DC~20GHz Microwave Monolithic SPDT Broadband Switch

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Abstract: a DC~ 20GHz monolithic SPDT broadband switch is presented in this paper. This switch has been realized by 0.15um GaAs process.it exhibits high performance: over DC~ 20GHz, Insertion loss is less than 2.0dB; The input 1dB compression point is more than 22dBm; input return loss is lower than -15dB; output return loss is lower than -15dB; Isolation is more than 40dB.

1. Introduction

Switch is a device that controls the microwave signal path. From a highly complex space communication system to a simpler application that requires RF signals to be switched from one path to another, microwave switches are indispensable key components. At present, the demand for high performance, small size, and universal microwave switches in commercial RF communication systems such as cellular GSM, UMTS, cable modems, live broadcast systems, point-to-point and point-to-multipoint broadcast systems continues to increase. As the complexity of information transmission increases, the bandwidth requirements continue to increase, and these functions need to be accommodated in a small form factor, even requiring low power consumption. The switch-guided microwave signal is transmitted through the target path of the system and the subsystem, and the realization of different schemes necessary for signal synthesis in the system application becomes possible.

At the same time, along with the development of wireless communication technology, the market demand for RF communication systems is also increasing. As an indispensable component of today's wireless communication systems, various performance indicators such as loss and power capacity of RF switches have also been put forward more stringent requirements. On the one hand, emerging technologies are constantly asking for new requirements. Multiple Input Multiple Output (MIMO) operation proposed by the 4G Long Term Evolution (LTE) standard, which is implemented using two antennas. This technology can be used for double-pole double-throw (DPDT) dual-antenna switches, allowing the baseband processor to dynamically select stronger received signals or simultaneously maintain two separate data to communicate with the base station. On the other hand, the existing communication technology has higher and higher performance requirements for RF switches.

2. Classification of RF switches

RF switches can be divided into single-pole single-throw (SPST), single-pole double-throw (SPDT), single-pole multi-throw (SPXT), and double-pole multi-throw (DPXT) switches depending on their number of tools and the number of throws. Different devices can be divided into three categories, namely PIN diode switches, MEMS switches and solid state FET switches.

2.1 PIN diode switches

The PIN diode is different from the general pn junction diode in that a high-resistance intrinsic isolation layer is inserted in the p-type region and the n-type region, and its characteristic is a variable resistor controlled by the bias current in the radio frequency band. . The holes and electrons reach the I layer under the forward current bias. These electrons and holes do not immediately combine with each other, but exist for a period of time, so that a certain amount of charge is stored in the PIN diode,

so that the capacitance of the I- layer is The increase increases the impedance at high frequencies; when the PIN diode is in a zero-bias or reverse-biased state, no charge accumulates in the I-layer, and the PIN diode has a very high impedance at high frequencies. Due to such characteristics, a PIN diode is used in a switching device that controls a radio frequency signal. However, this technique requires a large paranoid current and a low switching speed, so it is generally not used in mobile communication devices..

2.2 MEMS switches

MEMS combines microelectronics and precision mechanical fabrication techniques with ultra-low insertion loss and very good isolation performance, and is compatible with traditional CMOS processes. Although the prospects for MEMS have been good, there are not many MEMS devices actually put into the market in recent years, even including miniature gyroscopes and accelerators. Problems such as high voltage requirements, special packaging and reliability have become major factors limiting their application and development..

2.3 Solid state FET switches

Solid-state FET devices are widely used in RF systems for mobile devices due to their low cost, excellent performance and low drive voltage requirements. The solid-state FET switching devices currently on the market can be mainly divided into two types, GaAs pHEMT RF switching devices and Si-based SOI RF switching devices. GaAs pHEMT has always occupied the important position of the RF switch market with low insertion loss and high power capacity. However, with the application of CMOS RF chips in recent years, the voltage of the fundamental frequency controller is gradually reduced, especially the power supply of mobile phone batteries. The voltage is typically 1.7V and its operating voltage is close to the voltage of the enhanced GaAs pHEMT device. On the other hand, the performance of CMOS RF switches on the market has been greatly improved since the emergence of CMOS SOI RF switching devices. In general, GaAs pHEMT technology provides good power and linearity performance while consuming less chip area and having a smaller package size. In SOI MOSFET switches, it is necessary to integrate positive and negative voltage generators, usually requiring a relatively large chip area, but the advantage is that it can flexibly integrate CMOS logic circuits on the chip, making it high in throw and low control voltage. There are advantages in switching applications.

