Compact Sub Millimeter Wavelength heterodyne Radiometer for Arrays

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Abstract

We present a very compact front–end radiometer at 300-360 GHz, which requires a local oscillator power at 60 GHz. A single receiver element is developed to fit n x m element 2D focal plane array, where n and m > 2. This element array is packaged in a block with a cuboid outline. The attractiveness of this configuration is that the input/output of the receiver are contained within the footprint of the antenna, therefore a full two-dimensional array is possible.

1. Introduction

The need of atmospheric science goes to higher frequencies and higher sensitivities. Indeed, visible and infrared observations from geostationary satellites are available for already three decades and provide only information on the top of the clouds. The microwave frequency band from few Giga-Hertz (GHz) to a hundred of GHz is traditionally used for global characterization of water vapor content of clouds located in the troposphere from ground level up to an altitude of 5-6 km. Sub-millimeter wave radiometry offers new perspectives for the characterization of clouds and rain at global scale [1], with a better spatial resolution, the possibility to characterize the particle size and study multilayer cloud systems. Moreover, the use of high frequency multi-pixel receivers will offer new possibilities of observations that are currently limited by the current single-pixel radiometers. Meteorological prediction will benefit from regular and wide coverage data rate from space-born or airborne observations. This can be fulfilled with arrays of heterodyne receiver that offer a trade-of between sensitivity, mapping speed and coverage area.

We present the main issues for building airborne sub millimeter receiver arrays in order to determine the drivers of our study. As a result, a very compact radiometer is being build. The radiometer features an un-cooled combined Schottky diodes mixer /multiplier for detecting molecular signature in the 300-360 GHz frequency range. This radiometer requires a 60 GHz local oscillator signal with 20 dBm of output power. The array covers the focal plane in the two dimensions with a spatial sampling of less than 20 wavelength of the signal frequency. A first fabrication run is currently on going at the Rutherford Appleton Laboratory.

2. Technologic issues for building large sub millimeter heterodyne receiver arrays

The integration of sub millimeter heterodyne receiver array involve system analysis of every stage from feed-horn spacing, LNA or power amplifier chip(s) integration to the definition of the sub-systems interfaces, all related to technology and lower level circuit design architecture aspects. Therefore we separate the technological issues into two groups: the components and the system integration.

Firstly, the component integration is related to the technology used and its implications on the system. Multipixel receiver arrays using superconducting–insulator-superconducting (SIS) technologies are highly developed in ground astronomy. They are attractive because of their near quantum-limited performances. They are cooled down to 4 K and require little local oscillator power, i.e. few µW per element. Developing sub millimeter heterodyne receivers array for airborne instrumentation requires supplementary effort on weight and spacing. Some efforts have been conducted in [2] for monolithically integrating waveguide transitions in a S-MMIC amplifier technology. Despite of this, Schottky diode MMICs offer a better solution for the implementation of low loss sub millimeter-wave heterodyne receivers. This technology also opens the possibility to fly very compact un-cooled receiver arrays functioning up to few Terahertz with a sensitivity that is compatible to atmospheric sounding requirements (ΔT_{Sys} # few K). These heterodyne detectors require a local oscillator power of few mW per element. The aim of this study is to explore and

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consolidate an integrated approach of Schottky diode component in more compact systems [3]. However, the component integration has no impact on the system size if we don't put an effort in resolving system integration issues.

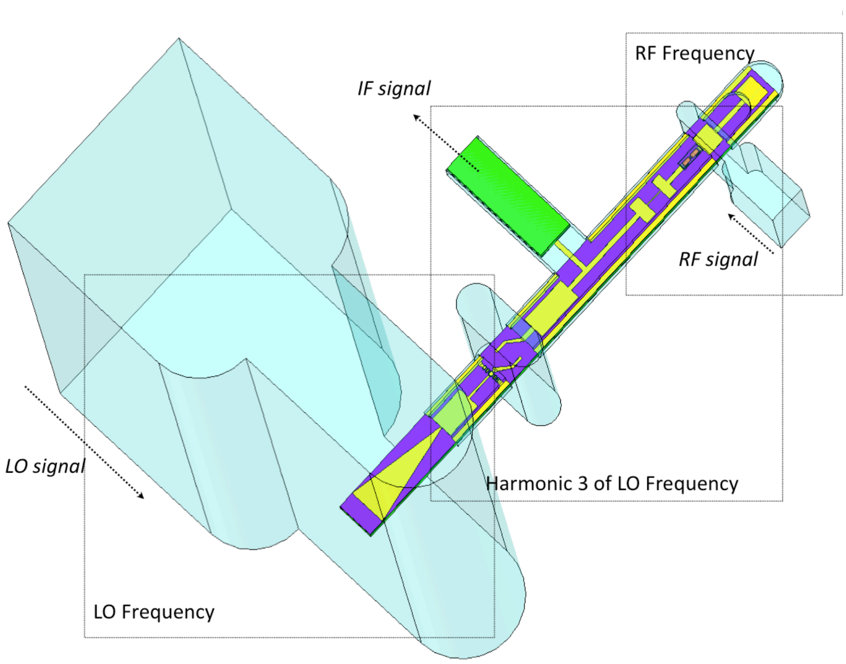
Today the main focuses for sub millimeter heterodyne array of receiver systems are: the injection of the local oscillator signal [4], the optical layout of focal plane elements and the quasi-optic arrangement [5], the calibration of the array, the inter-calibration between pixels, the intermediate frequency amplification and read out and finally the sub-system interfacing. The herein system study focus on the two first main issues, i.e the local oscillator power injection and the spacing between two antenna in the focal plane.

