A Differential Active Patch Antenna Element for Array Applications

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***Abstract*—This letter describes the implementation of an active receiving antenna at 5–6 GHz. An aperture-coupled patch antenna is designed to provide a differential interface toward monolithically integrated circuits. The integration with a low-noise amplifier is shown. The proposed structure offers new advantages for the construction of compact and robust adaptive antenna arrays.**

Measurements show around 5.5 dBi antenna gain with a cross-polarization below −27 dB. The differential low-noise amplifier provides more than 10 dB gain improvement.

***Index Terms*—Active antennas, active arrays, differential amplifiers, LNA, MESFET integrated circuits, microstrip antennas, wireless LAN.**

I. INTRODUCTION

RECENTLY, smart antennas have received increasing attention for their possible use in future communication systems. They are believed to be one of the most important measures to increase capacity in cellular mobile-radio systems. New wireless LAN standards such as HIPERLAN/2 and IEEE 802.11a work at sufficiently small wavelengths to make compact smart antenna arrays feasible. The key demands for those applications are low costs, robust and compact design. Therefore, it is desirable to integrate each single antenna element with a monolithic RF frontend.

Those frontends often are implemented using differential techniques, especially when image-rejecting architectures are chosen [1]. Furthermore, using balanced circuits, the crosstalk over common bias lines can be reduced significantly. As on-chip single-ended-to-differential conversion is linked with losses, a differential antenna signal is needed. A suitable antenna structure can be used as an almost lossless power divider [2].

An aperture-coupled patch antenna is well suited for the use in active arrays, because its fabrication is simple due to its planar nature. Additionally it is compatible with microstrip circuitry and monolithic integrated circuits. In this letter, the design of a differential aperture-coupled patch antenna is presented. Its successful integration together with a differential monolithic low-noise amplifier is further demonstrated.

II. ANTENNA DESIGN

Fig. 1 shows the basic structure of an aperture-coupled patch antenna [3]. Two independently chosen substrates carry a radiating patch and microstrip circuitry including a feed line for the antenna respectively. Magnetic coupling between patch and feed is ensured by a slot in the common ground plane.

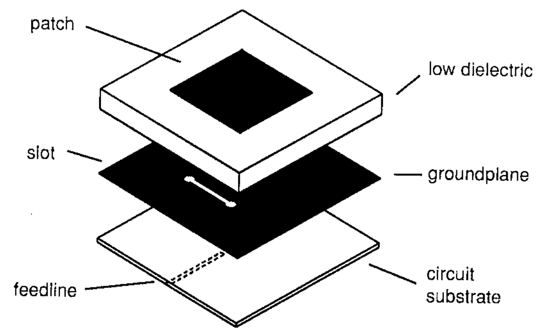

Fig. 1. Exploded view of aperture-coupled patch antenna.

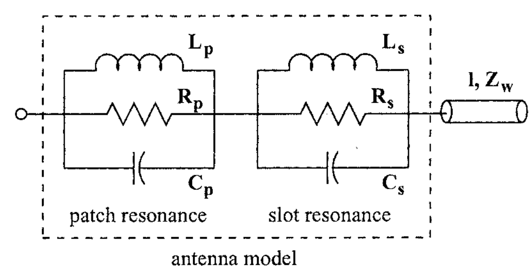

Fig. 2. Lumped element equivalent circuit.

For this design, Duroid 6010 ($\epsilon_r = 10.2$, $h = 635$ μm) is desired as the circuit substrate. To support the patch, a thick, low dielectric substrate (Polyguide, $\epsilon_r = 2.32$, $h = 3.175$ mm) is selected.

Employing two slots, the symmetric field distribution of the patch antenna is used to obtain the wanted balanced output.

The differential input impedance of the antenna was approximated using the two resonator model depicted in Fig. 2. The element values were determined from field simulations with HP-HFSS.

The two lumped resonators can be associated with the patch resonance and the resonance of the coupling slot. The geometry of the slot was chosen to meet the bandwidth requirements. The "dogbone" slot provides the highest bandwidth among the common geometries [4]. The value of the radiating resistance was set varying the slot area.