parameter	V_{dd} /V	I_{dd} /mA	V_{ctl} /V	IL / dB 0.9GHz / 1.9GHz	ISO / dB 0.9GHz / 1.9GHz	$P_{-0.1dB}$	Size	ESD
CMOS - SOI	2.5	51.4	High/ Low	0.41/ 0.65	26.9/ 25.7	>30 dBm	1.3* 0.7	1300
GaAs pHEMT	no need	0	High/ Low	0.27/ 0.52	24.1/ 31.3	>35 dBm	1.33 *0.7	400

Figure 1 CMOS-SOI and PHEMT process comparison

3. Main design indicators for switch

In order to reduce the noise figure of the receiving link, improve the efficiency of the transmitting link, reduce the energy consumption, and reduce the influence of nonlinear factors, the design of the RF microwave switching element should be as low as possible, with high isolation required by the system. High linearity and stronger power handling capability. The radio frequency switch used in

the mobile communication system includes a main antenna module radio frequency T/R transceiver switch, a diversity antenna part switch, and a frequency band/mode module switch. Modern smartphones integrate wireless communication standards/technologies (WCDMA/HSPA and LTE) and multiple wireless services (Wi-Fi, GPS}RFID) that are updated in a more humane way with the times, which is not possible. Avoiding higher demands on the smartphone's receiving and transmitting system - wide band and high linearity - puts higher demands on high performance RF switching performance. The switches in this type of system should have the characteristics of low loss, strong isolation and high linearity, which will not increase the signal distortion caused by the switch and enhance the fidelity of the signal.

3.1 Insertion loss

The switch acts as a switch in the RF circuit. The ideal state is that there is no impedance at all when turned on, and the impedance is infinite when turned off. However, in reality, due to the channel resistance in the on state, the signal will lose some energy when passing through the RF switching circuit. Therefore, the insertion loss (IL) is used to characterize the loss during the RF switching circuit in which the RF signal passes through. degree. The insertion loss index is one of the important indicators to characterize the performance of the RF switch. It is mainly determined by the on-resistance of the RF switch. The smaller the on-resistance, the smaller the insertion loss.

The impact of the insertion loss indicator on system performance: the switch insertion loss on the receive link reduces the signal level and ultimately the deterioration of the noise figure. The switch insertion loss on the transmit link causes the transmit signal level to decrease, and the transmit link is attached. The efficiency is reduced and the energy consumption is increased.

3.2 Isolation

Isolation is the difference between the signal power and the input power that is leaked to the output when the RF switch is turned off. It is generally expressed as an absolute value. Isolation is also one of the important performance indicators of RF switches. The isolation requires that the isolation between the two branches should be high to meet the safety requirements, such as the leakage of the transmission to the reception and the low-noise power devices such as low-noise. The greater the isolation, the smaller the mutual influence between the input and output of the RF switch, and the better the switching performance.

3.3 Power Capacity

Power capacity refers to the maximum power that an RF switch can withstand. Since the input signal is larger, the linearity of the switch is worse, so the power capacity index can guarantee a certain linearity under the condition of the maximum power signal input of the radio frequency signal. Since the working state of the RF switch is divided into the on and off states, the power capacity is also divided into the on power capacity and the off power capacity, and the smaller of the two is actually used as the power capacity of the switch.

The withstand power involves the safe operation and linearity of the switch. First of all, it is considered for safe operation. When the rated power is exceeded, the insertion loss will deteriorate or even burn out. Secondly, the nonlinear problem, when the input level exceeds the rated withstand power of the switch itself, on the one hand, the large harmonic generated by the switch nonlinearity will interfere with other systems, and the receiving signal of the switch port and the external strong interference signal The intermodulation caused by the non-linearity of the switch easily interferes with or even blocks the receiving channel.

