NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF:

April 5, 1971

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,417,399

Corporate Source : California Institute of Technology

Supplementary Corporate Source : Jet Propulsion Laboratory

NASA Patent Case No.: XNP-09832

Please note that this patent covers an invention made by an employee of a NASA contractor. Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of. . . ."

G Parker
Gayle Parker

Enclosure:
Copy of Patent

FACILITY FORM 602

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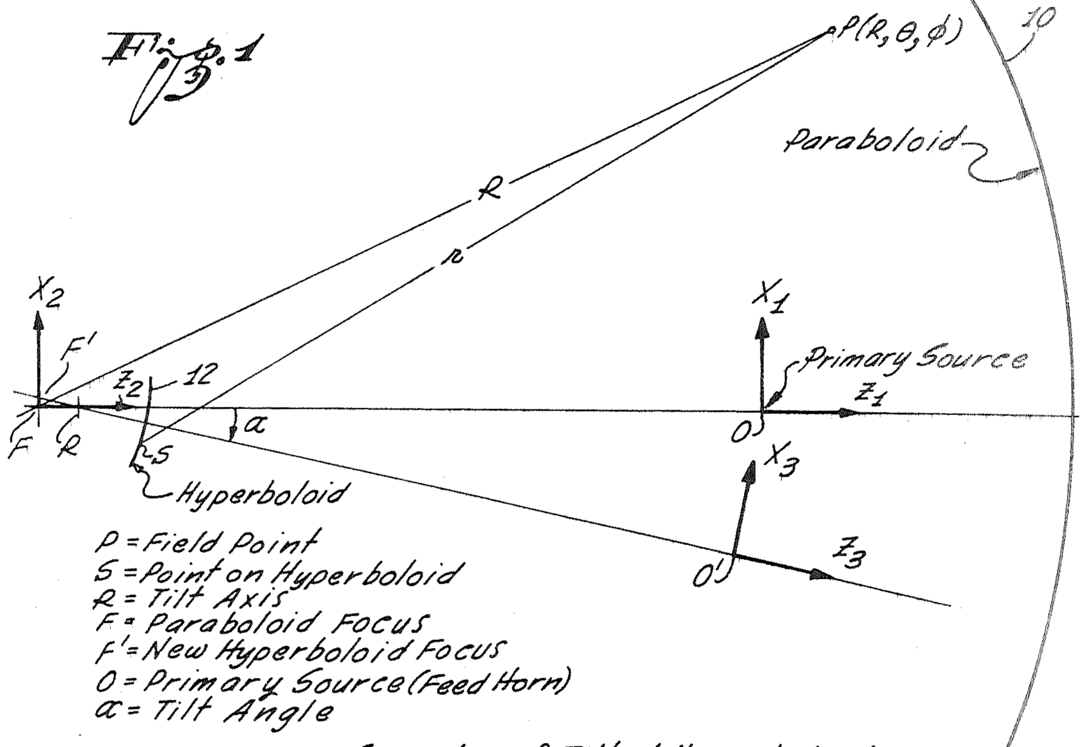
8 (PAGES) — (CODE) 30

(NASA CR OR TMX OR AD NUMBER) — (CATEGORY)

