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Natural Interference Phenomena Affecting Spaceborne Receivers

J.M. Stacey

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NASA
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16. Abstract

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The irradiance from the sun affects microwave receivers in two ways: (1) the infrared component of the irradiance causes non-uniform heating in metal structures and produces distortions that affect electrical performance; and (2) the graybody radiation component of the solar irradiance enters the collecting aperture of the antenna and the feed ports of the calibration circuits. The graybody radiation operates to degrade the isgnal-to-noise ratios and vitiate the internal calibration accuracy.

Analyses are given that explain the magnitudes of interference from the sun and the moon.

Mathematical expressions are derived which serve to quantify the expected interference levels.

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ABSTRACT

Earth-orbiting microwave receivers are vulnerable to the interference from natural sources...mainly, the sun and the moon.

The irradiance from the sun affects microwave receivers in two ways: (1) the infrared component of the irradiance causes non-uniform heating in metal structures and produces distortions that affect electrical performance; and (2) the graybody radiation component of the solar irradiance enters the collecting aperture of the antenna and the feed ports of the calibration circuits. The graybody radiation operates to degrade the signal-to-noise ratios and vitiate the internal calibration accuracy.

Analyses are given that explain the magnitudes of interference from the sun and the moon.

Mathematical expressions are derived which serve to quantify the expected interference levels.

BACKGROUND

Spaceborne receivers are vulnerable to electromagnetic interference produced by manmade devices and to the radiant emittances of natural sources.

Manmade interferers are two: companion sensors on the spacecraft and ground-based transmitters.

Manmade interferers are predictable in the sense that they radiate at particular frequencies and, to some extent, are more likely to occur at certain times and places than at others. Because manmade interference occurs at particular frequencies and within expected bandpasses it can sometimes be suppressed by filtering processes.

All sensor systems on a spacecraft, both active and passive, must operate together, in consonance, and simultaneously, on a no-mutual-interference basis.

The vulnerability of microwave receivers to active interferers, whose emissions lie within the bandpass of the receiver, is an especially serious matter. The potentiality of in-band interference is a continual threat to the viability of earth-orbiting receivers.

Protected frequency intervals (bands) within the microwave region are few; and where they are assigned, the bands are narrow and offer little protection to wideband receivers.

Spaceborne receivers require tens to hundreds of megahertz in their predetection bandwidths to achieve useful detection sensitivities. Protected frequency bands are significantly narrower than this -- usually a few tens of megahertz.

Because of the vulnerability of spaceborne receivers to manmade interference, it is not surprising that the coign of vantage offered by earth orbit is sometimes defeated by its increased vulnerability to manmade interference originating on the Earth.

NATURAL SOURCES OF INTERFERENCE

A. SOLAR IRRADIANCE

The sun and the moon are the chief sources of natural interference to spaceborne receivers. Interference from the irradiance of the sun is much greater than that of the moon. The emissions from celestial sources (e.g., Cassiopeia-A) are also potential sources of natural interference but the flux levels are very low and the occasions where interference is experienced are rare.

Two segments of the solar spectrum are important: (1) ultraviolet-visible-infrared (UVI) radiation produces thermal stresses (heating) in exposed mechanical structures and electrical components, (2) flux, originating in the microwave interval of the solar spectrum, enters the collecting apertures of receiving systems as graybody radiation. The flux introduces wideband noise that competes with the visibility of signals.

Solar irradiance sometimes enters the signal and calibration ports of the receiver and degrades its sensitivity and vitiates the calibration.

Solar flux may occasionally be reflected from specular surfaces on the Earth into the antenna gain pattern of the orbiting receiver. A smooth sea that is illuminated by the sun, at a grazing angle, is an example of an efficient natural reflecting surface.

Protective shields and devices must be applied to the structure of the receiving system to ensure that solar flux does not induce thermal gradients and stresses.

The solar constant defines the magnitude of the solar irradiance on the Earth and is given as 135.3 mw/cm^{-2} or 1.940 cal min^{-1} cm^{-2} (Ref. 1.)

