitor the temperature of the RAM and to adjust heating or cooling being applied to the plate accordingly. Alternatively, a closed loop system may comprise an element having a

temperature coefficient adapted to take it to, and maintain it at a given temperature when suitably powered. For example, a resistor having a strong positive temperature coefficient will increase its resistance as it gets hotter, effectively producing a negative feedback mechanism, and so limiting the temperature rise.

The means for changing the temperature may alternatively be used without any temperature controller. For example, a power resistor, driven from a power supply, may be used as a heating element, with no temperature feedback being used to regulate the power supply. For this embodiment preferably a thermal cut-out is provided in the heating circuit, such that should the load reach a temperature above some preset maximum, power is cut from the heating element to avoid any damage.

In this case the RAM temperature would be determined by the power supplied to the resistor, the ambient temperature, and the degree of thermal insulation present around the load. Beneficially, a non-contact means for measuring the physical temperature of the RAM will be used in these circumstances, which is more likely to provide an accurate measurement of the physical, and hence radiometric, temperature of the RAM.

According to a further aspect of the invention there is provided a calibration load for use at microwave, millimetre or sub-millimetre wavelengths, the load having a layered structure, and comprising a thermal distribution layer having high thermal conductivity coupled to which is a material absorptive of millimetre wave radiation, characterised in that it further includes a means for changing the temperature of the thermal distribution layer and a means for measuring the physical temperature of the material absorptive of millimetre wave radiation.

30

Advantageously a controller is incorporated that takes an input from the means for measuring the temperature, and which provides an output to the

means for changing the physical temperature of the material absorptive of millimetre wave radiation.

The invention will now be described in more detail, by way of example only,
5 with reference to the following Figures, of which:

Figure 1 diagrammatically illustrates a first embodiment of the present invention;

10 Figure 2 shows a graph indicating radiometric and physical temperatures at different parts of the first embodiment with time;

Figure 3 diagrammatically illustrates a second embodiment of the present invention, this time using a non-contact thermometer;

15 Figure 4 shows a graph indicating radiometric and physical temperatures at different parts of the second embodiment with time;

Figure 5 shows a third embodiment of the present invention wherein a
20 polythene insulation layer along with an air gap is used.

Figure 1 shows a first embodiment of a calibration load 1 according to the present invention. The load 1 comprises a layered structure, with a metal plate 2 of thickness 5mm acting as a thermally conductive thermal distribution
25 layer. A RAM layer 3 is in close physical contact with metal plate 2. A thermally insulating layer 4 is located in front of, and in partial contact with, the RAM layer 3. Heating element 5, comprising a 15W power resistor, is attached to the metal plate 2, and temperature sensor 6 is attached to the RAM layer 3 on a side or face opposing the metallic side.

30 Thermally insulating mounts 7 are provided that attach around the load, enabling it to be conveniently secured. A control circuit 8 is connected to the heating element 5 and temperature sensor 6.

Thermal modelling was done to determine an appropriate thickness for the metal plate. A 5mm plate was found to give a temperature non-uniformity across the plate of approximately 0.1°C, when held at 20°C above ambient temperature. This was suitably accurate for the intended use, although it was found that a plate of only 1mm also will provide adequate results for many systems.

In operation the calibration load is positioned with a normal 9 to the face of the layered structure in line with an optical axis of the radiometer being calibrated. The RAM 3 chosen for this embodiment was TKRAM made by Thomas Keating, which has a reflectivity of approximately -40dB normal to its face. Thus the criteria discussed above relating to the acceptable error when calibrating a "good" radiometer is satisfied. RAM having a different absorption may be suitable for some applications however, even if it has a lower absorption than the criteria discussed above. For example, a calibration load having an increased reflectivity may be suitable for use with a radiometer which has a lower system sensitivity, or for applications in which larger systematic errors in the calibration load may be acceptable.

When using the calibration load, the operator or designer may decide upon a desired temperature difference between ambient temperature and that of the calibrated load. This difference may be dependent upon the application to which the radiometer is put, the calibration accuracy required, and the expected radiometric temperature of the objects that the radiometer would normally view.

