LOW-NOISE ACTIVE RECEIVING ANTENNAS

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ABSTRACT

Microwave antennas integrated with active elements - or active antennas - have found a wide interest in the last years. In this contribution, two different receiving antenna arrangements - with two different types of active elements - are presented. The first one concerns a slot-coupled patch antenna integrated with a FET amplifier, resulting in a very low noise figure combined with considerably improved bandwidth compared to the respective passive antenna. This type of structure equally can be used in an active transition from microstrip to waveguide. The second example is a low-noise active receiving antenna based on a printed dipole and a Si/SiGe HBT in the 5.8 GHz band which might favorably be used in low-cost ISM applications. Design consideration, realization and results of these components are described in detail.

INTRODUCTION

In contrast to conventional arrangements - antenna and active element are separately optimized and matched and therefore can be operated independently - active antennas represent an integral set-up of both antenna element and active device where improved performance is achieved due to the close interaction of both. Most active antennas are transmitting antennas incorporating Gunn elements or FET oscillators; some of them are operated in a receiving mode /1/-/3/.

In this contribution, two different active receiving antennas are presented, one using a slot coupled microstrip patch antenna with a GaAs FET as active element, the other one is based on a printed dipole together with a SiGe HBT. For a receiving antenna, minimum noise figure is of prime importance, therefore, in both cases, antenna element and active device are integrated and optimized towards this goal. Knowing the impedance of the device for minimum noise figure, the antenna element is modified or slightly matched to present this impedance to the device. In this way, losses of matching networks can be avoided or minimized, and partly, an increased bandwidth can be achieved compared to a conventional design.

SLOT COUPLED MICROSTRIP PATCH ANTENNA

Slot coupled microstrip patch antennas have proven as a versatile planar antenna structure, as different substrates for the patch and for the feeding network are used and may be selected for optimal performance of both antenna and feeding structure. In addition, radiating elements and feed lines are fairly well decoupled so that the radiation diagram basically is not affected by feed line radiation, see Fig. 1. Due to the increased number of design parameters, full wave calculations are important for this type of antenna, e.g. /4/. Once these are available, the design of such antennas can include all parameters for optimal performance. For the active antenna presented here, this procedure was applied to optimize for minimum noise figure and maximum bandwidth around 10 GHz. A packaged GaAs MeSFET (CFY 25 from Siemens, gate length 0.5 µm, gate width 240 µm) serves as active element. The substrate material for the antenna element is a Duroid material of 1.58 mm thickness with a dielectric constant of 2.35. For the feeding line - and therefore for the amplifier circuitry - a material with a dielectric constant of 10.8 and a thickness of 0.635 mm was selected. This results in a good antenna efficiency on the one hand, and, on the other hand, suitable transmission line dimensions with low radiation for the amplifier.

In this example, a feed line characteristic impedance of only 20 Ω was chosen according to the real part of the device impedance for minimum noise figure. The length of the transmission line between slot position and active device as well as the length of the microstrip line extension on the other side of the slot (Fig. 2) then were optimized for a minimum noise figure over a bandwidth as large as possible. The transistor is operated at a drain-source voltage of 3 V and a drain-source current of 10 mA. H-plane radiation characteristics of this antenna are plotted in Fig. 3 compared to those of a respective passive antenna resulting in a gain of about 10 dB.

Noise measurements in non-insertable components like antennas require special precautions. The signal of a noise source may be radiated to the antenna; in this case some amplification of the noise signal is necessary to compensated the path losses between the antennas. Furthermore, a thorough calibration including these losses has to be done. The receiver, on the other hand, evaluates the signal over a rather small bandwidth only; thus nearly a sinusoidal signal results. Therefore, instead of a noise signal, a CW signal was used for the noise measurement; for calibration purposes, a passive antenna served as reference. Tests with insertable components did not show a difference in the results between a standard noise measurement and this procedure.

"Power gain" of an active antenna - i.e. the gain of the passive antenna plus the amplifier gain - can be measured in comparison with a standard gain horn.