The local oscillator signal injection issue relies on the available high power source in the sub millimeter frequency range [4]. A special care is given in the heterodyne chain to reduce the loss of the local oscillator signal from the source to the mixer, and therefore to reduce this particular interface. A solution is to combine the mixer and the last stage of the multiplier source onto a same circuit. Schottky-diode based combined systems are reported in [6], [7] and in this paper. Another solution for reducing the sub-terahertz frequency interface losses between the detector and source sub-systems is to micro machine receivers on silicon. Very recently a silicon-based layered receiver has been implemented in [8]. The current program focuses on traditional micro machining, which can be performed up to 3 THz.

The 330 GHz compact radiometer element features un-biased subharmonic mixer and a varistor tripler. This system offers several advantages. The first one is that the local oscillator frequency is 60 GHz, where powerful amplifiers are available in this range; moreover coaxial V-connectors are available in this range, which would reduce the back-panel area as compared to standard waveguide flanges. We note that the mechanical waveguide block is splited in two parts in order to reduce the machining complexity but require precise alignment of the back-panel connectors. This alignment and the connector size drive the spacing between antenna axis in the array. Our circuit requires only two connectors in order to have the antenna spacing in line with the requirement of recent instruments studies [5].

3. Combined circuit design for 330 GHz signal detection

Two different configurations can be used in order to integrate the mixer and the frequency multiplier at sub-millimeter frequencies (S-MMIC); either integrate the mixer and multiplier that are based on separate substrate via a waveguide interface as in [7] or combine the mixer and the frequency multiplier on a single substrate. The optimum performance of the mixer and the frequency multiplier generally require respectively different epitaxial thickness and doping layer of the substrate not possible in a fully integrated mixer/multiplier circuit case. Nevertheless, the integration of a mixer and multiplier on a single substrate offers a simpler assembly work and a higher integration level, which are suitable for large array development.



330-360 GHz Combined integrated Tripler /Sub harmonic flip- chip mounted mixer circuit: reported membrane.

This is demonstrated in [6] where a Schottky sub-harmonic mixer / doubler circuit features flip-chip only mounted planar diodes. In this study we propose to combine a MMIC Tripler, which epilayer has been optimized for third harmonic generation [9] with a flip-chip mounted subharmonic mixer.

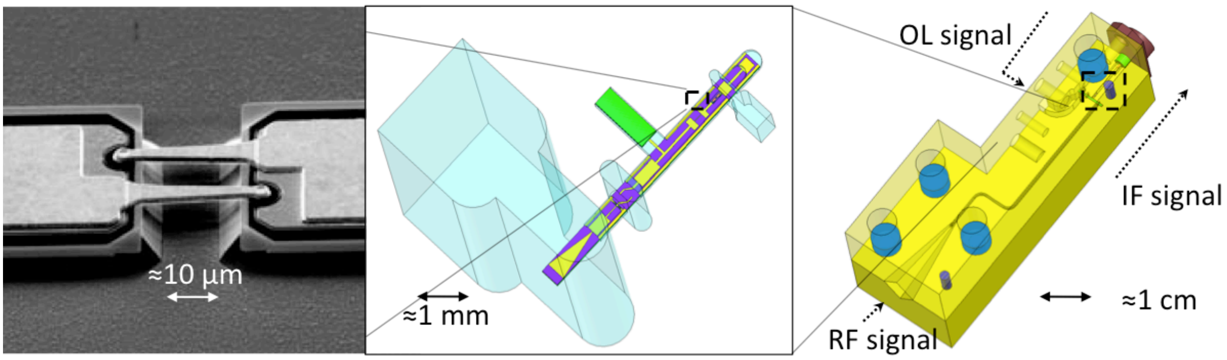
The circuit design complexity lies in its total matching network, which consists of four independent networks in-between the different ports of the structure - from which and to which the different power have to be adapted -, and this over four frequency bands spread between 9 to 360 GHz. In order to reach a RF bandwidth of 300-360 GHz, the frequency bands are set to: LO (50-60 GHz), output signal of the internal frequency tripler (150-180GHz) and intermediate frequency (IF) (9-21GHz). The matching circuit has to fulfill an optimum coupling respectively from the RF antenna input to the mixer diodes, the LO input to the tripler diodes and the tripler diodes to the mixer diodes and finally the IF mixer output, from the mixer diodes to the 50 ohm K-connector standard.