For the current application the control circuit 8 is set to heat the heating element 5 using a 24 volt power supply until a temperature of 40°C is recorded by the temperature sensor 6. Ambient temperature is measured using an independent system (not shown), and recorded for use by the radiometer. Typically a 15°C-25°C difference will exist between ambient and 40°C in this case, which is sufficient to carry out a two point calibration of the

radiometer. Alternatively, the control circuit may have a separate sensor input from a sensor measuring ambient temperature. In that case the control circuit 8 may be arranged to maintain a constant temperature difference between ambient and the temperature sensor taking its measurement from the RAM, or
5 to adjust the power provided to the heating element to ensure sufficient temperature difference between it and ambient.

When activated, the control circuit 8 applies power to heating element 5, and records the temperature of the RAM. The control circuit is an off the shelf
10 Proportional-Integral-Derivative (PID) controller. The thermally conductive metal plate 2 heats up over time due to the contact with the heating element 5, and heat from the metal plate 2 conducts through to the RAM 3. A thermally conductive paste is used between the heating element 5 and the plate 2, and between the plate 2 and the RAM 3 to improve heat transfer. The
15 temperature sensor 6, which is attached to the RAM 3 physically (with a screw) and thermally (again with the aid of thermally conductive paste), feeds the temperature measurement back to the control circuit 8.

The insulating layer 4 mounted on the RAM 3 helps to maintain the
20 temperature of the surface of the RAM 3 at a value different to that of the surrounding air, and so reduce the temperature difference between the metal plate 2 and the RAM 3. It also shortens the time taken for a steady state to be achieved. The insulating layer 4 is made from expanded polystyrene, of thickness 20mm, which has a low loss at millimetre wavelengths but is a good
25 thermal insulator. As expanded polystyrene is also a very soft material, and the RAM 3 used was relatively hard, it was found that an effective fit between the polystyrene and the RAM could be formed merely by pushing the polystyrene sheet onto the cones of the RAM. The resulting interface between the two layers is not completely flush, as air gaps 10 remain at the
30 bases of the cones of the RAM. This gap is of no significance in practice however. Indeed, as said above, the thermal insulation layer may be positioned such that an air gap exists between it and the RAM. The air gap should be small enough such that little heat is lost from the RAM in warming

the air layer. Preferably the air gap is sealed preventing the ingress or egress of air into the gap, so reducing any undesirable heating or cooling of the RAM caused by outside influences.

- 5 When the system is first activated there is a temperature lag between the temperature of the metal plate and that recorded by the temperature sensor. This is caused by the thermal inertia of the metal plate and the RAM. Because of this, it is preferable to leave the system to warm up to a steady state before it is used for calibration. However, during the warming up stage
10 the calibration load may be used, albeit with an increased error between actual RAM radiometric temperature and that recorded by the temperature sensor.

- The temperature sensor 6 used is a contact thermocouple. This will tend to
15 sink some of the heat being driven into the RAM and so cool the RAM locally around the sensor 6, leading to a systematic error in the system. This may be corrected for by using a correction factor based on an accurate radiometric measurement of the RAM as compared to the indicated RAM temperature.

- 20 The controller used is a West Instruments model 2300, a PID device, although any appropriate means of controlling the power delivered to the means for changing the temperature may be employed. For example, a positive temperature coefficient device as described above may be employed if the plate is to be heated.

- 25 If an open-loop control method is employed, then the temperature of the plate 2 may be merely dependent upon the power supplied to a heating (or cooling) element 5. Advantageously the power would be maintained at a constant level to enable the plate 2 to achieve a steady state temperature.

- 30 In use the control circuit 8 provides information on the temperature reading taken with temperature sensor 6 to a system undergoing calibration. The system being calibrated, having taken a radiometric measurement of the

calibration load, will calculate the difference between the measured radiometric temperature and the reading from the temperature sensor, and will apply the calculated difference to the radiometric temperatures measured, until the next calibration is performed.

5

Figure 2 shows a graph of measured temperatures taken from various parts of the embodiment of Figure 1, from initial power-up through to a reasonably steady state condition. For this run, the controller was set to take the RAM to
10 a measured steady state temperature of 32°C.

The lower trace, marked with diamonds, shows ambient temperature as measured by an independent thermometer. There are two traces marked with triangles. The lower of these indicates the temperature measured by the
15 thermocouple mounted on the RAM. The trace marked with crosses is the radiometric temperature of the RAM, as measured by an independently calibrated radiometer. The trace marked with squares is the recorded temperature of the metal plate, again recorded with an independent thermometer.

