A Compact SPDT Switch Amplifier for 5G Millimeter-wave Applications

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This paper describes a newly developed single pole double throw (SPDT) switch amplifier. It is designed to implement in a frequency conversion integrated circuits for 3GPP n257, n258 and n261 bands and its operating frequency range is from 29.15 to 34.40 GHz. The SPDT switch amplifier provides local oscillator (LO) signals to either a transmitter mixer or a receiver mixer and realizes more than 52 dB ON/OFF ratio and 12 dB small signal gain over the frequency range. Its gain can be changed to adjust the output power to the required LO power. The SPDT switch amplifier is fabricated using 0.13-μm SiGe BiCMOS technology and the area of core is 0.24 mm^2.

1. Introduction

Recently, the fifth mobile communication (5G) system is spreading all over the world and devices for 5G NR FR2 bands (n257, n258 and n261) were developed [1)2)]. Phased array antenna modules (PAAMs) are implemented in 5G base stations to achieve large distance wireless communication using antenna array with a large number of elements. The previously reported PAAM [3)] consists of antenna in package [4)], band-pass filters [5)], beam forming integrated circuits (BFICs) [6)] and frequency conversion integrated circuits (FCICs) [6)]. The function of the FCIC is to generate transmitter (TX) signals from local oscillator (LO) signals and TX intermediate frequency (IF) signals, and to generate receiver (RX) IF signals from received millimeter-wave (mm-wave) signals and LO signals. To satisfy n257, n258, and n261 bands, the frequency range of the RF signal needs to cover from 24.25 to 29.50 GHz. If the mixers in the FCIC operate using the lower sideband (LSB) mode, the LO signal needs to operate for a range from 29.15 to 34.40 GHz provided that IF frequency is 4.9GHz. Therefore, good performance in the frequency range from 29.15 to 34.40 GHz is required for the circuits operating the LO signal.

Figure 1 shows a block diagram of a conventional FCIC. In the FCIC, single pole double throw (SPDT) switch is used to select the path of LO signal to either LO AMP (TX) or LO AMP (RX). Regarding the SPDT switch, area reduction is important for reducing chip cost and achieving high ON/OFF ratio so that spurious emission can be reduced. Previously mm-wave SPDT switches have been reported [7)-10)]. Switches in mm-wave band have low isolation and occupy a non-negligible area. Integration of a switch and LO amplifiers has been done to decrease the area, a SPDT switch amplifier with small size and good ON/OFF ratio have been achieved 11). However, to select output destination, this SPDT switch amplifier needs to be controlled by a drain bias that flows a large current. GaAs technology that is costly as compared to SiGe technology has been used but cost reduction is difficult. Furthermore, this SPDT switch amplifier cannot change its gain. The LO signal power required for a mixer may change toward temperature fluctuations and process variations. The input power from a voltage controlled oscillator (VCO) may also fluctuate. Therefore, function of adjusting the gain of an LO amplifier is needed for the SPDT switch amplifier. We propose an SPDT switch amplifier [12)] with good performance and overcomes these problems.

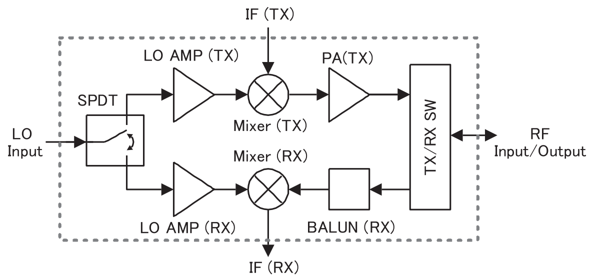

Fig. 1. Block diagram of a conventional frequency conversion IC [12)].

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Abbreviations, Acronyms, and Terms.

ON/OFF ratio—ON/OFF ratio
A difference of S21 between ON state switch and OFF state switch.

5G—Fifth Generation Mobile Communication System
The fifth-generation technology standard for broadband cellular networks.

5G NR—5G New Radio
A new radio access technology for the fifth generation network.

