A NOVEL PROXIMITY COUPLED ACTIVE INTEGRATED ANTENNA

Sasidhar Vajha*, Member, IEEE, and Prasad Shastry**, Senior Member, IEEE

*MMIC Design Engineer, TLC Precision Wafer Tech Inc, 1411, W. River Road N., Minneapolis, MN 55411, USA
Tel: +1(612)341-2795, Fax: +1(612)341-2799, Email: **svajha@tlcprecision.com**
**Professor, Dept. of Electrical and Computer Engg., Bradley University, 1501, W. Bradley Ave., Peoria, IL 61625,USA
Tel: +1(309)677-2733, Fax: +1(309)677-3670, Email: snp@cegt201.bradley.edu

Abstract — **In this paper, a novel design approach and measured results of a compact proximity coupled active integrated antenna (PCAIA) are presented. A new type of antenna feed structure is proposed. A single self-biased (through the RF port), two-stage low noise amplifier has been integrated with a proximity coupled patch antenna having a new feed structure. The proposed approach is useful in the design of compact PCAIA with good radiation characteristics for applications in microwave wireless systems.**

I. Introduction

The advantages of Active Integrated Antennas (AIAs) for applications in microwave and millimeterwave integrated transceivers in wireless systems is well known [1-3].

However, integration of the active circuitry and the microstrip patch antenna using the basic feeding techniques on a single substrate will not achieve compact circuit size and good radiation characteristics simultaneously. The patch antenna requires a low $\in_r$, thick substrate for good radiation characteristics [4-10], whereas the RF circuitry requires a thin, high $\in_r$ substrate for size reduction and low radiation loss.

Proximity coupled (PC) patch antennas, due to their multilayer architecture, provide a solution for developing a thin and compact feed network without compromising the antenna performance. This type of patch antennas is reported to have achieved higher bandwidths compared to other feeding techniques [6-8]. However, no reports have demonstrated a PC patch antenna with the feedline on very high $\in_r$ (>5) and thin (h<50 mil) boards due to the inadequate coupling between the conventional 50Ω feedline and the patch antenna on these boards. A modified feedline approach on a high $\in_r$ and thin board for use in the PC patch antenna configuration is necessary.

In the AIA presented here, a PC patch antenna is integrated with a two-stage GaAs FET LNA. A new type of feedline has been developed to achieve better radiation characteristics for the patch antenna, using a very high dielectric constant ($\in_r$=9.2) and thin (h=30mil) substrate for the feedline and LNA. The active antenna is biased through the RF port.

The PCAIA design approach and measured results are presented in the following sections.

II. PC Patch Antenna Design

The geometry of the new proximity coupled active integrated antenna with a widened feedline is shown in Fig. 1. The widened feedline increases the capacitive coupling between the patch radiator and the feedline, hence improving the radiation characteristics of the antenna. The substrates were chosen to simultaneously achieve minimum LNA circuit size and good antenna radiation characteristics.
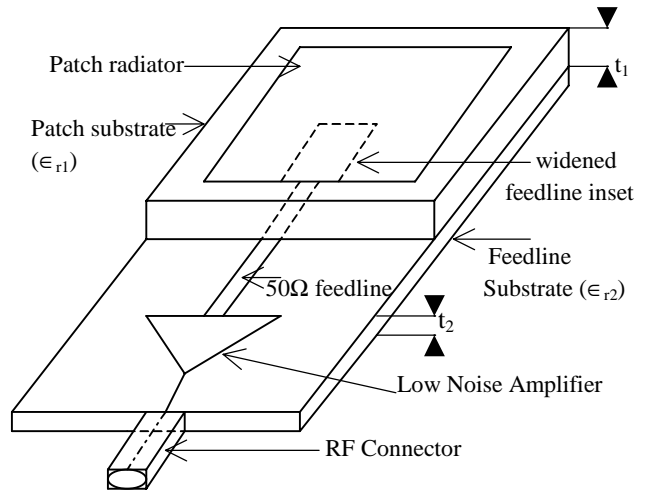

Fig. 1. Geometry of the proposed proximity coupled Active Integrated Antenna (PCAIA) with widened feed line inset

A 30 mil thick (t_1) substrate with a high dielectric constant (TMM10i from Rogers Corp.; $\in_r$=9.8) was selected for the feedline and the active circuit. A 120 mil thick (t_2) substrate with a low dielectric constant (RT duroid 5870; $\in_r$=2.33) was selected for the patch radiator. The design guidelines suggested in [9], and [10] were followed in the design of the PC patch antenna for a resonant frequency of 1.9 GHz. Patch length was calculated to be 4.7988 cm.

