# A Broadband Heterodyne Measurement Setup for Active Millimeter Wave Integrated Antennas

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## ABSTRACT

A novel heterodyne measurement setup for the characterization of circularly or elliptically polarized active millimeter wave antennas is presented. The major advantages of this setup are a very broad bandwidth from 75 to 110 GHz, a dynamic range of more than 50 dB and a cross-polarization purity of about 30 dB. This setup has been applied to characterize a circularly polarized active patch antenna. Numerically calculated and measured results of the antenna performance are compared.

## INTRODUCTION

Active antennas are ideally suited as integrated millimeter wave front-ends [1]. An active antenna consists of a planar antenna structure and an integrated active element like a Gunn diode or Impatt diode. The antenna acts simultaneously as a resonator. The spatial coincidence of signal generation and signal transmission avoids transmission lines between the oscillator and the antenna, which suffer from high ohmic and radiation losses at millimeter wave frequencies. Due to the small antenna dimensions monolithic integration of the active antenna is possible resulting in low costs and high reproducibility [2]. Due to these advantages integrated active antennas find various applications in millimeter wave sensor and communication systems. For many applications like rotational insensitive communication systems or sensors for object classification [3] the antennas must be circularly polarized. In order to identify insufficiencies of the design, precise experimental characterization of the antennas regarding radiation pattern and polarization purity is required.

The characterization of planar millimeter wave antennas is a challenging task, since the antenna's feeding line, usually a microstrip line or coplanar waveguide, has to be connected to the hollow guide based test set of a network analyzer without disturbing the antenna's near-field. With active antennas, where no feeding line exists, the situation is even worse. As an alternative scalar measurements have been performed by integrating a Schottky diode in the antenna at the place, where later the active element will be integrated [4], and using this antenna as a detector. This configuration exhibits only a small dynamic range and, thus, is not suited to determine polarization purity. Moreover, for characterization of circularly polarized antennas a linear-circular polarizer has to be employed, which is a very narrow-band device. Thus, no broadband measurements are possible.

## MEASUREMENT SETUP

In order to overcome these difficulties, we developed a novel measurement setup for the characterization of circularly or elliptically polarized active millimeter wave antennas based on a heterodyne detection scheme. The main problem with heterodyne antenna measurement is, that the signal received by the antenna under test (AUT) has to be fed into a mixer, which is a hollow guide harmonic mixer in a conventional antenna measurement system. The basic idea behind our measurement setup is to shift the functionality of the external mixer into the active antenna by using an active antenna structure with integrated

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Schottky diode. The local oscillator (LO) signal is injected into this Schottky diode by radiation coupling, i.e. the signal radiated from a millimeter wave source, which is mounted on the rotary stage together with the AUT, is received by the AUT (see Fig. 1). The actual measurement signal emerges from a stationary horn antenna, is detected by the AUT, and mixed in the Schottky diode with the LO signal. The 20 MHz IF signal is picked up from the DC bias lines of the active antenna by a bias-T and processed by a network analyzer (NWA). The IF signal is transmitted to the NWA by a simple coaxial cable. As one can see, the difficulties in connecting AUT and NWA as discussed above have been completely eliminated.

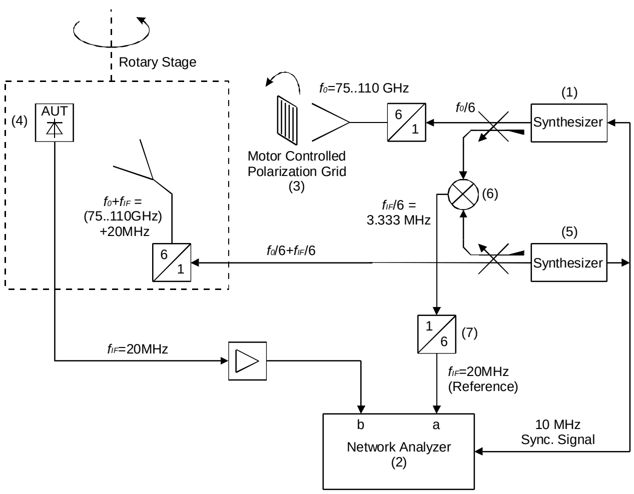


**Fig. 1**: Functional Diagram of the New Measurement Setup.

The NWA measures magnitude and phase of the signal received by the antenna for different operation frequencies, angles of azimuth and angles of elevation.

