

An L-band Radio Frequency Interference (RFI) Detection and Mitigation Testbed for Microwave Radiometry

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Abstract—A microwave radiometer specifically designed to detect and mitigate many types of Radio Frequency Interference (RFI) is described. The L-band RFI Detection and Mitigation Testbed (DetMit Testbed) will not be optimized for radiometric observation as much as it is optimized for flexibility in the presence of RFI. While the DetMit Testbed will be a fully functional polarimetric L-band radiometer, the ultimate application of this instrument is not so much brightness measurements as it will be validation of RFI mitigation strategies for employment in future L-band (and other frequency) radiometers. The design approaches for the L-band RFI Detection and Mitigation Testbed are expected to apply to C-band and X-band, and presumably also to other frequencies of interest that experience RFI.

Keywords—Detectors, digital radio, interference suppression, microwave radiometry.

I. INTRODUCTION

The DetMit Testbed is a radiometer designed around the concept of RFI detection and mitigation. The DetMit Testbed is designed for three interrelated RFI mitigation activities: First, in the laboratory, it is designed for the optimization of RFI mitigation approaches using many types of artificially generated RFI. Second, in the field, it is designed for the detection and identification of anthropogenic RFI. Third, again in the field, it is designed for the validation of the RFI detection and mitigation approaches. As such, the design includes a number of features not normally found on microwave radiometers that can be used as part of the mitigation approach or to deliberately locate and characterize RFI. Since RFI may take many forms, a flexible system is required to implement different mitigation strategies. Digital reception permits significant back-end flexibility, and so the DetMit Testbed will employ a streamer analyzer, which incorporates multiple 8-bit 250MSa/s analog to digital converters with a large capacity FPGA. This architecture permits rapid reconfiguration of the receiver to compare some of the common approaches for RFI mitigation: time-domain pulse detection, and frequency domain filtering of carrier frequencies. The DetMit Testbed will also be capable of state-

of-the-art detection approaches in the other domains, such as a kurtosis algorithm, or polarization signature algorithm. Because precompiled firmware is loaded onto the FPGA from an onboard computer, reconfiguration of the receiver can be performed in the field in seconds. The DetMit testbed will also incorporate other features to support RFI detection and mitigation. The DetMit Testbed will sport a variable center frequency and three different IF bandwidths (20, 50 and 100MHz) to locate and isolate RFI in the range from 1200 to 1600MHz. The frequency plan is designed to prevent corruption of the radio astronomy band by intermodulation of RFI. High compression point components are used throughout, to minimize the nonlinearities caused by high level RFI. The design includes capacity for a Correlated Noise Calibration System (CNCS) in the front end. The CNCS is useful not only as a means of calibrating this correlating polarimetric radiometer, but also as a method of generating artificial RFI of specified types for validating detection and mitigation algorithms.

II. HARDWARE DESCRIPTION

A. RF Power Considerations

The microwave component chain is shown in Figures 1 (RF components) and Figure 2 (IF components). Special care has been taken to use components appropriate not only for the power levels typical of L-band radiometry, but also for RFI signals at much higher power levels. The concern for RFI falls into two categories: compression and damage. Components driven into compression will distort any otherwise useful brightness measurements, and so render the instrument incapable of operating temporarily (while the RFI is present). With regards to compression, the components incorporating semiconductor materials, namely the PIN switches and the amplifiers, are all rated to at least +30dBm third order intercept point (IP3), which corresponds roughly to a +20dBm compression point. The devices with lowest compression are the two mixers, with IP3 at +10dBm and +15dBm. As a result, the receiver should have a maximum nonlinearity to brightness

of about 0.01K. To prevent out-of-band RFI from distorting the brightness measurement, the total power in the receiver should be about 20dB below the compression point of any device in the receiver. The maximum ratio of RFI power to brightness that does not compress the brightness signal decreases as the signal progresses through the stages of the receiver. However, at each filter, some out-of-band RFI will be removed. Prior to the first filter, this maximum ratio is about 100dB. Assuming a worst case of 100MHz bandwidth, this compression-free ratio reduces to 30dB prior to the band definition filter and 15dB prior to digitization. If the RFI power approaches this maximum limit, the band definition filter can be switched to reduce the bandwidth to remove spectrum that may contain this high power RFI.

(rated no damage to +30dBm). While the LNA is rated for no damage to only +13 dBm, it should never experience this level of power because of the insertion losses of the intervening components. Components further downstream cannot be damaged by saturated output of upstream components. Thus, the instrument should be protected from damage due to RFI at high power levels.

Using this RF front end architecture, we expect the receiver temperature for DetMit to be less than 450K.