The intensity of the solar irradiance at the Earth is compared qualitatively with the Planckian blackbody radiation curve shown in Fig. 1. The UVI dominates the wavelength interval that produces heat. The microwave radiation occurs in the far tails of the energy curve that are beyond the abscissa scale in the figure.

Microwave radiation from the sun occurs as graybody radiation with the expectation that it also contains particular spectral components.

The superposed envelope of Planck's blackbody radiation equation is plotted in Fig. 1 for a blackbody radiator operating at 6000 kelvins, where it is observed that the peak energy per unit wavelength interval occurs in the visible region. Planck's blackbody radiation formula is given by

$$P = \frac{h\nu}{e^{\frac{h\nu}{kT}} - 1}, \text{ watts/hertz} \qquad (1)$$

where

$h = 6.6252\ (10^{-34})$ joules, Planck Constant.

$k = 1.38046\ (10^{-23})$ joules, Boltzmann Constant.

T = Temperature of the body in kelvins.

ν = Frequency in hertz.

In the microwave region of the spectrum, the term $e^{(h\nu/kT)}$ is very small and the irradiance response is very flat because it occurs in the far tails of the exponential function. For the microwave region, the estimation of P is simplified by substituting the power series expansion substitution for $e^{(h\nu/kT)}$, where

$$e^{\frac{h\nu}{kT}} = 1 + \frac{h\nu}{kT} + \frac{(h\nu)^2}{2!} \;\ldots.$$

which, when substituted into (1) for the term $e^{h\nu/kT}$ and with the further assumption that the factorial terms are negligible, gives

$$P \approx kT \text{ , watts/hertz} \tag{2}$$

This is a very good approximation for the power density of the solar irradiance arriving at the antenna collecting aperture of a radiometer in earth orbit, where T is the brightness temperature of the sun at microwave frequence ν in hertz.

The solar irradiance available in the predetection bandwidth B_{if} is

$$P = kTB_{if} \text{ , watts}$$

P serves to estimate the magnitude of the solar irradiance, operating as gray-body interference to the radiometer, when for example the sun enters the beam-width of a sky calibration horn, or when the reflection arrives into the signal beam of the antenna after a specular reflection from some earth body.

The foregoing discussion makes a clear distinction between the portion of the solar irradiance which operates as an interferer by producing thermal gradients in the RF components of the radiometer (UVI), and the portion that produces broadband noise in the receiver bandpass as a natural noise source (kTB_{if}).

Ofttimes, when the sun is passing through, or is expected to pass through the antenna beamwidth, it is more convenient to estimate the magnitude of the interference from the sun more directly by the geometrical estimation approach. That is, the magnitude of the sun's interference is estimated by forming the ratio of the solid angle subtended by the sun to the solid angle subtended by the antenna beamwidth, with the solar brightness temperature taken as a parameter. For this purpose the brightness temperature of the sun is estimated at microwave frequencies (Ref. 2) by a least squares fitted line passing through the reported brightness temperature measurements given in the technical literature (Refs. 3 and 4). The data points are plotted in Fig. 2 with the fitted line. The equation of the line is given in the form of Horner's method which simplifies calculator manipulations rather than by the high-order polynomial which is the primitive function.

$T_{b,\,sun}$ = (((((C6*F+C5)*F+C4)*F+C3)*F+C2)*F+C1)*F+C0, K (20%, 1σ)

where

F = Frequency in GHz

C6 = 8.5440887E-06

C5 = -4.764871E-03

C4 = 0.54463974

C3 = -27.366904

C2 = 701.57984

C1 = -9141.998

C0 = 59106.387

The brightness temperature of the sun as referenced to the collecting aperture of the receiver is crudely estimated by

$$T_{b,Aper.} = T_{b,sun} \frac{\Omega_{sun}}{\Omega_{\theta_{B,HP}}} \quad , \text{ kelvins}$$

where

Ω_{sun} = Solid angle subtended by the sun's radio diameter.

$\Omega_{\theta_{B,HP}}$ = Solid angle subtended by the half-power beamwidth of the collecting aperture.

