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RADIOMETRIC TECHNIQUES APPLICABLE TO THE MEASUREMENT OF SOLAR ACTIVITY AND ATMOSPHERIC ATTENUATION AT MILLIMETER WAVELENGTHS

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ABSTRACT

A common method for measuring atmospheric attenuation at millimeter wavelengths is to monitor variations in the apparent intensity of the sun under various weather conditions. The available dynamic range for measurements of this type is determined by the brightness temperature of the sun and the sky noise fluctuation level at the frequency of observation. During the period of measurement, it is assumed that the solar flux intensity is constant and that all apparent variations in solar intensity are associated with atmospheric effects.

Similar radiometric measurement instruments are used for the determination of solar radiation characteristics at millimeter wavelengths. Useful data are limited to those periods when the weather conditions are relatively mild. Here, the assumption is made that all apparent variations in solar intensity are associated with the radiation characteristics of the sun istelf.

The most useful data concerning solar radiation characteristics are obtained under clear weather conditions; that concerning atmospheric attenuation is obtained under adverse weather conditions. This suggests a dual-purpose instrument capable of performing both functions without compromising the required measurement instrument performance for either type of measurement.

An example of the design approach as applied to a 35-GHz system, the dynamic range of atmospheric attenuation measurement capability, is in excess of 30 dB. Solar radiation characteristics with amplitude variations of a few percent are easily measured by the instrument which, at the same time, provides a 10-dB range above the quiet sun level to accommodate major solar flare activity. The atmosphere attenuation level is displayed directly on an output strip chart recording in dB.

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SUMMARY

The design of a radiometric instrument and technique appli-
cable to the measurement of both solar activity and atmospheric
attenuation at millimeter wavelengths has been discussed. The
dual-purpose instrument is capable of performing both functions
without compromising the instrument performance when performing
either type of measurement. An example of the design approach
as applied to a 35-GHz system is discussed.

INTRODUCTION

During recent years there has been an increase in interest
concerning the characteristics of both solar activity and the
attenuation and radiation characteristics of the atmosphere at
millimeter wavelengths. Though the determination of solar and
atmospheric characteristics at millimeter wavelengths might
appear to be quite dissimilar measurement objectives, the tech-
niques commonly applied to both pursuits represent a common
denominator in the form of millimeter radiometric sensors.

For the measurement of the millimeter characteristics of
solar radiation, the instrument is usually referred to as a solar
radio telescope. Two methods are used to obtain such measure-
ments; the first provides an integrated look at the entire solar
disk, the other derives maps of the solar disk brightness temper-
ature distribution by computerized scanning of a narrow pencil
beam across the solar disk. The use of an antenna beam, which
is large relative to the angular size of the sun as viewed from
Earth, assures opportunity of detecting all major solar flares
that occur while the sun is above the horizon. From detailed
maps derived from the pencil beam scanning of the solar disk,
one is able to see a time-varying picture of prominences and
valleys in the spatial brightness temperature distribution
(refs. 1, 2), hopefully indicative of future major solar events.

A common method for measuring atmospheric attenuation,
particularly at millimeter wavelengths, is to use the sun as an
exo-atmospheric source of "constant intensity" and relate

variations in measured intensity with weather conditions at the time of observation.

Hence, solar radio telescopes which provide an integrated view of the entire solar disk are very similar and, in several cases, identical to the instrumentation frequently used to measure atmospheric attenuation. The similarity in instrument requirements suggests an efficient means for accomplishing both measurement objectives using one instrument.

REVIEW OF MEASUREMENT INSTRUMENT REQUIREMENTS

The measurement of the solar characteristics of solar activity at millimeter wavelengths requires:

1. Ability to sense small changes ($\pm$ 2 percent) in the quiet sun level (undisturbed sun) and to detect bursts of very short duration, i.e., of the order of a few seconds, characterized by a relatively small increase to the total solar flux;

2. Measurement of the amplitude and duration of major solar flares which may, on occasion, provide a 5- or possibly 10-fold increase in solar flux intensity relative to the quiet sun level;

3. Measurement of sky noise temperature to an accuracy sufficient to subtract this contaminating source of noise from the desired observational data.

Since the phenomenon of solar activity is random with time and its occurrence is frequently unanticipated, particularly at millimeter wavelengths, a further requirement is continuous observation of the sun while it is above the horizon.

Unfortunately, when the antenna beam is pointed toward the sun, the received radiation includes the contaminating effects of atmospheric attenuation and radiation. The observed antenna temperature in this case can be expressed in the simplified form:

$$T_s = \frac{T_{sb}}{L_m} + \left(1 - \frac{1}{L_m}\right)T_m \qquad (1)$$

where:

T_s = apparent sun temperature;
T_{sb} = the antenna temperature that would be obtained in the absence of the atmosphere;

L_m = the path loss integrated along the ray path through the atmosphere from the antenna to the sun;

T_m = the average temperature of the atmosphere appropriately weighted to accommodate the relationship between the thermometric temperature profile along the path to the sun and variations in the atmospheric loss along the path.