4. SPDT broadband switch structure

The basis of the RF switch design is the design of the SPDT single-pole double-throw RF switch. Other RF switches are based on the SPDT design. A typical SPDT RF circuit is shown in Figure 2.

When the SPDT needs to receive a signal, the gate voltage controls the transistor at the receiving

end to enter a conducting state, and the transistor at the transmitting end enters an off state, and the signal can pass through the receiving terminal transistor to reach the receiving end. When the SPDT enters the emission state, the gate voltage controls the emitter transistor to enter the on state, and the receiver transistor enters the off state.

It is worth noting that in the receiving state, the transmitting port is in a floating state, so the resistor Rds is required to connect the source and the drain of the off-state transistor, so that the voltages on both sides are balanced to ensure the off state of the transistor. Generally, the resistance of Rds is equivalent to the source-drain resistance of the transistor off state. On the other hand, due to the parasitic capacitance between the gate source and the gate drain, a part of the RF signal will enter the gate. When the RF input signal is too large, the DC bias of the gate may be damaged. Therefore, a series resistor Rg in series with the gate can effectively isolate the RF signal from the DC offset and reduce the gate current, thereby reducing the power consumption of the RF switch. Generally, the gate resistance ranges from several thousand ohms to several tens of kilo ohms.
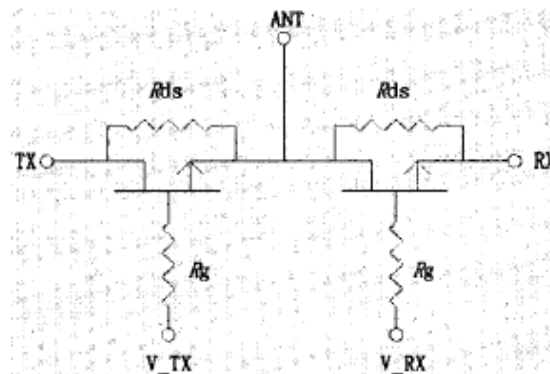

Figure 2 SPDT structure

In the actual design, due to the different emphasis of the design indicators, the typical SPDT RF switching circuit shown in Figure 2 cannot meet the design requirements. For example, in order to obtain better isolation characteristics, multiple transistors can be connected in series to increase isolation, but increase the insertion loss of the circuit. In order to obtain better isolation and obtain smaller insertion loss, a series-shunt structure is often used to improve the isolation while increasing the insertion loss. A typical series-parallel structure is shown in Figure 3.
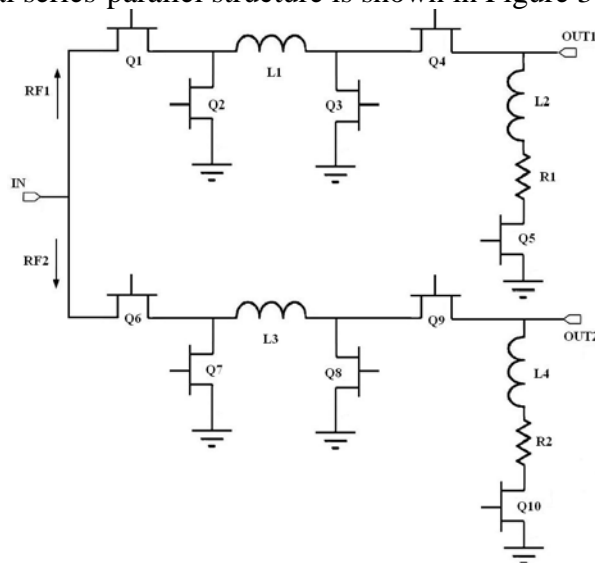

Figure 3 broadband SPDT structure

Figure 3 is a schematic circuit diagram of the Ultra Wideband Switch, these aspects are achieved by providing input and output match circuit for ultra wideband .

The ultra wideband SPDT switch have two SPST switches A1 and A2. A1 comprises five pHEMT

Q1, Q2, Q3, Q4 and Q5.a resistor R1, two inductors L1 and L2. The second switch A2 is the same structure with A1, comprisesives five pHEMT Q6, Q7, Q8, Q9 and Q10, a resistor R2, two inductors L3 and L4.