B. Frequency and Filtering Plan

To achieve DetMit's wide input frequency range of 1200-1600 MHz, a super-heterodyne receiver with two local oscillators (LO's) is necessary. It is not possible to downconvert the radio frequency (RF) signal directly to baseband without sideband fold over problems. The design adopted uses for the first LO a frequency synthesizer which can be stepped every 1MHz from 1670 to 2070MHz. Keeping the LO above the RF permits a variable LO design with smaller relative bandwidth, and keeps undesired harmonic products, both in the LO and in the mixer, farther away from the desired intermediate frequency (IF). The IF is centered at 470MHz, and is immediately filtered to 100MHz bandwidth. This signal can be passed unaltered, or further filtered down to either 50 or 20MHz bandwidth, in a switchable filter bank. This architecture, as opposed to switching amongst separate filters of 100, 50 or 20MHz, permits the 100MHz filter to be cascaded with the 50 or 20MHz filters. The advantage of this cascading of filters is that when high levels of RFI are present more than 50MHz from the DetMit center frequency, a reduction of the DetMit bandwidth also dramatically increases the out-of-band rejection, since the rejection of both of the two filters is applied to the signal. After more amplification, the 470MHz signal is downconverted again to 60MHz, which is then fed to the high speed analog to digital converter (ADC). The ADC has a sample rate of 250MSa/s, and thus the widest DetMit instantaneous IF bandwidth of 10-110MHz is sampled within the Nyquist requirements. All other processing is performed inside the Field Programmable Gate Array, and is discussed below.

DetMit L-band Radiometer Block Diagram
RF Front End Electronics

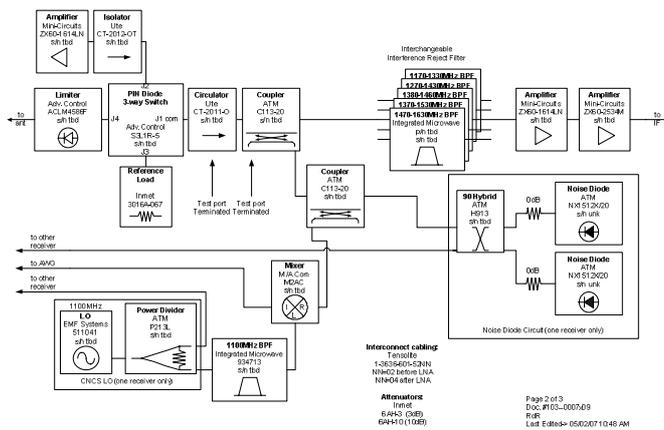


Figure 1: DetMit RF Front End with calibration hardware.

DetMit L-band Radiometer Block Diagram
IF Electronics

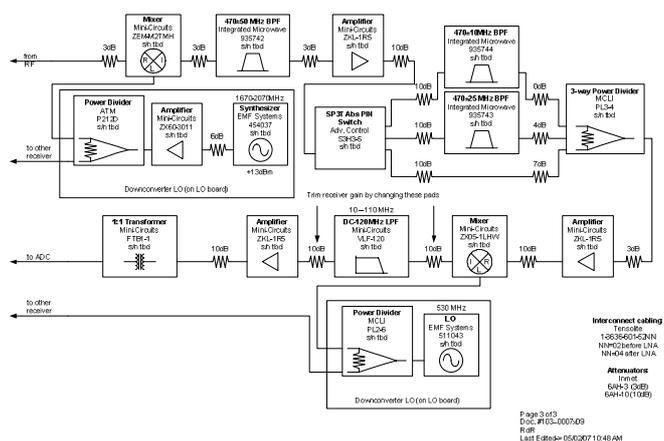


Figure 2: DetMit IF stages with center frequency and bandwidth control.

To prevent damaging power levels, a limiter is provided at the connection to the antenna, which limits its RFI output power to +13.5dBm, which will not damage the PIN switch

Within the front end, prior to the low noise amplifier (LNA), the DetMit design calls for an interference rejection filter on the order of 150MHz wide. Some form of filtering is required prior to the LNA or saturation of downstream components is virtually guaranteed, since this radiometer operates in the crowded L-band portion of the spectrum. Even with the careful frequency plan outlined above, higher order (intermodulation) mixer products will enter the IF unless the RF is adequately filtered prior to the LNA. The problematic terms are $2f_{RF}-f_{LO}$, $3f_{RF}-2f_{LO}$, and $4f_{RF}-3f_{LO}$. This last term has such low conversion gain that, even for strong RFI, it is not expected to be a problem. Since higher order terms have even less conversion gain, they have not been evaluated. The $2f_{RF}-f_{LO}$ term has a contribution to the IF only when DetMit is tuned to frequencies above 1500MHz, but if the RF is filtered to reject frequencies below 1270MHz no higher order products enter the IF. The remaining $3f_{RF}-2f_{LO}$ term is difficult to filter out. The DetMit Testbed is designed so as to not suffer intermodulation RFI while observing the radio astronomy

window of 1400-1427MHz. Therefore, the IF frequency was chosen to be 470MHz, so that the LO frequency that corresponds to the center of the radio astronomy band (1413.5MHz) becomes 1883.5MHz. The RF frequency that intermodulates to this IF via the $3f_{RF}-2f_{LO}$ term is 1412.33MHz, where little or no RFI is expected because it is within the radio astronomy window. Other choices of IF frequency result in possibly strong RFI intermodulating into the IF when DetMit is observing the radio astronomy window.