Since the objective is to obtain a measurement of T_{sb}, it is necessary to point the antenna beam away from the sun in some reference direction in order to measure the sky temperature, which is the second term in Eq. (1). By pointing the antenna beam alternately toward and then away from the sun, one is able to obtain the value of T_{sb}/L_m by direct subtraction of the measured antenna temperature values.

From the foregoing simplified description of the method of measurement, it is apparent that there are significant limitations. In particular, the value of L_m in the sun direction is not necessarily equivalent to the value of the reference direction, when the antenna beam is pointed away from the sun. This is particularly true if weather conditions at the time of observation indicate a relatively large value for L_m, with a correspondingly large variation in the value of L_m as a function of time. Even under mildly adverse weather conditions, the observed fluctuation level in the apparent sun temperature T_s at millimeter wavelengths is frequently determined by atmospheric effects indicative of substantial spatial inhomogeneities in air mass attenuation. As an air mass, typified as adverse weather, moves through the antenna beam while it is pointing in the sun direction, rapid and large scale variations in the apparent sun temperature attest to the non-uniform spatial distribution of atmospheric attenuation.

Unfortunately, the sun cannot be shut off, allowing measurement of the sky noise component along the path to the sun; hence, the compromise which requires that one look away from the sun jeopardizes the accuracy of the measurement. As a result, the experimental measurement of small changes in solar activity is extremely difficult at millimeter wavelengths under adverse weather conditions. Useful data are typically limited to clear or mild weather conditions. The ability to obtain useful and accurate data concerning solar characteristics at millimeter wavelengths is, therefore, primarily limited by the atmospheric conditions at the time of observation; and, in particular, by the degree to which the atmosphere exhibits a near-uniform horizontal stratification. Under these conditions, one may be able to apply a secant law correction (ref. 3) to the observed data, thus determining the value of L_m, and hence, the antenna tempera-

ture of the sun T_{sb} in the absence of the atmosphere. These
natural restraints can be accommodated, to some degree, through
appropriate selection of the observing site and care in observing
procedures.

INSTRUMENT DESIGN ANALYSIS

An important consideration in instrument design is selec-
tion of the antenna aperture size, the method of mounting and
the antenna drive mechanism. A simple mounting arrangement and
drive mechanism consists of an equatorial, or polar, mount driven
in the hour angle coordinate by a synchronous clock. On the
assumption that this approach is taken, the size of the antenna
aperture and, in particular, the angular size of the main beam
relative to the angular size of the sun as viewed from Earth,
becomes the most significant design consideration.

To provide an integrated view of the solar disk the main
beam angle should be at least 0.5 degree. An antenna beam angle
of this size, however, will accentuate degradation in observed
data caused by (1) the non-synchronous apparent diurnal motion
of the sun; (2) small errors in the mount polar axis alignment;
and (3) mount gear backlash.

These effects can be made negligible by increasing the an-
tenna beam angle (decreasing antenna aperture size), however,
not without decreasing the available signal-to-noise ratio. If,
for example, one assumes that the noise level is determined by
the statistical nature of system noise and exhibits a root mean
square value of $\overline{\Delta T}_N$, then the signal-to-noise ratio at the re-
ceiver output, when the antenna is pointed toward the sun, is
given by:

$$\frac{S}{N} = \frac{T_s}{\overline{\Delta T}_N} \tag{2}$$

The relationship between the observed antenna temperature of the
sun in the absence of an atmosphere and the angular size of the
antenna main beam angle is (to a good approximation) given by

$$T_{sb} = T_{SB}\left[\frac{\theta_S}{\theta_A}\right]^2 \rho \tag{3}$$

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where

θ_A = the half-power beamwidth of the antenna;

θ_S = the angular size of the sun as viewed from Earth (approximately 0.5 degree);

T_{SB} = brightness temperature of the sun;

ρ = antenna beam efficiency.

It is apparent from Eqs. (1) and (3) that the signal-to-noise ratio, when the antenna beam is pointed toward the sun, will be inversely proportioned to the square of the antenna beam angle size for beam angles greater than the angular size of the sun. Selection of the antenna beam size is, therefore, determined by the minimum signal-to-noise ratio needed to meet measurement accuracy requirements, since this allows use of the largest antenna beam consistent with the desire to minimize effects introduced by non-synchronous sun motion, mount alignment, and so forth. Non-synchronous sun motion is, of course, well-known; hence, an appropriate correction can be introduced in data reduction.