SPDT Switch—Single-Pole Double-Throw Switch
A switch has one input terminal and two output terminals and connects the input terminal and one of two output terminals. The switch can select output direction from the output terminals by ON/OFF configuration.

n257—n257
A band of 5G NR. The frequency range is from 26.5 GHz to 29.5 GHz.

n258—n258
A band of 5G NR. The frequency range is from 24.25 GHz to 27.5 GHz.

n261—n261
A band of 5G NR. The frequency range is from 27.5 GHz to 28.35 GHz.

LO signal—Local Oscillator Signal
Signal from local oscillator. Used for frequency conversion as a reference signal for heterodyne receiver.

Mixer—Mixer
A circuit that mixes two signals with different frequency and outputs signal with converted frequency.

CMOS—Complementary MOS
Semiconductor circuits based on P-type and N-type MOS transistors, or their manufacturing technology.

BiCMOS—Bipolar CMOS
A semiconductor circuit that uses bipolar transistor circuits and CMOS circuits, or its manufacturing technology.

PAAM—Phased Array Antenna Module
A module consists of phased array antenna, BFIC, FCIC and filter. It is used for FWA(Fixed Wireless Access), MBB(Mobile Broad Band), back hole applications and etc.

BFIC—Beam Forming IC
A integrated circuit to emit radio wave to desired direction by operating phased array antenna and to amplify received signal from the phased array antenna.

FCIC—Frequency Conversion IC
A integrated circuit to convert TX IF signal to TX RF signal and RX RF signal to RX IF signal.

IF signal—Intermediate Frequency Signal
A signal to which a carrier signal is shifted as an intermediate step in transmission or reception.

HEMT—High Electron Mobility Transistor
A transistor which has a junction between two materials with different bandgap as the channel.

S-parameter—Scattering parameter
A parameter showing the performance of high frequency circuit.

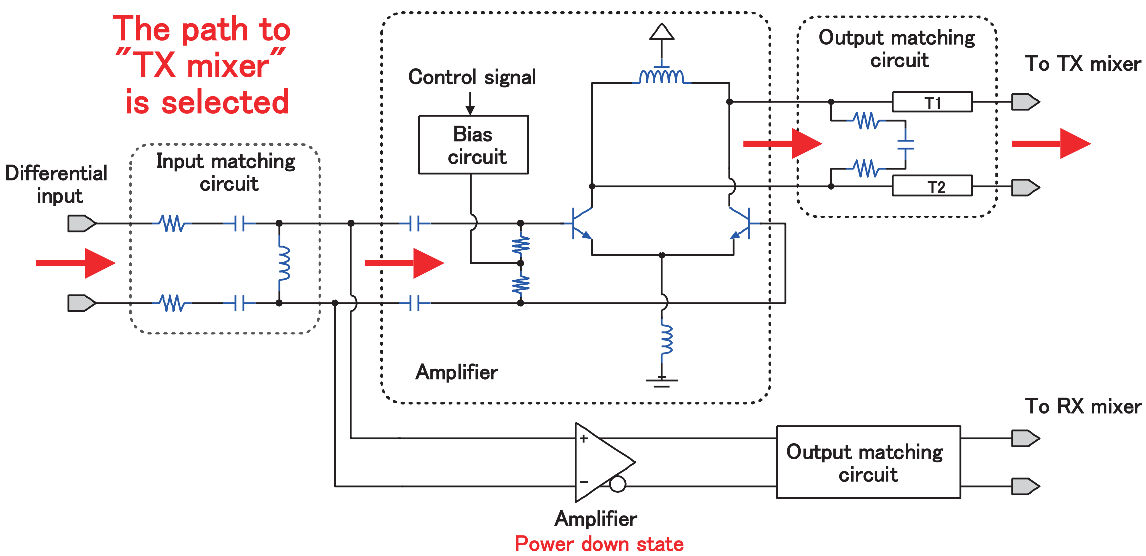

Fig. 2. Block diagram and circuit configuration of the proposed SPDT switch amplifier [12].