Fig. 4 displays power gain and noise figure of the active antenna compared to the minimum noise figure of the transistor. Due to the noise figure measurement procedure as described above, the noise figure of the active antenna does not include the antenna element losses, but these are supposed to be relatively low. Both power gain (which theoretically should increase with f^2) and noise figure show a bandwidth of approximately 1.6 GHz, or 16 %. As the respective passive antenna exhibits a bandwidth of 6 % only, this shows clearly the potential of active antennas.

ACTIVE PRINTED DIPOLE ANTENNA USING A Si/SiGe HBT

Due to the microwave frequency range, most active elements are based on GaAs. For mobile communication or local area network (LAN) applications, silicon still is the preferred material due to its mature technology and its compatibility with digital integrated circuits. With increasing frequency, Si/SiGe heterobipolar transistors (HBTs) have proven as an alternative to GaAs MeSFETs; even low noise performance has been demonstrated /6/, /7/. Therefore, Si/SiGe HBTs were investigated as active elements in a low noise active receiving antenna in the 5.8 GHz range which is of interest for LAN and applications like identification cards or intruder alarm.

As active device, a Si/SiGe HBT provided by the Daimler-Benz Research Institute in Ulm is employed. For the antenna element, a dipole is used printed on a thin dielectric sheet (Duroid material, substrate thickness 0.254 mm, dielectric constant 2.22) and placed a quarter wavelength in front of a metal plate (Fig. 5, left side). In the area of the amplifier, an additional back side metallisation of the substrate is provided. For low noise performance, the input impedance of the dipole has to match the impedance for minimum noise figure of the transistor. For the antenna presented here, a dipole length of $l/\lambda=0.28$ gives an input impedance close to the device impedance for minimum noise. The optimal impedance then is achieved with a shunt inductance realized by a thin microstrip line stub. Output matching is done with a stub, too. Stability of the amplifier is assured employing a series resistor (330 Ω) at the collector and a 50 Ω resistor in series with a capacitor to ground placed at the "cold" position of the input matching stub. This last measure does not affect the amplifier at the center frequency of 5.8 GHz, neither does it deteriorate the noise figure, but contributes considerably to stability outside the band of operation. The complete layout of the amplifier including additional discrete quasi-concentrated devices and the DC network is presented in the right part of Fig. 5 (see /8/).

Fig. 6 shows the output return loss of the active antenna. The experimental results indicate a -15 dB bandwidth of about 15%. At 5.8 GHz, the power gain compared to a passive, impedance matched antenna amounts to 8.3 dB and the noise figure to 1.4 dB, very close to the minimum noise figure of the HBT (Fig. 7). For this antenna, the noise figure was measured radiating an amplified noise signal to the active antenna, calibrating the resulting excess noise ratio (ENR) with a passive antenna. As a consequence again, the noise figure does not include losses of the dipole itself; these however, are very small. The theoretical noise figure was calculated based on the measured noise performance of the HBT. Due to a slightly different radiation diagram of the passive antenna with increasing frequency (different impedance match and therefore slightly different current distribution on the dipole), the evaluation of the experimental noise figure resulted in a value slightly too low at 6.2 and 6.4 GHz.

The radiation diagrams of the active antenna in E- and H-plane are plotted in Fig. 8, showing, as expected for the small antenna size, wide beamwidths. The ripple in the curves is due to the finite size of the backside reflector plate.