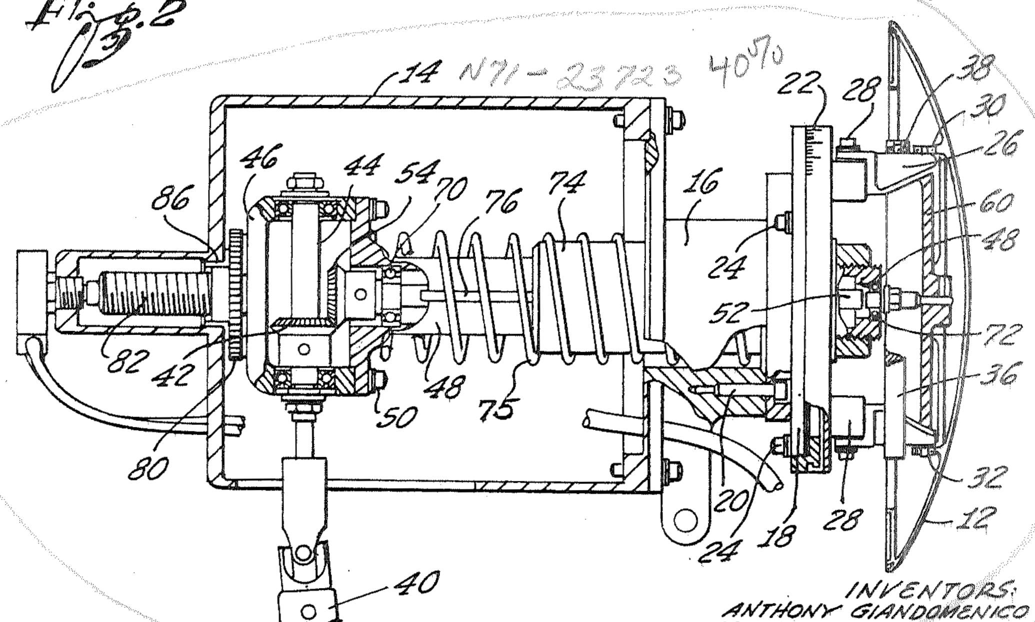
N71-23723

Fig. 1



Geometry of Tilted Hyperboloid

Fig. 2



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1423

Dec. 17, 1968 JAMES E. WEBB 3,417,399
ADMINISTRATOR OF THE NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
MILLIMETER-WAVE RADIOMETER FOR RADIO-ASTRONOMY
Filed April 18, 1967 4 Sheets-Sheet 2

Fig. 3

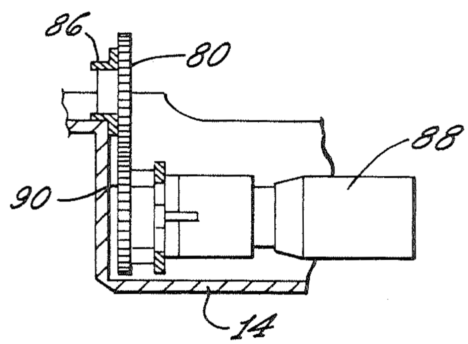


Fig. 4A

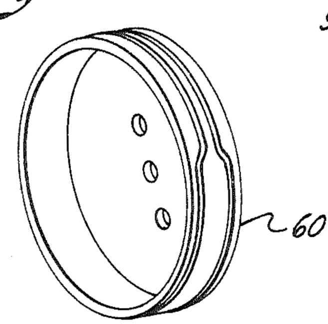
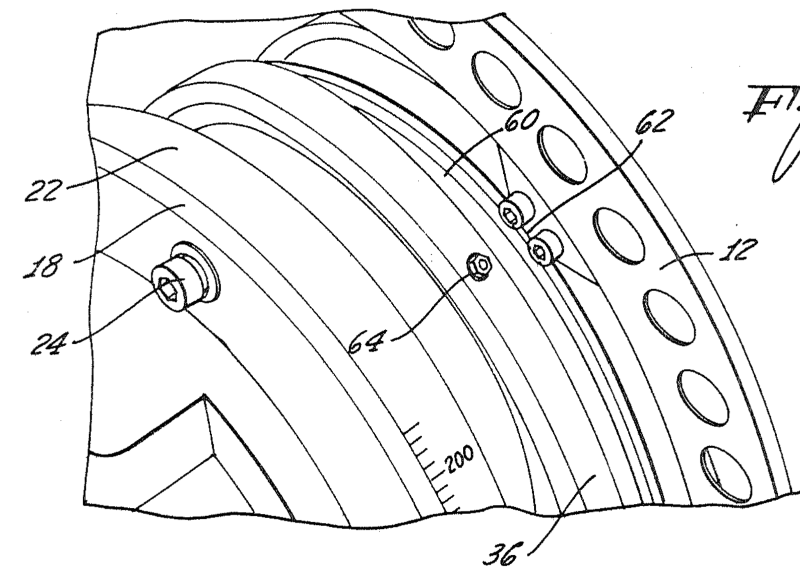


