DESIGN AND IMPLEMENTATION OF ACTIVE TUNABLE DUPLEXER FOR WIRELESS APPLICATIONS AT 900 MHz

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Abstract - A duplexer is a device that allows simultaneous transmission and reception of signals from a single antenna. The new Active Tunable Duplexer proposed here will operate in full duplex mode at a frequency of 900 MHz. The Duplexer provides a transmitting gain of 16.140 dB and a receiving gain of 16.364 dB. The isolation between port 1 and port 3 is obtained as -26.557 dB correspondingly between port 2 and port 4 is obtained as -25.612 dB. The reflection coefficients at each port are measured as less than -10 dB. The bandwidth is calculated as 25 MHz for both transmitting and receiving signal. The duplexer is found to be unconditionally stable.

Keywords- Duplexer, Distributed Amplifier, Tunable active duplexer, MOSFET, PIN diode.

I. INTRODUCTION

A duplexer is a critical component in the functioning of wireless transceivers, such as mobile phones, wireless network adapters, and PDAs. It allows simultaneous transmission and reception of signals from a single antenna. It provides isolation between transmitter and receiver. It allows a transmitter operating at one frequency and a receiver operating at a different frequency to share one common antenna with a minimum interaction and degradation of the different RF signals. There is a growing interest in tunable or reconfigurable microwave circuits for applications in wireless systems. The duplexers currently used in transceivers are passive filters and hence have insertion loss[1]. Furthermore, they are not tunable [3]-[4]. The new tunable active duplexer proposed here offers nearly constant gain between coupled ports in both transmitter and receiver modes of operations respectively and also providing high isolation between isolated ports. This duplexer also have less noise figure in the receive mode of operation.

The design of duplexer is based on single distributed amplifier (DA) cell architecture [1]. Distributed amplifiers (DA) are circuit design that in corporate transmission line theory into traditional amplifier design to obtain a larger gain bandwidth product than is realizable by conventional circuit. The DA consists of a pair of transmission lines with characteristic impedance of $Z_0$ independently connecting the inputs and outputs active devices. The DA is inherently bi-directional because of the symmetry in its architecture. The signal paths of Active Tunable Duplexer are shown in Figure 1. The parameters $S_{21}$ and $S_{34}$ represent the gain of transmitter and receiver respectively. A DA can be designed in such a way as to produce low crosstalk between isolated ports. The parameters $S_{13}$ and $S_{42}$ represent the isolation between the adjacent ports. This is achieved by inserting phase-shifting networks between the adjacent ports to cancel the signals between the transmitting and receiving ports at a given frequency.

The single DA cell is made up of MOSFET which acts as an amplifier. In the MOSFET distributed amplifier, a discrete component transmission line is constructed out of the gate - source input admittance, the gate line. Another identical transmission structure is drain - source input admittance, the drain line. This is done to operate the duplexer in full duplex mode such that the gain is providing in both transmit and receive mode of operation. This implies that the duplexer transmitting as well as receiving the signal at the same frequency.

Fig. 1 Signal paths of Distributed amplifier (DA) cell

PIN diode is considered as varactor that is used for the tuning purpose which means that the proposed duplexer is electronically tunable unlike the mechanically tunable duplexer [5]-[6]. It also used to improve the isolation between the transmitting and receiving ports.

The following sections are described about the design guidelines of the active tunable duplexer and its measured results. The parameters going to be measured
are gain \((S_{21}\) and \(S_{34}\)), isolation \((S_{13}\) and \(S_{42}\)), reflection coefficients \((S_{11}, S_{22}, S_{33}, \) and \(S_{44}\)) and noise figure.

II. DESIGN METHODOLOGY

A. Transmit and Receive module

The functionality of transmit and receive module is shown in Figure 2. The DA cell consists of a single Metal Oxide Semiconductor field-effect transistor (MOSFET) with its gate and drain line inductors. The active tunable duplexer consists of a transmitter at port 1 and a receiver at port 3. Since a DA is a symmetrical device, cancellation of the signals arriving at port 2 will also occur when a wave enters port 4. The tunable phase shifting networks between the adjacent ports are designed such that the waves arriving at port 4 through the DA cell are out of phase with each other and hence cancel. Therefore, port 1 and port 2 are isolated from port 3 and port 4 respectively. Transmit and receive ports consist of matching network which providing perfect match between input and output impedance of the transmitted and received signal. Port 2 and port 4 consist of antenna which transmitting the signal to the output networks. The duplexer transmits the signal using port 2 antennas where it receives the signal using port 4 antennas.

B. Antenna configurations

According to the mode of transmission, the antenna should be connected at different ports. At the output of the transmitting side correspondingly input of the receiving side.

If an antenna is connected to ports 2 and 4, in the transmit mode, the signal is amplified from port 1 to port 2. During the receive mode, the signal is amplified from port 4 to port 3. The received signal is prevented from entering the transmitting antenna because of isolation between ports 2 and 4. This configuration requires isolation between ports 1 and 3 and ports 2 and 4.

