THE HIGH ALTITUDE MMIC SOUNDING RADIOMETER (HAMSR)*

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ABSTRACT

HAMSR is a millimeter wave temperature and humidity sounder that utilizes state of the art technology to enable substantially reduced size and mass. HAMSR is capable of measuring combinations of tropospheric, stratospheric and mesospheric temperature, water vapor and liquid water profiles (as well as precipitable water and column liquid water). In addition it has the potential to measure upper-atmosphere water vapor and ozone profiles (from high altitude aircraft), cloud ice content, rain rate, surface temperature, surface spectral emissivity, and related parameters which can be derived from those measurements. The near term applications focus on tropospheric temperature and water vapor profiles. HAMSR has been under development for the past two years and the first flight demonstrations are planned for the summer of 2001 aboard a NASA ER-2 aircraft. The instrument operates in three frequency bands centered around 53, 118 and 183 GHz. The receivers for the two lower frequency bands are based on state of the art Microwave Monolithic Integrated Circuit (MMIC) technology and other solid state technology that enables the small instrument size and mass. HAMSR has a flexible, modular system design so the instrument can be easily reconfigured to meet mission-specific measurement objectives.

1 BACKGROUND

1.1 MEASUREMENT CONCEPT

Figure 1–1 shows the microwave absorption spectrum for oxygen and water vapor. (Not shown are absorption spectra of other molecular species, such as ozone, which can be used to make soundings for other gases.) It demonstrates that certain spectral regions are dominated by oxygen absorption (e.g., 50-60 GHz and 118.75 GHz)—suitable for temperature sounding—while other regions are dominated by water vapor absorption (e.g., 183 GHz)—suitable for humidity sounding. It may be noted that the water vapor spectrum consists of spectral absorption lines overlaid on a background absorption (the 'continuum') that increases as the square of the frequency. Also shown in Figure 1–1 is the absorption spectrum of liquid water (shown for a liquid density of 0.075 g/cm^2, 100 times less than for the vapor absorption plot). It has no spectral lines, but increases approximately as the square of the frequency in the vicinity of 100 GHz and is approximately proportional to the frequency in the vicinity of 200 GHz. At 100 GHz the liquid water specific attenuation coefficient (i.e. per volume density) is approximately two orders of magnitude greater than that of water vapor. At the peak of the 183-GHz water vapor line it is about 4 times greater.

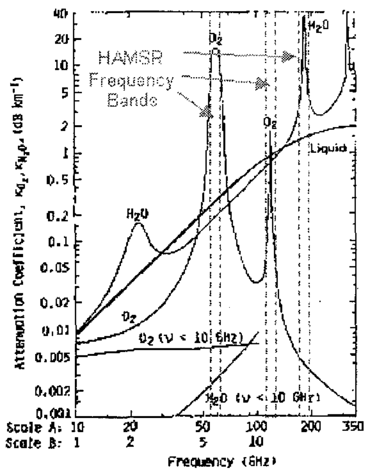

Figure 1–1. (a) Microwave absorption spectrum

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1.2 MEASUREMENT REQUIREMENTS

The sounding accuracy that can be achieved depends on the instrument's measurement accuracy as well as its vertical sampling density. The measurement accuracy is expressed in terms of a "noise equivalent temperature change", usually referred to as NEDT. This is in effect a measure of the thermal noise generated by the instrument itself, which tends to mask out the thermal emission from the target being viewed. It depends on receiver characteristics (e.g., "receiver temperature") and bandwidth, as well as the integration time (i.e. the dwell time for a single view of the target). For temperature sounders it is generally required that NEDT be on the order of about one-quarter of the desired atmospheric temperature accuracy. Thus, in order to achieve a temperature sounding accuracy of 2 K, the instrument's NEDT should not exceed 0.5 K. In order to achieve a humidity sounding accuracy of 20%, the NEDT should not exceed about 1 K. Vertical resolution depends on the spacing of the weighting functions. Thus, in order to achieve a vertical resolution of 2 km in the troposphere, at least 5-6 equally spaced weighting functions, i.e. 5-6 spectral channels, are required.