Fig. 4



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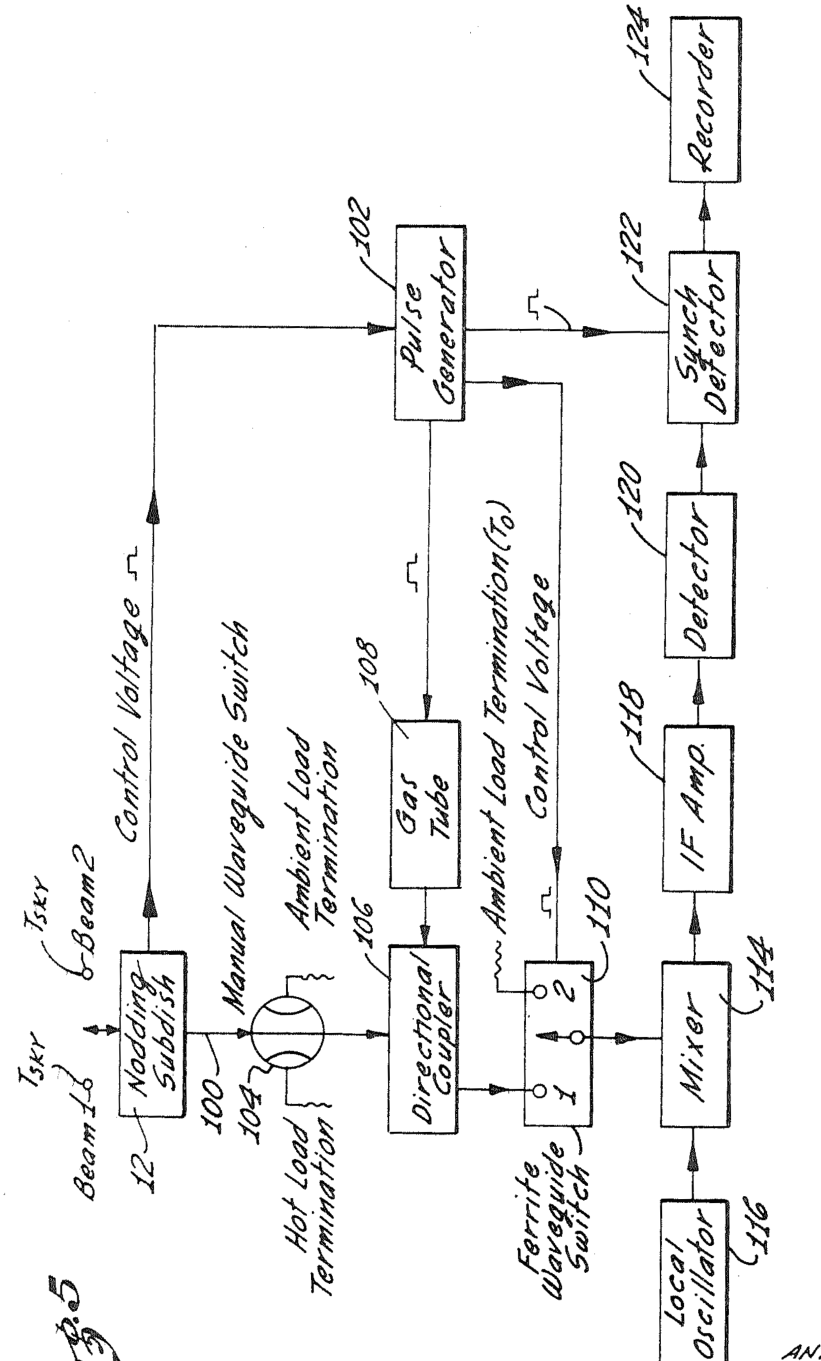

Fig. 5

Block Diagram of Nodding Subdish Calibration System

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Fig. 6A

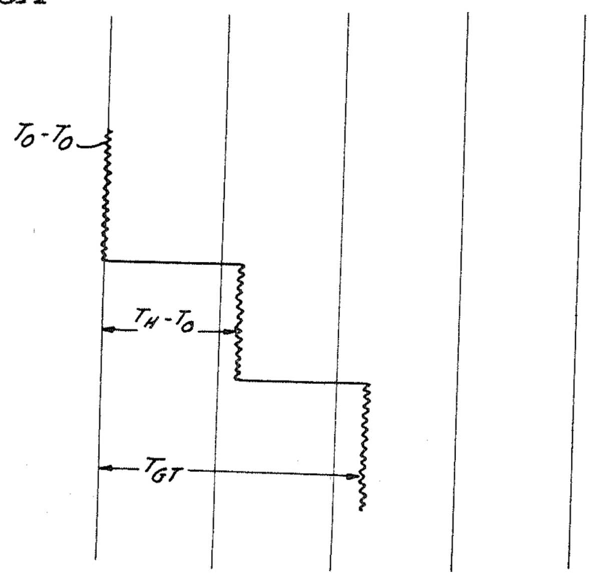
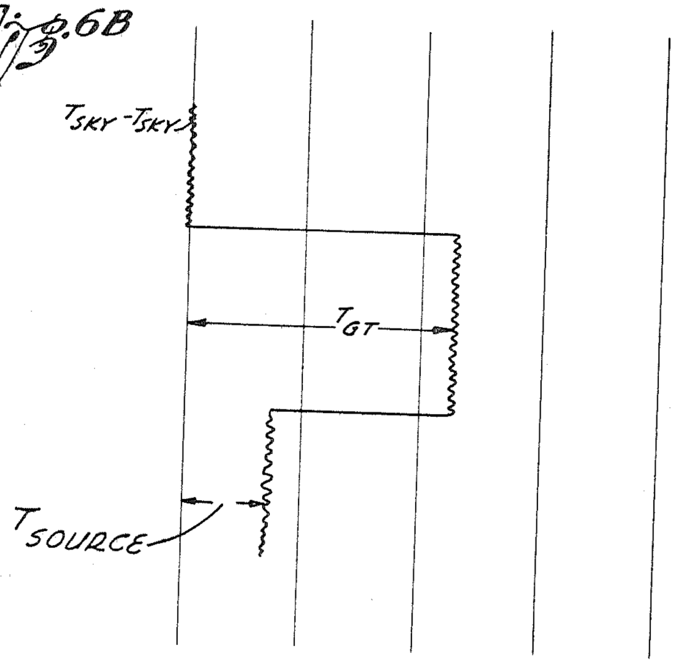


