A Low Noise Active Integrated Antenna Receiver for Monopulse Radar Applications

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***Abstract* — A low noise active integrated antenna receiver is presented. This new design consists of a pair of low noise amplifiers (LNA) integrated on each feed of a dual-feed planar quasi-Yagi antenna. The outputs of the LNAs are combined to form a sum and difference radiation pattern suitable for monopulse radar applications. Simulation and measurement methodology for designing a low noise active integrated antenna receiver is also presented. A peak gain of 7.7 dB and minimum noise figure of 3.6 dB is measured for a C-band prototype.**

I. INTRODUCTION

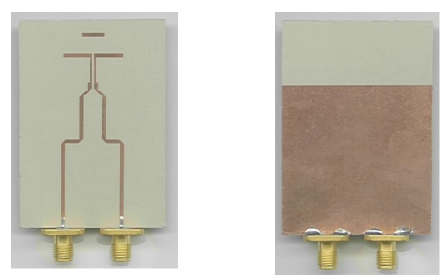
A high degree of interest remains in developing economical and compact radar systems for automotive applications, as such systems are still only available in high-end luxury cars and experimental systems. The cost and complexity of such systems still must be reduced. Thus, the concept of active integrated antenna, in which the circuit is matched directly to the antenna rather than a 50 ohms common interface, can be used advantageously to enhance the design and performance of the radar front-end.

The planar quasi-Yagi antenna developed at UCLA [1] is an ideal antenna to develop a low noise active integrated antenna. This single-feed antenna is fabricated on a single layer of high-dielectric substrate and uses the truncated ground plane of the microstrip feed line as a reflector so that a well-defined endfire beam is achieved. In spite of its very compact design, an extremely broad bandwidth (>50%) with excellent front-to-back ratio and low cross-polarization levels has been demonstrated.

An FMCW radar transceiver using a quasi-Yagi antenna array has been presented in [2]. In this paper, we demonstrate that by properly combining the dual-feed nature of the quasi-Yagi antenna with a hybrid circuit, excellent monopulse operation can be achieved with the simplicity of using only one single antenna. The new design concept has been verified by both simulation and measurement, showing great potential of this novel design for ultra-low-cost microwave and millimeter-wave radar applications.

II. ANTENNA DESIGN

A conventional quasi-Yagi antenna, as reported in [1], has a single microstrip feed, with a microstrip-to-coplanar strips (CPS) transition that acts as a balun. Thus in single-feed operation, each dipole driver element is driven out-of-phase, and the antenna operates similar to printed dipole antenna. Additionally, when operated with two feeds, it is possible for each driver element to operate independently, similar to two monopoles. This characteristic is exploited in this work to form sum and difference radiation patterns by combining the outputs from each feed out-of-phase, and in-phase, respectively. The picture of the proposed dual-feed antenna is shown in Fig. 1.



(a) (b)

Fig 1 Picture of dual-feed quasi-Yagi antenna (a) front side (b) back side.

In order to design the antenna, simulations are conducted based on the Finite-Difference Time Domain (FDTD) method. The antenna is treated as a two-port network, with one feed of the antenna excited, while the other feed is terminated in 50 ohms. Radiation patterns and two-port *S*-parameters for a C-band antenna are obtained from the simulations. The simulated *S*-parameters compare closely to *S*-parameters measured on a network analyzer calibrated with TRL standards, thereby validating the simulation. The simulated *S*-parameters are imported into a circuit simulator for impedance matching.

Fig. 2 shows the simulated radiation pattern of each feed of the antenna. Note that the peak of each pattern is not

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centered at 0 deg., but rather shifted by ±21 degrees. Therefore, a sum and difference pattern can be obtained by combining the two patterns with appropriate excitation phases. A sum pattern is obtained when the two ports are excited out-of-phase, similar in operation to a conventional quasi-Yagi antenna, and a difference pattern is obtained when the two ports are excited in-phase.

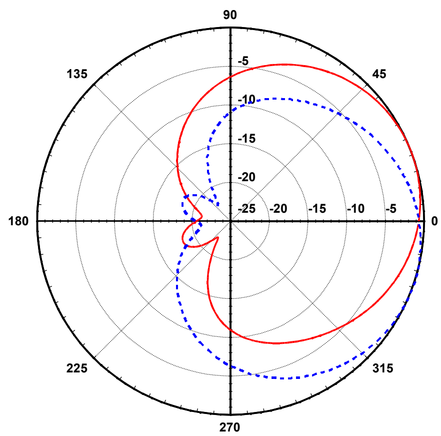

Fig. 2 Radiation pattern of both feeds of a dual-feed quasi-Yagi antenna.