If magnitude and phase information for a certain AUT is known, the antenna's radiation pattern and the cross polarization discrimination factor (XPD) can easily be calculated [7]: Considering small amplitudes and constant LO power, the magnitude and phase of the detected IF signal is directly proportional to the magnitude and phase of the base-band signal at the detector diode. Let $\underline{U}_x$ and $\underline{U}_y$ be the detected (complex) IF voltages for purely *x*- and *y*-polarized, incident electromagnetic waves respectively. The XPD of the antenna for linear- and circular polarization can now be calculated as given in eqn. (1) and (2).

$$\text{XPD}_{\text{(linear)}} = \left| \frac{\underline{U}_y}{\underline{U}_x} \right| \tag{1}$$

$$\text{XPD}_{\text{(circular)}} = \left| \frac{\underline{U}_x + j\underline{U}_y}{\underline{U}_x - j\underline{U}_y} \right| \tag{2}$$

As the used NWA (HP 8510B) is only capable to measure magnitude and phase of a fixed 20 MHz frequency, additional components are required. Suppose the antenna has to be characterized at the frequency $f_0$ in the W-band, a synthesizer (1), synchronized with the NWA (2), is generating a RF-signal $f_0/6$, which is applied to a 6$^{th}$ - harmonic millimeter wave source module. The generated electromagnetic wave is radiated by a linearly polarized horn antenna, which is mounted at a 45 degree twist with respect to the horizontal plane. A motor-controlled polarization grid (3) selects either horizontal or vertical polarization. At a distance of 1.5 m, the AUT is mounted on a rotary stage capable of adjusting both angle of azimuth and angle of elevation of the antenna (4). In the vicinity of the AUT (typical distance: 20cm), a second millimeter wave source module, driven by a second synchronized synthesizer (5) radiates the LO signal $f_0$ + 20 MHz as discussed above. In order to measure the 20 MHz IF signal, the NWA requires a reference signal. Please note that due to the discrete frequency resolution of the synthesizers, the IF-frequency may be not exactly 20 MHz. Thus a reference signal has to be generated from the synthesizer output signals by the discrete output frequencies of both synthesizers (6). The resulting IF/6 (3.333.. MHz) is converted by a 6$^{th}$ harmonic frequency multiplier (7) to the final reference signal. All system components (including the motor-controlled polarizer) are controlled by a PC, providing fully-automated measurement and data storage.

## EXAMPLE: CHARACTERIZATION OF A CIRCULARLY POLARIZED PATCH ANTENNA

As AUT, we used a novel purely planar silicon integrated W-band direct detection receiver. The layout of the antenna is shown in Fig. 2. Both almost-quadratic patches support two fundamental modes ($TM_{01}$ and $TM_{10}$). Properly adjusting the aspect ratio of the patches and positioning the feeding point of the patches yields phase quadrature, and hence circular polarization. A Schottky diode is located at the center of the antenna. Two impedance transformers connecting the diode to the patches are used to match the impedance of the patches and the Schottky diode. The biasing network supports both the IF signal and the bias current. A two-step approach was used to design the antenna. In a first step, we used a simple transmission line equivalent circuit model of the antenna to obtain a rough estimate of the antenna's dimension. In a second step, this was used as an initial guess for an EM simulation and optimization process based on the combination of a method of moments (MoM) and a nonlinear simplex algorithm [5,6]. The optimization accounts for the impedance transformer's and biasing network's parasitic radiation.

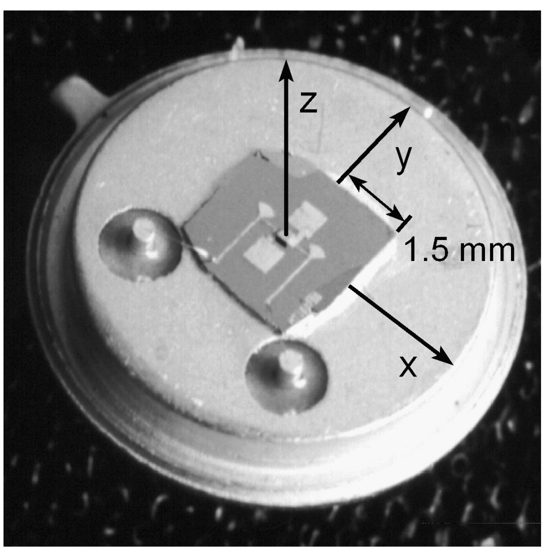


**Fig. 2:** Circularly Polarized Active Integrated Antenna for 76.5 GHz used as AUT [6].

RESULTS

The diagrams in Fig. 3 and 4 show the calculated and measured characteristics of the AUT for an angular scan of azimuth and elevation. As can be seen, calculated and measured curves agree very well. Only for large angles of elevation or azimuth, major deviations of the cross polarization pattern can be observed. We attribute this as well as the ripple of the measured curves to the finite lateral extent of the substrate. In the calculations infinite lateral extent of the substrate of has been assumed. The figures demonstrate the impressively large dynamic range and high polarization purity. The dynamic range of the measurement setup was calculated to be 56dB. As the polarization grid suffers from a finite XPD of approximately 30dB, a (worse case) measurement uncertainty of 1.5dB has to be considered.