The slot is driven below its self resonance to avoid radiation to the backside. At the working frequencies, this adds an inductive part to the input impedance. To obtain matching, the endings of the feed lines form open stubs that act capacitively. The neces-

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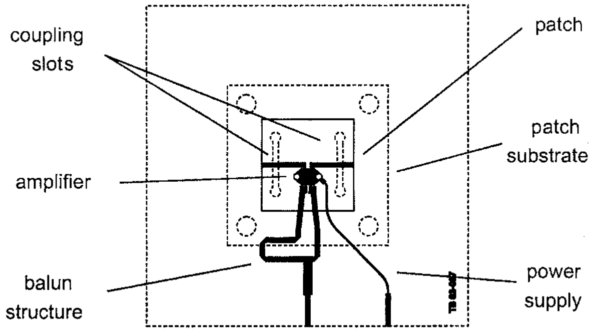

Fig. 3. Layout of differential active antenna.

sary capacity can be directly computed from the element values of the used model.

Employing the above design method, different possible slot arrangements were investigated. The layout seen in Fig. 3 was chosen, because it gives the most compact design at the expense of a reduced front-to-back ratio.

III. Low-Noise Amplifier

The employed low-noise amplifier was fabricated using the Triquint TQTRx 0.6 μm GaAs process, which offers enhancement and depletion mode MESFETs with an F_t of 20 GHz and on-chip spiral inductors with quality factors of about 20 at 5 GHz.

The differential amplifier design was started with a single-ended stage based on the source degeneration technique: An inductive source feedback was chosen to provide a real input impedance which is noiseless. Furthermore the optimal reflection coefficients for noise and power matching, Γ_{opt} and Γ_{sm1}, move together. The remaining impedance transformation was done using reactive components.

The resulting stage was used to form the differential couple. To guarantee common-mode stability, the virtual grounds were loaded with resistors, which do not affect the differential noise performance.

The amplifiers output was kept differential without any internal conversion to provide the signal as it would be used in an integrated system.

One amplifier from the same wafer was bonded to a test substrate including two microstrip baluns for single-ended to differential conversion. Measured gain is more than 12 dB, with a noise figure between 3 dB and 3.5 dB.

IV. Measurements

Two different antennas were manufactured: A simple passive antenna and one active antenna using the monolithic low-noise amplifier described above. The layout of the active antenna is shown in Fig. 3. To allow measurements, both circuits use a microstrip balun to obtain a single-ended output. For later applications this balun would be omitted to interface directly with a balanced mixer.

Both structures were measured inside an anechoic chamber using a Narda 642 standard gain horn. The measured gain in Fig. 4 shows about 5.5 dBi gain for the passive structure. The active antenna has 14 dBi to 17 dBi over the 5–6 GHz band. Both curves show some ripple over frequency which is due to the presence of the connectors.

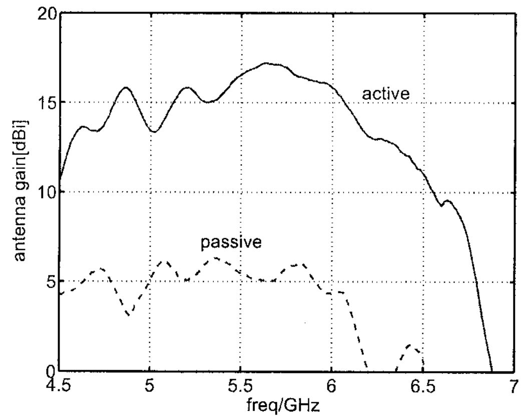

Fig. 4. Gain of active (—) and passive (- - -) antenna.