Table 1-1. HAMSR specifications

Chan #	Center freq. [GHz]	Offset [GHz]	BW [MHz]	NEDT[1] [K]	Wt-func. peak [mb or mm]
I-1	118.75	-5.500	1500	<0.3	Sfc/[30 mm]
I-2	"	-3.500	1000	<0.3	Surface
I-3	"	-2.550	500	<0.3	Surface
I-4	"	-2.050	500	<0.3	1000 mb
I-5	"	-1.600	400	<0.3	750 mb
I-6	"	-1.200	400	<0.3	400 mb
I-7	"	±0.800	2x400	<0.3	250 mb
I-8	"	±0.450	2x300	<0.3	150 mb
I-9	"	±0.235	2x130	<0.3	80 mb
I-10	"	±0.120	2x100	<0.3	40 mb
II-1	50.30	0	180	<0.3	Sfc/[100 mm]
II-2	51.76	0	400	<0.3	Surface
II-3	52.80	0	400	<0.3	1000 mb
II-4	53.596	±0.115	2x170	<0.3	750 mb
II-5	54.40	0	400	<0.3	400 mb
II-6	54.94	0	400	<0.3	250 mb
II-7	55.50	0	330	<0.3	150 mb
II-8	56.02 & 56.67	0	270 & 330	<0.3	90 mb
III-1	116	±2.0	4000	<0.5	[11 mm]
III-2	183.31	±10.0	2x3000	<0.5	[6.8 mm]
III-3	"	±7.0	2x2000	<0.5	[4.2 mm]
III-4	"	±4.5	2x2000	<0.5	[2.4 mm]
III-5	"	±3.0	2x1000	<0.5	[1.2 mm]
III-6	"	±1.8	2x1000	<0.5	[0.6 mm]
III-7	"	±1.0	2x500	<0.5	[0.3 mm]

The required spatial coverage and sampling density determine other instrument characteristics, such as the Instantaneous Field of View (IFOV), sampling step, scan width, scan speed, etc. The scan characteristics may also be driven by the need to perform calibration measurements. (Calibration measurements must be done frequently enough that instrument 1/f-noise does not dominate.)

The required measurement accuracy should be specified in terms of a general "effective NEDT per sounding cell": typically, 0.3-0.4 K for temperature sounding and 0.5 K for humidity sounding for a satellite system. A sounding cell corresponds to the desired resolution of the derived data product and is not necessarily equal to the measurement cell. For example, the desired sounding cell might consist of a cluster of four adjacent sampling cells. Then the effective NEDT is less than the NEDT per measurement by a factor of two. It may be noted that, due to very different sampling requirements, HAMSR will far outperform a typical satellite sounder.

The HAMSR microwave specifications, given in Table 1-1, were designed to meet the minimum all-weather (i.e. fully overcast) sounding requirements for the planned National Polar-orbiting Operational Environmental Satellite System (NPOESS). Band I is intended as the primary temperature sounding band, while Band II serves as a backup sounder for high-opacity conditions (e.g., in the tropics). Band III is the primary water vapor/liquid sounding band. This system thus requires three microwave receiver units, with ten, eight, and seven channels, respectively. Other channels can be added for stratospheric and mesospheric temperature sounding.

2 INSTRUMENT DESCRIPTION

2.1 INSTRUMENT DESIGN

The HAMSR instrument is designed to be flown in a variety of aircraft, but the first series of flights will be aboard a NASA ER-2. A block diagram of the instrument is shown in Figure 2-1 and a photograph of the senor part of the instrument is shown in Figure 1-2. The radiation from the atmosphere and calibration sources are received by two scanning reflectors and diplexed into three bands by a quasi-optics system which directs the signals into feed horns at the inputs of the radiometers. The calibration sources consist of two pairs of high emissivity, broadband black body absorbers. The 54 and 118 GHz radiometer designs employs InP MMIC low noise RF amplifier (LNA) front-ends, mixers and intermediated frequency (IF) amplifiers and were developed for the JPL IMAS program. To minimize cost the 183 GHz band receiver will use a more conventional planar mixer receiver and will not utilize MMICs. Following the mm-wave receivers frequency multi-