Fig. 6B



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United States Patent Office 3,417,399 Patented Dec. 17, 1968

3,417,399
MILLIMETER-WAVE RADIOMETER FOR RADIO-ASTRONOMY

James E. Webb, Administrator of the National Aeronautics and Space Administration with respect to an invention of Anthony Giandomenico, San Gabriel, and Willard Van Tuyl Rusch, Pasadena, Calif.

Filed Apr. 18, 1967, Ser. No. 632,163
10 Claims. (Cl. 343—100)

ABSTRACT OF THE DISCLOSURE

A synchronous detection system capable of detecting exceptionally weak radio-astronomical signals, the system including a Cassegrainian type microwave antenna having a mechanical switching assembly whereby the antenna beam may be periodically switched from a distant source of radio-astronomical signals to a position in space adjacent to but displaced from the source so as to permit the detection system to distinguish an actual signal from background noise. Mechanical switching within the system is achieved by a periodically tilting or "nodding" of the auxiliary hyperboloidal reflecting subdish which forms a part of the Cassegrainian antenna. The synchronous detection system also includes means for thermal noise calibration of the system.

Origin of the invention

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85–568 (72 Stat. 435; 42 USC 2457).

Background of the invention

The synchronous detection system of this invention, which affords exceptionally good capabilities for the detection of particularly weak radio astronomical signals provides radiometry capabilities which facilitate continuing studies and discoveries relating to the universe through radio astronomy.

Radio astronomy involves the study of celestial objects through observations of radio waves emitted by the celestial objects. The detection of radio waves from outer space was first accomplished in 1932 by K. G. Janksy of the Bell Telephone Laboratories in New Jersey.

In order to practice the art of radio astronomy particularly well developed and exceptionally sophisticated scientifically conceived antennas and receivers are required. More particularly, in order to practice the art of radio astronomy exceptionally good antennas, which are sufficiently large and sensitive for accurately resolving details of signals emitted from celestial objects, and additionally, sufficiently large and sensitive for capturing adequate amounts of energy so as to provide a detectable signal for observation, are required. During the approximate years of World War II, and subsequent thereto, antenna and receiver development and production facilitated the serious beginning, growth and evolution of radio astronomy.

Since high-frequency radio astronomical signals generally are particularly weak radio signals there has been a particularly basic requirement for a highly sensitive receiving system, afforded by antenna beam mechanical switching in conjunction with the synchronous detection system provided by this invention, having capabilities for detection and resolution of particularly weak radio astronomical signals which have exceptionally small magnitude.

Since 1945, radio astronomical studies have been made of the sun, moon and numerous other celestial objects.

Radio waves have been detected, for example, from the sun's atmosphere. A uniform level of emission which has been detected is believed to be caused by thermal collisions between electrons and ions in the hot solar atmosphere. Also, relatively sharp bursts of radio waves have been detected at certain wavelengths. Measurements of the received solar radio signals give information relating to the temperature and electron density of the solar atmosphere.

Likewise, radio signals have been observed from the moon. These signals are thermally generated in the outer layers of the moon's surface. Measurement of variations in intensity of the signals with frequency, and with varying phases of the moon produces information relating to the thermal and electrical properties of the moon's surface.

It is usual in the art to detect weak radio-astronomical signals by means of a highly directional microwave receiving antenna which precisely directs an antenna beam at the distant source. It is also known in the art to provide an electrical switching arrangement which periodically causes the antenna beam to be displaced from the source to a position in space adjacent the source. Such a switching arrangement significantly reduces the effects of slow changes in the sky background radiation as well as fluctuating atmospheric absorption. Also, electrical switching techniques have been used in the prior art to detect the weak radio-astronomical signals in the presence of relatively high noise contributions from the atmosphere and from the receiving equipment itself.