At this point in the analysis, the major difference in measurement instrument requirements for radio telescopes devoted solely to atmospheric attenuation measurements and those for measurement of the characteristics of solar activity are noted. The difference lies primarily in signal-to-noise ratio requirements. As noted previously, adverse weather conditions negate accumulation of the useful solar data; hence, the signal-to-noise ratio required to detect variations of 1 or 2 percent in the quiet sun level can be easily accommodated by a signal-to-noise ratio of 20 dB under essentially clear weather conditions. For solar measurements, achievement of the desired signal-to-noise ratio is considered a lesser restraint than the ability to accommodate simultaneously the large dynamic range associated with major solar flares.

The observing conditions are just the reverse for atmospheric attenuation measurements since useful data, in this case, exclude periods of major solar activity and the most useful observational data are obtained under adverse weather conditions. Since it is desirable to measure high levels of attenuation occurring over short time intervals (typical of heavy rain), atmospheric attenuation measurements imply the need for the highest practical signal-to-noise ratio that can be obtained under clear weather conditions. Where a 20-dB signal-to-noise ratio would be perfectly acceptable for solar measurements, a 30- or 40-dB instrument capability is frequently desired for atmospheric attenuation

measurements. It is the dynamic range of atmospheric attenuation measurement capability, therefore, that determines the antenna aperture size if one instrument is to perform both solar and atmospheric attenuation measurements.

Since the maximum signal is obtained when the antenna beam angle is equivalent to the observed angle of the solar disk, one might conclude that further improvement beyond this point would require a sophisticated low noise receiving system, i.e., a maser amplifier or equivalent. Though this would improve the signal-to-noise ratio under clear weather conditions, the introduction of a maser-type amplifier provides no improvement in measuring large values of attenuation under adverse weather conditions. This is a consequence of the fact that the fluctuation level at the output indicator system under adverse weather conditions is determined by rapid non-statistical spatial variations in atmospheric attenuation, even in the case where a conventional super-heterodyne mixer is used as the receiver input circuit. The simple fact is that the maximum value of atmospheric attenuation that can be measured at millimeter wavelengths is not determined by the performance of present day equipments, but rather by the ratio of the brightness temperature of the sun on a clear day to the sky noise fluctuation level under adverse weather conditions at the frequency of observation.

These natural restraints determine measurement capability, even in the case where the antenna aperture is made sufficiently large to obtain the maximum possible signal when the entire antenna main beam is contained within the projection of the solar disk. For example, if one assumes a "perfect" antenna system which provides an antenna temperature equivalent to the brightness temperature of the sun (approximately 8000°K) (ref. 4) at 35 GHz, a 36-dB atmospheric attenuation measurement capability implies that the fluctuation level at the output indicator, either when the antenna beam is pointed toward or away from the sun, must be less than 1°K, since the magnitude of that component of the signal received with the antenna pointing in the direction of the sun, in this case, would be only 1°K. The interplay of non-statistical atmospheric noise fluctuations is quite apparent in this example when one notes that the sun component would be 10°K for 26-dB attenuation and only 0.1°K for 46-dB attenuation. In each case, non-statistical fluctuations at the output indicator must be correspondingly smaller to provide a valid measurement of the average atmospheric attenuation value.

Measured values of the amplitude of sky noise fluctuations under weather conditions typical of 15 to 20-dB attenuation levels (ref. 5) indicate that a 30-dB measurement capability would be extremely difficult to validate. Fortunately, such large values of attenuation at 35 GHz are experienced occasionally

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(ref. 6) and then only at extremely low elevation angles where refractive bending of the ray path may carry it through a much longer path of adverse weather than typical of even practical point-to-point Earth-based communication systems.

The magnitude of atmospheric attenuation and the relative time interval of its occurrence at millimeter wavelengths must include consideration of the elevation angle of observation. Knowledge of the percentage of time during which relatively high values of attenuation are observed is irrelevant without consideration of the elevation angle of observation at the time of occurrence.

It is important to note the marked difference in the significance of weather conditions on millimeter communication links between two Earth-based terminals and a communication link between Earth-based and space terminals. The path to space at reasonable elevation angles very quickly passes through the lower troposphere and encounters less contamination by rain than would be experienced on an extended link between two Earth-based terminals.

DESIGN FACTORS

The final design consideration concerns the method by which the antenna beam is periodically cycled between the sun and reference directions. Factors which enter into the design include:

1. The time required between the measurement in the sun direction and the reference direction relative to the time during which significant fluctuations may occur in the signal received from either direction;

2. The direction and angular displacement of the reference direction relative to the sun direction;

3. The contribution of the sun in the antenna sidelobe pattern when the antenna beam is pointed in the reference direction.

4. Variations in the antenna beam pattern while observing the sun from horizon-to-horizon or when measuring the antenna temperature difference between the sun and reference directions.