When the sun enters the beam of a sky calibration horn during some time-segment of the orbit, the calibration accuracy is degraded or fails because of the graybody noise. Where the sun's occurrence in the sky calibration horn is inescapable, in certain segments of an orbit, at one time or another, the observer is left with two choices: (1) to ignore the cold sky calibration; or (2) to accept the degraded precision.

When the sun illuminates machined metal surfaces either on the side of a feed structure or directly within a collecting aperture, the solar irradiance can produce thermal gradients amounting to tens of degrees within minutes of time. Thermal stresses produced in the collecting aperture propagate down the waveguides and affect other microwave components and negate the precision of calibration circuits until thermal equilibrium is again restored. Moreover, UVI irradiance efficiently transits microwave coupling apertures and propagates down the reflecting walls inside waveguides. From this, RF components connecting to the waveguides may also be thermally stressed.

A preventive measure to control the UVI component of the solar irradiance from affecting the calibration and RF components is by incorporating a UVI-dome over the entire primary feed structure. (See Fig. 3). The only protection offered to eliminate the kTB_{if} component of the sun is to seek a preferred pointing angle for the sky calibration where the sun only enters the beam briefly, or to choose an orbit where the precession rate maintains the sky horn in an attitude away from the solar disk.

B. EMISSION FROM THE MOON

Earth-scanning antenna systems sometimes possess extremely sensitive receivers that are vulnerable to interference from the emission from the moon. As an interferer, the moon may be regarded as a celestial object whose radiometric temperature ranges from about 150 to 250 K with a subtended disk diameter of approximately 0.5 degrees as viewed from earth orbit. The moon's irradiance may affect the sky calibration circuits by its graybody radiation in the sky calibration horns or affect signal intensities by reflections from a specular sea or surface. The average brightness temperature of the moon's disk is estimated throughout a lunation for several selected microwave frequencies, as illustrated in Fig. 4 (Ref.2).

Planets of the solar system, other than the moon, appear as point sources to earth-orbiting receivers. The interference potentiality of a point source is estimated from its flux level arriving at the collecting aperture of the earth-orbiting receiving system.

C. CELESTIAL SOURCES

Celestial sources of radiation arise for consideration as interference media because their intensities may be sufficiently high to be intercepted by receiving systems that exhibit high antenna gains or very low system temperatures in some suitable combination. Earth-orbiting antenna systems, it would seem, are potentially vulnerable to the radiation from celestial sources that enters through a high gain sky calibration horn that views the cosmic background, or directly into the signal aperture.

The intensity of stellar sources is characteristically wavelength dependent; Taurus-A is the most intense in the microwave region and radiates 450 X 10^{-26} janskys (watts/m^2/Hz) at 1-cm wavelength (30 GHz), and 550 X 10^{-26} janskys at 3-cm wavelength (10 GHz).

The estimation of the flux density of a strong celestial source at one of the collecting apertures of the earth-scanning receiver is best illustrated by example for the case where, at some point in the orbit, the sky calibration horn views a celestial source in its beam center. Consider a sky calibration horn that views the celestial background at 2.7 kelvins and intercepts the flux from Taurus-A at a collecting aperture (15-cm diameter). The receiver system noise power P_n as referred to the collecting aperture of the sky calibration horn is given approximately by

$$P_n = K\,T_o(F_{dc}L_{sys} - 1),\ \text{watts/Hz}$$

$$= 9.37 \times 10^{-21},\ \text{watts/Hz}$$

where

K = Boltzmann Constant (1.38 X 10^{-23} joules).

F_{dc} = Noise figure (double sideband), a power ratio, assumed to be 4 dB.

L_{sys} = RF dissipative losses in the waveguides' components between the mixer and the feed aperture, a power ratio, assumed to be 1.24 dB.

T_o = 290 kelvins, the standard reference temperature for noise figure measurements.

Now, the incident flux from Taurus-A, P_{stel}, that is intercepted by the collecting aperture area, is

$$P_{stel} = JA, \text{ watts/Hz}$$

$$= (550 \times 10^{-26}) \left(\frac{\pi(0.15^2)}{4}\right) = 9.72 \times 10^{-26} \text{ watts/Hz}$$

where

J = Flux density of Taurus-A.

