A Modular Vector Field Measurement System at 150 GHz, 300 GHz and 450 GHz

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Abstract — The paper describes the design and the implementation of a modular high precision heterodyne vector field measurement system at 150 GHz, 300 GHz and 450 GHz. The system uses two channels for the measurement of the magnitude as well as the phase characteristics of an electromagnetic field. The fundamental mixers at 150 GHz respectively the harmonic mixers at 300 GHz and 450 GHz are pumped by a phase locked two-channel local oscillator unit at 150 GHz consisting of a one-channel frequency synthesizer at 9.375 GHz and a frequency multiplier cascade with a 0° power splitter at 75 GHz and two subsequent frequency doublers separately for each channel. The IF receiver unit enables a minimum detection level of -80 dBm with 80 MHz bandwidth at 160 MHz center frequency and a phase uncertainty better than 2 degrees. The RF signal is received by dielectric field probes in both channels and is fed via a flexible dielectric waveguides system to the mixer ports. The dielectric antennas, the flexible waveguides as well as the mixers are modularly mounted on a high precision 3D-scanning platform. A considerable reduction of the measurement time is achieved by moving the measurement probe continuously with exact position triggering by an electronic linear encoder and simultaneous sampling of the measurement values. The measurement accuracy is significantly enhanced by fast software correction algorithms.

I. INTRODUCTION

In the millimeter and sub-millimeter wavelength region above 100 GHz, the availability of tunable and compact signal generators with sufficient output power is a well-known problem which has not been satisfyingly solved so far. One promising strategy to overcome this is to combine the fields of an array of diode oscillators quasi-optically in free space as well as to multiply the resulting fields effectively by quasi-optical frequency multiplier setups.

Flexible dielectric waveguide (150 GHz)

LO

flexible coaxial transmission line

Field probe (reference)

RF

IF

ielding a minimum detection level of -80 dBm with 80 MHz bandwidth at 160 MHz center frequency and a phase uncertainty better than 2 degrees. The RF signal is received by dielectric field probes in both channels and is fed via a flexible dielectric waveguides system to the mixer ports. The dielectric antennas, the flexible waveguides as well as the mixers are modularly mounted on a high precision 3D-scanning platform. A considerable reduction of the measurement time is achieved by moving the measurement probe continuously with exact position triggering by an electronic linear encoder and simultaneous sampling of the measurement values. The measurement accuracy is significantly enhanced by fast software correction algorithms.

Fig. 1. Principle of the heterodyne measurement system

This has been successfully demonstrated at a fundamental frequency of 150 GHz by the MEMSTIC (an acronym for Multi Element Multi Substrate THz Integrated Circuits) project, a joint research project of several German university institutes [1]. For optimizing the efficiency of the sparsely extended quasi-optical holographic power combining setup [2], a vector field measurement system at 150 GHz has been developed [3]. The key components of this system are low-loss flexible rectangular dielectric waveguides (DWGs) made from HD-PE ([4],[5]), to guide the field from the dielectric field probe [6], which is mounted on the moving mechanical scanning system, or from the adjustable reference antenna to the mixers which are directly mounted to the local oscillator system (LO).

Following the basic structure of the system described above, an advanced vector measurement system has been designed recently to fulfill the following extended requirements:

- Vector field measurements at 150 GHz, 300 GHz and 450 GHz by use of one single LO at 150 GHz
- IF receiver bandwidth increase from 40 MHz to 80 MHz, minimum detection power at -80 dBm and a dynamic range of 70 dB
- Reduction of measurement time by continuous instead of stepped field scanning
- Separation of unwanted harmonics by dielectric directional coupler filters

The different components of the measuring system are presented in this paper.

II. THE LOCAL OSCILLATOR SYSTEM AND THE MIXERS

In figure 1, the general setup of the vector field measurement system at 150 GHz, 300 GHz and 450 GHz is shown. In order to enable phase measurements, the heterodyne receiver consists of a signal channel and a spatially fixed reference channel. As both of the fundamental mixers at 150 GHz respectively the harmonic mixers at 300 GHz and 450 GHz have to be pumped by this single local oscillator, 150 GHz was again chosen as LO frequency. To reduce transmission losses caused by the DWGs at 300 GHz and 450 GHz, which are considerably higher than at 150 GHz (150 GHz: 4 dB/m, 300 GHz: 9 dB/m, 450 GHz: <15 dB/m), the lengths of the DWGs at the RF frequency should be kept as short as possible. Therefore, the mixers are mounted on the 3D scanning platform together with the dielectric field probes and the coupler filters.

The LO signals are transmitted via flexible DWGs at 150 GHz. As seen in figure 2, the LO system consists of a one-channel frequency synthesizer at 9.375 GHz and a frequency multiplier cascade with a 0° power splitter at...
75 GHz and two subsequent frequency doublers separately for each channel. It is electronically tunable via a serial interface over the entire LO bandwidth between 145 GHz and 155 GHz. The impedance has to be matched by tunable backshorts at the input and the output of the multiplier heads of the LO as well as the mixers. The LO as well as the mixers have been designed and built by Radiometer Physics RPG in Meckenheim, Germany.

![Diagram](image)

Fig. 2. Principle of the local oscillator system at 150 GHz consisting of a frequency synthesizer at 9.375 GHz and two subsequent frequency doublers separately for each channel. It is electronically tunable via a serial interface over the entire LO bandwidth between 145 GHz and 155 GHz. The impedance has to be matched by tunable backshorts at the input and the output of the multiplier heads of the LO as well as the mixers. The LO as well as the mixers have been designed and built by Radiometer Physics RPG in Meckenheim, Germany.

