# Designing a Climate-Monitoring Microwave Radiometer

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***Abstract*—The Climate-Monitoring Microwave Radiometer (CliMMR) will address the requirements for measuring long-term trends in atmospheric temperature with excellent stability and linearity, and very low antenna sidelobe contributions. CliMMR would also serve as an on-orbit calibration standard for weather-satellite instruments. Small satellites in carefully chosen non-sun-synchronous orbits could compile a diurnal-cycle climatology of temperature, to reduce uncertainties in the past satellite temperature record.**

## I. Introduction

Although the temperature at Earth's surface is well represented by *in situ* measurements, with records dating back more than a century, satellites provide the only truly global sensing of atmospheric temperature above the surface. Microwave radiometers on weather satellites have been used to monitor global trends in atmospheric temperature extending over the past 38 years [1]-[3], even though they were designed to observe weather phenomena. Satellite temperature measurements are a crucial resource for tracking global-scale changes in the temperature of the Earth and for evaluating climate models. The geographical and altitude distribution of temperature trends can distinguish between anthropogenic forcing and natural variability [4].

## II. Design Considerations

Weather observations benefit from good spatial resolution and radiometric resolution because individual measurements are assimilated into a numerical prediction model. For monitoring of climate, the measurements are spatially averaged and temporally smoothed, so calibration-related uncertainties predominate in the error budget. Table I and the next few paragraphs compare the requirements for the two types of measurements.

The antenna of a climate-monitoring radiometer should have extremely low sidelobe levels to minimize errors caused by variations in altitude and attitude. There is no trade-off with respect to a narrow beamwidth requirement as in the case of weather satellites.

Excellent radiometer stability, in both frequency and calibration accuracy, is required for climate monitoring. Some weather-satellite instruments, for example the NOAA-16 AMSU-A, exhibit long-term drifts on some channels [2],[3].

In the case of MSU and AMSU-A, corrections for nonlinearity of the radiometer response have been done by deriving coefficients from measurements made in pre-launch thermal-vacuum testing. However, errors in determination of nonlinearity coefficients or changes after launch lead to measurement errors dependent on the temperature of the on-board calibration target [1],[2]. A radiometer measures thermal noise with amplifiers whose output has finite limits and whose gain may fluctuate, but good amplifier design should reduce the nonlinearity to a negligible level.

Instruments and satellites have a finite lifetime, so over a multi-decadal time period, it is necessary to do inter-satellite calibrations, with possible errors in joining the temperature record from one instrument to another. Therefore, a climate-monitoring instrument should be designed to have a very long life.

A "sun-synchronous" orbit is chosen for weather satellites, mainly to accommodate the requirements of visible-band instruments. However, the local equator-crossing time (LECT) has a tendency to slowly change over the multi-year lifetime of a satellite [5]. If not taken into account, this diurnal drift would introduce a spurious trend in climate measurements, as well as inter-calibration errors due to different LECT's. In a Monte-Carlo simulation [5], uncertainty in the diurnal correction is the largest contribution to the error budget for the tropospheric layers. In contrast, a microwave climate-monitoring instrument would not require a sun-synchronous orbit. A small number of satellites in carefully selected orbits whose LECT's precess over a time scale short compared to that of the climate trend could produce a climatology of the diurnal temperature cycle, which would reduce the above-mentioned uncertainty in the past temperature record, and also yield a truer global average temperature [6].

The above considerations lead to the conclusion that a microwave spectrometer designed for climate monitoring would differ in several respects from weather-satellite instruments, and should be in an orbit optimized for climate monitoring, perhaps on a small single-instrument satellite. The next section proposes a design for such an instrument.

TABLE I. Comparison of radiometric and orbital requirements

| Weather Observing Requirements | Climate Monitoring Requirements |
|---|---|
| 1. Antennas: good spatial resolution. | 1. Very low antenna sidelobes |
| 2. Good radiometric resolution. | 2. Good long-term stability in frequency, gain, and calibration. |
| 3. Linearity. | 3. Ultra-linearity. |
| 4. Nominal 5-year or 8-year life. | 4. Long life, to minimize handoffs of calibration between instruments. |
| 5. Polar, circular, sun-synchronous orbit. Altitude presents a tradeoff between spatial resolution and swath width. | 5. Polar, circular orbit, high enough to ensure long life. |