A = Area of a circular collecting aperture of diameter 0.15 m.

The power ratio of P_{stel}/P_n = -50 dB.

The flux intensity of Taurus-A will therefore not significantly affect the cosmic-background temperatures observed by the sky calibration horn in this example.

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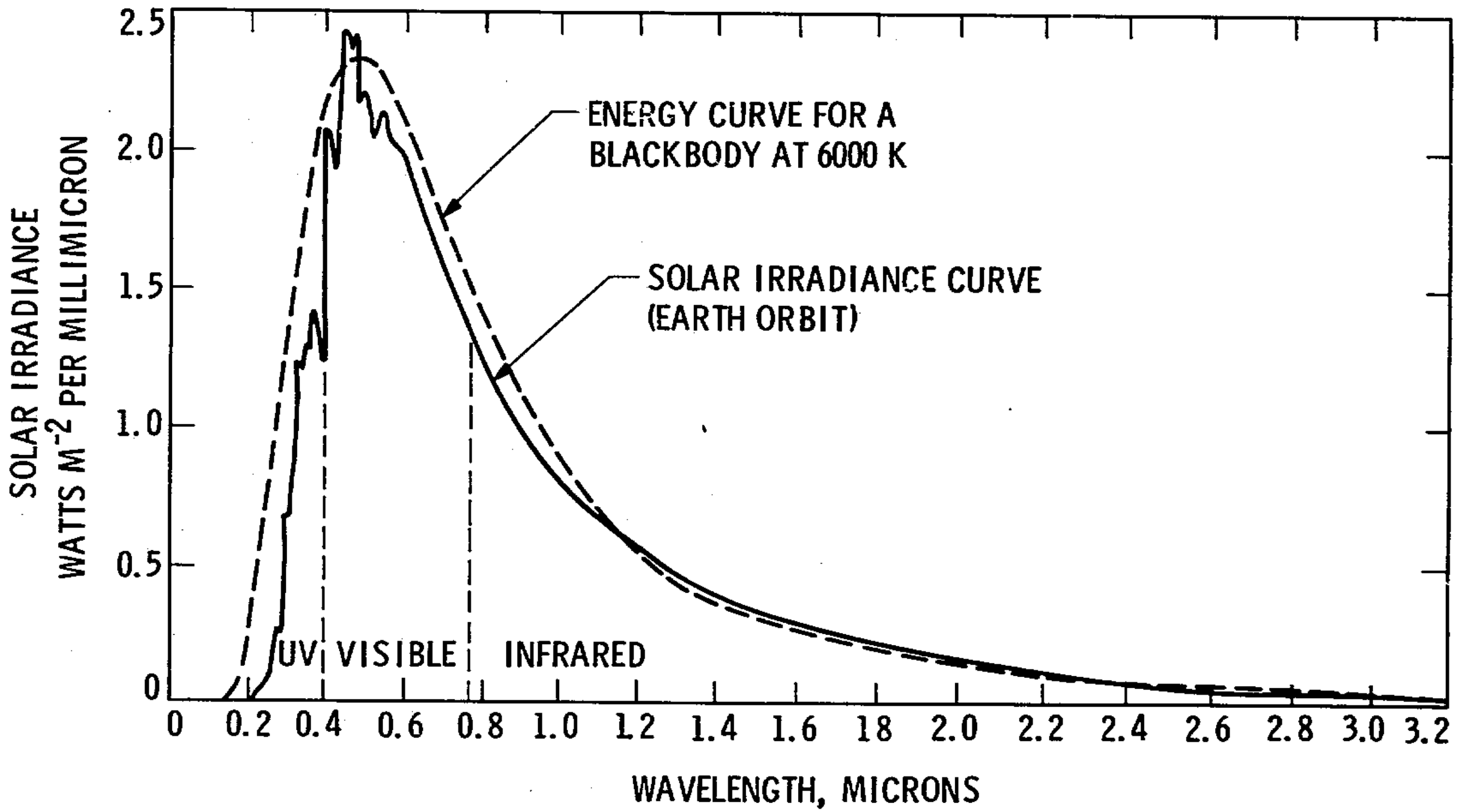

Fig. 1. Solar spectral irradiance responses.