20

The upper trace marked with triangles is the estimated radiometric temperature of the RAM. This is equal to the actual temperature as shown in the lower triangle trace, multiplied by a correction factor. The correction factor is calculated from known actual and radiometric temperatures (measured with
25 an independent radiometer) of the system when in a steady state. It can be seen that this value tracks quite closely the radiometric temperature during the first twenty minutes from switch-on, when the system elements are warming up. This knowledge allows the system to be used for calibration purposes at any point. In other words, by using knowledge of the RAM temperature as
30 provided by the sensor attached thereto, the radiometric temperature of the RAM can be estimated by applying a previously calculated correction factor.

The correction factor α in this case is equal to:

$$\alpha = (T_{\text{Radiometer}} - T_{\text{ambient}}) / (T_{\text{contact}} - T_{\text{ambient}}) \quad (\text{Eqn.2})$$

where

5 $T_{\text{Radiometer}}$ = RAM radiometric temperature as measured using an independent radiometer, steady state conditions;

T_{ambient} = ambient temperature;

T_{contact} = RAM temperature as measured with the attached thermocouple, steady state conditions.

10 Equation 2 can be rearranged to calculate the radiometric temperature of the RAM, based on the contact thermocouple measurement. The result of the calculation will be valid during the warm-up period as well as during the steady state condition.

15 Figure 3 shows a second embodiment of the present invention. This is broadly similar to the first embodiment, and similar features are identified with corresponding reference numerals.

Calibration load 11 comprises a layered structure, with a metal plate 2 acting
20 as a thermally conductive layer. A RAM layer 3 is in close physical contact with metal plate 2. A thermally insulating layer 4 is located on the RAM layer 3. Heating element 5 is attached to the metal plate 2, and temperature sensor 12 is located in the insulating layer 4.

25 This embodiment differs from that of the first in that the temperature sensor 12 used to measure the physical temperature of the RAM is a "non-contact" infra-red (IR) sensor. The sensor is physically located in a tight hole in the insulating layer 4, and positioned so that it can measure IR radiation from the RAM 3. This type of sensor uses the principle that the IR radiation levels
30 measured can be converted to a physical temperature if the IR emissivity of the RAM is known. The output of the IR sensor is equivalent to that of a type K thermocouple, and so is conveniently processed by similar circuitry to that used for the first embodiment.

The use of a non-contact sensor has the benefit that the sensor does not provide any localised cooling on the RAM, unlike the sensor used in the first embodiment. Thus the temperature indicated by the IR sensor may be taken
5 as the temperature of the RAM as a whole. No non-unity correction factors as described in relation to Equation 2 are needed to achieve a satisfactory accuracy.

10 Figure 4 shows a graph of measured temperatures taken from various parts of the embodiment of Figure 3, from initial power-up through to a reasonably steady state condition.

The lowest trace, marked with diamonds shows ambient temperature. The
15 upper trace, marked with squares, shows the temperature of the metal plate. The remaining two traces track each other very closely. The trace marked with triangles is the temperature as measured using the IR sensor, whereas the trace marked with crosses is the radiometric temperature as indicated with an independent radiometer. There is a temperature discrepancy between the
20 two of around 1°C, which is around the limit of accuracy of the experimental process.

In both Figure 2 and Figure 4, it can be seen that the metal plate temperature rises initially somewhat above the required RAM temperature. This is due to
25 the relatively low thermal conductivity of the RAM, which means that it takes some time to come up to the temperature of the metal thermal distribution plate, creating a lag in the system. The characteristics of the PID controller used cause this over-temperature, but it has the positive result in achieving a steady state condition earlier than if the back plate were driven to a fixed
30 temperature.

If the temperature measurement were taken from the metal plate, then due to the relatively quick heat transfer throughout the plate area, there would be

little overshooting of the plate temperature beyond that desired. This may be useful in circumstances where the RAM material is used at temperatures close to those where it may be damaged. It has the downside however that then the control system is not recording the temperature of the RAM, and so
5 the radiometric temperature of the RAM could not be easily predicted until a steady state condition had been reached. An extension of this that avoids this problem is to have two temperature sensors. A first, connected to the metal plate may be used in regulating the heating element, whilst the second, adapted to measure the temperature of the RAM, may be used as the output
10 of the calibration load.

As an alternative to using a controller 8, a device such as a positive temperature coefficient heater element may be attached to the metal plate as described above, whilst a separate temperature sensor is used to monitor the
15 temperature of the RAM. The temperature sensor in this case may be either the contact or the non-contact types, although the latter is preferred.