There are several possible approaches, viz.:

1. Mechanically move a single antenna beam between the sun and reference position in a time period short compared with anticipated time of significant signal events;

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2. Electronically switch between two antenna feeds equally displaced about the boresight axis of a parabolic antenna;

3. Electronically switch the input to the receiver between two identical antennas; one pointing in the sun direction, and the other in the reference direction.

One can move a single antenna beam on and off the sun by either moving the entire feed and reflector structure or by moving one of these elements relative to the other. Nearly equivalent performance would be obtained by either approach insofar as mechanizing the motion for a small angular displacement between the sun position and the sky reference position. One need only be concerned in the case in which the reflecting element is mechanically moved with respect to the prime feed to accomplish the full angular daily converage from horizon-to-horizon. This would, undoubtedly, require the introduction of a correction factor in the measured data to accommodate antenna beam distortion as a function of elevation angle of observation.

Either method, however, suffers from limitations imposed by the time required to mechanically cycle the antenna system between two directions and obtain a measure of sun temperature, followed by sky noise temperature. Though this is not a serious consideration in the measurement of atmospheric attenuation, it may, however, negate the possibility of observing very critical radiation characteristics at the onset of a solar flare, i.e., the antenna motion on and off the sun, though cycled over a period of a few seconds, does not meet the performance requirements for continuous patrol of solar activity. For this reason, mechanical motion of a single antenna beam is not favored.

The optimum approach involves selection of either electronic beam switching between paired feeds in the focal plane of a parabolic antenna or electronic switching between the antenna feed outputs of completely separate antenna elements mounted on a common elevation over azimuth pedestal at a fixed-look angle separation. The latter approach is definitely favored since it affords greater flexibility in selecting and adjusting the angle between the two observing directions (sun and sky); in addition, it offers the opportunity to use a variety of low-noise antenna systems without introducing the contaminating effects of aperture blockage associated with multiple feed systems. An important consideration in the selection of the antenna system is the sidelobe level, in particular, the backlobe structure which intercepts the Earth terrain. This may act as a variable component at the radiometer output. The amplitude would be determined by the backlobe power pattern and the spatial distribution of terrain emissivity as a function of the look angle of the antenna.

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A further consideration in the design of the antenna is the effect of precipitation on the reflecting surface and feed element. The use of cornucopia or folded horn antennas, for the most part, eliminates precipitation effects. If a parabolic antenna is used, a cylindrical tunnel extending beyond the focal plane is required to reduce the level of backlobe contributions associated with the prime pattern spillover near the lip of the reflector. A small "splash plate" located directly behind the feed is very effective in diverting water droplets away from the feed system, even under the most adverse conditions of heavy rainfall.

A summary of the design considerations for a dual-purpose millimeter radio telescope for measuring the characteristics of solar activity at millimeter wavelengths as well as the characteristics of atmospheric attenuation is presented in Table I.

TABLE I

SUMMARY OF DESIGN CONSIDERATIONS

Parameter	Determined by	Approach
Antenna mount	Apparent sun motion	Equatorial mount
Antenna mount drive	Apparent sun motion (to first order)	Synchronous
Antenna Aperture Diam.		
Maximum	Non-synchronous sun motion	Effect $<4\%$
Minimum	S/N = 30 dB for measurement of L_m	Base on ΔT_{atmos} natural restraint
Receiver sensitivity	a) S/N,Q.S.[*]=20 dB for sun measurement, standard atmosphere. b) S/N,Q.S. = 30 dB for atmosphere measurement. c) Measured ΔT_{atmos} for $L_m \geq 15$ dB.	Base design on receiver output peak-to-peak fluctuation level = ΔT_{atmos}
Outputs	1) Sun measurements	a) Linear from 1/2 to 2 x Q.S. Accuracy $\pm$ 1% Linearity <1% b) Log from Q.S. to 10 x Q.S.
	2) Atmospheric measurements	c) Log from 0 to -30 dB where Q.S. = 0 dB.

*Q.S. = antenna temperature of quiet sun

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DESIGN OF A 35-GHz MEASUREMENT INSTRUMENT

As an example of the foregoing design philosophy, consider a measurement instrument operating at 35 GHz. The analysis includes trade-off considerations associated with the various requirements for an optimum system configuration. Reference data required for the analysis include:

1. Diurnal angular deviation of the sun from synchronous rate throughout the year in both right ascension and declination (see Table II);

2. Signal intensity of an extended, uniformly illuminated source as a function of a normalized angular displacement off an antenna boresight relative to the intensity obtained when the source is on the antenna boresight;