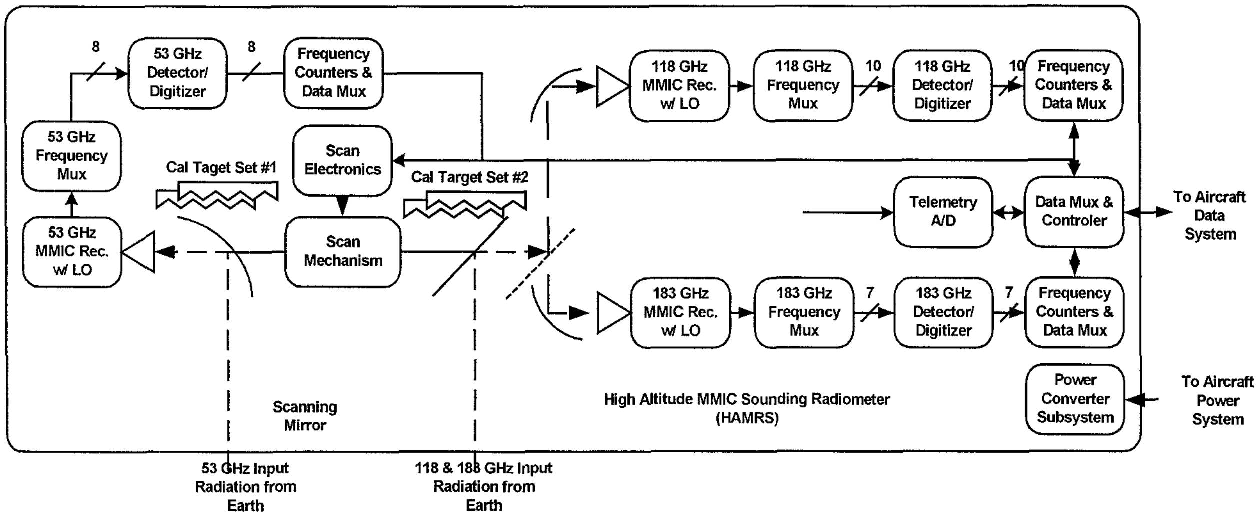

Figure 2-1 HAMSR Electronics Block Diagram

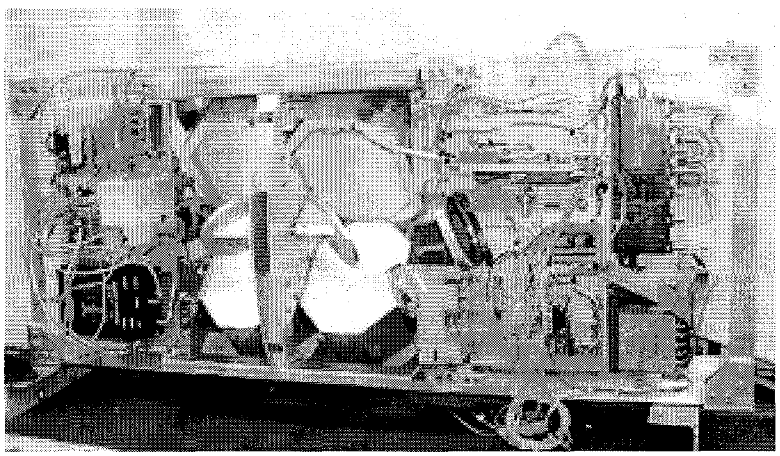

Figure 2-2 HAMSR Sensor Unit, the length is approximately 1 m, 53. GHz Radiometer is to the left, 118 and 183 GHz with optics are shown at the right, to left of center are the four calibration targets.

plexers (filter banks) select narrow bandwidth (100 to 4,000 MHz, see Table 1-1) channels to analyze the atmospheric emissions. The power in each of these channels is detected, integrated and digitized. An analog integrator and analog to digital converters provide digitization of the 25 HAMSR radiometer signals. The instrument is provided with a digital data system to interface with the aircraft system and a scan motor control electronics subsystem to control the scanning mirrors. A power converter will condition the aircraft unregulated power to produce the highly regulated power required by the HAMSR instrument subsystems.

2.2 OBSERVATION APPROACH

The scanning system is designed to provide a 2 km nadir footprint at all frequencies (5.8° half power full width) and scans approximately 60 steps in increments of 3° to cover about a 60 km swath, with 1 km overlap between footprints. A diagram of a typical set of scans is shown in Figure 2-3. The scan system is designed for a nominal ground track speed of 450 km/hr at 20 km altitude to provide 1x1 km pixels spaced 0.5 km apart in the cross and along track directions. These footprints are achieved by averaging a number of over sampled pixels. To mitigate gain drift effects, scanning is done in a 1.1 s period with integration time of 8 ms. During each scan approximately 15 measurements of each calibration target are made. A 2x2 km measurement may be constructed from approximately 2 cross track by 8 along track pixels for a total of 16 for the 53 and 118 GHz To achieve the required bandwidth the 183 GHz receiver uses a switched local oscillator that alternates measurements of two parts of the spectrum every other scan cycle. Thus only 8 pixels are averaged for this band.