During the initial instrument design phase, we intended to provide a switchable filter bank for the interference rejection filter. However, subsequent analysis indicated that the best hardware available for this filter bank is very bulky, somewhat lossy and thermally unstable. Filter banks can be implemented with a switch, the filters themselves, and a power divider/combiner, as is done in the IF of DetMit. However, prior to the LNA, a divider/combiner would be much too lossy. Even a two-way divider would double the receiver noise figure, and DetMit should have more than two filters to cover the input range. The only practical switches that could be used twice prior to the LNA are electromechanical multi-throw switches. These switches are very bulky, and as we have not been able to locate multi-throw electromechanical switches that latch, they produce heat as the DC coil current holds the switch in a particular position. The amount and location of this heat generation can be different in different switch positions, and this is known to cause radiometer instabilities [1]. Also, the modest losses in these switches, while much less than the lowest loss PIN diode switches, would still add at least 0.6dB to the receiver noise figure. Therefore this filter bank concept has been simplified. The interference reject filter will be installed so that it is easy to replace with another interference reject filter in another band, or to remove entirely from the receiver. This may somewhat limit the flexibility of the DetMit system, but the enhanced performance is worth it.

C. Internal Calibration

The DetMit Testbed contains extensive calibration capabilities. After the limiter which protects the receiver from damaging RFI, the next component is a 3-way PIN switch. This device permits observations of two known brightnesses in addition to the antenna temperature. A 50ohm matched load provides one known brightness point at the receiver set temperature. A Coldfet device (an isolated LNA input) provides a stable cold brightness reference. This Coldfet will need to be calibrated after fabrication by comparing its brightness to a matched load immersed in liquid nitrogen connected to the receiver's antenna port, but is expected to be stable as long as the temperature is adequately controlled. The manufacturer specifications for the Coldfet components indicate that the Coldfet brightness will be in the neighborhood of 100K. These two calibration sources can be used to calibrate the individual receiver gain and receiver temperature (eg. [2]).

Cross channel calibration, needed for polarimetric radiometry or for RFI detection based on polarization, requires that signals be injected simultaneously into both receivers. Moreover, these signals must have a known correlation (magnitude and phase). A noise diode with its signal divided

to both receivers, and coupled into the receiver front end after the calibration switch, provides a correlated brightness. This system is shown in the lower right quadrant of Figure 1. By using a 90° hybrid as the signal splitter (as opposed to a 180° hybrid or a power divider), a second correlated brightness point can be added to the correlated noise injection system with the inclusion of a second noise diode. While the magnitude of correlation is nominally the same when either noise diode is on, the phase of correlation is changed by 180° when one noise diode is turned off and the other is on. This noise diode system, with the Coldfet and reference load calibration hardware, will always be available on DetMit to monitor receiver drifts.

The calibration of the noise diode injection network can be achieved with the EMAG Technologies L-band Correlated Noise Calibration System (CNCS) in a laboratory setting [3]. Because the DetMit receiver already contains a Coldfet and warm reference load background and a coupler for signal injection, each DetMit receiver already contains about half of a CNCS RF head. Since there are very few additional components needed to complete a CNCS RF head within the DetMit receiver (namely, one coupler, one mixer and one filter), these components have been designed into the DetMit receiver. An integrated CNCS in the DetMit receiver will permit not only a more thorough polarimetric calibration in the field, but, since the CNCS permits generation of artificial RFI, an integrated CNCS could also facilitate hypothesis testing in the field when DetMit is being used for RFI surveys. Therefore, integrated CNCS hardware is designed into the DetMit receiver hardware as a follow-on option.

