Doctoral Thesis

Active antenna radio frontends for multiple antenna communication systems

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ACTIVE ANTENNA RADIO FRONTENDS
FOR MULTIPLE ANTENNA COMMUNICATION SYSTEMS

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presented by
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Abstract

Goal of the work presented in this dissertation is to implement and characterize a 5 GHz active antenna array. Planar aperture-coupled patch antennas and monolithically integrated active circuits are combined to yield a compact, robust and easy-to-manufacture multiple antenna frontend. The realized hardware is intended for the use in both, in multiple antenna wireless LAN systems and for a multi-dimensional channel sounding equipment.

To enable the application in the measurement system, the frontend is optimized for low-noise and high linearity. A classical superheterodyne architecture is chosen to maintain flexibility when adopting the system to different environments. An internal calibration signal is provided at all receiver inputs to determine and compensate all variations of the active hardware.

A commercially available 0.6 µm GaAs MESFET process is used to integrate the complete RF-frontend, including low-noise amplifiers, a lumped-element image filter and downconverter, onto a single chip of 3.2 mm². Thereby, a state-of-the-art single side-band noise figure of less than 4 dB and an image rejection of more than 35 dB are reached. An active switching concept is proposed to select between receiving and calibration mode without degrading the noise figure. To evaluate the ability of modern silicon-based technologies, an 11 GHz receiver frontend is demonstrated on a low-cost 47 GHz SiGe process. Using the MOSFET device to form a resistive mixer, a single-sideband noise figure of 7 dB and a input compression point of $-14$ dB can be realized at the same time.

Through the development of an equivalent circuit model, an efficient design of the passive antenna structure for given specifications is facilitated. The model is heuristically extended to include the mutual coupling between adjacent elements. The co-design of the receiver and the antenna structure allows to optimize the common interface. A differential antenna interface and the reduction of mutual coupling by controlling the antenna termination impedance are both experimentally verified.

The realized four element active integrated antenna array reaches an excellent long-term stability of transmission gain and phase. For a com-
Abstract

Complete receiver system, including conversion to the digital baseband, gain variations of less than ±0.1 dB are measured over three days in an office environment. These fluctuations are mainly due to changes of the ambient temperature and are similar for all channels. The resulting distortions of the array pattern, therefore, stay even lower. The dynamic behavior of the transfer functions is studied for the case of jointly switched power amplifiers, which experience strong thermal changes due to self heating. It is found, that fast changes are correlated well for the employed monolithically integrated circuits. For typical burst lengths up to several milliseconds it is demonstrated that no significant pattern error occurs.

On a system level, the noise correlation between the individual channels is studied. Some correlation of the receiver noise was noticed due to correlated spurious occurring in the digital receiver part. A small phase decorrelation with a $1/f$-characteristic is found, which is almost negligible for most practical applications.

Furthermore, available calibration methods are studied and applied to the active array. The effect of mutual coupling is removed using an inverted coupling matrix. Over a the range of the element beam-width the behavior of the calibrated array can be approximated by the simple geometrical ray-model. A novel transmission line method is proposed, which allows to calibrate the variations of the active circuits without the need for a precise divider network.

With the help of the new calibration method and the highly integrated frontend a novel type of conformal active array is demonstrated. The circuitry is first assembled in standard planar technology and then bent to the final shape, which enables a low cost production. Further advantages of this array are a reduced mutual coupling and a wider angular range of operation.
Zusammenfassung


Um eine Anwendung im Messsystem zu ermöglichen, ist das Frontend auf niedriges Rauschen sowie eine hohe Linearität optimiert. Eine klassische Überlagerungsempfänger-Architektur wurde ausgewählt um die nötige Flexibilität sicherzustellen, wenn das System an verschiedene Umgebungen angepasst werden soll. Die Variationen der aktiven Schaltungen können mit Hilfe eines Kalibrationssignals bestimmt und kompensiert werden.


Durch die Entwicklung einer Ersatzschaltung kann der effiziente Entwurf der passiven Antennenstruktur nach gegebenen Spezifikationen vereinfacht werden. Das Modell wird heuristisch zur Erfassung der gegenseitigen Antennenkopplung zwischen benachbarten Elementen erweitert.
Zusammenfassung

Der gleichzeitige Entwurf von Empfänger und Antennenstruktur erlaubt die gemeinsame Schnittstelle zu optimieren. Sowohl eine differentielle Antennenschnittstelle, als auch die Reduzierung der gegenseitigen Antennenkopplung durch die optimale Wahl der Antennenfusspunktpedanz werden beide experimentell bestätigt.


Mit Hilfe des neuen Kalibrationsverfahrens und den hochintegrierten HF-Frontend kann eine neue Art von konformen aktiven Arrays demonstriert werden. Die Schaltung wird zunächst in gewöhnlicher planarer Technologie hergestellt, um dann in die endgültige Form gebogen zu werden, was eine kostengünstige Produktion ermöglicht. Weitere Vorteile dieses Antennenarrays sind eine geringere Antennenkopplung und ein größerer abgedeckter Winkelbereich.