A Microwave Instrument for Temperature and Humidity Sounding from Geosynchronous Orbit.[1]

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INTRODUCTION

The first geostationary sensors produced dramatic images of storms on short time scales, permitting their evolution to be monitored as never before. Prediction of weather now benefits from numerical weather prediction models, which require temperature and humidity inputs from soundings. Significant weather is often located in cloudy areas where infrared (IR) soundings are degraded or fail, and since numerical weather models are often hypersensitive to such baroclinic regions, microwave sounders can improve predictions by providing needed data. Both theoretical studies and data from polar weather satellites make clear the superiority of combined IR and microwave sounder systems relative to either system operating alone [1].

To date, the size and weight of microwave sounders have limited their use to low earth orbit. The use of higher frequencies can provide reduced antenna size so that a useful microwave sounder using a ~2-meter diameter aperture can be packaged on a geosynchronous satellite [2].

METEROLOGICAL APPLICATIONS

Fig. 1 shows an example for Tropical Cyclone Oliver of microwave images from a 118 GHz temperature-sounding spectrometer on the NASA ER-2 aircraft flying near 65,000 feet altitude [3]. Significant meteorological information regarding the strength of a hurricane lies in the magnitude of its warm core temperature anomaly (~10 °C in this case) and in the extent and position of its rain bands. Both of these features are hidden from IR sounders by high clouds. Fig. 1 shows the altitude (km) of the precipitation cell tops deduced from the microwave signature of large ice particles convected aloft [4]. Rain near the eye builds storm strength faster than rain farther away. These two images 3 hours apart suggest a slight drop in the energy input (note the weakened eyewall and the enhanced outer rainbands at 20:00). The storm faded away about one day later.

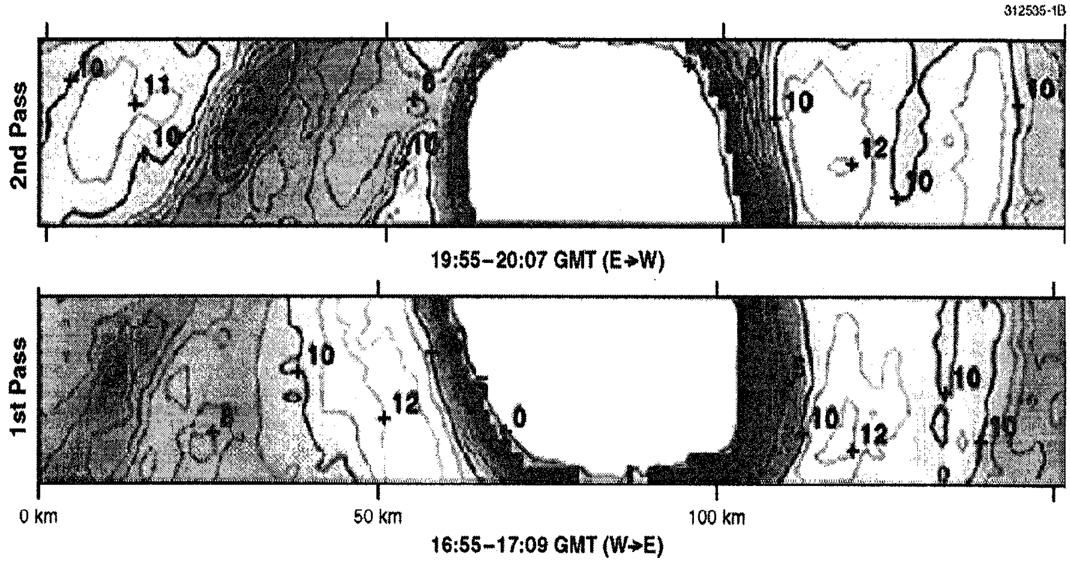

Fig 1. Cloud-top altitudes (Km) retrieved from MTS 02-07-93 data over the eye of Tropical Cyclone Oliver, using a feed-forward neural net.