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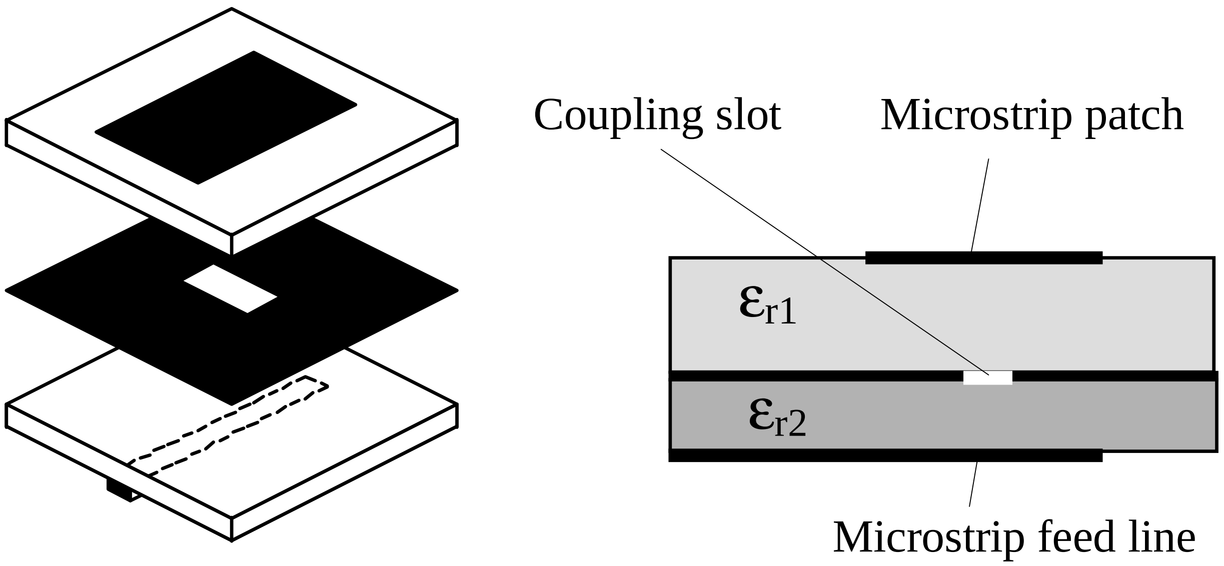


Fig. 1: Exploded view and cross section of a slot coupled microstrip patch antenna.

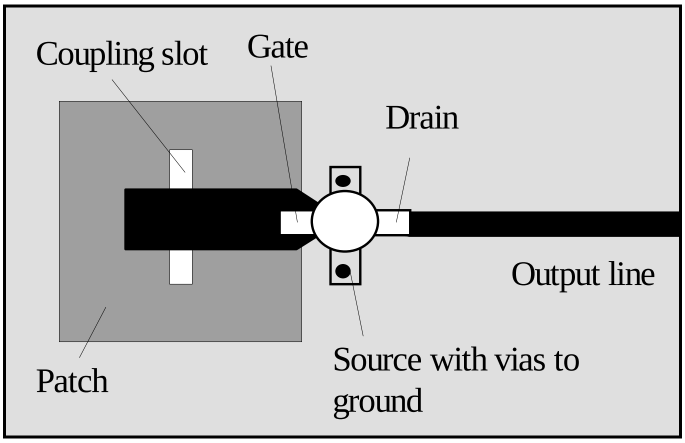


Fig. 2: Basic layout of active antenna based on a slot coupled patch antenna.

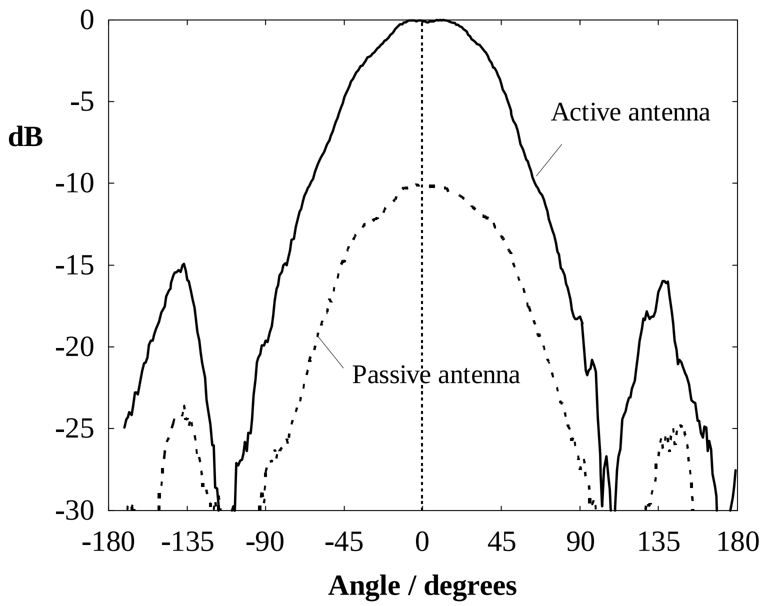


Fig. 3: H-plane radiation diagram of active and passive slot coupled patch antenna.