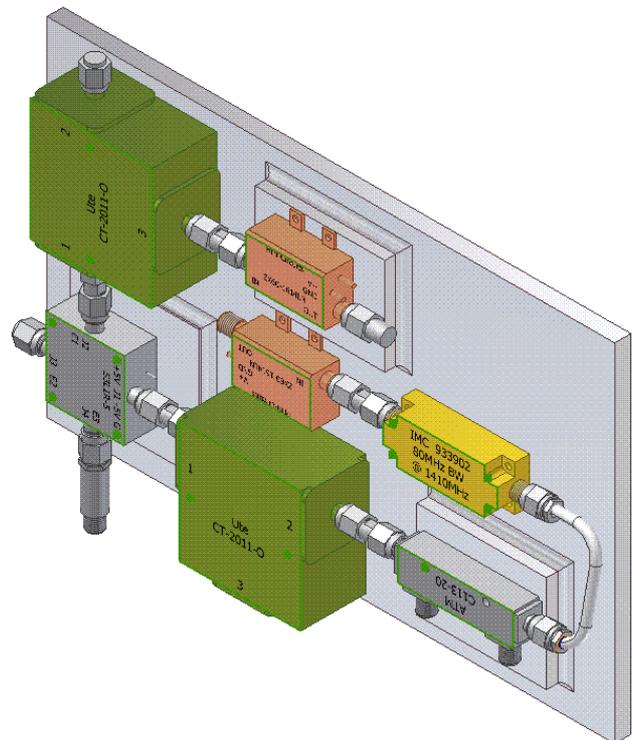


Figure 3: Layout of Front End components.

Figure 3 shows a screen snapshot of an example of a mechanical drawing of the layout of the DetMit hardware. This particular drawing is of the RF front end, which requires a thermal plate with perhaps the most complex dimensions. The tight coupling of the components insures minimal front end losses and minimizes the effects of temperature changes on return losses. Similar, but less complex, drawings are for the LO and IF portions of the DetMit testbed.

D. Digital Back-end

The digital back-end requires two high speed digitizers coupled with a large capacity FPGA. These two components are central to an emerging technology known as “software radio”. Many vendors are available for the individual components needed for a 100MHz bandwidth software radio, but prior experience strongly suggests obtaining a complete software radio system already packaged from a single vendor. Nallatech provides systems with different motherboards hosting high speed FPGAs and interconnects, and mezzanine boards with differing capabilities of analog to digital conversion, digital to analog conversion, and additional digital processing capabilities. DetMit will employ a BenERA motherboard, which is in the form of a compact PCI (cPCI) card. The BenERA motherboard sports a Xilinx Virtex-E XCV2000E-6 FPGA and four DIME-II Expansion slots for compatible mezzanine cards, also produced by Nallatech. The BenERA does not have a built-in digitizer. For this purpose, several options are available, but for the DetMit Testbed the only one with sufficient speed is the BenADC-V4, which has 4 channels of 14-bit 250MSa/s analog to digital converters. There are three FPGA options on the BenADC-V4 itself, and the most appropriate of these are under consideration. The motherboard’s remaining three DIME-II slots are available for additional digital I/O or more FPGAs, which could be used, for example, to parallel process received data with different RFI detection schemes. Nallatech provides extensive software tools for firmware development and testing, which gives it the edge over the Acqiris system.

Baseline firmware is currently being prepared for DetMit that will use the Nallatech hardware. This firmware is being developed primarily under the Agile Digital Detector (ADD) project [4], but the experience gained with Nallatech, and at least 90% of the firmware development, can translate directly to DetMit, where the firmware will serve as the first amongst several receiver implementations.

This firmware accepts data digitized by two 250MSa/s digitizers, divides the incoming data into 16 input sub-bands using polyphase filters [5] (8 sub-bands if FPGA resources are exhausted). As the baseband signal is digitized at the Nyquist rate, the signal can be decomposed into in-phase and quadrature (I and Q) components for further processing. The first four moments of each of these channels is then accumulated, and cross products of the same frequencies are accumulated. The first four moments facilitate the detection of RFI using the kurtosis algorithm [6],[7] with sub-banding. The cross products of the sub-bands facilitates the reconstruction of the polarization of the wave input to the antenna. These accumulations are offloaded from the FPGA to a dedicated

computer for calculations of the calibrations, polarization states, kurtosis values, and the detection/mitigation of RFI.

E. DetMit Status

All RF hardware necessary to fabricate two DetMit receiver RF chains have been ordered. Many components have been received and have either passed or are undergoing acceptance testing. The DetMit Testbed is scheduled to be completed at the end of CY2007. We are currently pursuing opportunities to use the DetMit Testbed to measure soil moisture on either an airborne or ground-based platform. Of particular interest is measurements of the surface soil moisture of the Arctic permafrost, an environment sparsely observed at L-band, and which hosts many long range L-band radars.

III. CONCLUSIONS

An L-band dual channel microwave radiometer receiver has been designed with the objective of evaluating the performance of RFI detection and mitigation strategies. RF component selection has been made with a focus on preventing possible damage and avoiding compression. The frequency and filtering plan permits operation over the extended band from 1200 to 1600MHz with RF bandwidths of 20, 50 and 100MHz. Extensive internal calibration capabilities are included in the the design. The back-end employs a “software radio” architecture rather than an analog detector to permit flexibility in signal processing. The RFI DetMit Testbed is currently being fabricated.

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