For occasions where a RAM, or other component (such as the thermal insulator) is being used close to its maximum temperature, temperature
20 controlled switch, such as a bimetallic thermostat, may be fitted to the metal plate to act as a safety device and cut heater power once the metal plate reaches a predetermined temperature. Power would be restored by such a device once the metal plate temperature dropped.

25 Figure 5 shows a third embodiment of the present invention. A calibration load 50 comprises an aluminium plate 51 acting as a thermal distribution later. A resistive heater element 52 is mechanically and thermally attached thereto on a surface of the plate 51. On a second surface of plate 51 is attached a sheet of RAM 53, again in close thermal contact with plate 51. Nylon screws
30 are used as the attachment means, along with a thermally conductive paste, although other suitable methods of attachment exist, including glue. A polythene window 54 is held in place in front of the RAM 53 with an approximately 2mm air gap 55 between the tips of the RAM 53 and the

polythene 54. The polythene was approximately 12 microns thick. Thermal insulation 56 consisting of solid nylon surrounds the remaining sides of the load 50, so preventing both cooling of the plate 51 by air currents and heating of any surrounding elements by heater element 52. An infra-red thermometer 57 is located away from direct contact with insulation 54, 56 in some convenient position, such that it is able to receive radiation from the RAM 53. Controller 58 is connected to the thermometer and also to heater 52, and acts to control the temperature of the heater plate in a similar manner to the previous embodiments.

10

In use radiation at millimetre wavelengths will be emitted from the calibration load roughly in the direction shown by arrows 59.

As the polythene insulating material 54 is highly transparent to both the millimetre wave radiation emitted by the RAM and the IR radiation similarly emitted, it does not have any significant impact on the measurement recorded by the thermometer 57. Thus a complete thermal seal may be made in front of the RAM using the polythene.

The embodiment was made and its performance measured. Controller 58 was arranged to heat the RAM to 50°C, using the IR thermometer 57 as its temperature measurement input. After a period of settling to allow the load to reach a thermal equilibrium, the IR temperature was measured as being 52.1°C while an independent, calibrated radiometer measuring radiation at around 94GHz measured the temperature as being 52.2°C. Thus the embodiment was operating well within the accuracy requirements of many radiometer systems.

As relatively bulky expanded polystyrene has been replaced in this embodiment by the thin polythene, a thinner calibration load has been achieved, which adds to its versatility. It is particularly suitable for use where the load may be moved periodically for example by intermittently locating it in front of a radiometer during a calibration phase and then moving it back out of

the receive beam area of the radiometer. During any such movement the IR thermometer may be moved along with it so that it continues to take thermal measurements of the RAM during the calibration procedure, or may alternatively be positioned so that it does not move with the load. This latter approach is more convenient in that the load to be moved is smaller and lighter, but care must be taken to ensure that the controller 58 does not cause the temperature of the plate 51 to change significantly due to the control loop being temporarily broken by removal of the input to the thermometer 57. This can be done by for example ensuring the loop is broken only for a short time relative to the ability of the heater to change the plate temperature, or by disabling the output of the controller during the time the control loop is broken, and keeping this time short in relation to any significant cooling of the RAM.

For certain applications the calibration load may be physically located in a system in such a way that any cooling effect, such as moving air currents, do not result in a significant cooling of the RAM. For example, the system in which the load is located may itself be well thermally insulated. In such a situation, or in situations where the calibration accuracy requirements of the radiometer being calibrated are not so onerous, a solid thermal insulation layer may not be needed in front of the RAM. Instead, the surrounding air may be regarded as the thermal insulation layer. In this case, then advantageously the thermal distribution layer may be made to have a greater thermal inertia, by for example making it from a thicker piece of metal than would otherwise be used. This makes it less susceptible to any cooling effects that may be present, but of course also requires a longer time to stabilise at its required temperature.

A calibration load as described herein may be used alone, or may be used in conjunction with other calibration devices. In particular, it is convenient to have a pair of calibration loads, one of which is heated (or cooled), whilst the other remains at ambient temperature. Thus a two point calibration may be performed using such loads.

The scope of the present disclosure includes any novel feature or combination of features disclosed therein either explicitly or implicitly or any generalisation thereof irrespective of whether or not it relates to the claimed invention or mitigates any or all of the problems addressed by the present invention. The

5 applicant hereby gives notice that new claims may be formulated to such features during the prosecution of this application or of any such further application derived there-from. In particular, with reference to the appended claims, features from dependent claims may be combined with those of the independent claims and features from respective independent claims may be

10 combined in any appropriate manner and not merely in the specific combinations enumerated in the claims.