The detection system of the present invention is provided with capabilities for reducing losses heretofore incurred by prior art electrical beam switching systems. The improved results obtained by the detection system of this invention are achieved by antenna beam mechanical switching in conjunction with a synchronous detection system. The mechanical switching of the antenna beam is achieved in the system of the invention by periodically tilting or "nodding" the hyperboloidal subdish reflector of the Cassegrainian antenna.

As described, for example, in U.S. Patent 3,243,805, I. D. Smith, Jr.; and in U.S. Patent 3,255,455, G. Von Trentini, the Cassegrainian antenna is essentially a microwave antenna assembly consisting of a paraboloid-shaped primary reflector and an auxiliary hyperboloidal subdish reflector which is positioned ahead of the primary reflector. For transmitting purposes, the subdish cooperates with a primary radiator disposed near the primary reflector, and the subdish serves to flood the primary reflector with radiations. When the antenna is used for receiving radiations from a distant source, as is the case in the system of the present invention, the radiation path is oppositely directed. That is, the radiations are first directed to the primary reflecor, and from the primary reflector to the subdish reflector, there to be directed by the subdish into the synchronous detection system.

Summary of the invention

The synchronous detection system of the invention provides for the periodical angular displacement of the hyperboloidal subdish in a Cassegrainian antenna so as to deflect the antenna beam periodically from the distant source to a position in space displaced from but adjacent to the source. In this manner the desired switching of the antenna beam is achieved mechanically so that losses as incurred by the prior art electrical beam switching arrangements are thereby reduced.

By means of the radiometer which includes the synchronous detection system of this invention radio-astronomical signals may be detected, displayed and measured. The synchronous detection system of the invention is so conceived and constructed that radio sky and atmosphere may be used for providing a reference noise input level which thereby considerably enhances facility for radio signal detection. Also, as indicated supra, by reducing losses heretofore incurred by the prior art antenna beam electrical switching arrangements the antenna beam mechanical switching in conjunction with the synchronous detection system of this invention provides a radiometer which has capabilities for detecting radio astronomical signals of significantly smaller magnitude than heretofore has been possible with known prior art antenna beam electrical switching apparatus.

The synchronous detection system of this invention uniquely incorporates a Cassegrainian microwave antenna having a drive means for the nodding subdish of the antenna for periodically displacing the antenna beam from the source of radio-astronomical signals. Additionally, the system is synchronously controlled so that the two groups of received noise signals, only one group of which contains the desired signal, may be separated and the desired signal thereby detected. Also, the system of the invention incorporates an effective calibration means whereby known thermal sources are observed in order that the system may be used for the quantitative measurement of the received radio-astronomical signals.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself both as to its organization and method of operation as well as additional objects and advantages thereof, will best be understood when read in connection with the accompanying drawings.

Description of the drawings

FIGURE 1 is a schematic representation of the geometry involved in the Cassegrainian antenna;

FIGURE 2 is a side elevational view, partly in section, of the mechanical construction of a mount for the nodding subdish assembly of the Cassegrainian antenna used in the system, in accordance with one embodiment of the invention;

FIGURE 3 is a fragmentary view of a portion of the mechanism of FIGURE 2, which is hidden in the view of FIGURE 2;

FIGURE 4 is a further fragmentary view of the nodding subdish assembly, on an enlarged scale, showing in detail certain components of the assembly;

FIGURE 4A is a perspective view of a cam wheel which is included in the assembly;

FIGURE 5 is a block diagram of one embodiment of the synchronous detection system of the present invention, including a thermal calibration means for the system; and

FIGURES 6A and 6B are graphical representations of the signals displayed by the recorder portion of the system of FIGURE 5.

Description of the invention

FIGURE 1 shows the main, or primary, paraboloid reflector **10**, and the nodding subdish auxiliary reflector **12**. The mount assembly and control mechanism for the subdish **12** are shown in section in FIGURE 2, with further details shown in the fragmentary views of FIGURES 3 and 4. The mount assembly of FIGURE 2 supports the subdish **12** in a position facing the primary paraboloid reflector **10**, as shown schematically in FIGURE 1.

As described above, the mount assembly of FIGURE 2 must tilt the subdish **12** periodically in order to obtain the desired mechanical switching of the antenna beam. The tilt is extremely small, and may be of the order of 2°, by way of example. The subdish is tilted as shown in FIGURE 1 about an axis which is perpendicular to the axis of symmetry of the mount assembly. The rate of tilting of the subdish may be from 5–15 cycles per second, for example.