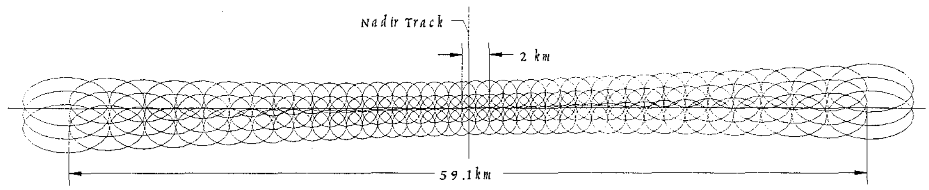

Figure 2-3 Surface Scan Pattern from 20 km and 450 km/hr Speed

2.3 CALIBRATION SUBSYSTEM

The calibration subsystem consists of two pairs of blackbody targets. One pair for the 53 GHz band and the other for the 118 and 183 GHz bands. Each pair consists of one target at the instrument ambient temperature and the other is heated to 75 C. The targets were designed and fabricated by Zax Millimeterwave Corporation, San Dimas, CA. The targets consist of wedges of absorber material approximately 40 mm long and spaced approximately 10 mm apart. The targets were designed to have less than -50 dB return loss from 40 to 220 GHz. The targets each contain four thermistors embedded near the tips of selected wedges. The blackbody absorbers are attached to heavy aluminum plates and are enclosed in insulation. Laboratory tests indicate temperature gradients across the targets of less than 0.1 C.

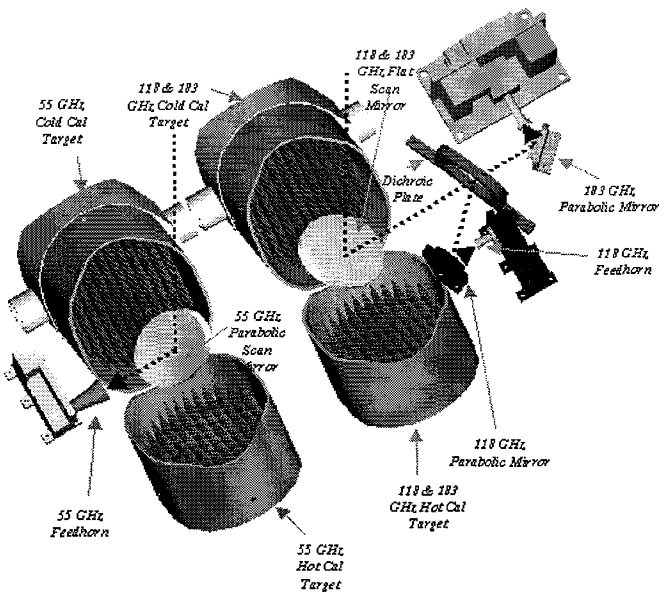

Figure 2-4 HAMSR Optics Layout

2.4 OPTICS DESIGN

A layout of the HAMSR optics subsystem is shown in Figure 2-4. The key challenges in the design of the optics subsystem are maintaining a compact size while meeting the low cross-polarization coupling and low sidelobe requirements. To enable the system to be easily re-configured, a simple and flexible set of optics was designed, but with some sacrifice in compactness. Two scanning reflectors are utilized in this design, one is a parabolic reflector which receives the 55 GHz signal with 75 mm projected aperture and the other is a smaller flat reflector for the 118 and 183 GHz signals. The two highest frequency signals are diplexed by a dichroic plate and separate fixed parabolic reflectors focus them. The three parabolic reflectors focus the received signals into corrugated feed horns. All reflectors are illuminated with -30 dB edge illumination to assure high beam efficiency. A scan motor drives the scanning mirrors which are mounted on a common rotation axis. The motor includes an encoder and is controlled by servo drive electronics controlled by the data system.