Claims

1. A calibration load for use at microwave, millimetre or sub-millimetre wavelengths, the load having a layered structure, and comprising a thermal distribution layer having high thermal conductivity, a thermal insulation layer having high millimetre wave transmissivity, and a material absorptive of millimetre wave radiation located between the thermal distribution layer and the thermal insulation layer, characterised in that it further includes a means for changing the temperature of the thermal distribution layer and a means for measuring the physical temperature of the material absorptive of millimetre wave radiation.
2. A calibration load as claimed in any of the above claims wherein the thermal distribution layer comprises a metallic plate.
3. A calibration load as claimed in claim 2 wherein the metallic plate is made from a metal chosen from aluminium, steel, brass and copper.
4. A calibration load as claimed in any of the above claims wherein the load takes the form of a tile.
5. A calibration load as claimed in any of the above claims wherein the material absorptive of millimetre wave radiation comprises a solid, homogeneous material.
6. A calibration load as claimed in claim 5 wherein the material absorptive of millimetre wave radiation has a multiple pyramidal form on a front face thereof.
7. A calibration load as claimed in any of claims 1 to 6 wherein the thermal insulation layer comprises a layer adapted to prevent convective heat loss from the material absorptive of millimetre wave radiation.

8. A calibration load as claimed in any of the above claims wherein the thermal insulation layer comprises a layer adapted to prevent conductive heat loss from the material absorptive of millimetre wave radiation.
- 5 9. A calibration load as claimed in claim 8 wherein the thermal insulation layer comprises an expanded polystyrene material.
10. A calibration load as claimed in any of the above claims wherein the means for measuring the physical temperature comprises an infra-red sensor.
- 10 11. A calibration load as claimed in claim 10 wherein the infra-red sensor is located such that it measures a front face of the material absorptive of millimetre wave radiation.
- 15 12. A calibration load as claimed in any of the above claims wherein the means for measuring the physical temperature comprises a temperature sensor physically mounted on the material absorptive of millimetre wave radiation.
- 20 13. A calibration load as claimed in any of the above claims wherein the means for changing the physical temperature of the thermal distribution layer comprises a heating element.
14. A calibration load as claimed in claim 13 wherein the heating element is
- 25 an electrically resistive component.
15. A calibration load as claimed in any of claims 1 to 12 wherein the means for changing the physical temperature of the thermal distribution layer comprises a cooling element.
- 30 16. A calibration load as claimed in claim 15 wherein the cooling element comprises a heat pump.

17. A calibration load as claimed in any of the above claims wherein the thermally insulating layer and the material absorptive of radiation are positioned with an air gap there between.
- 5 18. A calibration load as claimed in any of the above claims wherein a temperature controller is incorporated, the controller receiving an input from the means for measuring the physical temperature and providing an output to the means for changing the physical temperature, and being adapted to maintain a temperature difference between ambient and the material
10 absorptive of radiation.
19. A calibration load as claimed in claim 18 wherein the controller is adapted to maintain the material absorptive of radiation at a fixed absolute temperature.
15
20. A calibration load as claimed in claim 18 wherein the controller is adapted to maintain a fixed difference in temperature between ambient and that of the material absorptive of radiation.
- 20 21. A calibration load for use at microwave, millimetre or sub-millimetre wavelengths, the load having a layered structure, and comprising a thermal distribution layer having high thermal conductivity coupled to which is a material absorptive of millimetre wave radiation, characterised in that it further includes a means for changing the temperature of the thermal distribution
25 layer and a means for measuring the physical temperature of the material absorptive of millimetre wave radiation.
22. A calibration load as claimed in claim 21 wherein a temperature controller is incorporated, the controller receiving an input from the means for
30 measuring the physical temperature and providing an output to the means for changing the physical temperature, and being adapted to maintain a temperature difference between ambient and the material absorptive of radiation.

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Fig.1.