3. Antenna temperature of the sun at 35 GHz as a function of antenna aperture diameter (Figure 1).

From Table II, it is apparent that the maximum angular displacement of the sun from synchronous motion occurs in the declination angle coordinate during the period from March 16 through April 1. The average change per 24-hour day during this period is 25.2 arc minutes; hence, the change in a 12-hour day while the sun is above the horizon is 12.6 arc minutes. Since the motion is known to be from south to north in equatorial coordinates, the antenna boresight can be positioned slightly to the north of the sun position at sunrise by an amount such that the sun will pass through the antenna boresight position at noon as it crosses the local meridian at upper culmination. At sunset, the sun will have moved north in declination relative to the antenna boresight position by the same amount that the antenna boresight was displaced north of the sun position at sunrise. A 4 percent decrease in received intensity relative to that when the souce is on the antenna boresight occurs where the argument of $sinc^2 x$ is 0.11. The corresponding value of the antenna aperture diameter is 62.3 wavelengths or 54 cm at 35 GHz. For an antenna of this size, the nominal value of the antenna temperature when the sun is on the antenna boresight would be approximately 1000°K. This value is obtained from Figure 1 in which the graphical plot assumes a brightness temperature of 9100°K (ref. 7) at 15 GHz, and 8200°K at 35 GHz; and, further, in that there is no atmospheric attenuation at either frequency.

From extensive atmospheric attenuation measurements initiated during the latter part of 1967 and extending through the summer of 1968, it was determined that the sky noise fluctuation level (95 percent peak-to-peak values) was 0.9°K at 15 GHz, and 1.5°K at 35 GHz under those weather conditions in which the total

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TABLE II

NON-SYNCHRONOUS SUN MOTION

| From	To	Declination Angle Change/Day (min. of arc)	Hour Angle Change/Day (min. of arc)
January 1	January 16	8.0	6.1
January 16	February 1	15.2	3.9
February 1	February 16	18.8	0.6
February 16	March 1	23.5	1.9
March 1	March 16	23.2	3.6
March 16	April 1	25.2	4.8
April 1	April 16	22.4	4.2
April 16	May 1	21.4	2.9
May 1	May 16	16.4	1.0
May 16	June 1	12.0	1.3
June 1	June 16	5.6	2.6
June 16	July 1	0.4	3.2
July 1	July 16	6.8	2.1
July 16	August 1	14.8	0.4
August 1	August 16	16.8	1.9
August 16	September 1	21.6	4.0
September 1	September 16	22.4	5.0
September 16	October 1	24.8	5.5
October 1	October 16	23.2	4.2
October 16	November 1	22.4	2.0
November 1	November 16	17.2	0.9
November 16	December 1	13.7	3.9
December 1	December 16	6.4	5.9
December 16	January 1	0.8	7.3
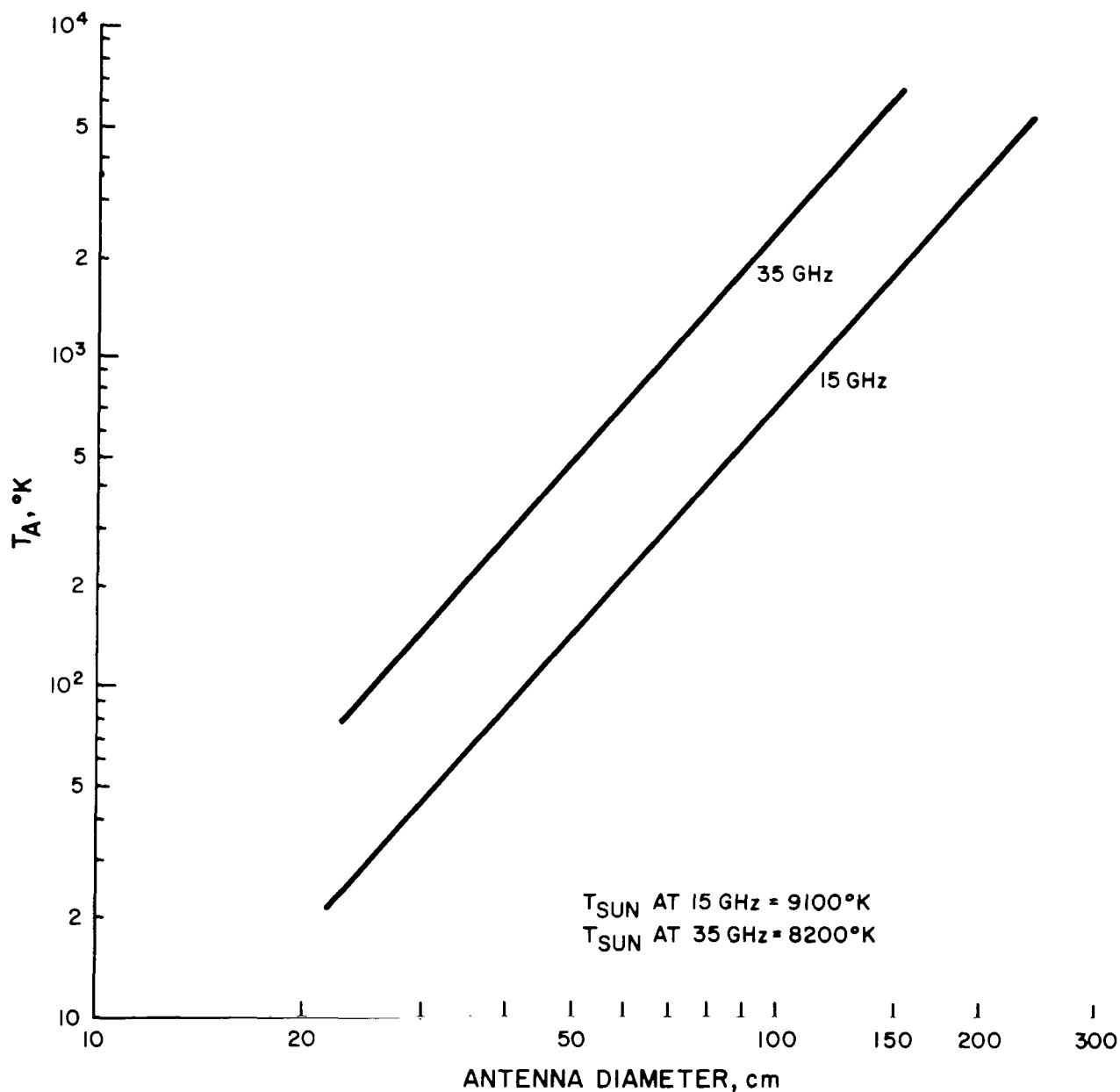
Figure 1.- Antenna temperature vs. antenna diameter in centi-
meters for two frequencies

