Direct Conversion Receiver with Active Integrated Antenna

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Abstract **-** This paper describes numerical simulation, fabrication and experimental measurement of a compact miniature integrated antenna using direct conversion detection at 2.4 GHz. In this receiver design, Agilent's ADS software using momentum simulation and circuit simulation is employed to analyze the entire structure. Microstrip dipole antenna is integrated with 90^0 hybrid coupler, oscillator and diodes for direct conversion or zero-IF detection is presented here. Microstrip dipole antenna that is presented here has a wide bandwidth up to 23.85 % bandwidth. The 90^0 hybrid coupler can act as a phase shifter to provide the necessary 90^0 characteristics to operate with I and Q signal for direct conversions. Two schottky diodes (HSMS 8101) are mounted onto each of two coupler's output port to act as a mixer. One pin of the diodes is connected to the edge of output port and the other pin is grounded via a small hole to ground plane. One kHz sinusoidal signal act as a baseband have been generated and modulated using signal generator. The demodulated signal is detected using direct conversion receiver circuit and the baseband signal at the output ports is successfully detected using oscilloscope.

1. Introduction

Most of radio receivers adopt superheterodyne technique, which can provide high selectivity and sensitivity. Superheterodyne receiver contains RF, IF and baseband stages. The system has many advantages such as good stability, high gain, low noise and flexibility for channel selection. However, superheterodyne receiver has some disadvantages such as high power consumption, complex circuitry and the existence of an image frequency signal. To overcome this problem, direct conversion or zero-IF detection has been proposed as alternative receiver architecture [1-3]. Zero IF or direct conversion detection is a kind of coherent detection method. A modulated signal is mixed with the unmodulated carrier to produce zero IF signal.

The output signal contains the baseband signal's amplitude and phase information [4]. This kind of receiver can eliminate the IF stage and the band pass and band reject filters, thereby reducing the circuit complexity.

A compact miniature direct conversion receiver constructed with microstrip dipole antenna, a local oscillator (LO), diodes mixer and hybrid coupler has been designed for this research. This design can be realized in an active integration antenna (AIA) [5-8]. AIA can be regarded as an active microwave circuit in which the output or input port is free space instead of a conventional 50Ω interface[9].In this case, the antenna can provide certain circuit functions such as resonating, filtering, and duplexing, in addition to its original role as a radiating element. On the other hand, from an antenna designer's point-of-view, the AIA is an antenna that possesses built-in signal- and wave-processing capabilities such as mixing and amplification. Miniature size, low cost and simple circuitry is the main advantages to implement this AIA design using direct conversion technique. 2.4 GHz frequency is chosen since it is within the license free frequency bands, Industrial, Scientific and Medical (ISM) bands [10].

In this paper, simulation and measurement results of antenna, coupler and direct conversion AIA receiver is being shown here.

2. Design Procedure and Methodology

2.1 Microstrip Dipole Antenna

Figure 1 shows the structure of a microstrip dipole of length ***L***, width ***W*** and gap ***G*** that were used in simulation. The proposed antenna element is printed on a FR4 substrate with a dielectric constant of 4.7, a thickness of 1.6 mm and a conductor loss of 0.019. The two hatched rectangular pieces in figure 1 are copper on the top of the substrate. Each of it is connected with the microstrip bend. The gap between the two pieces is ***G*** and the microstrip dipole is fed at the middle of the gap. One piece of the hatched is fed with connector and another one is connected to the ground.

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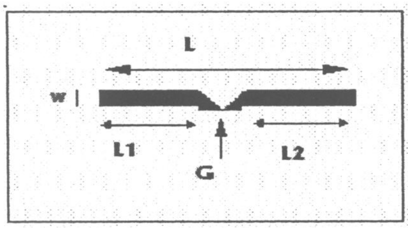

Figure 1: Microstrip Dipole Layout.