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Another useful predictor for the development of severe storms such as tornadoes has been the GOES IR Sounder Lifted Index (LI) product that indicates atmospheric stability. LI values less than zero indicates unstable atmospheric conditions. LI is a function of atmospheric temperature and humidity profiles which are also measurable by a microwave sounder. The value of this product is illustrated in Fig. 2 which shows the conditions associated with the tornado outbreak near Jarrell, TX on May 27 1997. At 1915 UTC, extremely unstable conditions (LI's ranging from -11 to -18°C) were present to the south and west of the thunderstorm complex, including the area in the white box where a tornado hit Jarrell two hours later at 2115 UTC. Note the location of additional tornadoes (*) in the cloudy area where IR-derived LI values are not available [2] and where a microwave sounder could provide some additional coverage.

Passive microwave sounding of atmospheric temperature and water vapor profiles utilizes measurements near the microwave oxygen and water vapor absorption lines illustrated in Fig. 3. Current polar orbiting microwave sounders in low earth orbit utilize the 60-GHz oxygen line for temperature sounding and the 183-GHz line for water vapor sounding. The use of higher frequencies permits reduced antenna size for a given spatial resolution.

Weighting functions show the extent to which a given frequency observation responds to atmospheric temperatures or humidity for various altitudes. A candidate set of frequency offsets and channel bandwidths for temperature soundings in the 118 and 425 GHz oxygen-band channels and water vapor in the 183 and 380 GHz water vapor bands has been presented [2], [5]. These show that the 118-GHz channels can monitor atmospheric temperatures from the surface to the stratosphere, whereas the 425-GHz band is blocked below ~1-5 km, depending on atmospheric humidity.

Even in extreme humidity, however, the 380-GHz and 425-GHz images with ~20-km resolution could map most significant precipitation cells, hurricane warm cores, and other storm phenomena because they usually extend to altitudes well above 5 km. Exceptions would be low-altitude precipitating stratus, which could be monitored at 54, 118 and 183 GHz. The use of multiple bands will also provide information on particle size in the upper atmosphere

INSTRUMENT DESCRIPTION

Fig. 4 shows a baseline instrument operating near 54, 118, 183, 380 and 425 GHz. It can provide spot diameters near nadir of 143, 66, 42, 20 and 18 km respectively. Spatial resolution can be improved by ~15 percent by oversampling during scanning and signal processing.

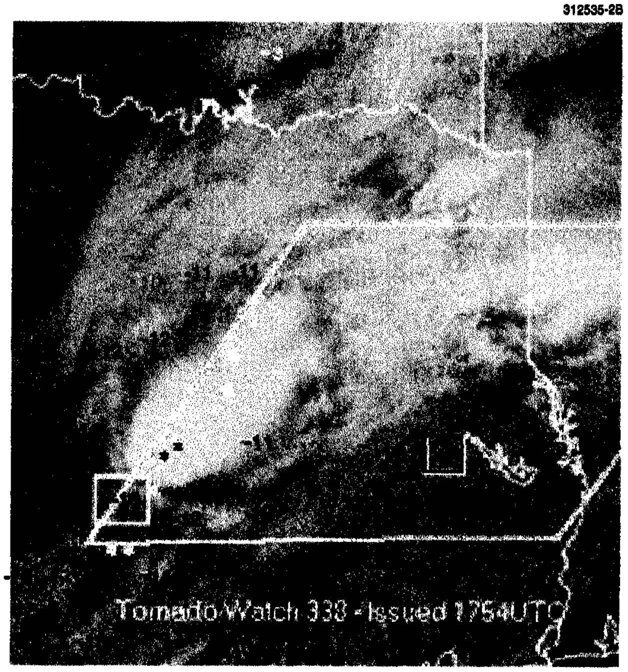

Fig 2. 1915 UTC GOES-8 image during the Jarrell, TX, tornado outbreak on May 27, 1997. The colored asterisks show where tornadoes touched down. Overlaid on the image are the GOES IR Sounder Lifted Index (LI) values derived from the 1900 UTC soundings which show the high likelihood of severe weather near where the tornadoes were formed. A microwave sensor on GOES would extend the area for which the LI is produced to more of the cloudy regions.