Fig. 5 shows the frequency dependence of the measured XPD of the antenna. It can be seen that the optimum XPD is obtained at 76 GHz while the desired frequency of operation has been 76.5 GHz. The noisy parts of the curve at higher an lower frequencies result from the decreasing sensitivity of the antenna. The asymmetry of these noisy parts with respect to the maximum of the curve indicate the fact that maximal sensitivity of the antenna is obtained for a frequency of 77 GHz. Obviously the optimizer could not simultaneously maximize sensitivity and XPD and, thus, found a compromise between both optimization targets. This figure highlights the essential benefit of high dynamic range, high polarization purity, and broad bandwidth of the measurement system for a reliable design of planar and active millimeter wave antennas.

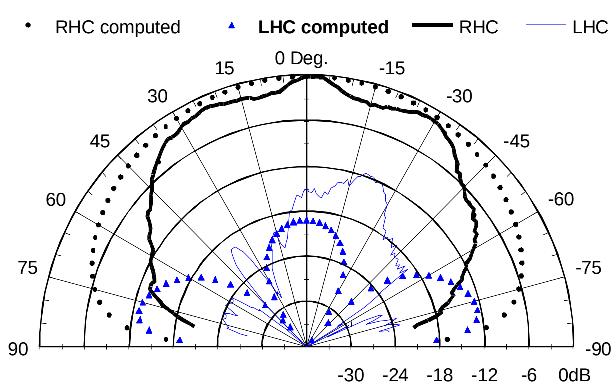


**Fig. 3:** Computed and Measured Normalized Detection of Incident LHC and RHC Polarized Waves Plotted over an Angular Scan in the *x*-*z* Plane at the Design Frequency 76.5 GHz.

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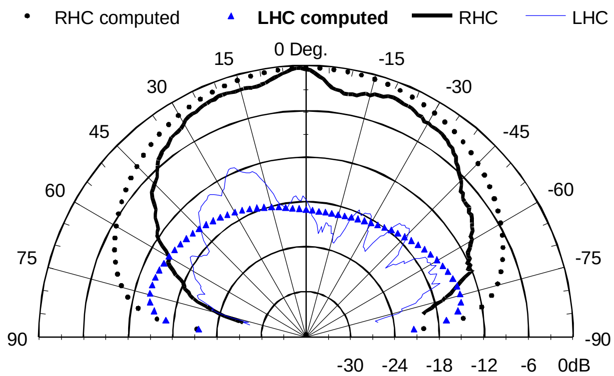


**Fig. 4:** Computed and Measured Normalized Detection of Incident LHC and RHC Polarized Waves Plotted over an Angular Scan in the *y-z* Plane at the Design Frequency 76.5 GHz.

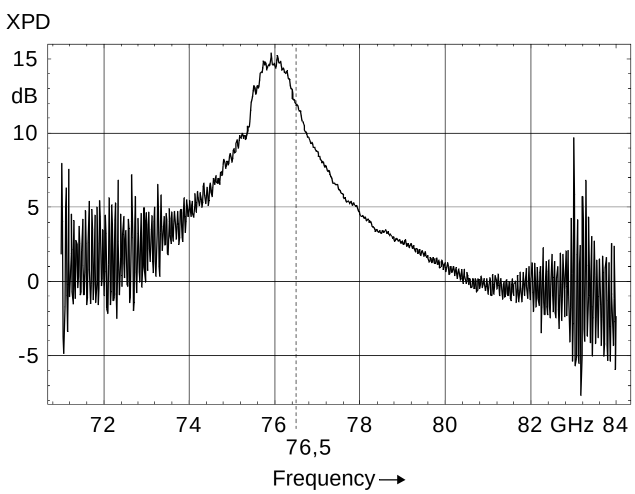


**Fig. 5:** Measured XPD of the AUT plotted over a frequency range from 75 to 84 GHz.

## CONCLUSION

A new, broadband measurement setup for the characterization of active millimeter wave antennas has been presented. The new setup is capable to measure antennas in the whole W-band (75-110 GHz) and features a dynamic range of more than 50dB. When measuring circularly polarized millimeter wave active antennas, a cross-polarization purity of about 30dB is obtained over the whole bandwidth. Using a new integrated circularly polarized active antenna as antenna under test, a fair match between numerically calculated and measured data has been obtained.

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