Thus, sum and difference beams can be formed from one antenna, in contrast to a traditional monopulse system, which requires an array of at least two antennas separated by about one-half free-space wavelength. This distinctive feature of the dual-feed quasi-Yagi antenna can be utilized to create a very compact receiver front-end for monopulse radar applications.

III. LNA DESIGN AND SIMULATION

Because of the low isolation (<6 dB) between the two feeds of the quasi-Yagi antenna, designing an LNA matched to the antenna presents a unique challenge. The source impedance seen by one LNA depends on the impedance of the antenna, and also on the impedance looking into the other LNA integrated on the second feed of the antenna. So the source impedance varies during the design process, as a function of the input matching network of the LNAs. Consequently, the source impedance cannot simply be specified as a termination network element available in most commercial simulation software.

Instead, the antenna *S*-parameters are included in the simulation by using a user-defined three-port combiner circuit. The combiner element allows the LNA to be simulated and optimized as if it was a standard two-port network terminated in 50 ohms, while the actual source impedance seen by the LNA is the quasi-Yagi antenna in series with the other LNA. The simulation schematic is shown in Fig. 3. Both LNAs are identical, and the output is matched to 50 ohms. As a final step after the desired LNA performance is obtained, the outputs are combined with a ratrace hybrid, yielding a sum and difference patterns. The final circuit is pictured in Fig 4.

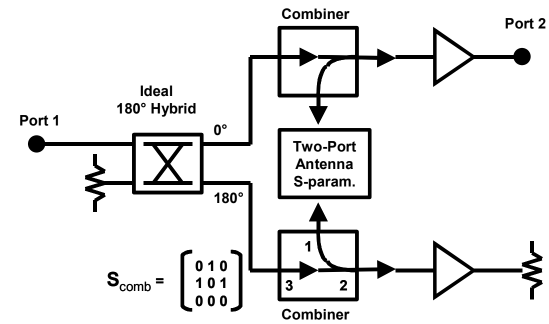

Fig. 3 Schematic of LNA design used for simulation purposes.

While the standard measurement for gain in commercial simulators is still applicable for this circuit, a user-defined measurement for noise figure must be specified. Following the concepts presented in [3], noise figure is defined as an output equation in the simulator as:

$$F = 1 + P_{no}/(P_{ni}*|S_{21}|^2*2) \qquad (1)$$

where $P_{no}=V_{nout}^2/50$ is the noise power delivered to the load (R_L=50 ohms) with all source and load terminations set as noise free, and $P_{ni}= kT$ is the available noise power at the input of the circuit. The noise voltage V_{nout} is a predefined measurement in the simulation software. The denominator in (1) represents the noise power at the output of the amplifier due to the noise power at input of the circuit multiplied by the gain of the circuit. The reason that $|S_{21}|^2$ is multiplied by a factor of 2 is that the input power is split between the two LNAs, so the gain obtained from the predefined measurement of S_{21} must be doubled.

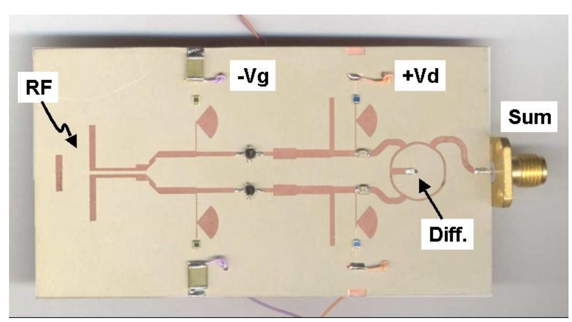

Fig. 4 Picture of low noise active integrated antenna receiver.

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Using output equations specified above, the low noise active integrated antenna can now be designed for gain and noise figure as if it was a simple two-port network terminated in 50 ohms. A prototype is designed to operate from 5-6 GHz. The low noise active integrated antenna receiver is fabricated on h=50mil ε_r=10.2 duroid substrate, using packaged GaAs MESFETs.

IV. MEASUREMENTS

All measurements of the low noise active integrated receiver were conducted inside an anechoic chamber. Fig. 5 shows the measured E-plane co-polarization pattern for the sum port. Fig. 6 shows the monopulse sum and difference pattern measured in the E-plane. A null depth of greater than 20 dB is obtained from 5-6 GHz (18% bandwidth), with a null better than 30 dB obtained for most of the band. The null depth is most likely limited by the bandwidth of the output ring hybrid. With a wide main beam sum pattern, this active integrated antenna is suitable for applications that require wide angular coverage, such as side sensing automotive radar.