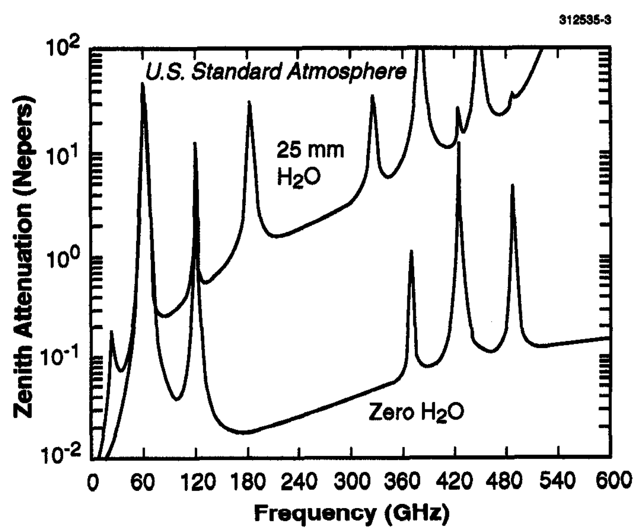

Fig 3. Oxygen and water vapor absorption lines, 0-600 GHz.

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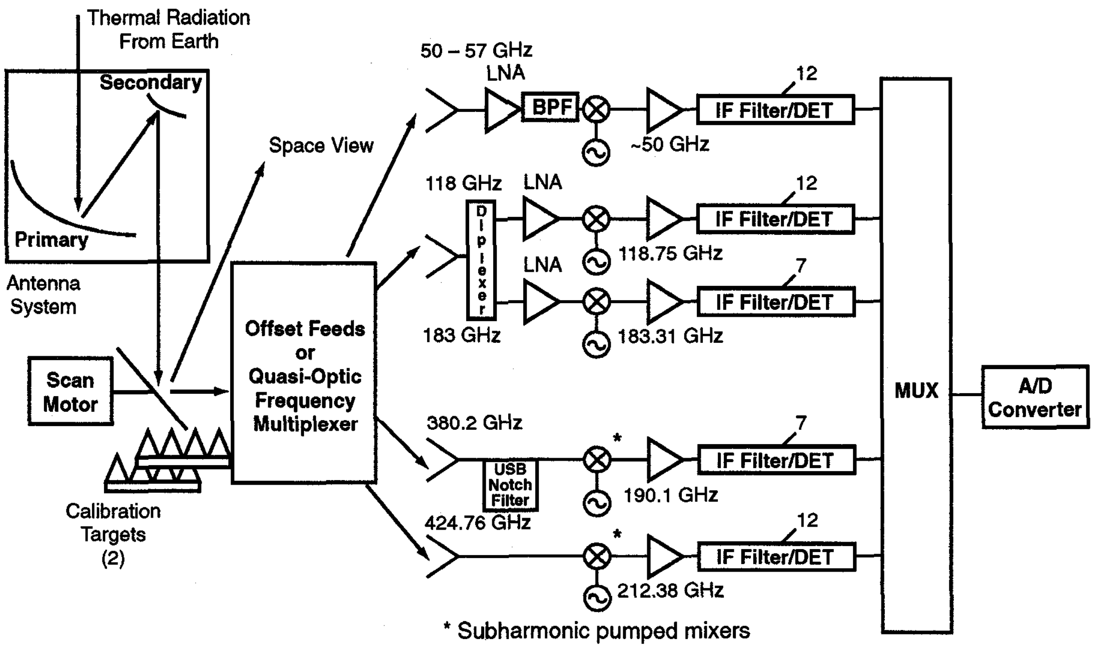

Fig 4. Radiometer Block Diagram.

The radiometer sensitivities for a one-hour scan of the continental United States range from 0.08 K at the lowest frequency to 0.54 K at the higher frequencies. The use of additional antenna beams at the higher frequencies can further improve sensitivity or reduce the time to scan an area.

The receiver technology needed for this instrument can be implemented with room temperature receivers. For the three lower frequency bands, MMIC receiver front ends are being developed with noise temperatures in the 1000 to 2000 degree Kelvin range. For the two higher bands, subharmonically pumped mixers are being developed with a projected noise temperature under 5000 K. Approximately 10 spectral channels will be provided for each band. Receiver temperature calibration will be provided with a movable mirror switching between a space look and two warm loads at different temperatures as shown in Fig. 5.