Considering parasitic resistors, parasitic capacitors of the pHEMT; parasitic capacitors, parasitic resistors and parasitic inductors of integration inductor, when switch A1 is on state, add to a integration inductor L1 in series, A1 make up of a filter in the end for providing a good wideband match of the input resistance and wideband frequency response. when switch A1 is off state, adding the L2 and R1 in parallel also make A1 providing a good wideband match of the output resistance and wideband frequency response.

5. Circuit design

Using the new configuration, a DC~ 20GHz SPDT switch has been realized by 0.15um GaAs process. The simulation of our SPDT broadband switch have been presented based on the ADS2016. over DC~ 20GHz, Insertion loss is less than 2.0dB; The input 1dB compression point is more than 22dBm; input return loss is lower than -15dB; output return loss is lower than -15dB; Isolation is more than 40dB. the layout of the SPDT swith with a chip size of 2.5*1.2 mm^2.
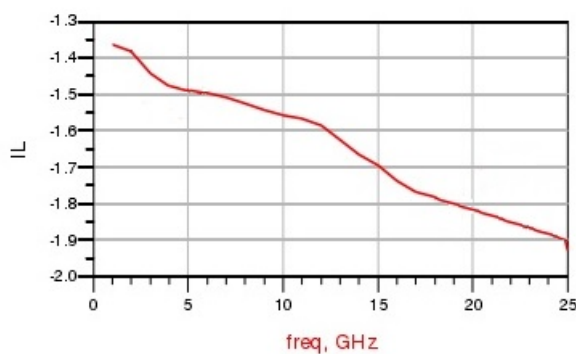

Figure 4 Simulated Insertion Loss

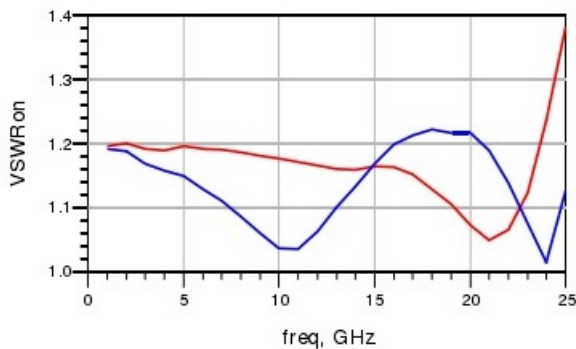Figure5 Simulated Noise figure

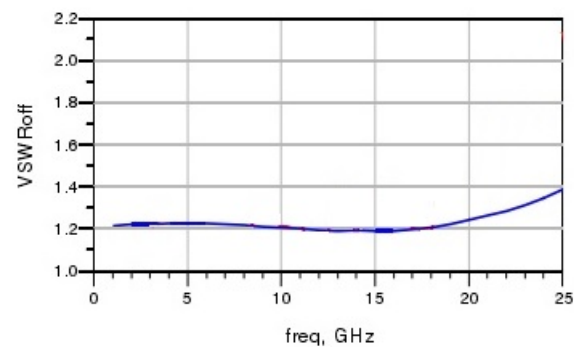Figure 6 Simulated on VSWR

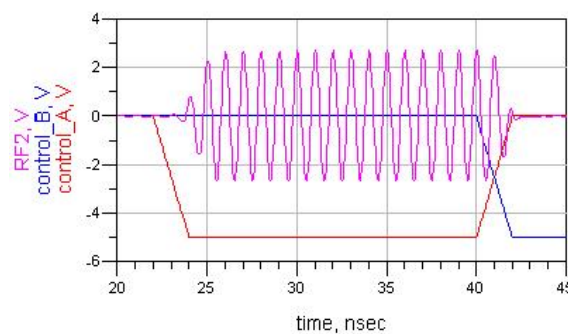Figure7 Simulated off VSWR

Figure8 Simulated Switching Characteristics

6. Conclusions

In this paper a suitable configuration is used for a Microwave Monolithic SPDT broadband switch. the sumulation results shows over DC~ 20GHz, Insertion loss is less than 2.0dB; The input 1dB compression point is more than 22dBm; input return loss is lower than -15dB; output return loss is lower than -15dB; Isolation is more than 40dB. the proposed one is good candidate for Microwave Monolithic SPDT broadband switch applications.

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