As shown in FIGURE 2, the mount assembly is contained, for example, in a housing **14**. The housing is provided with a tubular end portion **16**, and an index plate

18 is mounted on the end of the tubular portion **16** by screws, such as the screw **20**. An adjustment plate **22** is supported in coaxial relationship with the index plate, and against the index plate by means of screws, such as the screws **24**. A support **26** is provided for the subdish **12**, and is mounted on the adjustment plate **22** by means, for example of bolts **28**. The subdish **12** is mounted on the support **26** by means, for example, of a pair of bearings **30** and **32** so as to permit the subdish to be tilted about an axis extending perpendicular to the axis of symmetry of the mount assembly.

A counterweight **36**, which has a ring-shaped annular configuration, is also supported on the support **26** by a pair of bearings, such as bearing **38**. The annular counterweight **36** is supported on the mount adjacent the support of the subdish **12**, as shown.

A drive shaft **40** is provided for driving a bevel gear **42** which, in turn, is affixed to a shaft **44**. The shaft **44** is journaled in a yoke-shaped bracket **46**. A tubular shaft **48** is affixed to the bracket **46** by means, for example, of bolts **50**. A cam shaft **52** extends coaxially within the tubular shaft **48**. A further bevel gear **54** is mounted at the end of the shaft **52** in meshing relationship with the gear **42**. A cam wheel **60** is mounted at the right hand end of the cam shaft **52** as seen in FIGURE 2. Therefore, when the drive shaft **40** is rotated, the gears **42** and **54** transmit the rotary motion to the shaft **52** which, in turn, drives the cam wheel **60**.

As best shown in FIGURE 4, the subdish **12** has a cam follower **62** which extends down into a first groove in the periphery of the cam wheel **60** shown in FIGURE 4A. The annular counterweight **36** also has a cam follower **64** which extends into a second peripheral groove in the cam wheel **60** adjacent the first groove. The cam wheel **60** is best shown in the perpective view of FIGURE 4A, and the two adjacent grooves in the periphery of the cam wheel are best shown in that view.

The cam shaft **52** is supported in the tubular shaft **48** in bearings **70** and **72** at the opposite ends thereof. The shaft **48** is keyed to a sleeve **74** by means, for example, of a key **76**, the sleeve **74** being mounted on one end of the housing **14**. The tubular shaft **48** is slidable in the sleeve **74** so that the subdish **12** can be moved to the left or right as shown in FIGURE 2 for focussing purposes. A spring **75** biases the shaft **48** to the left as shown in FIGURE 2.

A focus gear **80** is mounted on the side of the bracket **46** remote from the shaft **48** coaxially with the axis of symmetry of the assembly. A lead screw **82** extends through the gear **80**, and the gear **80** together with the bracket **46** and tubular shaft **48** move back and forth in a guide bushing **86** as the gear **80** is rotated. Such movement causes the subdish **12** to move relative to the housing **14**, back and forth along the axis of symmetry. The spring **75** biases the bracket against the lead screw to prevent "play" in the assembly.

The focus gear **80** is driven by an electric motor and gear set **88** shown in FIGURE 3. The motor is mounted in the housing **14**, and its drive shaft is coupled to the gear **80** through a gear **90**, the latter gear being mounted on the drive shaft. The motor **88** is reversible, and can be controlled to drive the gear **80** in either direction. This enables the subdish **12** to be moved controllably towards or away from the primary reflector **10** as shown in FIGURE 1 for focussing purposes.

It will be appreciated, therefore, that when titled, the nodding subdish **12** moves between two off-axis positions (FIGURE 1). The axis about which the subdish **12** tilts may be indexed merely by releasing the bolts **24** and moving the adjustment plate **22** relative to the index plate **18**. A suitable scale is provided on the index plate so that the pivotal axis of the subdish can be adjusted with respect to any desired reference.

The cam wheel **60** is located on the back of the subdish **12**, and the subdish and annular counterweight **36** have respective cam followers **62** and **64** which engage the respective perpipheral grooves in the cam wheel. Rotation of the cam wheel **60** causes approximate "square wave" motion of both the subdish **12** and the annular counterweight **36**. The subdish **12** remains in one off-axis position for about 45% of the rotation of the cam wheel; it switches to the second position for about 5% of the rotation of the cam wheel; it remains in the second position for about 45% of the rotation of the cam wheel; and it then switches back to the first position during the remaining 5% of the cam wheel rotation. The counterweight moves in a direction opposite to that of the subdish **12** in order to complement the movement of the subdish so that vibration to the overall assembly thereby is reduced to a minimum.