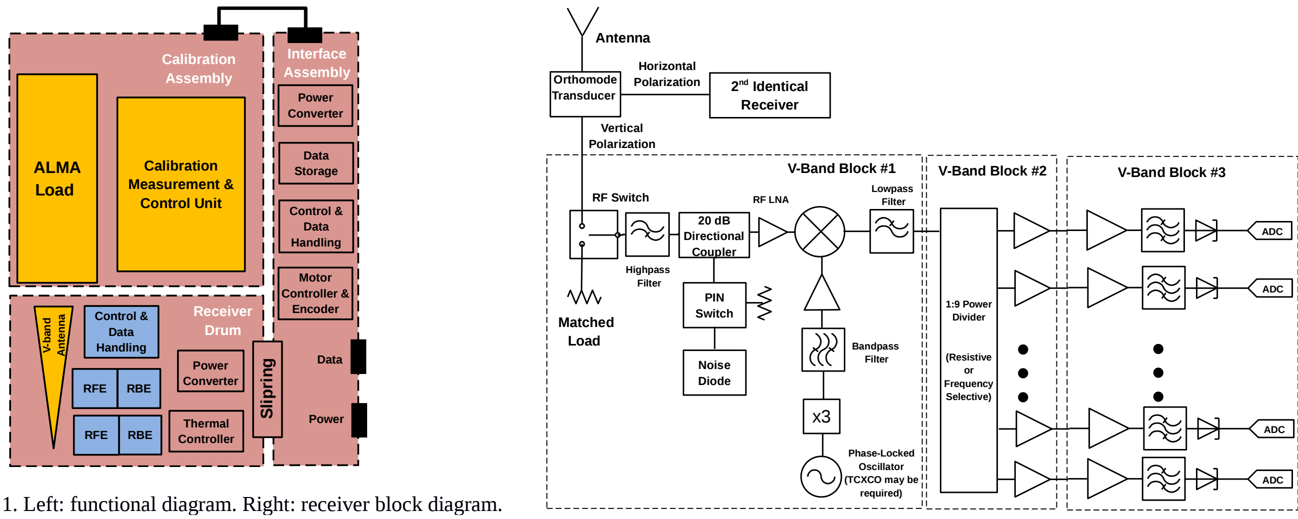

Fig. 1. Left: functional diagram. Right: receiver block diagram.

## III. Baseline Instrument Design

As shown by Fig. 1, the antenna and radiometer will rotate to view the earth, cold space, and an inverted-cone calibration target [7]. The horn-antenna and receivers will be mounted in a pancake-shaped scanning drum with electromechanical, power, and data system electronics similar to CoSMIR [8]. The rotating antenna and radiometer assembly avoids reflector spillover and allows close-coupling of the antenna to the calibration target. Dual Dicke-switched receivers will measure orthogonal linear polarizations and also provide redundancy, and thus high reliability, for all channels (both opaque and semi-transparent) at nadir. Table II lists the baseline channel set. Phase-locked local oscillators prevent frequency drift, and weakly-coupled noise diodes provide on-orbit linearity testing.

Table III lists instrument performance goals. Calibration stability derives from 10% of a nominal ~2 K/century temperature trend. Long-term (multi-year) gain stability is derived from the influence of gain changes on nonlinearity error; hence if $Q_{max}$=0.1, then the goal would be <3 %/yr. Calibration accuracy and $\Delta T_{rms}$ are motivated by the objective of providing a calibration standard for other microwave instruments like ATMS.

The antenna beamwidth should be no larger than ~15°, but within that limit, its value will follow from the choice of antenna parameters to achieve the desired low sidelobe energy, especially at angles off the earth (Table III). For cross-calibration, ATMS measurements would be spatially averaged to the resolution of CliMMR.

TABLE II. CliMMR Channels

| Ch. no. | Center Frequency (GHz) | Passband Width (MHz) | notes |
|---|---|---|---|
| 1 | 50.300 | 180 | =MSU1, AMSU3, ATMS3 |
| 2 | 52.800 | 380 | =AMSU4, ATMS5 |
| 3 | 53.452 | 220 | (a) |
| 4 | 53.740 | 220 | =MSU2 (mid-troposphere) |
| 5 | 54.400 | 220 | (b); ~AMSU6, ATMS7 |
| 6 | 54.960 | 220 | =MSU3, ~AMSU7, ATMS8 (troposphere-stratosphere) |
| 7 | 55.500 | 330 | =AMSU8, ATMS9 |
| 8 | 57.290 | 330 | =AMSU9, ATMS10 (lower stratosphere) |
| 9 | 57.950 | 220 | =MSU4 (lower stratosphere) |

a) Averaging ch. 3 and ch. 4 simulates AMSU5 and ATMS6.
b) 2.3 (ch. 4) – 1.3 (ch. 5) yields lower-troposphere temperature.

Future design studies are planned to examine the potential of alternative calibration and receiver architectures to improve stability and accuracy.

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TABLE III. Performance Goals

| | |
|---|---|
| Max. deviation from linearity ($Q_{max}$), 3< $T_A$<300 K | 0.1 K |
| Frequency stability over lifetime | ±1 MHz |
| Antenna stray factor beyond 64° from boresight | 0.1 % |
| Radiometric resolution ($\Delta T_{rms}$) | 0.25 K |
| Calibration accuracy for $T_A$ | ±0.1 K |
| Calibration stability | ±2 mK/yr |
| Long-term gain stability | ±0.3/$Q_{max}$ %/yr |