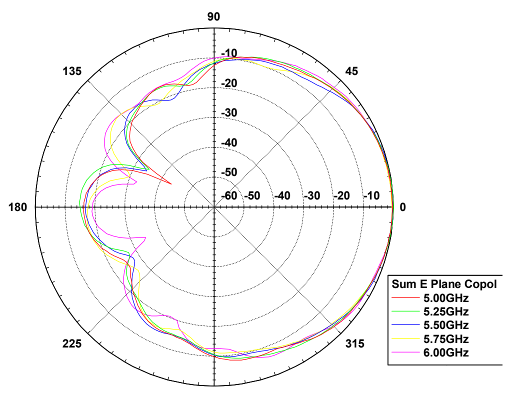

Fig.5 E-Plane co-polarized pattern measured at the sum port.

As an active integrated antenna, the gain and noise figure of the LNA cannot be measured independent of the antenna since it is matched to the antenna and not 50 ohms. Instead, both quantities must be derived from other measurements, all made with the antenna illuminated in the endfire direction. The received power of a passive reference quasi-Yagi antenna is compared to the received power from the sum port of the active integrated antenna. The LNA gain is the difference between the two measurements. The passive reference antenna consists of a dual-feed quasi-Yagi antenna in which both feeds are combined using the same ring hybrid as in the active integrated antenna. This measurement assumes that the quasi-Yagi antenna is well matched to both the ratrace hybrid, and the LNA, and will lead to some uncertainty in calculating the LNA gain.

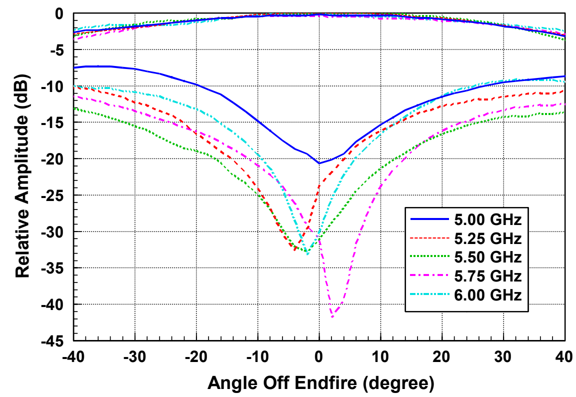

Fig.6 Sum and difference radiation patterns.

Noise figure is determined using the method outlined in [4]. Noise figure is defined as:

$$F = 1 + P_n/G_T - T_a/290 \qquad (2)$$

where P_n is the noise power density referenced to 290 Kelvin. It is directly measured with a noise figure meter. T_a is the antenna temperature, which is equal to the ambient temperature inside the anechoic chamber, and G_T is the transducer power gain of the LNA, calculated previously.

The measured gain and noise figure of the low noise amplifier is compared against simulated results in Fig. 7. A peak gain of 7.7 dB and minimum noise figure of 3.6 dB is measured at 5.5 GHz, compared to a simulated gain of 8.7 dB and noise figure of 1.5 dB. The general frequency response of the measured data agrees well with the simulated data, with greater discrepancy in the amplitude levels. Because the measured gain of the LNA is lower than the simulated results, the measured noise figure is higher than simulated since the measured noise figure is calculated from the measured gain. Additionally, any error in calculating G_T directly affects the measured noise figure. A more accurate measurement of noise figure could be obtained using hot/cold load technique, at the expense of a much more complicated test setup.

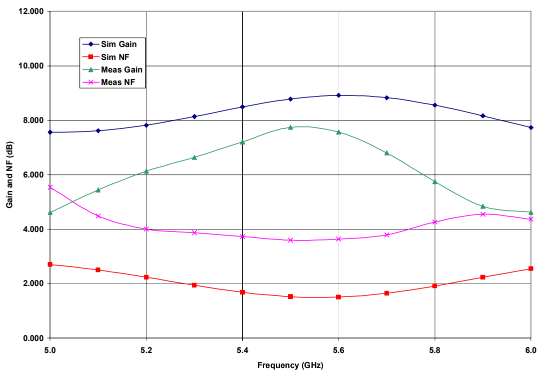

Fig. 7 Measure and Simulated gain and noise figure.

V. CONCLUSION

The wide bandwidth, moderate gain, and wide beam width characteristics of the quasi-Yagi antenna make it suitable for applications such as side sensing automotive radar. A low noise active integrated antenna based on a dual feed version of the quasi-Yagi antenna has been prototyped and is presented in this paper. A simulation technique for matching a circuit to an antenna with two coupled feeds, and a measurement technique for determining the LNA gain and noise figure has also been discussed. Measured data is compared to simulated results, with reasonable agreement between the results. Since the sum and difference radiation patterns are obtained from a single antenna, this new design concept offers a significant size reduction over conventional antenna array based monopulse systems.

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