The antenna technology required can be implemented with low temperature-coefficient-of-expansion graphite epoxy materials for the reflector. An offset-fed parabola is often used to obtain high beam efficiency but a Cassegrain feed is feasible for this system and provides mechanical and packaging advantages. The surface tolerance required for the

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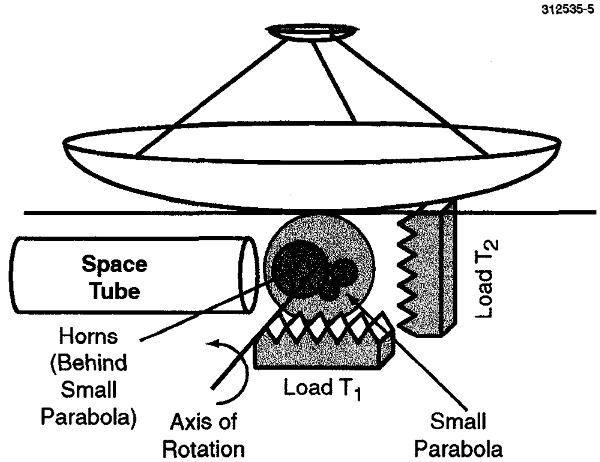

Fig 5. Calibrator Concept

higher frequencies is approximately 10 microns and can be achieved by a polishing process. Since some thermal distortion will occur in the antenna reflector and feed support structure, a laser shape sensing/control system, Fig. 6, has been designed to move (or possibly reshape) the subreflector to mitigate the effects of these distortions. The subreflector is nodded to scan the smaller spot sizes, thus reducing the required scan speed of the main reflector.

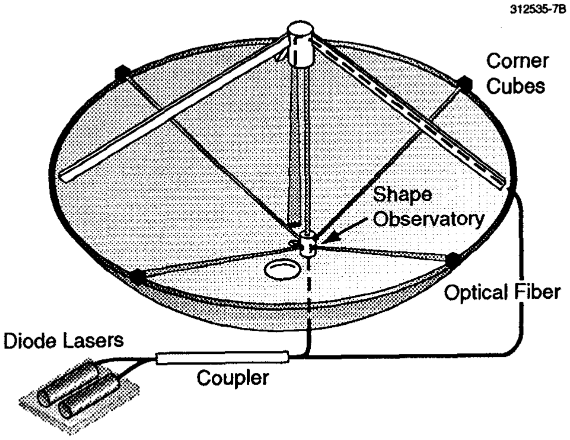

Fig. 6. Antenna Shape Sensing System

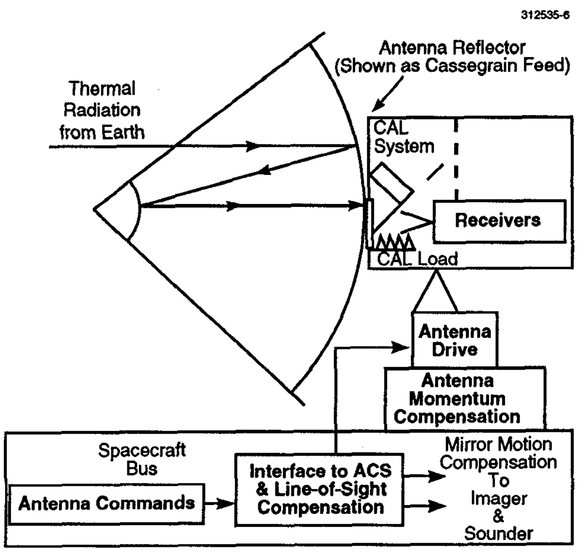

Fig. 7. GMS System Components.

ENGINEERING READINESS

The engineering readiness of a Geosynchronous Microwave Sounder depends on system requirements, spacecraft bus capabilities and the radiometer and antenna technology base. Fig. 7 suggests the principal system components for an instrument hosted on a 3-axis stabilized bus (a dedicated small sat bus would allow scanning of the antenna by bus motion). The components include the receivers and calibration system, the antenna with its drive and momentum compensation, and the spacecraft bus with its associated command, telemetry and interface systems. Trade-offs studied include scanning patterns versus momentum compensation, and satellite perturbation versus various multibeam or subreflector scanning approaches.

SUMMARY

The use of higher frequencies provides reduced antenna size so that a useful microwave sounder can be packaged on a geosynchronous satellite. The proposed microwave sounder could provide sensing of atmospheric temperature and humidity profiles with spatial resolution approaching 15-20 km under many conditions. System engineering studies have been done and these results, including inputs from industry, suggest a useful GOES microwave sounder can be flown based on currently demonstrated technology.

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