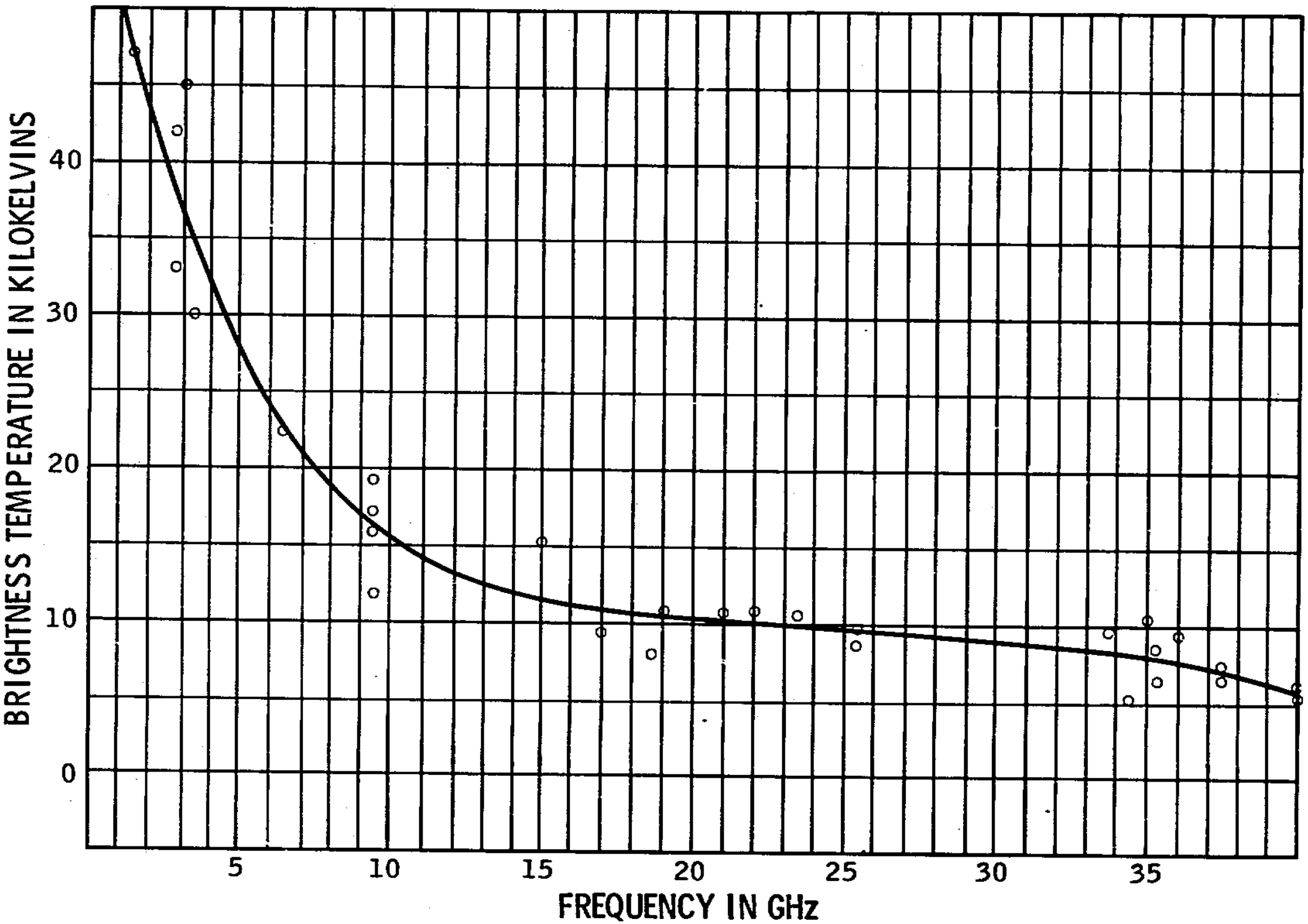

Fig. 2. Solar brightness temperature of the quiet sun versus frequency (1 to 40 GHz).