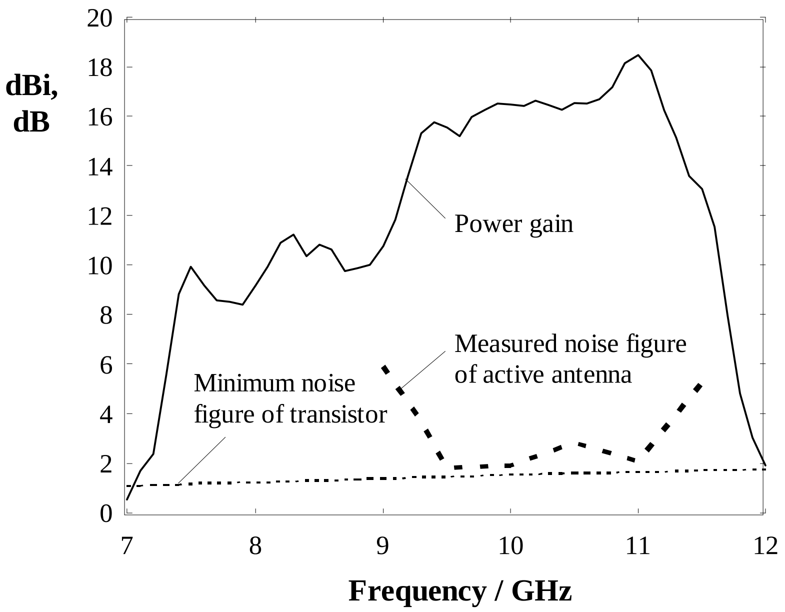
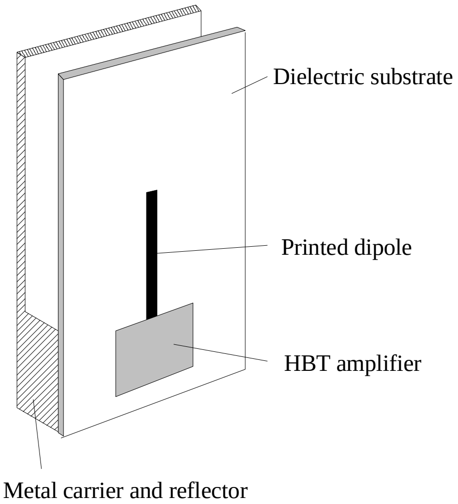


Fig. 4: Power gain and noise figure of active of active slot coupled patch antenna. For comparison, the noise figure.



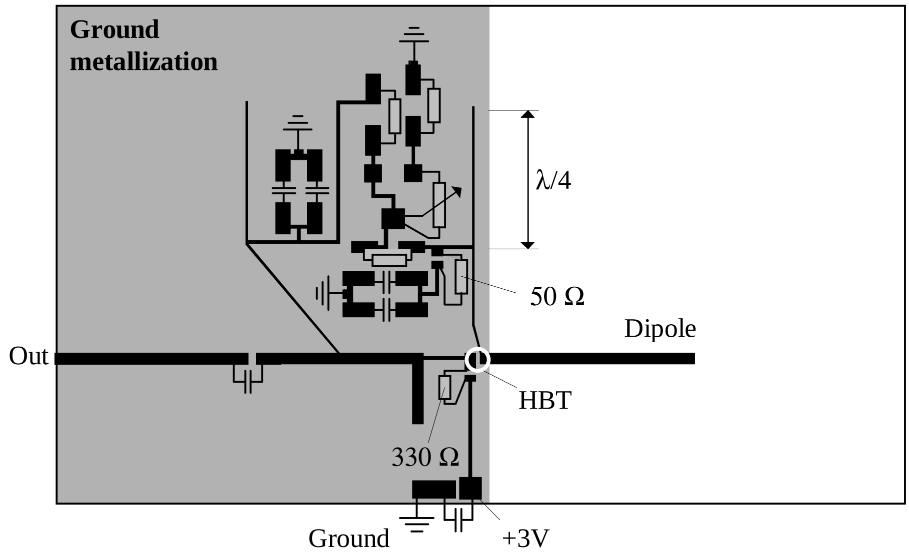


Fig. 5: Basic setup and layout of active dipole antenna.