atmospheric attenuation exceeded 5 dB. Complete statistics on
the sky noise fluctuation level are not yet available. The
measurements, however, indicate that the fluctuation level is
not a simple function of the total atmospheric attenuation. The
values quoted above are conservative and can be used with con-
siderable confidence in establishing natural restraints which
sky noise fluctuations impose on atmospheric attenuation measure-
ments.

If an antenna diameter of 54 cm is used at 35 GHz the max-
imum atmospheric attenuation that can be measured is 31.5 dB.
Under this condition, the differential antenna temperature be-
tween the sun position and the sky noise position is equal to
one-half of the non-statistical 95 percent peak-to-peak sky noise
fluctuation level. This would qualify as a discernible signal.

A simplified functional block diagram of a millimeter radio-
metric sensor for measurement of solar radiation characteristics
and atmospheric attenuation characteristics is shown in Figure 2.
The system parameters determined by natural restraints are de-
rived from the foregoing discussion, in particular:

1. The dual antennas have identical aperture diameters
    of 54 cm.

2. The angular displacement between the antenna directions
    and the hour angle coordinates must provide a sidelobe
    response at least 30 dB down from the on-boresight
    response for the sky reference temperature antenna
    when it is pointing in the reference direction.

3. The dynamic range of the instrument for atmospheric
    attenuation measurements is 31.5 dB.

DUAL ANTENNAS

The antennas (R and S) are identical and are mounted
above the declination axis of an equatorial mount driven by a
synchronous clock. The boresight directions of the two antennas
would be displaced in the hour angle coordinate by an amount
adequate to assure that the sidelobe contribution of the sun in
antenna R (sky temperature reference) is at least 5 dB below the
dynamic range of atmospheric attenuation measurement capability.
It is desirable to make this angular displacement small to mini-
mize the effect of sky temperature gradients which will be sensed
by the dual-antenna beam system near sunrise and sunset. One
might consider using other directions of angular displacement of