Various widened feedlines of characteristic impedances 50Ω, 40Ω, 30Ω, 20Ω, 10Ω, 8Ω, and 5Ω were fabricated

TABLE I

MEASURED RESULTS OF THE PC PATCH ANTENNA WITH
WIDENED FEEDLINE INSETS (50% overlap with patch)

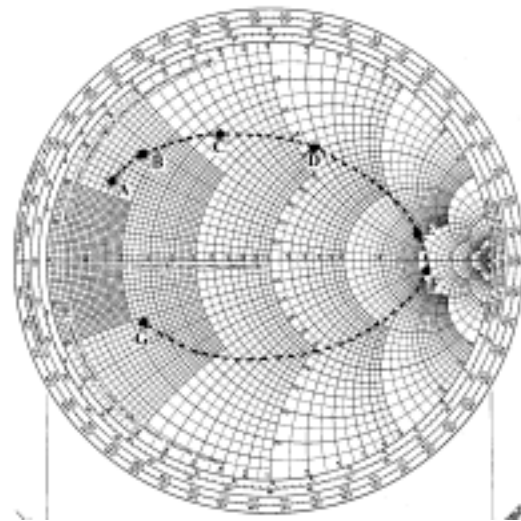| Characteristic impedance of the feedline inset (Ω)	50	40	30	20	10	8	5
Width of the feedline inset (mil)	29.3	44.6	71.6	128	300	389	655
Resonant frequency of the PC patch (GHz)	1.8	1.8	1.8	1.84	1.84	1.84 and 1.5	1.48
Return loss of the PC patch (dB)	-2.0	-2.3	-3.9	-6.8	-3.4	-3.0	-3.5
Input impedance of the PC patch (Ω)	6+ j12	8+ j18	17+ j32	38+ j58	217 +j95	282 -j53	12 -j11
Input Impedance point in Fig. 2	A	B	C	D	E	F	G

Fig. 2.   Measured input impedances of the proximity coupled patch antenna with widened feed lines

Fig. 3.   Measured return loss of the PC patch antenna with a 20Ω feedline inset

Fig. 4.   AIA Architecture

to test the antenna performance. A feedline overlap of 50% with the patch antenna was considered. Table I summarizes the measured results for various widened feed line insets. Minimum return loss occurred for the feedline having 20Ω characteristic impedance. The results also show that further widening of the feedline would make the effective feedline-antenna combination to resonate at a different frequency.

Input impedances of the antenna with various feedlines at the resonant frequencies are shown on the smith chart in Fig.2. Points A, B, C, D, E, F, and G in Fig.2 correspond to the input impedances of the PC patch antenna with widened feedline insets of characteristic impedances 50Ω, 40Ω, 30Ω, 20Ω, 10Ω, 8Ω, and 5Ω, respectively. It can be
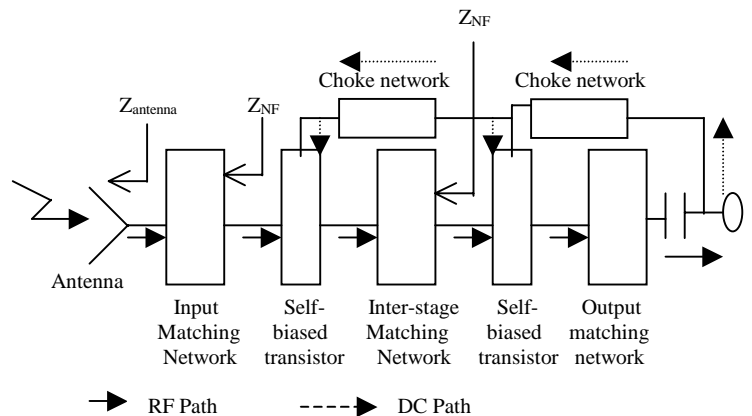
observed that the path traced by the points A-G in Fig.2 follows a regular pattern. This observed phenomena could be further investigated to predict the optimum width of the feedline (20Ω feedline here) required to achieve the lowest return loss for a given PC patch antenna configuration. Also, the input impedance data is useful in the design of a matching network to further reduce the return loss and increase the bandwidth of the antenna as reported in [6].

The optimum feedline with 20Ω charactersitic impedance was chosen for integration. The measured return loss of this patch antenna is shown in Fig. 3. The input impedance of the antenna is 37.592+j57.66Ω at the resonant frequency (1.8388 GHz). This impedance was used as the source impedance in the design of the LNA.