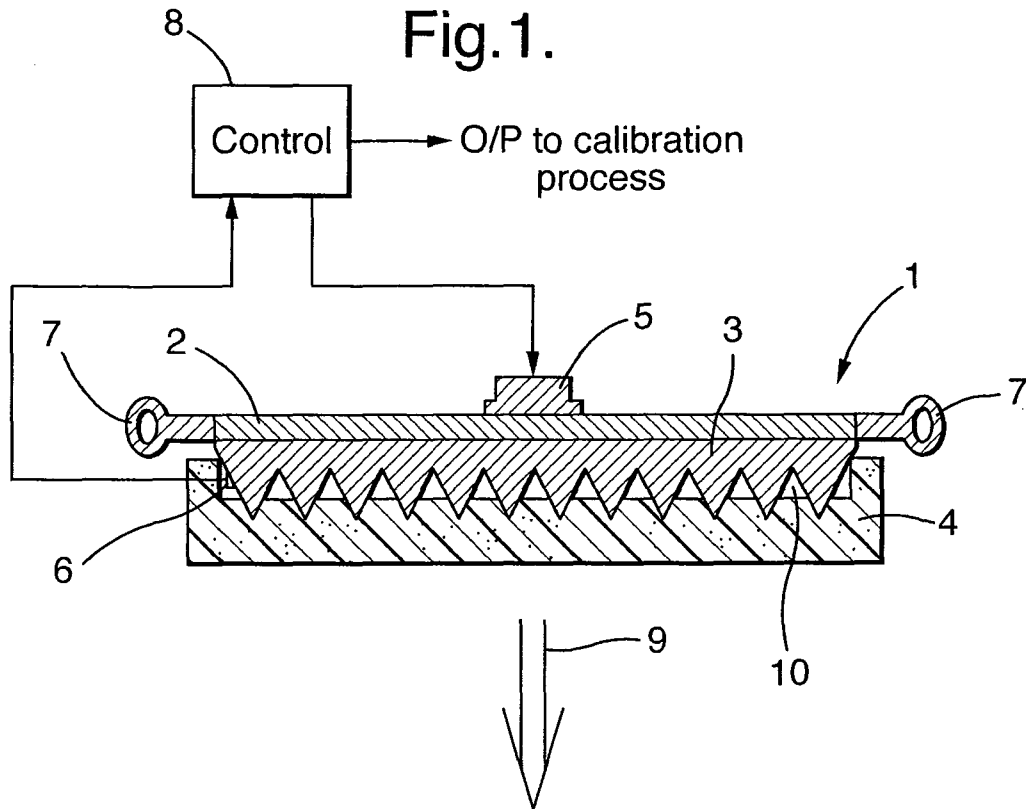
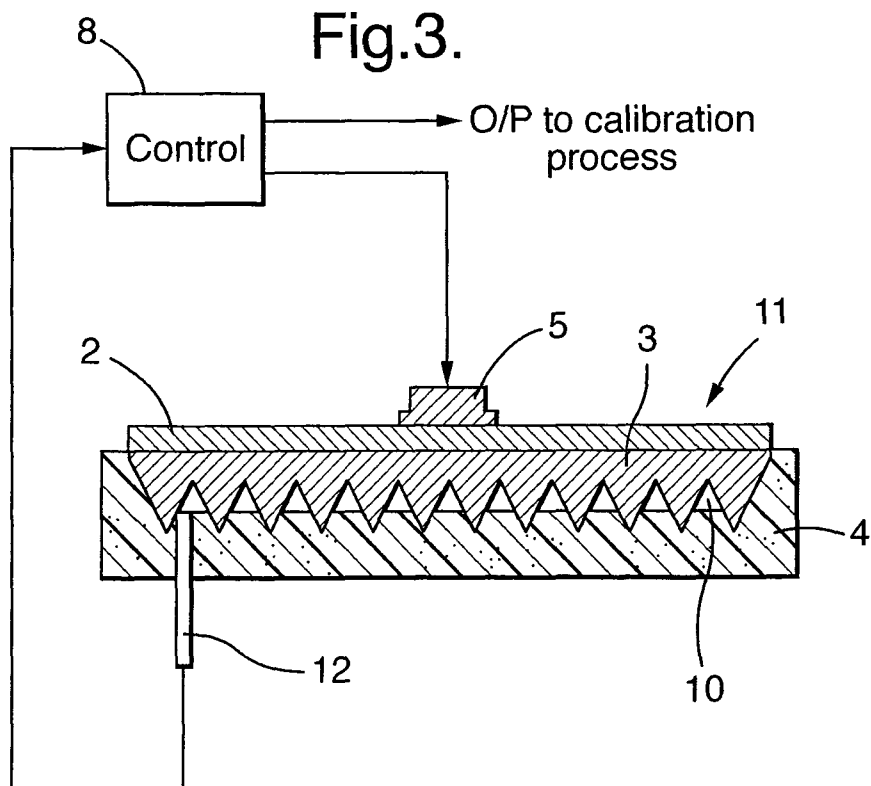