As shown in FIGURE 5, the nodding subdish in the Cassegrainian antenna system of the invention directs its energy by means of a wave guide section **100** into a synchronous detection system. A switch such as, for example, a photo-electric switch is also provided in the nodding subdish assembly, so that a control pulse may be generated each time the subdish is tilted from one axis to the other. This pulse is applied to a pulse generator **102**, and causes the generator to produce control pulses for the different components of the system. It will be appreciated that all the different control pulses generated by the pulse generator **102** occur at the same frequency, which is the synchronous frequency of the system.

The waveguide **100** from the nodding subdish **12** is coupled to a manually operated wave-guide switch **104**, the output of which is connected to a directional coupler **106**. The manual waveguide switch can be turned manually to receive energy from the waveguide section **100**. Additionally, the waveguide switch can be turned to a reference source of radiation designated the "hot load termination" (FIGURE 5) and to a second reference source of radiation designated the "ambient load termination." The "hot load termination" may represent, for example, a reference temperature of 120° C., whereas the "ambient load termination" may represent a reference temperature of 20° C.

A first series of synchronous pulses from the pulse generator **102** is used to trigger a gas tube **108** which, in turn, passes pulses through the directional coupler **106** with energy derived through the manual waveguide switch **104**.

FIGURE 5 shows a block diagram of one embodiment of the synchronous detection system of the invention which includes a thermal calibration means for the system. For calibration purposes, the directional coupler **106**, shown in FIGURE 5 for example, is coupled to a first terminal of a ferrite waveguide switch **110**. The latter switch is operated at the synchronous frequency by a second series of control pulses derived from the pulse generator **102**. A second terminal of the ferrite waveguide switch is connected to a source of radiation also designated "ambient load termination," and which, likewise, may represent a reference temperature of 20° C. The common terminal of the ferrite waveguide switch is connected to a heterodyne mixer stage **114** in the electronic synchronous detection section of the system.

The electronic section is a usual synchronous heterodyne radiometer, and it includes a local oscillator **116**. The signal from the local oscillator heterodynes the incoming signals in the mixer **114** to a selected intermediate frequency signal. The resulting intermediate frequency signal is amplified in an intermediate frequency amplifier **118** of one or more stages and the output from the intermediate frequency amplifier is applied to a detector **120**. The detector output from the detector **120** is then passed to a synchronous detector **122**, which in turn is coupled to a recorder **124**. The synchronous detector **122** is operated at the synchronous frequency of the system by a third series of pulses derived from the pulse generator **102**. The recorder **124** may be a usual digital paper recorder.

The ferrite waveguide switch **110** is used for calibration purposes only. During normal operation of the synchronous detection system, the ferrite waveguide switch is replaced by a usual straight waveguide section extending from the directional coupler **106** to the mixer **114**. The calibration of the system may, for example, take place before and after a run which might, for example, be six or eight hours of looking at the moon, or other source of millimeter radiation.

Each of the various elements of the system shown in block form in FIGURE 5 are, in themselves, known to the art. Therefore, a detailed description of these elements per se is deemed to be unnecessary for the full understanding of the present invention.

The directional coupler **106** permits power from the gas tube **108** to be carried through the ferrite waveguide switch **110** to the mixer **114**, and at the same time the directional coupler permits power from the manual waveguide switch **104**, likewise, to be carried through the ferrite waveguide switch **110** to the mixer. The directional coupler prevents the energy from the two sources from taking any other path.

For calibration purposes, the manual waveguide switch **104** is first turned to the ambient load termination (T_O), and the ferrite waveguide switch **110** is switched synchronously by the control pulses from the generator **102**, between the output from the manual waveguide switch **104** and the ambient load termination (T_O). The result is a reference trace by the recorder **124** corresponding to T_O-T_O (FIGURE 6A), since the synchronous detector output is proportional to the difference of the two signals examined.

The manual waveguide switch **104** is then switched to the hot load termination (T_H), and the ferrite waveguide switch continues to be switched synchronously. The recorder **124** now moves up the scale to a new level corresponding to T_H-T_O (FIGURE 6A).

With the ferrite waveguide switch **110** still being switched synchronously, the manual waveguide switch **104** is again turned to the ambient load termination (T_O), and the gas tube **108** is now fired synchronously. The signal now fed to the mixer **114** is the combined output (T_O+T_{GT}) from the directional coupler **106** for one position of the ferrite waveguide switch **110**, and (T_O) for the other position of the ferrite waveguide switch. Therefore, the detected output from the system, as displayed by the recorder **124** is $(T_O+T_{GT})-T_O=T_{GT}$, this being displayed, as shown in FIGURE 6A.

Therefore, by means of the calibration procedure outlined above, the actual reference value of the noise pulses (T_{GT}) produced by the gas tube **108**, insofar as the electronic portion of the detection system is concerned, has been determined with respect to the zero axis of the recorder. The scale factor is known because the temperature of the reference terminations T_O and T_H are accurately known.