III. AIA Low-Noise Amplifier Design

A. AIA Architecture

The block diagram of the AIA consisting of an antenna and two-stage LNA is shown in Fig. 4. Unlike the conventional design approach where the antenna and the amplifier are first matched to 50Ω and then connected together, here the input impedance of the antenna is directly transformed to the source impedance needed for minimum noise figure.

The DC and RF paths in the AIA are shown in Fig.4. The transistors are self-biased from a single DC source, through the RF port.

B. Bias Network and FET stabilization

Fig. 5 shows the self-biased FET configuration. The transistor used is NE34018, as it has good noise performance and gain in the L to S band.
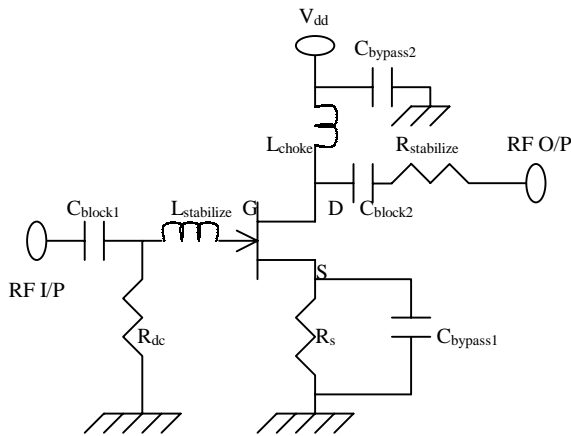
Fig. 5.   Biasing, stabilization scheme for the self-biased FET

A bias condition of V_{ds}=3V and I_{ds}=20mA was selected corresponding to a minimum noise figure of 0.62dB (Γ_{opt}=0.62∠42°) and an associated gain of 16.8dB at 2GHz.

A 100KΩ (R_{dc}) resistor was chosen to provide a DC ground for the gate. A choke network consisting of a 22nH inductor (L_{choke}) and a 2400pF ($C_{bypass2}$) bypass capacitor was used to bias the drain. The self-biased transistor was simulated on HPADS considering parasitics associated with the inductors, via posts, and component pads. Simulation results showed that the transistor was unstable. Hence, the transistor was made unconditionally stable with a series inductor ($L_{stabilize}$=10nH) on the gate and a series resistor ($R_{stabilize}$=22Ω) on the drain as shown in Fig.5.

The values of circuit elements needed for stabilization were calculated following the stabilization rules suggested in [11]. The stabilized self-biased transistor was simulated for S-parameters and noise parameters using HPADS circuit simulator. The parameters of the stabilized self-biased transistor were used in the design of the LNA.

C. LNA Design

The low noise amplifier was designed by implementing the matching networks as shown in Fig. 4. Short circuited single stub matching networks were used. The input matching network was designed such that the input impedance of the antenna was transformed to Z_{NF}, which corresponds to the Γ_{opt} of the self-biased transistor. The inter-stage matching network was designed to transform the output impedance of the first stage to Z_{NF} to provide a noise match for the second stage. The output matching network transforms the output impedance of the second
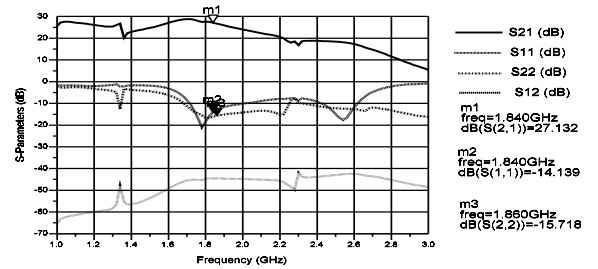
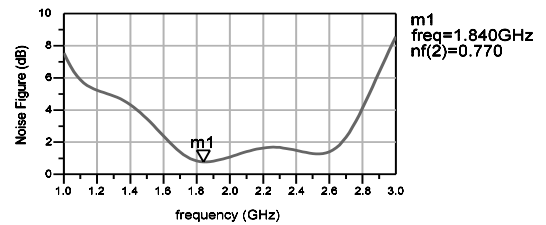Fig. 6.   Simulated S-parameters of the AIA amplifier with input port impedance (source impedance) of 37.592+j57.7Ω

Fig. 7.   Simulated noise figure of the AIA amplifier with and input port impedance (source impedance) of 37.592+j57.7Ω

stage to 50Ω port impedance. Choke networks as shown in Fig. 4 were provided to bias the FETs. The 50Ω input line of the amplifier was extended and widened (20Ω) to serve as the feedline for the PCAIA as shown in Fig.1. The amplifier circuit was simulated using HPADS for S-parameters and noise figure. The input port impedance (source impedance) was adjusted to be equal to the antenna input impedance (37.592+j57.66Ω). The

simulated S-parameters and noise figure are shown in Fig.6 and Fig.7 respectively. It is evident from Fig.6 and Fig.7 that the LNA has a gain of 27.3dB, noise figure of 0.77dB, input return loss of –14.14dB, and output return loss of –15.8dB at the design frequency (1.8388 GHz).

