

THE CORRELATION RADIOMETER- A NEW APPLICATION IN MM-WAVE TOTAL POWER RADIOMETRY

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ABSTRACT

We describe the design and performance of a 180 GHz correlation radiometer suitable for remote sensing. The radiometer provides continuous comparisons between a the observed signal and a reference load to provide stable radiometric baselines. The radiometer was assembled and tested using parts from the GeoSTAR-II instrument and is fully compatible with operation in a synthetic aperture radiometer or as a standalone technology for use in microwave sounding and imaging . This new radiometer was tested over several days easily demonstrating the required 6 hour stability requirement for observations of mean brightness temperature for a geostationary instrument.

Index Terms—Microwave radiometry, MMICs

1. INTRODUCTION

The microwave correlation radiometer was developed several decades ago for use in radioastronomy [1]. It has been used widely in both interferometry and differential brightness measurements of the cosmic microwave background [2], but has found little application in remote sensing. This is largely due to broad availability Dicke radiometers and their associated components (e.g. switches, amplifiers and isolators). At higher frequencies, many of these components are either unavailable or lossy enough to severely impact radiometric performance. Given the fact that amplifiers with very low noise are now available at frequencies up to hundreds of GHz [3], significant advantages can be realized in the correlation technique. We will describe the basic functionality of this receiver architecture, adapting the concept to total power radiometry. We then present a prototype correlation receiver operating at 180 GHz, which has been designed to perform mean field brightness temperature measurements for the GeoSTAR-III PATH demonstration instrument. We describe the resulting performance of the receiver with special attention paid to the receiver stability. Finally, we explore other remote sensing applications of the correlation radiometer given the exceptional stability demonstrated by the prototype.

2. CORRELATION RADIOMETER FUNCTIONALITY

Like a Dicke radiometer [4], the correlation radiometer produces a signal which is proportional to the difference between a reference load of known temperature and the antenna temperature. But instead of the Dicke switch, which periodically switches between the antenna and reference load, the correlation radiometer uses a hybrid splitter to produce two signals for which the cross-correlation is proportional to the difference temperature. The correlation radiometer is shown schematically in Fig 1, configured as a differential continuous comparison receiver. The correlation radiometer receives inputs from two signals, the antenna and a reference, which are passively combined both in and out of phase (or quadrature phase), amplified , phase shifted and multiplied. Phase shifting is accomplished either at the RF frequencies with a PIN or ferrite modulator or conveniently in the local oscillator (LO) chain. It is important to note that this modulation can occur after amplification resulting in no signal loss. Signal multiplication can be accomplished using an RF or IF hybrid coupler with diode detectors on the

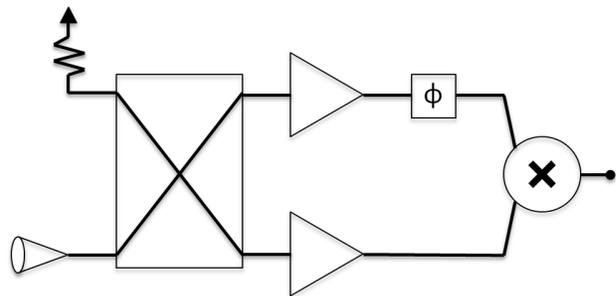


Figure 1. The correlation receiver concept is shown schematically with a signal coming from an antenna, combined with a reference load signal in a hybrid coupler, followed by signal amplification and modulation prior to multiplication.

outputs or as a signal processing product after IF digitization. Since the signal paths pass through both amplification chains, amplifier gain fluctuations are common mode in the differential output and are therefore reduced by many orders of magnitude. The function of the phase switch is negate back end biases caused largely by digitizer offsets, signal leakage, etc. This circuit also provided a means to resolve the phase of the correlation-- which may drift with instrument temperature, amplifier gain drift, etc.

The ideal correlation radiometer is calibrated purely with knowledge of the effective receiver noise temperature, T_R , and the ambient temperature of the hybrid load, T_o , as measured directly with on-board temperature sensors. In the practical system one must also correct second-order effects of correlation null-offset, ρ_o , that is caused by leakages between receivers through the hybrid coupler, and correlator efficiency, E_c , which is degraded by passband mismatches between the two receiver chains. These estimates are combined to estimate antenna brightness temperature, T_A , from the observed complex correlation, ρ_A , as

$$T_A = \frac{E_c T_o - |\rho_A - \rho_o|(T_o + 2T_R)}{E_c - |\rho_A|} \quad (\text{Eq 1})$$

when $T_A < T_o$.

The sensitivity and stability of the receiver have been calculated in [5] including effects of noise temperature fluctuations and higher order terms from residual amplitude imbalance in the various phase states and with complex correlation affords a $\sqrt{2}$ performance improvement over a balanced duty cycle Dicke radiometer of equal noise temperature.

3. THE GEOSTAR CORRELATION RADIOMETER

The correlation radiometer is ideally suited to measure the mean field brightness temperature (or “zeroth visibility”) of the GeoSTAR [6] instrument, as the architecture already includes the phase shifted LO and an array of digital correlators. Our test architecture is shown in Fig 2 and a photograph of the test set is shown in Fig 3a. The receiver comprises a feed horn, waveguide hybrid coupler, waveguide mounted reference load, a pair of MIMRAM downconverter modules [3], a multiplied LO subsystem with phase shifters, digitizers and an FPGA-based correlator. The receiver covers the frequency range 165-183 GHz with a 1 GHz IF band selectable by tuning the LO frequency.

The GeoSTAR design requires elements near the center of the array, placed on an irregular grid, in order to adequately sample the u-v plane with a cropped field designed for alias suppression [7]. These extra elements provide an ideal location in the array for the correlation receiver since the input hybrid coupler may then be mechanically integrated into the LO distribution manifold.