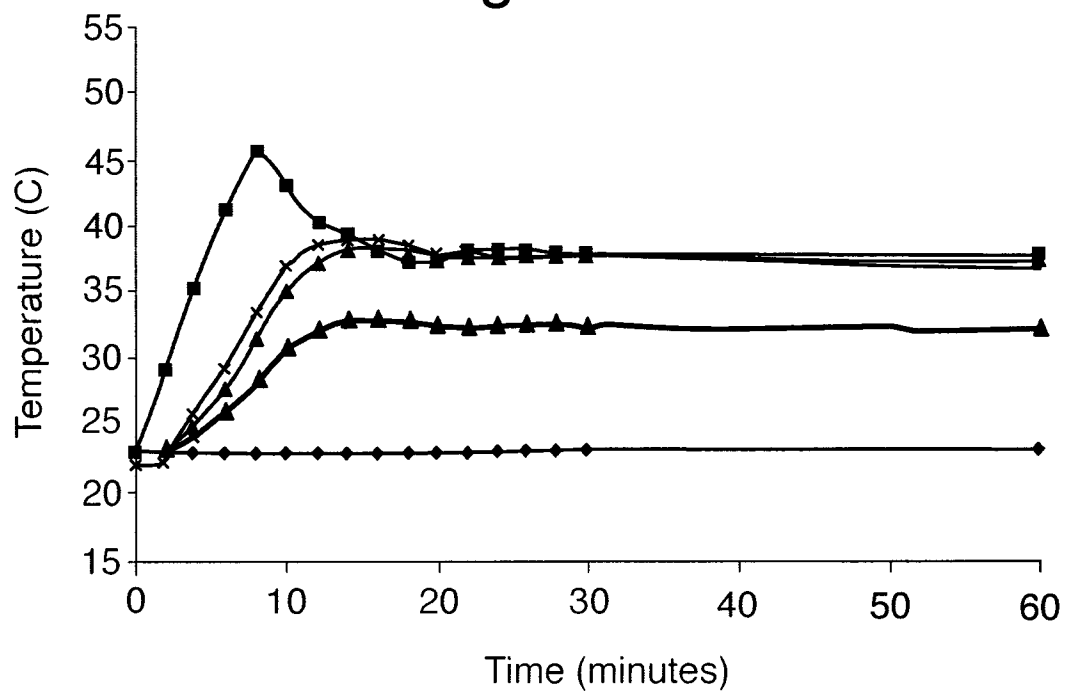