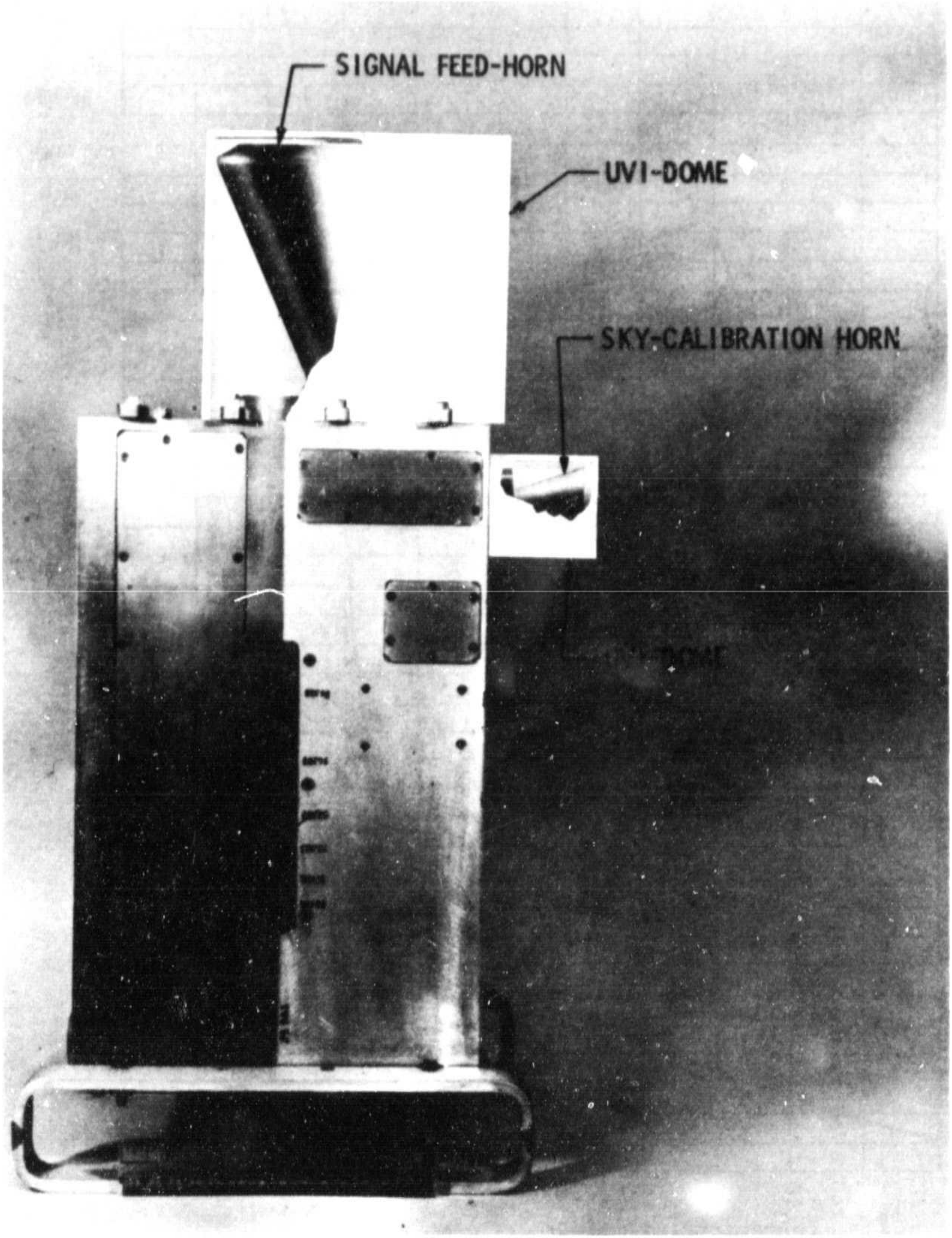

Fig. 3. UVI domes protecting the signal and sky calibration feed horns