If an antenna is connected to port 4 with port 2 terminated, in the transmit mode, the signal is attenuated along the gate line of the DA. However, during the receive mode, the signal is amplified from port 4 to port 3. If an antenna is connected to port 2 with port 4 terminated, in the transmit mode, the signal is amplified from port 1 to port 2. During the receive mode, the signal is attenuated along the drain line. Furthermore, the noise figure of the duplexer increases. Therefore, this configuration is not a viable option.

C. Circuit diagram and its design guidelines

The biasing scheme was chosen for the MOSFET analysis. The transistor used here is biased at \(V_{ds} = 2\) V, \(I_d = 20\) mA, \(V_{gs} = 3\) V. The MOSFET used in this circuit is found to be unconditionally stable. The non linearity of the MOSFET also balanced using harmonic balance analysis. The measured parameters are used in the design and simulations.

The required phase shift between the DA cells for obtaining the isolation between ports 1 and 3 in an active duplexer is determined by the number of transistors\((n)\) used. The phase shift required is given by,

\[
\phi = \frac{180}{n}
\]

The Phase shift network consists of a simple low pass filter which gives 90° phase shift of each side.

The gate and drain line inductor \((L)\) and capacitor \((C)\) values were calculated using the following equations,

\[
f_c = \frac{1}{\pi \sqrt{LC}}
\]

\[
Z_0 = \frac{1}{\sqrt{LC}}
\]

where,

\(f_c = \) Center frequency (MHz).

\(L = \) Effective inductance between the transistor gate or drain terminals of the DA cell \((\text{nH})\).

\(C = \) Effective capacitance between the transistor gate or drain terminals of the DA cell \((\text{pF})\).
III. SIMULATION RESULTS

A. Gain

The gain is measured in terms of two parameters such as transmitting gain ($S_{21}$) and receiving gain ($S_{34}$) as shown in figure 4. The transmitting gain and the receiving gain are measured to be 16.140 dB and 16.364 dB respectively.

![Fig. 4: (a) Transmitting gain (b) Receiving gain](image)

B. Isolation

The isolation parameters are measured to cancel the signal from the adjacent ports. $S_{13}$ and $S_{42}$ are the measure of isolation between port 1 and port 3, port 2 and port 4 respectively which less than -25dB as shown in figure 5.

![Fig. 5: Isolation between adjacent ports](image)

C. Reflection coefficients

The return losses or reflection coefficients at each port are measured as $S_{11} = -15.811$ dB, $S_{22} = -13.213$ dB, $S_{33} = -11.159$ dB, and $S_{44} = -10.630$ dB are shown in figure 7.

![Fig. 6 Reflection coefficients in each port](image)

D. Stability

The results of Stability factor ($\geq 1$) and Stability measure ($<1$) for both the transmitter and the receiver reveals that the Active Tunable Duplexer is 'unconditionally stable'.

![Fig. 7 (a) Transmitter Stability (b) Receiver Stability](image)
E. Noise figure

![Image of noise figure graph]

The noise figure in port 4 is measured as 0.270 dB since port 4 is the receiving port.

Table 1: Tabulation of various parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Transmitter 900 MHz</th>
<th>Receiver 900 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>16.140 dB</td>
<td>16.364 dB</td>
</tr>
<tr>
<td>Stability factor (≥1)</td>
<td>1.001</td>
<td>1.000</td>
</tr>
<tr>
<td>Stability measure (&lt;1)</td>
<td>0.597</td>
<td>0.005</td>
</tr>
<tr>
<td>Isolation constant between Port 1 and Port 3</td>
<td>-26.557 dB</td>
<td></td>
</tr>
<tr>
<td>Isolation constant between Port 2 and Port 4</td>
<td>-25.612 dB</td>
<td></td>
</tr>
<tr>
<td>Reflection coefficient at port 1</td>
<td>-16.811 dB</td>
<td></td>
</tr>
<tr>
<td>Reflection coefficient at port 2</td>
<td>-13.213 dB</td>
<td></td>
</tr>
<tr>
<td>Reflection coefficient at port 3</td>
<td>-11.159 dB</td>
<td></td>
</tr>
<tr>
<td>Reflection coefficient at port 4</td>
<td>-10.630 dB</td>
<td></td>
</tr>
<tr>
<td>Bandwidth</td>
<td>25 MHz</td>
<td></td>
</tr>
<tr>
<td>Noise figure at port 4 (receiving port)</td>
<td>0.270</td>
<td></td>
</tr>
</tbody>
</table>

IV. CONCLUSION

The proposed Active Tunable Duplexer provides a better gain, isolation constants with less than -25 dB between the adjacent ports and less noise figure. The duplexer has been tested for its stability and hence found to be unconditionally stable. Thus the proposed duplexer can be implemented as monolithic microwave integrated circuit.

REFERENCES


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