The design methodology consists in several steps involving 3D electromagnetic simulations[1] and linear / non linear (harmonic balance)[2] circuit simulations. As a first step we generate a set of impedance for both Schottky mixer and tripler at every frequency, during a non-linear optimization of the conversion losses. In parallel, each step impedances and waveguide transitions are simulated in their 3-D electromagnetic environment, with appropriate boundaries, waveport assignment and de-embedding planes. The simulation outcomes are 2-D S-parameter matrix and their attenuation, impedances and permittivity values at central guided frequencies that will be used in the linear optimization network. They are combined in a same optimization run for the three RF, LO and tripler output frequency-matching network defined previously. Then the circuit is simulated in its full 3D electromagnetic environment. The last step consists in matching the mixer diodes to the K-connectors at IF.

Several iteration of the circuit structure are necessary to obtain wide band matching, good LO signal isolation from the waveguide input to the mixer cell. For this last issue a novel band-bass cavity 150-200 GHz filter has been developed.

3. Front end receiver fabrication

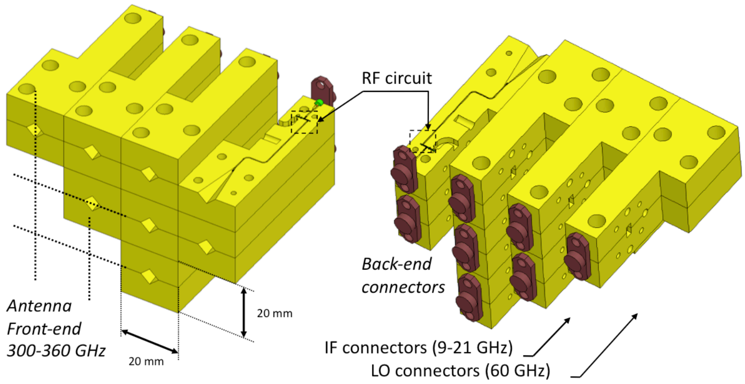
The MMIC features a GaAs membrane reported onto quartz with a post process described in [10] in order to reduce the line dielectric constant and improve its thermal conductivity. The T-shape structure is done with two distinct circuits (RF and IF parts). The mixer grounding is secured by epoxy contact instead of squeezing the beamleads between the two sides of the split bloc. Nevertheless, one central beamlead is still necessary in order perform the IF link between the two parts of the circuit and keep as possible the precision of alignment of the matching network. The tripler grounding is achieved by epoxy contact of the side gold line.



From left to right: Integrated Schottky Diode (Rutherford Appleton Laboratory), Combined Circuit, Full front-end 300-360 GHz element receiver.

This receiver element allows a total coverage of the focal plane in the two dimensions. This gives the possibility to dissociate each element from the array if some maintenance is needed. The spacing between the center of the horn is limited by the size of the standard connectors. In this case the IF connector is a standard K-connector and the LO connector is a WR-229 waveguide.

[1] High Frequency Simulation Software, V10, Ansoft Corporation
[2] Advanced Design System 2005A, Agilent Technologies.



n x m 330 GHz heterodyne receivers array: antenna focal plane front panel, connectors back panel.

4. Conclusion

E-band commercially available power sources are reaching up to 5 W. Therefore the 330 GHz compact radiometer array can handle up to 30-elements (5 x 6) – splitter losses not included - and 100 x 120 mm^2 focal plane coverage with 20 λ of antenna beam spacing. The local oscillator millimeter frequency requirement of the proposed sub millimeter array opens the path to new possibilities of using integrated HEMT amplifiers in the local oscillator chain and V-connector for local oscillator injection.

5. Acknowledgments

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