4. EXPERIMENTAL RESULTS

The correlation radiometer was operated in the laboratory for a period of 3 days. During this time it observed targets ranging from 77 K to 320 K. No attempt was made to temperature control the system and it operated in an ambient environment which varied naturally by ~5 K. The radiometer was measured to have a noise of 700 K, consistent with the MIMRAM module noise temperature and 0.5 dB loss from

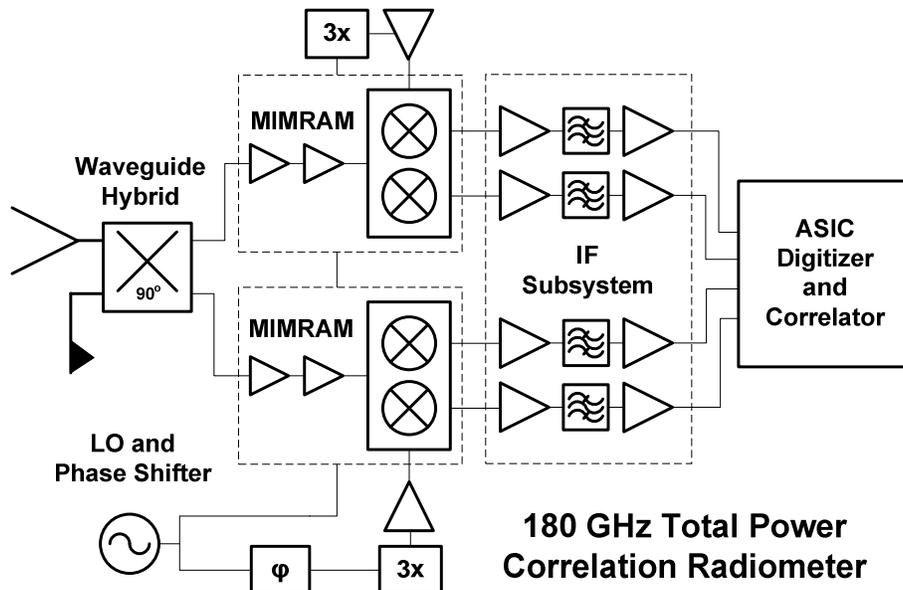


Figure 2. 180 GHz correlation radiometer block diagram. The receiver uses parts developed for the GeoSTAR instrument, reconfigured as a total power radiometer.

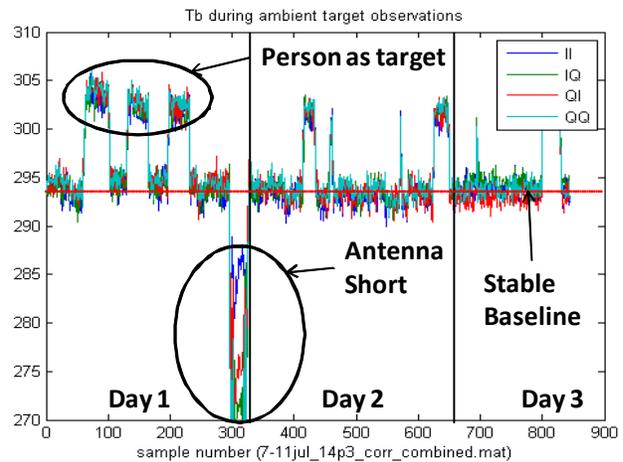
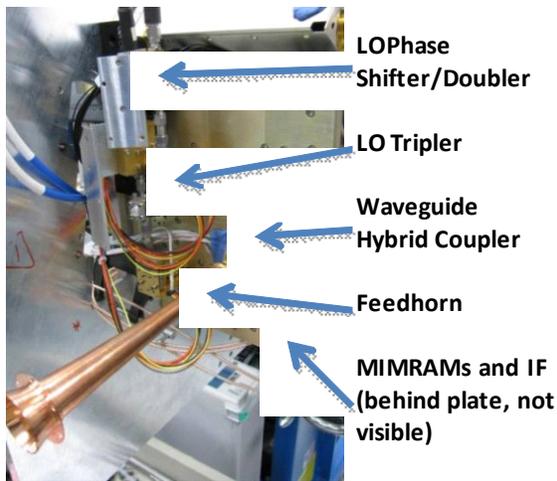


Figure 3. 180 GHz correlation radiometer tests for GeoSTAR a)Left: Test configuration with the major components except the correlator b)Right: Correlator output over several days in ambient laboratory environment. Stability over this time is roughly 1K correcting for the load temperature.

the input coupler. The IF bandwidth was measured to be 65 MHz (limited by the current correlator) although aliased signals up to 700 MHz were processed.

The stability data for the three days are shown in Fig 3b. Over this period, the radiometer was stable to a remarkable 1 K as referenced by the load. This stability is consistent with Eq 1 given the input offset of ~3K and is more than adequate to meet the brightness temperature calibration requirements of PATH, given the 6 hour maximum period between underpass measurements with absolutely calibrated LEO instruments.

5. DISCUSSION

The demonstrated stability of the millimeter wave correlation radiometer is comparable to that of a Dicke radiometer operating at microwave wavelengths. The advantage of the correlation radiometer is to eliminate the considerable losses otherwise incurred by a diode or ferrite Dicke switch at millimeter wavelengths. This improves performance and simplifies the radiometer front-end design at the cost of more advanced digital back end processing. For interferometric systems such as GeoSTAR where such processors already exist, the correlation radiometer also represents a great simplification to the overall system. And with the advent of low-cost digital back-end processors we anticipate that this approach will find broader use among conventional radiometric systems that cannot receive frequent calibration (e.g. Jason-I to III, SMAP, Aquarius, etc).

6. ACKNOWLEDGEMENTS

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