IV. MEASURED RESULTS

The PC patch radiator was fabricated on RT duroid 5870 and the AIA low noise amplifier was fabricated on TMM10i boards, both from Rogers corporation. The radiator and the amplifier were properly aligned and attached. The AIA was mounted in a metal housing. The photograph of the PCAIA is as shown in Fig.8. The PCAIA was tested for gain in the anechoic chamber at Bradley University. The measured gain of the PCAIA was found to be 20dBi. The measured radiation characteristics of the proximity coupled (PC) patch antenna are summarized in Table II.
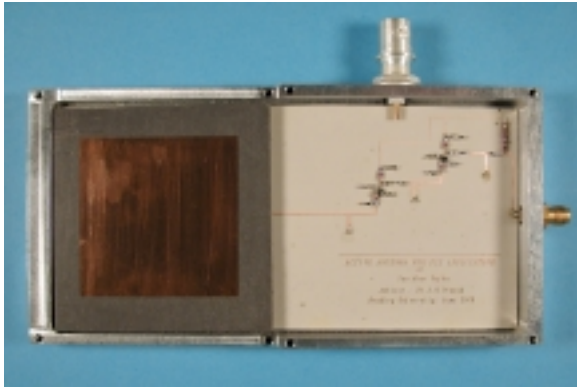

Fig. 8.   Proximity coupled Active Integrated Antenna
(BNC Connector on top was not used)

TABLE II
MEASURED RADIATION CHARACTERISTICS OF THE
PC ANTENNA WITH FEEDLINE INSET OF 20 Ω

Characteristic	E-plane	H-plane
Beam Width	75°	90°
Side-lobe level	-14dB	-16dB
PC Antenna gain	4dBi	
PCAIA gain	20dBi	

V. CONCLUSIONS

A novel design approach and measured results for a proximity coupled active integrated antenna (PCAIA) have been presented. A new widened feed structure (on high $\in_r$ substrate) is proposed. The PCAIA inherits well known advantages of the proximity coupled patch antenna. The proposed approach is useful in the design of compact PCAIA having good radiation characteristics for applications in microwave wireless systems.

ACKNOWLEDGEMENT

REFERENCES

[1] Yongxi Qian and T.Itoh, "Progress in Active Integrated Antennas and Their Applications," IEEE Transactions on Microwave Theory and Techniques, Vol. 46, No. 11, pp.1891-1900, November 1998.
[2] M.J. Cryan and P.S. Hall, "An Integrated Active Circulator Antenna," IEEE Microwave and guided wave letters, Vol.7, No. 7, pp. 190-191, July 1997.
[3] A.S. Andrenko and et.al, "Impedance Matching in Active Integrated Antenna Receiver Front-end Design," IEEE Microwave and Guided Wave Letters, Vol. 10, No. 1, January 2000, pp. 16-18.
[4] C.A. Balanis, "Antenna Theory, Analysis and Design," John Wiley & Sons Inc., 1997.
[5] Dr. Max Amman, "Design of Rectangular Microstrip Patch Antennas for the 2.4 GHz Band," Applied Microwave & Wireless, pp. 24-34, Nov./Dec. 1997.
[6] D.M. Pozar and B. Kauffman, "Increasing Bandwidth of a Microstrip Antenna by Proximity Coupling," Electronics Letters, Vol.23, No. 8, pp. 368-369, April 1987.
[7] G. Splitt and M. Davidovitz, "Guidelines for Design of Electromagnetically Coupled Microstrip Patch antennas on Two-layer substrates," IEEE Transactions on Antennas and Propagation, Vol. 38, No. 7, pp. 1136-1140, July 1990.
[8] Daniel H. Schaubert, "A Review of Some Microstrip Antenna Characterstics," Microstrip Antennas, IEEE Press, pp. 59-67, 1995.
[9] Sasidhar Vajha, "A Proximity Coupled Active Integrated Antenna," MSEE Project Report, Bradley University, Peoria, Illinois, 2000.
[10] Sasidhar Vajha and S.N. Prasad, "Design and Modeling of Proximity Coupled Patch antenna," 2000 IEEE AP-S Conference on Antennas and Propagation for Wireless Communication Digest, pp. 43-46.
[11] G. Gonzalez, "Microwave Transistor Amplifier Design," Prentice Hall, 1998.