Fig.3.

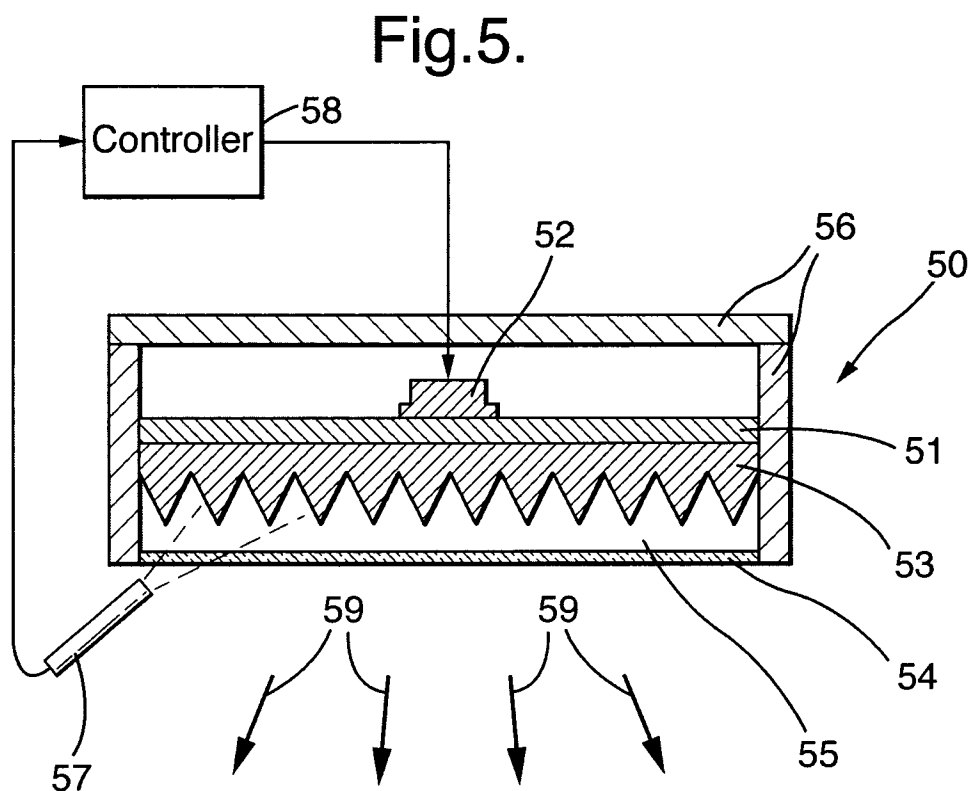
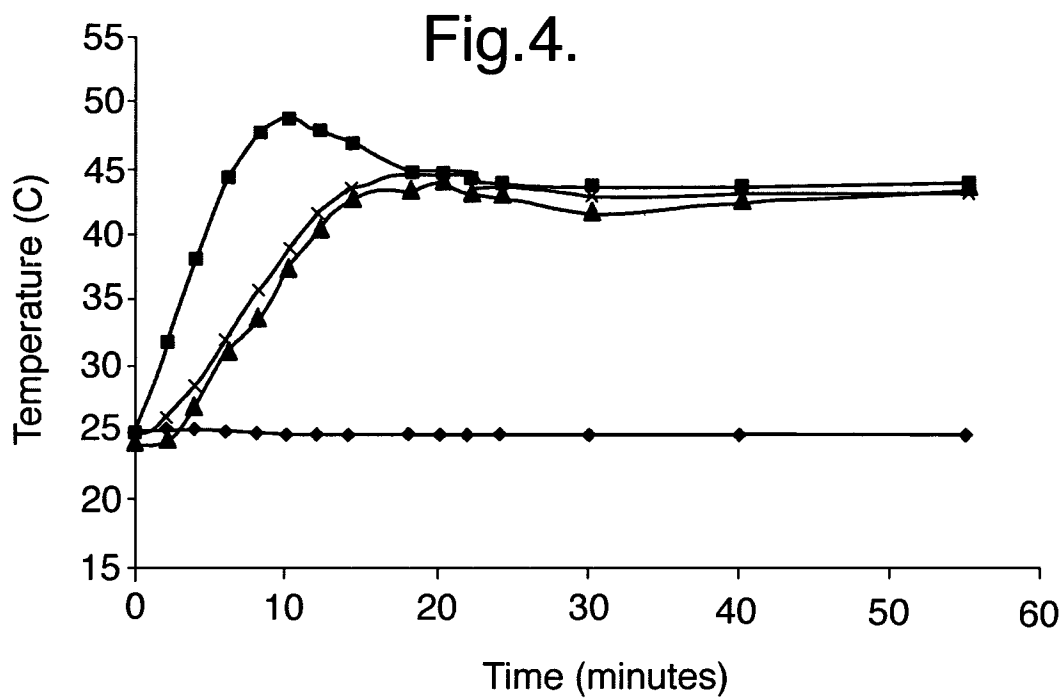


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Fig.2.



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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2008/002565

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01K11/00 G01K15/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01K G01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GIOVANNI DE AMICI ET AL: "Stabilization of the Brightness Temperature of a Calibration Warm Load for Spaceborne Microwave Radiometers" IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 45, no. 7, 1 July 2007 (2007-07-01), pages 1921-1927, XP011186343 ISSN: 0196-2892	1-9, 12-14, 17-22
Y	page 1921 - page 1922 ----- -/-	10, 11, 15, 16

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

4 November 2008

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13/11/2008

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INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2008/002565

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2005/026674 A (THE UNIVERSITY COURT OF THE UNIVERSITY OF ST ANDREWS) 24 March 2005 (2005-03-24)	10,11, 15,16
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A	US 6 308 043 B1 (SOLHEIM ET AL) 23 October 2001 (2001-10-23) column 11, line 66 - column 12, line 9; figure 12 -----	1-22

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2008/002565

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		EP 1664694 A2	07-06-2006
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