Microstrip dipole of rectangular hatched or rectangular geometry as shown in figure 1 can be designed for the lowest resonant frequency using transmission line model. The formula to calculate the value of λ, L_2 and W can be found through formulation as follows [11]:

The effective dielectric constant (ε_{eff}) constant of a microstrip line:

$$\varepsilon eff = \frac{\varepsilon r + 1}{2} + \left(\frac{\varepsilon r - 1}{2}\right)\left(\frac{1}{\sqrt{1 + 12\, d/W}}\right) \quad (1)$$

Where ε_r = Dieletric Constant
d = substrate thickness
W= width of microstrip line
(Approximation is made for the simulation)

The length (L_1 and L_2) of microstrip line using formula:

$$\lambda g = \frac{\lambda o}{\sqrt{\varepsilon eff}} \quad (2)$$

where λ= wavelength
C= velocity of light
f = frequency

Thus $L_1 = L_2 = \lambda g/4$

The length of each hatched rectangular is about quarter-wavelength. In this case the length of rectangular hatched, $L_1=L_2=\lambda_g/4$= 16.52 mm and the gap between the two pieces, G = 1.0 mm. At the designed frequency, approximation of the width W is made and it is equal to 7 mm. Overall, the length of the dipole is about, L = 47mm. In addition the microstrip bend is added between the two rectangular hatched which has length and width is equal to 7 mm.

2.2 Quadrature 90^0 Hybrid Coupler

Quadrature hybrids are 3 dB directional couplers with a 90^0 phase different in the outputs of the through and coupled arms [10]. The example of the design of hybrid coupler at 2.4 GHz is shown in figure 2. Figure 2 shows the layout of microstrip hybrid coupler. The basic operation of the hybrid coupler is as follows. With all ports matched, power entering port 1 is evenly divided between ports 2 and 3, with a 90^0 phase shift between theses outputs. No power is coupled to port 4 (the isolated port).

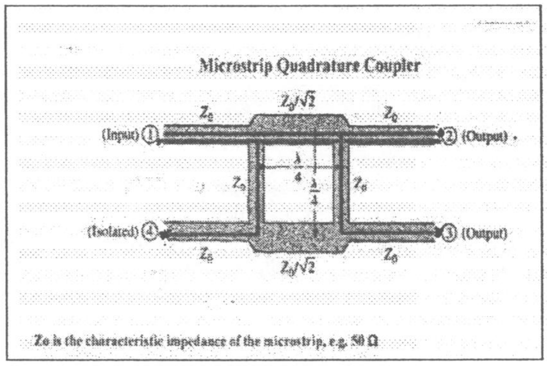

Figure 2: 90^0 Hybrid Coupler.

2.3 AIA Direct conversion receiver

The I and Q direct conversion receiver is constructed with 90^0 hybrid coupler and diodes mixer in addition to the microstrip dipole antenna is shown in figure 3.

Port 1 of the hybrid coupler is connected to microstrip dipole antenna and Port 2 is connected to the local oscillator (LO). Port 3 and Port 4 of the coupler is set as the output port. Two schottky diodes (HSMS 8101) are mounted onto each of two coupler's output port to act as a mixer. One pin of the diodes is connected to the edge of output port and the other pin is grounded via a small hole to ground plane

The LO is tuned to the carrier frequency and divided into two output of hybrid coupler, one of which has 90^0 phase shift. The baseband signal I(t) can only be detected at the in-phase port. Owing to the 90^0 LO phase shift, the baseband signal Q(t) can be detected at the quadrature port. This demodulator can be directly used to detect QPSK and QAM.

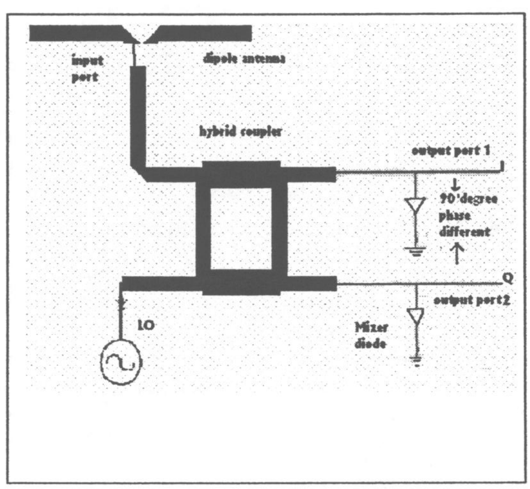

Figure 3: Direct conversion receiver with AIA

3. Simulation and Measurement Results

In this section, simulation results for microstrip dipole antenna and hybrid coupler is shown in figure 4 to 6 The parameters involved with the simulation are return loss and phase different. Measurement results of Direct Conversion Receiver with AIA also described in this chapter. A FR4 substrate with dielectric constant of 4.7, a thickness of 1.6 mm and a conductor loss of 0.019 has been used in the simulation and measurement process

3.1. Microstrip Dipole Antenna Results

The result of microstrip dipole antenna has been discussed in term of bandwidth response and return loss of the antenna. The simulation and measurement results of the antenna return loss is shown in figure 4. The resonance of the antenna can be seen by observing the dip in the return loss. The dip of antenna can be seen at 2.4 GHz frequency. The bandwidth from simulation result is 13.4% and for measurement is about 23.85 %. The experimental result shows the frequency has been shifted down by 100 MHz. From the graph, it is shown that the bandwidth of measurement result is much higher than the simulation result.