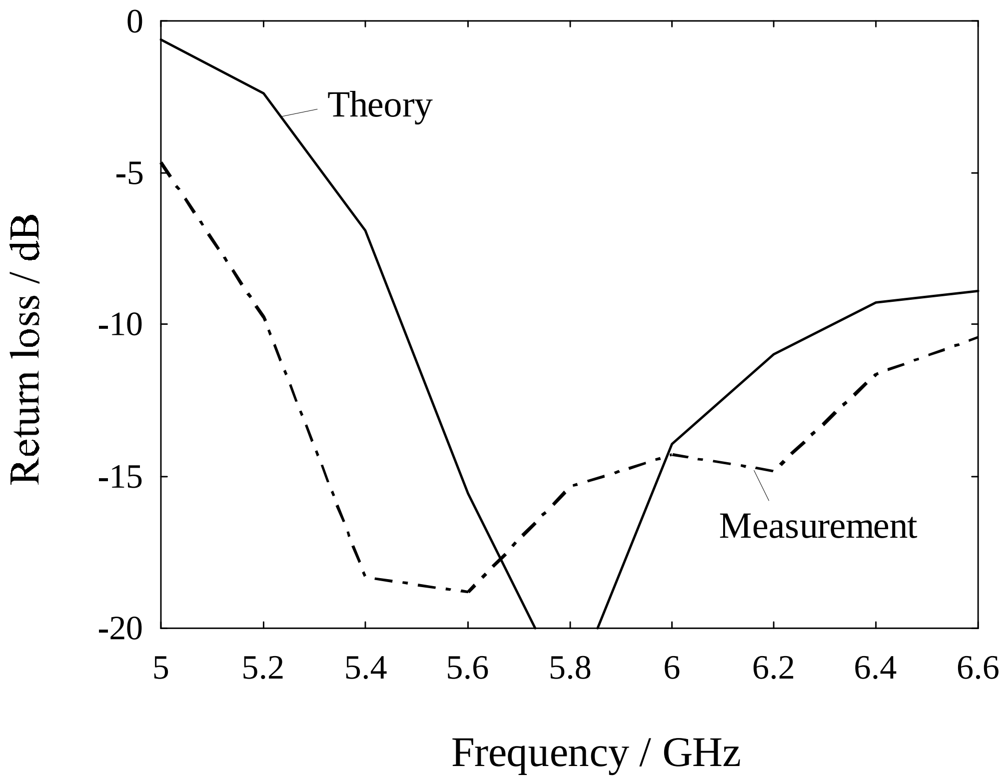


Fig. 6: Output return loss of active dipole antenna.