2.5 RADIOMETER RECEIVERS

The HAMSR receivers utilize a single-sideband super-heterodyne approach. The 53 and 118 GHz receivers consist of an InP MMIC low noise amplifier, cascaded with a microstrip (planar) image reject filter and a mixer which downconverts the signal to an intermediate frequency (IF) of approximately 4–12 GHz. The mixer is a second-harmonic MMIC design on InP. Additional IF gain is provided by MMIC amplifiers operating from 4-12 GHz. An active MMIC multiplier chain is used to provide a source of local oscillator (LO) power and is driven by a dielectric resonator oscillator (DRO). All modules employ gain compensation to stabilize the gain over the operating temperature range. A photograph TRW 118 GHz MMIC radiometer is shown in Figure 2-5. The input feed horn, a SMA IF connector and a power connector are shown. The double sideband system noise temperatures of the radiometers are 700 K for the 53 GHz band and 1,400 K for the 118 GHz band..

The 183 GHz receiver front-end is a broadband (12 GHz) double sideband 183 GHz sub-harmonic (x2)

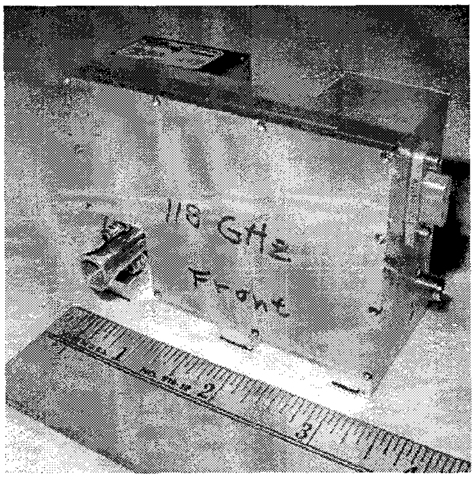

Figure 2-5 TRW 118 GHz MMIC Radiometer Module, scale in inches

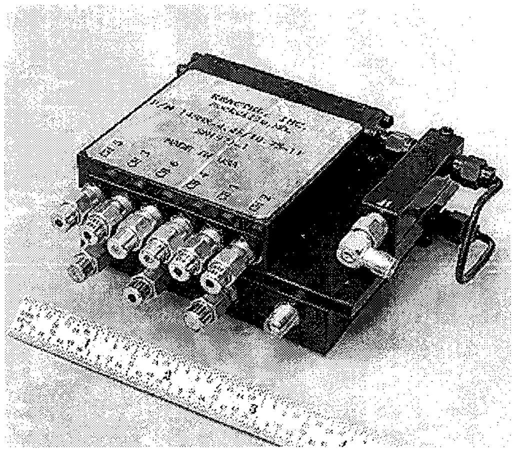

Figure 2-6 HAMSR Reactel 118 GHz Band Miniature Filter Bank

mixer using planar Shottky diodes. To cover the band from 164-195 GHz the receiver operates with switched local oscillators which center the receive band at either 183.31 or 166 GHz. The local oscillators are derived, through a x6 frequency multiplier, from two DROs at 13.8 and 15.3 GHz. The 183 GHz double sideband noise temperature will be less than 3,000 K.

2.6 FILTER BANK SPECTROMETERS

Miniaturized filter banks perform measurements of the oxygen and water vapor line shapes required to retrieve atmospheric profiles. The required center frequencies, bandwidths and resulting brightness temperature sensitivities for a 300 ms integration time are given in Table 1-1. The out of band rejection is specified at >40 dB at twice the filter bandwidth or greater for filters with center frequencies less than 4 GHz and >30 dB for filters greater than 4 GHz, to simplify the filter design. The filter bank approach has been chosen to avoid multiple down conversions, to make the HAMSR receivers smaller, lighter and less expensive than those flown on other microwave sounder missions. A photograph of the 118 GHz band filter bank developed by Reactel is shown in Figure 2-6.

2.7 DETECTOR/DIGITIZERS

The 25 IF outputs of the filter bank spectrometers are applied to the Detector/Digitizers that detect, amplify, integrate and digitize each channel. HAMSR utilizes seven of these units, each of which handles four input channels, to process the 25 required channels and provide three spares. A photograph of the Detector/Digitizer is shown in Figure 2-7. The detectors are off the shelf Agilent devices and have high linearity for signals levels less than -15 dBm. The detected outputs are applied to highly stable, wideband op amps for amplification and integration. Digitization is provided by 12-bit analog to digital converters and applied to a storage buffer. The computer system then sequentially polls the buffers of each channel to diplex the data.