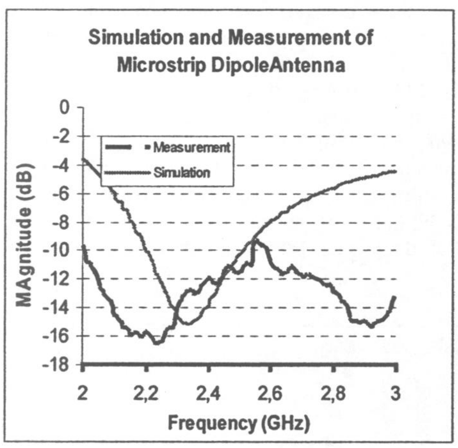

Figure 4: Input Return Loss for Microstrip Dipole Antenna.

3.2 Quadrature 90^0 Hybrid Coupler Results

In this section the results of measurement of hybrid coupler has been discussed in term of S parameter and output phase at the two output port.

S parameter measurement of the hybrid coupler is shown in figure 5 and the output phase between port 2 and port 3 is shown in figure 6. From figure 5a, measurement return loss, S_{11} = -40.1 dB and the isolation between port 1 and port 4, S_{14} = -24.3 dB. The gain at the output port 2, S_{12} = -4.59 dB and the gain at the output port 3, S_{13} = -4.4 dB. While for simulation results in figure 5b it shown that simulated return loss, S_{11} = -32.809 dB and the isolation between port 1 and port 4, S_{14} = -41.775 dB. The gain at the output port 2, S_{12} = -3.322 dB and the gain at the output port 3, S_{13} = -3.838 dB.

Figure 6 shows a 90^0 phase different between port 2 and port 3. The hybrid coupler integrated with dipole antenna and is suitable for I and Q signals that keep 90^0 phase different.