the reference antenna beam relative to the sun antenna beam other
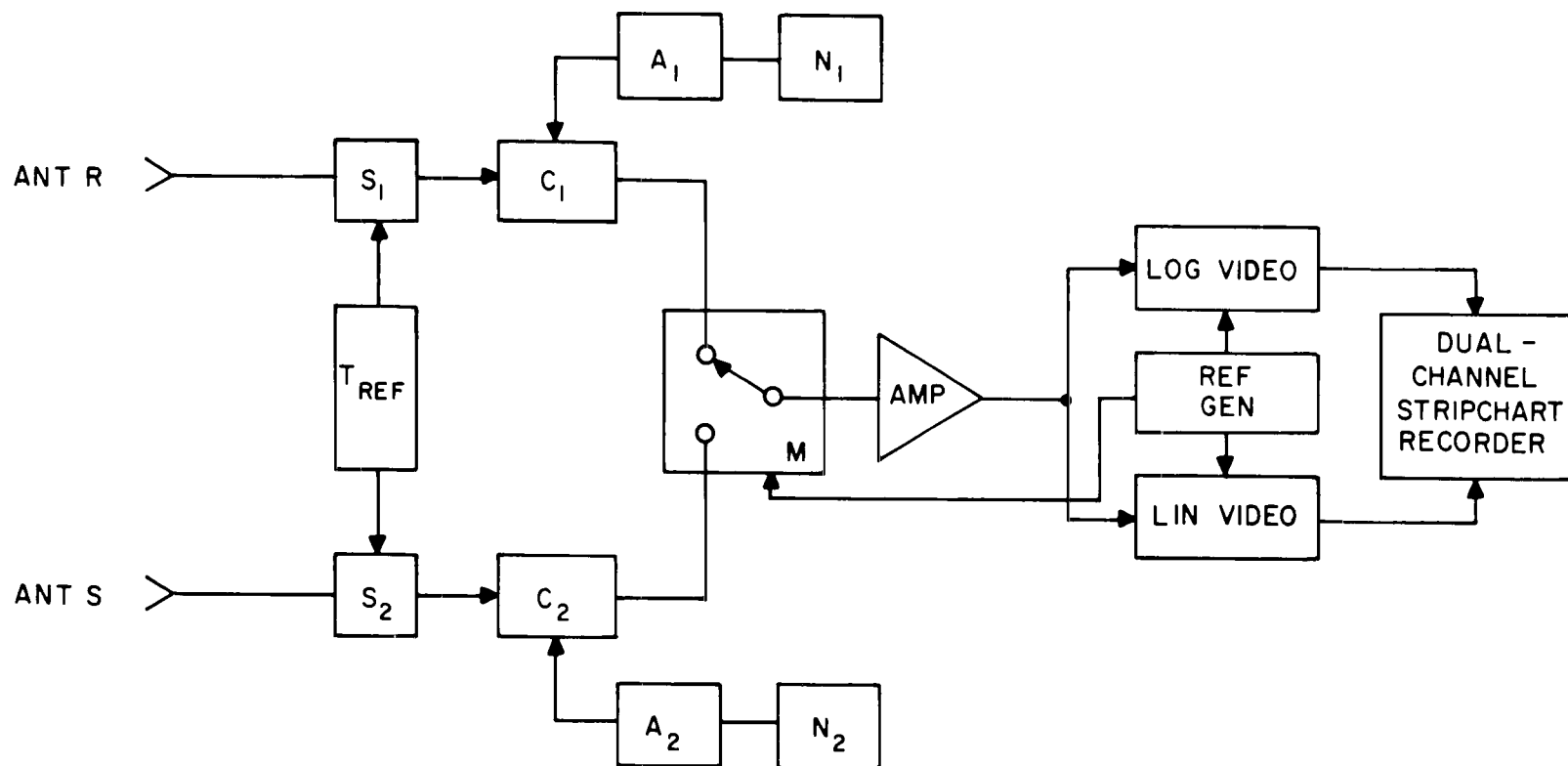than the hour angle direction; however, this tends to complicate

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Figure 2.- Simplified block diagram of millimeter radiometric sensor for measurement
of solar radiation and atmospheric attenuation characteristics

data analysis. For observing sites within the United States, other than possibly the southern tip of Florida, angular separation of the two beams in the hour angle coordinate is most convenient. For observing sites closer to the equator, angular displacement of the two beams in the declination coordinate would be more appropriate. For low latitudes, the declination angle separation provides a near-equivalent elevation angle for the two antennas at sunrise and sunset. In addition, the high elevation angle of the sun at local meridian crossing is less susceptible to differential path legnths through the atmosphere. Reverse conditions, of course, apply at northern latitudes. In any event, these effects are of greatest concern in the measurement of solar radiation characteristics; in particular, small changes about the quiet sun level. Even under mildly adverse weather conditions, the observed atmospheric attenuation as a function of the elevation angle of observation shows little correlation with the elevation angle of observation for elevation angles above 10 to 15 degrees.

RF INPUT CIRCUIT

The signals received by the dual antennas are fed over identical RF transmission line paths to the input of the ferrite modulator M. It is important that the RF transmission line losses and their corresponding noise radiation components be made as near identical as possible. The best measurement instrument for trimming and adjusting these characteristics is the basic radiometric receiver itself.

The RF zero or input balance condition of the radiometer is established by introducing a common reference temperature derived from dual resistance loads in a common temperature-controlled environmental chamber to either input of the ferrite modulator via the action of switches S_1 and S_2. This balanced mode is used to set the output zero of the linear channel to the zero input signal value of the strip chart recorder.