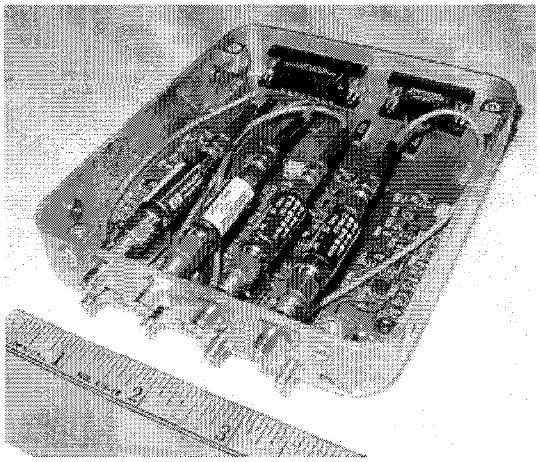

Figure 2-7 Four Channel Detector/Digitizer Electronics, scale is in inches

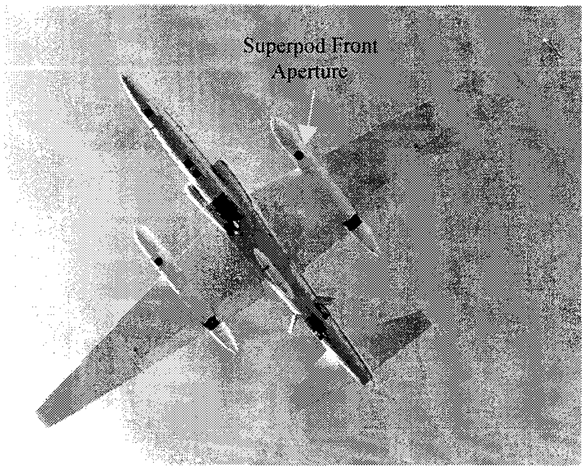

Figure 2-8-NASA ER-2 with superpod location noted.

2.8 DIGITAL SUBSYSTEM

The digital subsystem manages the simultaneous acquisition of the 32 channels of data from the Detector/Digitizers, collects housekeeping and aircraft navigation data, including physical temperatures; controls and sequences the scan system; and provides mass storage for the data collected. The core of this subsystem will be a PC-Compatible CPU card with a PC-104 bus and IDE mass storage. The mass storage is a removable ATA Flash PCMCIA card (up to about 250 MB). The most intensive processing in the digital subsystem is the high-speed acquisition of Detector/Digitizer radiometric data. HAMSR incorporates measurement of physical temperatures, both for 'first-order' calibration (reference and calibration targets, for example) and for 'second order' housekeeping such as instrument component temperatures and navigation data. These measurements are handled by two 16-channel 12-bit PC-104 analog to digital converters with appropriate scaling for each parameter.

2.9 MECHANICAL AND THERMAL DESIGN

The HAMSR instrument will be mounted in a pressure vessel in the superpod of the ER-2. The superpod is pressurized and, to avoid performance degradation due to a window, HAMSR will look through an open aperture. To accommodate this, the sensor unit will be mounted in the pressure vessel looking through an open window and will be at the outside air pressure. The electronics units, including the data system and power supplies will be mounted inside the pressurized portion of the superpod. The location of the superpod is shown in Figure 2-8

2.10 HAMSR INSTRUMENT CHARACTERISTICS

A summary of the HAMSR instrument characteristics is given in Table 2-1.

Table 2-1 HAMSR Instrument Requirements/Characteristics

Specification	54 GHz	118 GHz	183 GHz
Frequency Range, GHz	50-57	112-120	167-199
LO Frequency, GHz	46 GHz	124 GHz	83 & 91.7 GHz
IF Frequency, GHz	4-12	4-12	0.75-10
Sideband Rejection, dB	>15	>15	>15
Frequency Channels	8	10	7
Frequency Stability, MHz	10	10	5
System Noise Temperature, K	<1,000	<1,500	<2,000
NEDT, K	<0.3	<0.3	<0.5
Antenna Beamwidth (HPFW), deg.	5.7		
Antenna Beam Efficiency, %	>95		
Scan Type	Crosstrack		

3 SUMMARY

HAMSR is designed to meet requirement similar to the minimum all-weather (i.e. fully overcast) sounding requirements for the planned for NPOESS to provide millimeter wave temperature and humidity sounding. However, it utilizes state of the art technology to enable substantially reduced size and mass compared with existing instruments. HAMSR will be flown on the NASA ER-2 during the summer of 2001 to demonstrate this technology and to carry out studies of hurricanes.

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