The conversion loss of the fundamental mixers is 8.5 dB at 150 GHz, 11 dB for the harmonic mixers at 300 GHz and 24 dB at 450 GHz. All mixers convert the received RF signal directly down to the IF center frequency at 160 MHz.

### III. THE INTERMEDIATE FREQUENCY RECEIVER

The intermediate frequency (IF) receiver which performs the vector analysis of the measured signals at 160 MHz±40 MHz is a key component of the system with respect to measurement precision. Figure 3 shows a block diagram of the IF processing unit.

The input signal in both channels is amplified by a low noise amplifier (LNA, F < 2 dB) and bandpass filtered to lower the minimum input level down to -80 dBm. To achieve the required high IF bandwidth, further signal processing is done by a commercially available logarithmic amplifier / limiter amplifier chip (Analog Devices AD 8306). The RSSI (received signal strength indicator) output signal, a DC signal, is directly coupled out of the signal path can be used to monitor the tests have been undertaken with the same signal generator and the same coaxial cables used to calibrate the system.

A small part (-10 dB) of the limited reference signal power acts as "LO channel" for the IQ mixers, the limited reference signal is amplified to 9 dBm. The hereto used amplifier has a very flat gain (ΔP < 0.15 dB) over the entire 80 MHz bandwidth.

A small part (-10 dB) of the limited reference signal power is used to feed a frequency counter. Correspondingly, the power coupled out of the signal path can be used to monitor the measurements by a spectrum analyzer.

The phase between signal and reference channel is measured by an IQ demodulator. The phase information is represented by the in-phase ($\sim \cos(\varphi)$) and the quadrature ($\sim \sin(\varphi)$) output. All components have been integrated in a 19" rack. Special attention has been paid to avoid EMC problems. Both the RSSI signals of the two signal amplitudes as well as both IQ outputs are sampled simultaneously to allow a continuous field scan.

To enhance the measurement accuracy of the IF receiver system, software algorithms for real-time reconstruction of the signal power by linear interpolation as well as a correction algorithm for the phase measurement have been developed in C++. Both algorithms can be loaded as DLL into Visual Basic as well as in graphical programming languages like LabView to allow highest programming flexibility.

The information of the RSSI outputs is stored in a single look-up table for both channels versus power and frequency to reduce the time of loading the data into the RAM of the PC. The amplitude reconstruction algorithm has been examined by random experiments, whereby frequency and power are uniformly distributed. Figure 4 shows the result of such a random experiment. To achieve this extremely high accuracy, the tests have been undertaken with the same signal generator and the same coaxial cables used to calibrate the system.

To improve the phase accuracy, the in-phase and the quadrature voltage from the IQ demodulator are normalized...
(between ±1), and the offset is corrected. The phase is then calculated with these processed values. As the resulting phase error shows periodic behavior over 360°, we further increase the accuracy by subtracting $K \cdot \cos(2\varphi)$ from the angle $\varphi$ calculated before. $K$ is a frequency-dependent correction factor and stored in a look-up table. The remaining error is $< \pm 1.5^\circ$ over full IF bandwidth (compare figure 5).

IV. THE FIELD SCANNING SYSTEM

The mechanical base for the field measuring system is a 3-axis field scanning unit driven by high resolution stepper motors ($0.9^\circ$/step) and ball screws with a thread lead of 2.5 mm, resulting in a spatial resolution of 6.25 µm.

For reducing the measuring time significantly, the field probe, a long asymmetric tapered dielectric antenna [6] is moved continuously parallel to the y-axis. The drive is designed as compact as possible to reduce reflections. The probe is triggered by an electronic linear encoder with a maximum resolution of 1 µm. This high resolution permits a minimum spatial step size of $\lambda/10$ (300 GHz: 100 µm). The encoder position is read out simultaneously with the 4 ADCs sampling the amplitude and phase information to avoid errors due to the movement of the probe.

V. CONCLUSION

A modular high precision heterodyne field measurement system with two channels for vector measurements at 150 GHz, 300 GHz and 450 GHz is presented. One phase locked two-channel local oscillator unit at 150 GHz pumps the mixers at all 3 frequencies. The latter are modularly attached to the field measurement system which allows fast changes between the measurement frequencies. The IF receiver unit offers a minimum detection level of -80 dBm with 80 MHz bandwidth at 160 MHz center frequency and a phase uncertainty better than 1.5 degrees. The measurement accuracy is significantly enhanced by fast software correction algorithms. The RF signal is received by dielectric field probes and is fed via a flexible dielectric waveguides system to the mixer ports. The dielectric antennas, the flexible waveguide as well as the mixers are modularly mounted on a high precision 3D-scanning platform. A considerable reduction of measurement time is achieved by moving the measurement probe continuously with exact position triggering by a linear encoder and simultaneous sampling.

ACKNOWLEDGEMENT

The authors want to express their thanks to G. Bauer, L. Höpfel and J. Popp of the mechanical workshop of the LHFT for their fast, precise and dedicated fabrication of the mechanical components, as well as to O. Wick from the electronic workshop of the LHFT for his support at assembling the IF receiver unit and the many fruitful discussions. The authors also indebted their thanks to H. Trägler from the electronic workshop of the Lehrstuhl für Fertigungstechnik, University of Erlangen, for his invaluable advices.

This work is sponsored by the DFG (German Research Society, Bonn, F.R.G.) which is gratefully acknowledged.
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