To provide an absolute measurement of the noise temperature at the output of the "sky noise antenna," an absolute radiometric mode (ref. 8) is incorporated in this input arm of the radiometer. The calibrated noise injection circuit is provided by noise generator N_1 via attenuator A_1 into the side-arm of coupler C_1. When used in the absolute radiometric mode, the input to switch S_2 is permanently connected to the reference temperature load (T_{ref}). The noise injection circuit in the other input arm of the radiometer (antenna S) provides a noise injection level referenced to the input of the modulator equivalent to the value of the sun antenna temperature in the absence of atmospheric attenuation. The adjustment of attenuator A_2 requires the accum-

ulation of considerable observational data, particularly under clear weather conditions, in order to arrive at the desired operational value. All atmospheric attenuation measurements are recorded by connecting the output of the log video channel to the strip chart recorder via switch S_3. With the modulator inputs terminated at the reference temperature at the oven-controlled resistive load, noise generator N_2 is ignited and the gain of the log video channel adjusted so that the output corresponds to the strip chart recorder reading of zero dB. The chart recorder amplifier provides a linear response. The log characteristic is provided by matching an intermediate frequency log amplifier response to the video logarithmic response.

With the inputs to the modulator terminated in the antenna outputs, the noise generator N_2 is extinguished and antenna S positioned to obtain a maximum signal when pointed in the sun direction.

SIGNAL PROCESSING AND CALIBRATION

The required radiometric sensitivity is determined when making atmospheric attenuation measurements by the sky noise fluctuation level. With present-day mixer preamplifiers, a sensitivity of $0.25^\circ K$ rms can easily be achieved with a post-detection integration time constant of 10 seconds. The statistical noise fluctuation at the output indicator associated with the inherent receiver noise will not be significant in determining the dynamic range of atmospheric attenuation measurement capability. Hence, the use of exotic low-noise amplifiers would be redundant.

The atmospheric attenuation signal and that of major solar flare activity are processed by the "log video" channel. The 0-dB level would be preset at the antenna temperature corresponding to the quiet sun in the absence of atmospheric attenuation. A noise calibration signal is provided by noise generator N_2, injected via the side-arm of coupler C_2 via attenuator A_2. Attenuator A_2 is adjusted to set the calibration level at the 0-dB value as previously defined.

The log response is provided by matching the characteristics of an intermediate frequency logarithmic amplifier to the logarithmic response of a video amplifier. The strip chart recorder would have a linear response characteristic. The chart paper, however, would be scaled logarithmically from +10 to -30 dB with 0-dB corresponding to the antenna temperature of the quiet sun in the absence of atmospheric attenuation.

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The linear channel response would be used to provide a precise setting of the radiometric system gain for adjustment of the RF input zero level (infinite attenuation on the log channel), and simultaneous measurement of small changes in solar radiation characteristics on clear weather days. The 10-dB portion of the log video channel recording would be adequate to accommodate major solar flares which would go off-scale on the linear channel. The 0 to -30 dB portion of the log video channel output would be used primarily for the measurement of atmospheric attenuation.

The function of noise generator N_1 is to provide an appropriately adjusted noise injection signal to the side-arm of coupler C_1 via adjustable attenuator A_1 so that the system can be operated at night in the absolute temperature mode (ref. 8) for sky temperature measurements. In this mode of operation, the input to switch S_2 is connected to the reference temperature source which consists of two resistive loads in a common temperature-controlled environmental chamber.

A modulation frequency at a nominal value of 1000 Hz is adequate to meet the requirement of rapid comparison (1 millisecond) of the antenna temperature in the direction of the sun and in the reference sky noise temperature. The subtraction of these two input temperatures is accomplished at the modulation rate. The difference temperature is converted to a dc output in either video channel by the action of a synchronous detector.

The operation of the instrument and the analysis of the data require relatively simple procedures. The RF input zero reference point on the output indicator is established by terminating the inputs to the modulator in the reference temperature T_{RF} by action of switches S_1 and S_2. The 0-dB level on the log channel is noted by igniting gas discharge noise generator N_2. The antenna is then positioned with the inputs to switches S_1 and S_2 connected to the antenna output terminals. The antenna mount is positioned in hour angle and declination to provide a maximum response from the sun in antenna S. The mount is then placed in an automatical synchronous drive mode in the hour angle coordinate for automatic operation from sunrise to sunset.

The output data are directly recorded on a log scale with 0 dB corresponding to the antenna temperature of the quiet sun in the absence of atmospheric attenuation. Further data analysis of atmospheric attenuation characteristics can easily be accomplished by magnetic tape recording of the output analog signal in dB or by tape recording of threshold detectors at preset dB

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levels. The time must be recorded in parallel on the magnetic
tape by introducing a date and time code on the magnetic tape.
The elevation angle at the time of observation can easily be
introduced into a computer analysis program via solar ephemeral
data for the observing site position coordinates.

Electronics Research Center
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