A typical mode of operation, by which radio emissions from celestial objects are detected by means of the synchronous detection system of this invention, is set forth hereinbelow. Initially the ferrite waveguide switch **110** is replaced with a straight waveguide section and the manual waveguide switch **104** is switched to receive its signal from the nodding subdish **12**. The system is then aimed away from the source, so that the signal applied to the mixer **114** for each position of the noddling subdish is T_{SKY}, without the source signal being included in either of the T_{SKY} signals. This first reception therefore, is displayed along the zero axis of the recorder as $T_{SKY}-T_{SKY}$ (FIGURE 6B).

As the next step in the detection process, the antenna is still aimed away from the source and the gas tube **108** is fired synchronously. Now the signal applied to the mixer **114** is $T_{SKY}+T_{GT}$ for one position of the nodding subdish, and T_{SKY} for the other position, since the gas tube is on for only one position of the subdish. Therefore, the signal detected by the detector **122** and displayed by the recorder 124 is $(T_{SKY}+T_{GT})-T_{SKY}=T_{GT}$ (FIGURE 6B).

The gas tube **108** is now turned off, and the antenna is aimed at the source. Now, the signal applied to the mixer **114** is such that the detected output is

$$(T_{SOURCE}+T_{SKY})-T_{SKY}=T_{SOURCE}$$

this being represented by the corresponding curve in FIGURE 6B, as generated by the recorder **124**. By using the calibrated value of T_{GT}, the result of T_{SOURCE} can accurately be determined.

It is understood that those familiar with the art may make modifications in the arrangements as shown and described herein without departing from the true scope and spirit of the invention. Therefore, all much modifications and equivalents are deemed to fall within the spirit and scope of the invention as claimed in the appended claims.

What is claimed is:

1. A system for detecting radio signals, said system including:
   - an antenna having a primary reflector member and a secondary reflector member, said secondary reflector member facing said primary reflector member for receiving reflected radio waves from said primary reflector member;
   - an electronic synchronous detection system coupled to said secondary reflector for detecting the radio waves received thereby;
   - drive means for said secondary reflector for periodically tilting said secondary reflector about a selected axis and through a selected arc;
   - and means for introducing control pulses to said synchronous system in synchronism with said periodic tilting of said secondary reflector.

2. The system defined in claim **1** in which said primary reflector member has a parabolic configuration, and in which said secondary reflector member has a hyperbolic configuration.

3. The system defined in claim **1**, and which includes a mount assembly for said secondary reflector;
   - a cam wheel rotatably mounted in said mount assembly and coupled to said drive means to be rotatably driven thereby;
   - and cam follower means coupled to said secondary reflector member and engaging said cam wheel for causing said secondary reflector member periodically to tilt about said selected axis.

4. The system defined in claim **3**, and which includes an annular counterweight mounted in said mount assembly, and further cam follower means coupled to said counterweight and engaging said cam wheel to cause said counterweight periodically to tilt in a direction opposite to that of said secondary reflector member so as to reduce vibrations to a minimum.

5. The combination defined in claim **1** and which includes a mount assembly for said secondary reflector member;
   - shaft means for supporting said secondary reflector member slidably in said mount assembly;
   - and focussing drive means coupled to said shaft means for causing said secondary reflector member to move reciprocally in said mount assembly so as to position said secondary reflector member at a selected position relative to said primary reflector member for focussing purposes.

6. The combination defined in claim **1** and which includes a mount assembly for said secondary reflector member;
   - and means including an indexing plate for mounting said secondary reflector member on said mount assembly, so as to permit the axis of tilt of said secondary reflector member selectively to be adjusted about the axis of symmetry of the assembly.

7. The combination defined in claim **1** in which said synchronous detection system includes a source of noise pulses to serve as a reference for the received signals.

8. The combination defined in claim **7** in which said synchronous detection system includes waveguide switching means for calibrating said source of noise pulses against sources of predetermined reference radiations.

9. The combination defined in claim **7** in which said synchronous detection system includes a ferrite waveguide switch for selectively connecting said synchronous detection system to said source of noise pulses and to a predetermined thermal load termination for calibrating said source of noise pulses.

10. The combination defined in claim **1** in which said synchronous detection means includes a synchronous detector responsive to said control pulses, and which further includes a source of calibrated noise signals also responsive to said control pulses for producing reference noise pulses at the synchronous frequency of the system.

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RODNEY D. BENNETT, *Primary Examiner*.

T. H. TUBBESING, *Assistant Examiner*.

U.S. Cl. X.R.

325—363; 343—761, 781