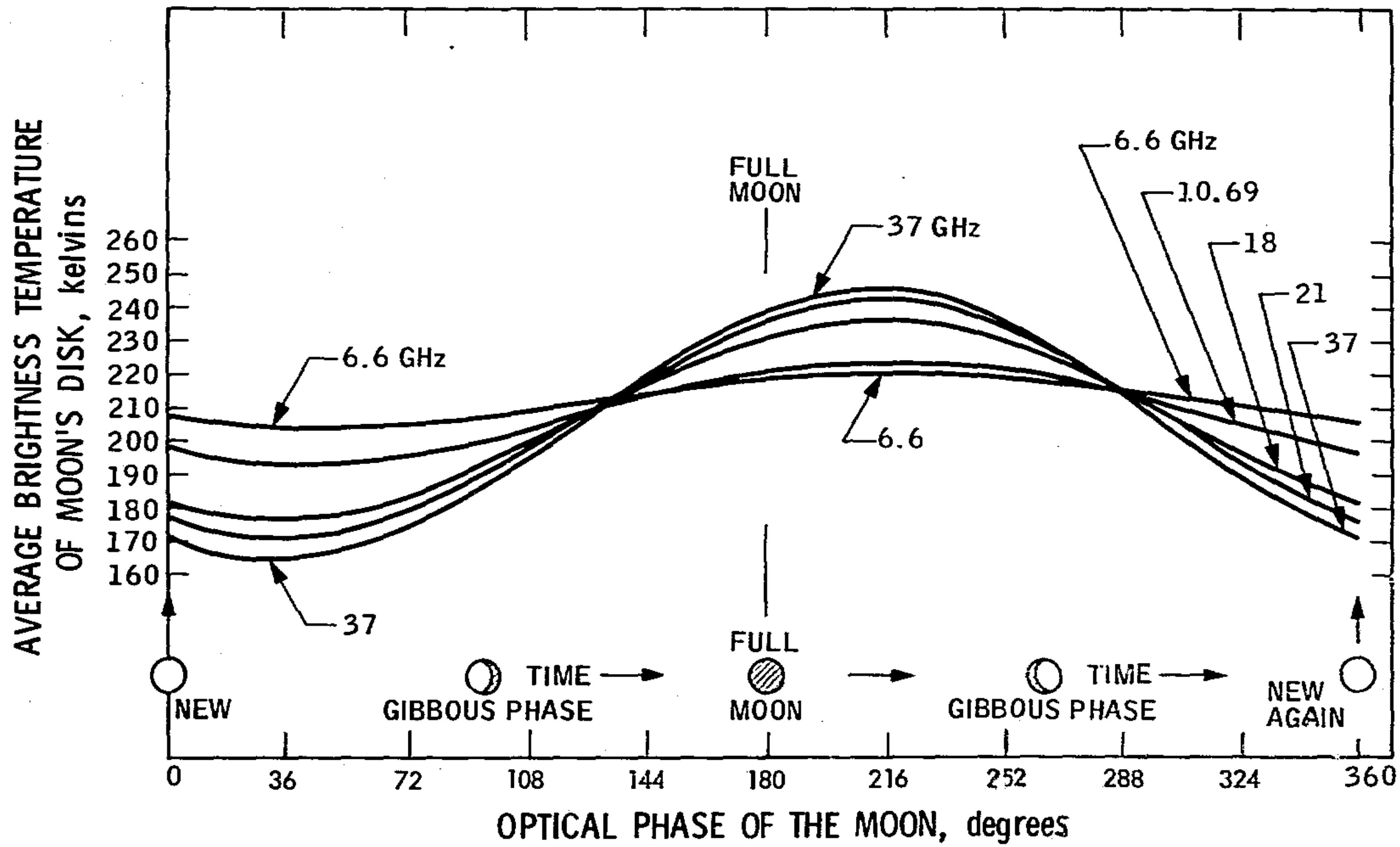

Fig. 4. Average brightness temperature of the moon's disk.