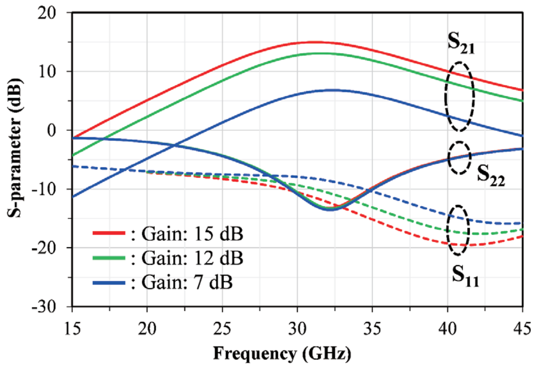

Fig. 3. Simulated S-parameters when the gain of amplifier changes to 7 dB, 12 dB and 15 dB by the outer control signal.

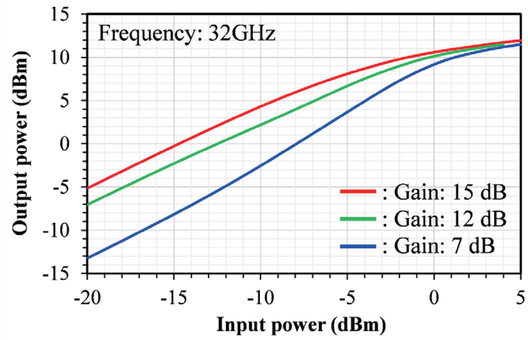

Fig. 4. Simulated input power versus output power characteristics at 32GHz.

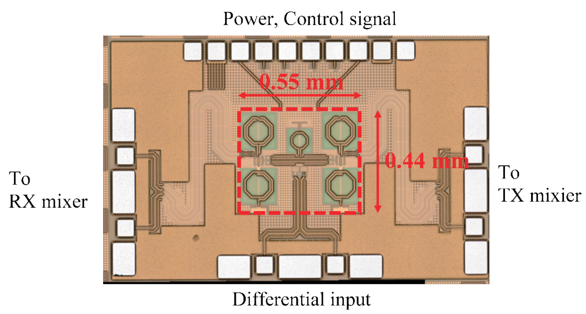

Fig. 5. Photograph of the fabricated SPDT switch amplifier chip for measurement [12].

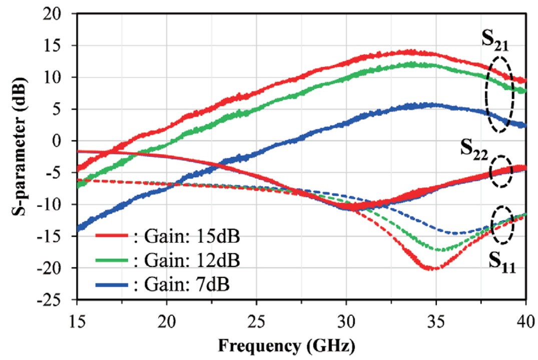

Fig. 6. Measured S-parameters when the gain of amplifier changes to 7 dB, 12 dB and 15 dB by the outer control signal.

2. SPDT Switch Amplifier Design

Figure 2 shows the proposed SPDT switch amplifier consists of a common input matching circuit and two amplifiers. To select output destination, the power down function of each amplifier is used. Since either switch circuit or power distributor is not used, the SPDT switch amplifier can decrease its size and improve the ON/OFF ratio.

The input matching circuit consists of R-C-L network. They are designed to match 50-ohm load when a differential amplifier is ON state and the other one is OFF state.

Both amplifiers have the same configuration and are composed of SiGe npn transistors and inductive loads. The loads consist of a stacked spiral inductor and the collector bias is provided from its center tap to decrease the amplifier size. Each amplifier has its own bias circuit that generates base biases of the npn transistors. By the outer control signal, the bias circuit can vary the gain of each amplifier independently to achieve a wide input and output power range and turn the amplifier to power down mode. Figure 3 shows simulated S-parameters when the gain of the amplifiers changes. The output matching circuit consists of R-C network and impedance conversion lines (T1 and T2) that are designed to match 50-ohm load.

Since a SiGe transistor can achieve high gain and high output power with small device size, the amplifier has small parasitic capacitance and high isolation.