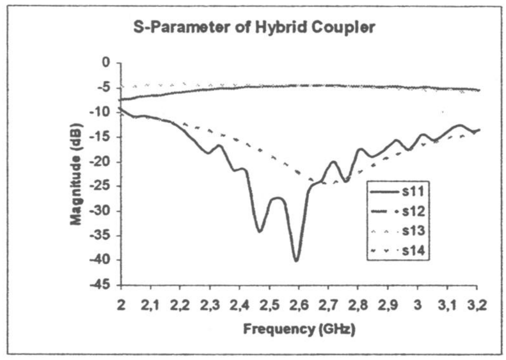

Figure 5a: Hybrid Coupler S parameter measurement

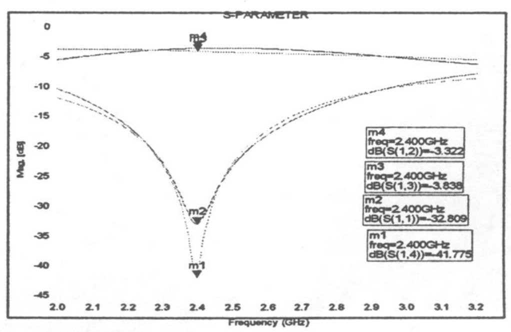

Figure 5b: Hybrid Coupler S parameter simulation

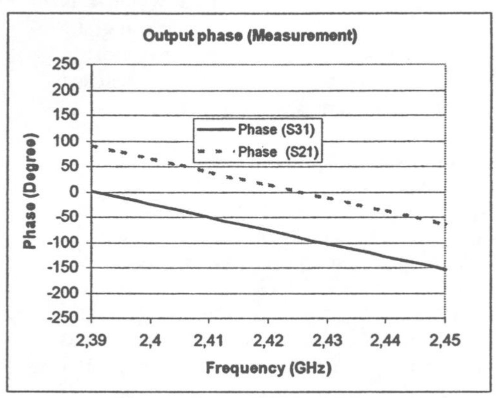

Figure 6a: Measurement of output phase at port 2 and port 3

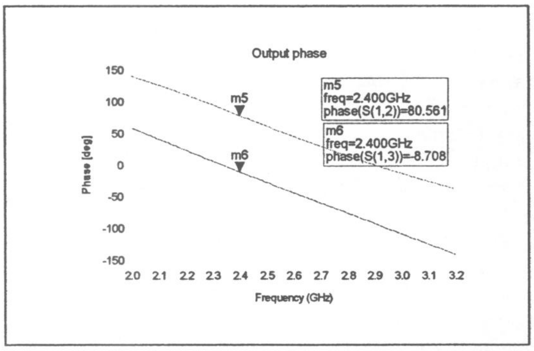

Figure 6b: Simulation of output phase at port 2 and port 3

3.3 AIA Direct Conversion Receiver measurement

The fabricated of Direct Conversion Receiver circuit is shown in figure 7. All of the DCR components are integrated on one FR-4 Board. The experimental setup is shown in figure 8. Synthesizer Signal Generator is used to transmit the baseband signal. The baseband signal is than radiated from monopole antenna. The DCR circuit is placed in front of the transmitting antenna with 1 meter separation. When the diodes are forward biased by a voltage 0.1 - 0.25 V, the LO signal will be mixed with the RF signals received by microstrip dipole antenna. The down conversion components of the mixer include all the baseband signals information.

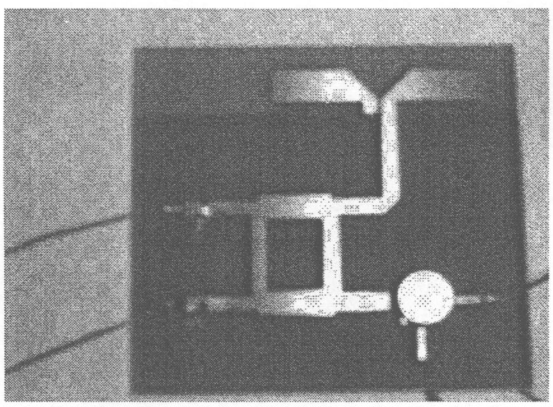

Figure7: Fabricated Direct Conversion Receiver

1 kHz sinusoidal baseband signal have been generated and detected at DCR circuit. The baseband signal can be detected using oscilloscope. The baseband signal at the output port 1 and port 2 of the circuit can be seen as figure 9. Since the transmitting side does not use I/Q modulator, the signal detected at output port 1 and 2 are the same.

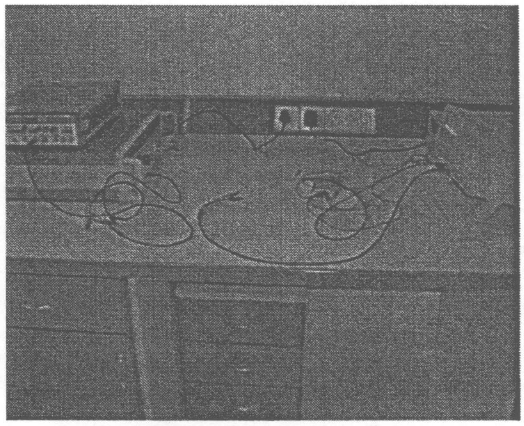

Figure 8: Experimental setup

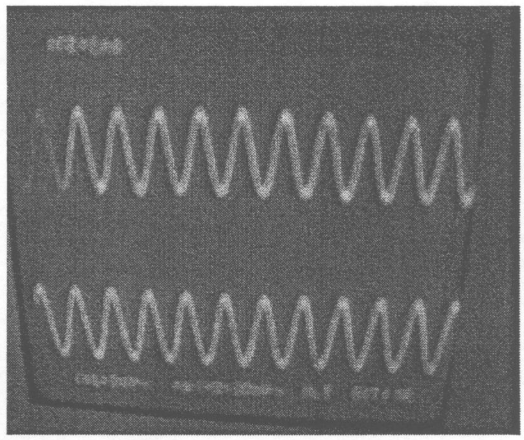

Figure 9: Detected baseband signal at oscilloscope

4. Conclusion

A low cost and compact integrated receiver at 2.4 GHz band for direct conversion has been proposed. The proposed microstrip dipole antenna with a narrow width is easy to implement. The hybrid coupler provides the required 90^0 characteristics to operate with the I and Q signal for direct conversion. Two schottky diodes are connected at the end of the coupler's output ports are used as the mixer. Overall, the microstrip dipole antenna, coupler and mixer can be integrated into one board which allows a low cost receiver. 1 kHz sinusoidal wave have been successfully modulated and detected throughout the receiver. Thus overall this receiver can be applied to the zero IF and QPSK technique.

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