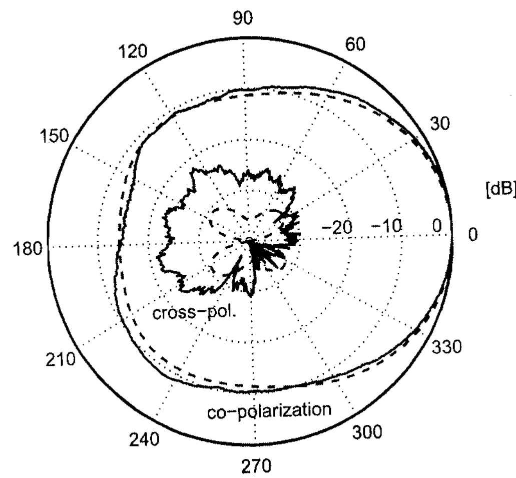

Fig. 5. Measured (—) and simulated (- - -) E-plane pattern at 5.8 GHz of passive antenna.

For comparison with a standard system, where antenna and amplifier are separated, the transducer gain of the embedded amplifier can be calculated if the gain of the active antenna and of a passive reference are known [5]. The computation using the averaged gain curves lead to 10 to 12 dB gain over the band, where it has to be mentioned that the integrated amplifier was drawing less current than the amplifier used in the test environment. Therefore it is believed to show less gain.

Fig. 5 shows the measured and simulated pattern of the passive antenna at 5.8 GHz. The agreement between measurement and simulation is good regarding the co-polarization. The sensitive measurement of the cross-polarization is influenced by the near connectors as well as by the balun structure on the backside (90°–270°). The antenna pattern was found to be similar over the whole band. The diagram of the active antenna depicted in Fig. 6 shows no remarkable change, except of the different cross-polarization pattern. The measured front-to-back ratio is higher than 8 dB, the cross-polarization is better than 27 dB.

Fig. 7 shows a photography of the manufactured active antenna.

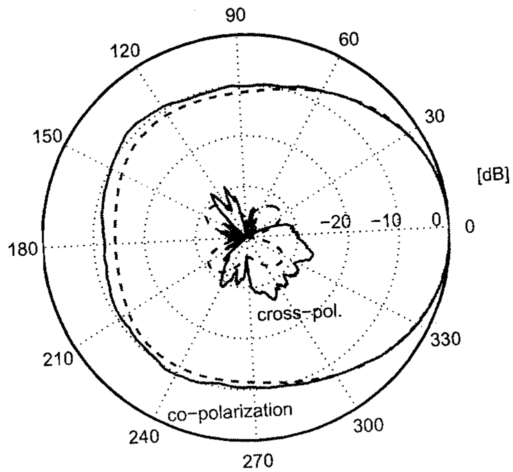

Fig. 6. Measured (—) and simulated (- - -) E-plane pattern at 5.8 GHz of active antenna.

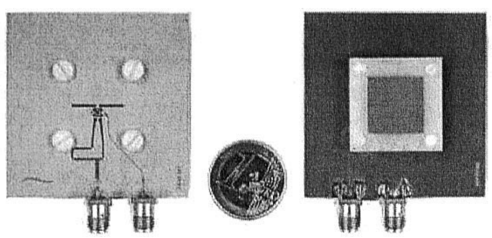

Fig. 7. Manufactured differential active antenna (substrate size is 50.8 mm × 50.8 mm, core element without balun 25.4 mm × 25.4 mm).

V. Conclusion

A differential aperture-coupled patch antenna is proposed to provide an air interface to monolithically integrated circuits. The antenna gain is around 5.5 dBi over the 5–6 GHz band. The integration with a monolithic low-noise amplifier is shown. The gain is improved up to 17 dBi without changing the antenna characteristics noticeably. Cross polarization is below −27 dB.

Due to its compact size, the obtained active antenna element can be applied to larger antenna arrays. The use of a differential layout can reduce significantly the coupling between receiver paths over the common supply. This leads to an easier and more compact design.

Furthermore the presented antenna structure can be used to interface with monolithic differential downconverters without the use of additional lossy balun structures offering a new possibility to build compact and cost-effective smart antenna arrays.

To our knowledge this is the first time that an aperture-coupled patch antenna is used to connect a monolithic amplifier in the proposed way.

Acknowledgment

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