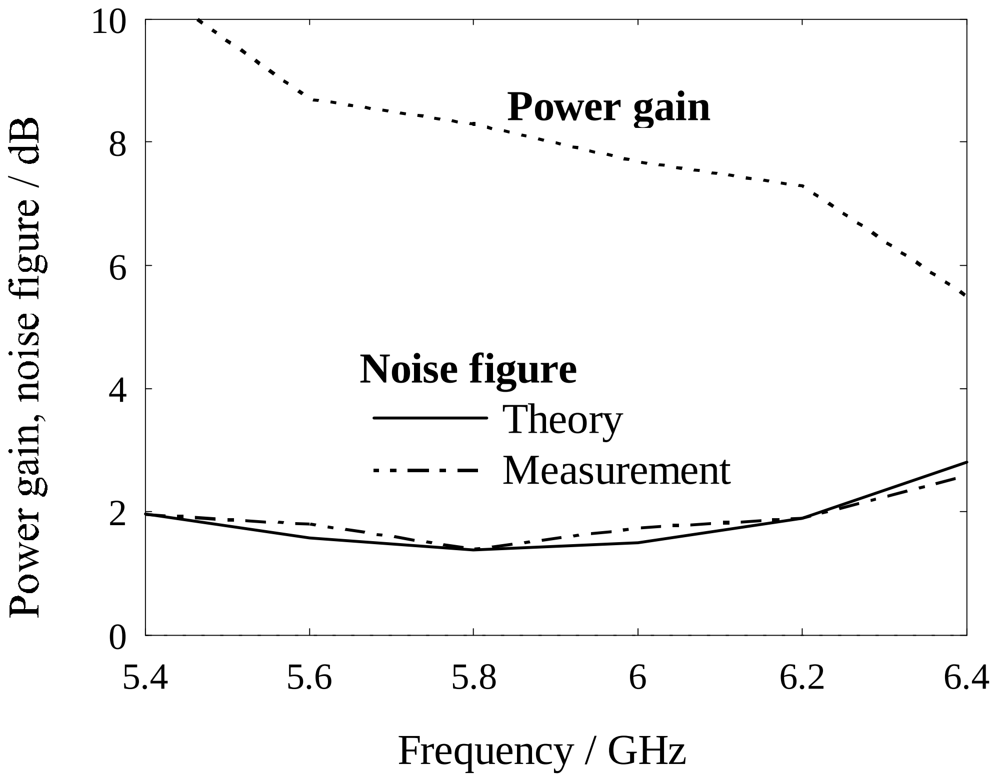


Fig. 7: Experimental power gain (compared to a passive antenna) and noise figure of the active antenna.

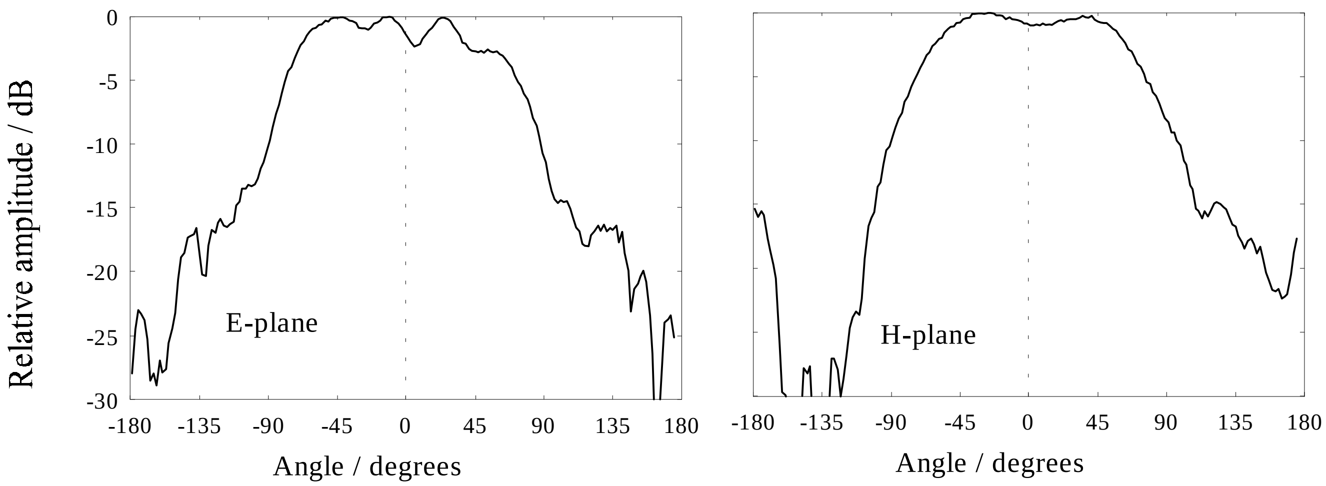


Fig. 8: E- and H-plane radiation diagram of the active antenna (f=5.8 GHz).