A previously proposed FCIC requires LO power of 5 dBm [6]. Figure 4 shows simulated input power versus output power performances of the SPDT switch amplifier at 32 GHz when the gain of amplifier changes. Output power of 5 dBm can be achieved with all the gain states.

3. Measured Results

A photograph of the fabricated SPDT switch amplifier using 0.13-µm SiGe BiCMOS technology is shown in Fig. 5. The total IC size is 1.60 mm^2 and its core area is 0.24 mm^2. The right amplifier is measured with the condition that the output ports of the left amplifier is terminated with 50 ohm. The measured S-parameters with the gain states set to 7dB, 12dB and 15dB are shown in Fig. 6. The S-parameters between the measured results and simulated results are well matched. With all the gain states, the measured S11 and S22 are under -8 dB and -7 dB in the frequency range from 29.15 to 34.40 GHz. The measured S21 is over 12 dB and its flatness achieves a good value of 1.6 dB over the frequency range with the maximum gain state. This S21 measured result is also well matched to the simulated result.

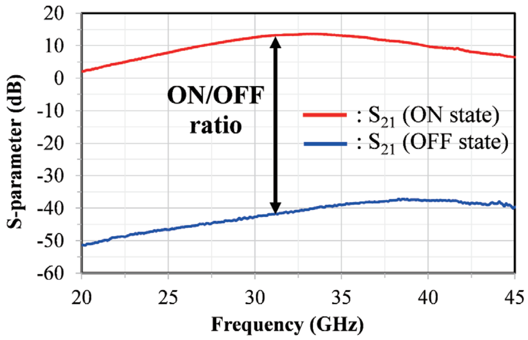

Fig. 7. Measured ON/OFF ratio.

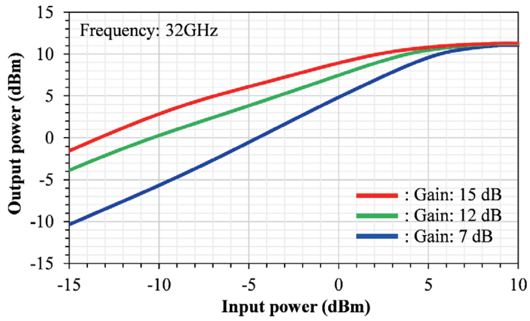

Fig. 8. Measured input power versus output power characteristics at 32 GHz.

Table 1. Comparison with some published SPDT switches, amplifiers, and SPDT switch amplifiers [12].

Reference	This work	[7]	[8]	[9]	[10]	[11]
Topology	SPDT switch amplifier	SPDT switch	SPDT switch	SPDT switch	SPDT switch and LNA	SPDT switch amplifier
Frequency	29.15-34.40 GHz	27-50 GHz	17-100 GHz	50-67 GHz	19.15-34.40 GHz	24-27.5 GHz
Area	0.24 mm2	0.4 mm2	0.42 mm2	0.3 mm2	0.77 mm2	0.37 mm2
Gain	12 dB	-2.7 dB	-2.8 dB	-1.9 dB	22 dB	6 dB
ON/OFF ratio	52 dB	23.3 dB	17.2 dB	39.9 dB	25 dB	24 dB
Technology	0.13 μm SiGe	0.13 μm CMOS	65nm CMOS	90nm CMOS	0.13 μm SiGe	0.15 μm pHEMT

ON/OFF ratio shows the difference between the ON state and the OFF state of S21 and is one of the most important features for the SPDT switch amplifier. Figure 7 shows measured ON/OFF ratio and more than 52 dB over the frequency range is realized. Figure 8 shows measured input power versus output power characteristic at 32 GHz with the maximum gain state and good performances are demonstrated.

The comparison of main characteristics with some published works is shown in Table 1. Compared to the published works, the proposed SPDT switch amplifier can achieve smaller area and better ON/OFF ratio.

4. Conclusion

A newly developed SPDT switch amplifier using 0.13-μm SiGe BiCMOS technology has been introduced. It achieves smaller size and higher ON/OFF ratio than previous reported millimeter-wave SPDT switches and SPDT switch amplifiers. The SPDT switch amplifier can decrease the FCIC cost and spurious emission.

Reference

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