Receiver Electronics for Axion Experiment at CAPP

Seung Pyo Chang[1,2], *Young-Im Kim*[2], *Myeongjae Lee*[2], *Yannis K. Semertzidis*[1,2]

[1]Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea
[2]Center for Axion and Precision Physics Research (CAPP), Institute for Basic Science (IBS), Daejeon, South Korea

DOI: http://dx.doi.org/10.3204/DESY-PROC-2015-02/chang_seungpyo

The CAPP/IBS aims to do an axion search by detecting the axion using a resonant cavity. In this experiment, the axion signal should be amplified and down-converted because it is very weak (10^{-24} W) and the frequency is very high for digitization ($2 \sim 8$ GHz). In the radio frequency (RF) signal processing at room temperature, the amplifier and mixer play a crucial role. One of the amplifiers and the mixer is tested. Also the entire RF signal processing system is tested with a very weak artificial signal (10^{-19} W).

1 Introduction

The CAPP/IBS is searching for the cosmic axion using a resonant cavity. In this experiment, the extremely weak, axion signal is supposed to be generated in a resonant cavity inside a very high magnetic field ($> 8T$) and a very low temperature ($\sim$ 100 mK). After the axion signal exits from the cavity, it goes through the radio frequency (RF) signal processing system which amplifies the signal and downconverts the frequency from GHz to MHz at room temperature. The amplifier and the mixer have an important role in the RF signal processing system at room temperature (RT). The RF signal processing chain has been designed. The measurement results of the two components of the entire system are described in this paper. The entire RF signal processing system has been tested with a very weak artificial signal (10^{-19} W).

2 Measurement

The amplifier HMC-C059 and the mixer HMC-C009 have been tested with 8 GHz, 5 GHz signals respectively. These frequencies are chosen because they are at the middle of the available frequency range of each component. The input power range varies from -140 dBm to 10 dBm. For the mixer, the local oscillator (LO) frequency is set to 4.9 GHz and the intermediate frequency (IF) is 100 MHz. The entire RF signal processing system, which is composed of two amplifiers, a mixer, a band pass filter and a power splitter, has been tested with 2 signal generators and a signal analyzer. The test signal amplitude is set to -160 dBm at 6 GHz.

2.1 Amplifier

The gain is the ratio between the input and output amplifier's powers and can be defined as

$$\text{Gain [dB]} = 10\log(\mathrm{P_{out}}/\mathrm{P_{in}}). \quad (1)$$

The gain can be obtained by subtracting the input power and output power since the signal generator and signal analyzer shows the power in log scale. The basic set up for measuring the gain of an amplifier is shown in Figure 1. The output as a function of the input of an amplifier 'HMC-C009' is shown in Figure 2. The key parameters of an amplifier 'HMC-C059' are shown in Table 1 [1].

2.2 Mixer

The mixer is used for converting the frequency of RF signal. The conversion loss is the ratio between the input and output powers of a mixer. The conversion loss is defined as

$$\text{Conversion loss [dB]} = -10\log(\mathrm{P_{out}}/\mathrm{P_{in}}). \quad (2)$$

The basic set-up for measuring the conversion loss is shown in Figure 3. The left signal generator next to the mixer is used as input signal. Meanwhile, the signal generator below the mixer works as a local oscillator (LO). Finally, the signal analyzer is used for detecting the mixer's output signal. The quantitative relation between the RF, IF and LO frequency can be written as

$$f_{\mathrm{IF}} = f_{\mathrm{RF}} - f_{\mathrm{LO}}, \quad (3)$$

where f_{RF} and f_{IF} are respectively the frequencies of the input and output signals and f_{LO} is the frequency of a local oscillator. The Figure 4 shows the output of a mixer HMC-C009 as a function of the input. The key parameters of the mixer HMC-C009 are shown in Table 2 [2].

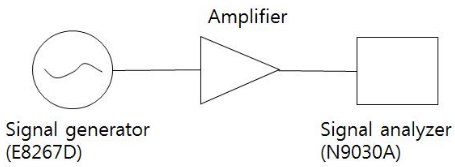

Figure 1: The set-up diagram for measuring the gain of an amplifier.

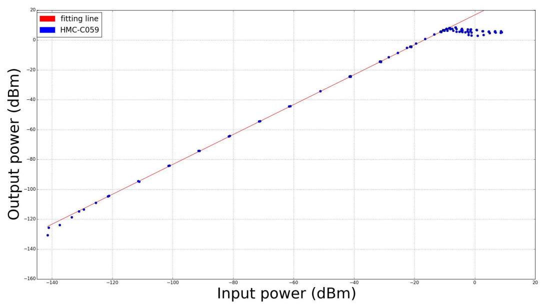

Figure 2: The input-output graph of an amplifier HMC-C059. The input frequency is 8 GHz.

Model	HMC-C059	
Freq. range (GHz)	1∼8	8∼12
Gain (dB)	16	14
DC voltage	$V^+/V^- = +6/\text{-}5$ V	

Table 1: Specifications of the HMC-C059 amplifier.

Model	HMC-C009
RF frequency (GHz)	4 ∼ 8
IF frequency (MHz)	100
LO power (dBm)	15
Conversion loss (dB)	7.5

Table 2: Specifications of the HMC-C009 amplifier.

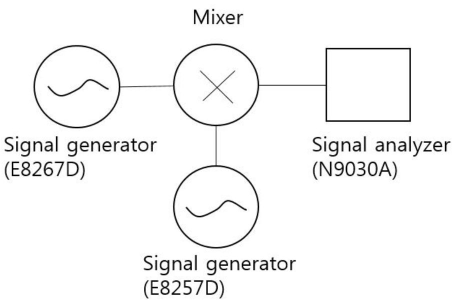

Figure 3: The diagram of set-up for measuring the mixer conversion loss.

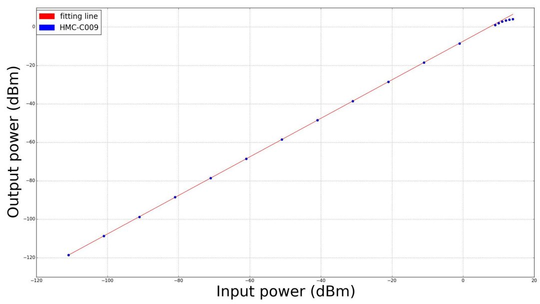

Figure 4: The input-output graph of an amplifier HMC-C009. The input frequency is 5 GHz.

2.3 RF signal processing system

The RF signal processing system is shown in Figure 5. The minimum input power which the signal generator can generate is - 160 dBm (10^{-19} W) with three 10 dB attenuators connected at the signal generator. This signal power is still stronger than the real axion signal - 210 dBm (10^{-24} W). This is reasonable to be tested because the axion signal would be amplified in the cryostat ($<$ 100 dB). Table 3 shows a summary of the gain/loss of this system. The screen shot of -160 dBm measurement of the signal analyzer is shown in Figure 6. The total system noise factor is 1.94 dB and the total system gain is 24. 3 dB. The performance of this electronics was measured using a spectrum analyser and running a VSA 89600 application. Figure 4 shows one of the results. The injected signal power is -160 dBm which is around 10^{-19} W. The expected noise floor with a 30 mHz resolution bandwidth is -163 dBm and the measured one is -156 dBm. The expected signal power is -135.7 dBm and the measured one is -129 dBm. The differences between the expected and measured values are possibly due to LO leakage and/or EMI.

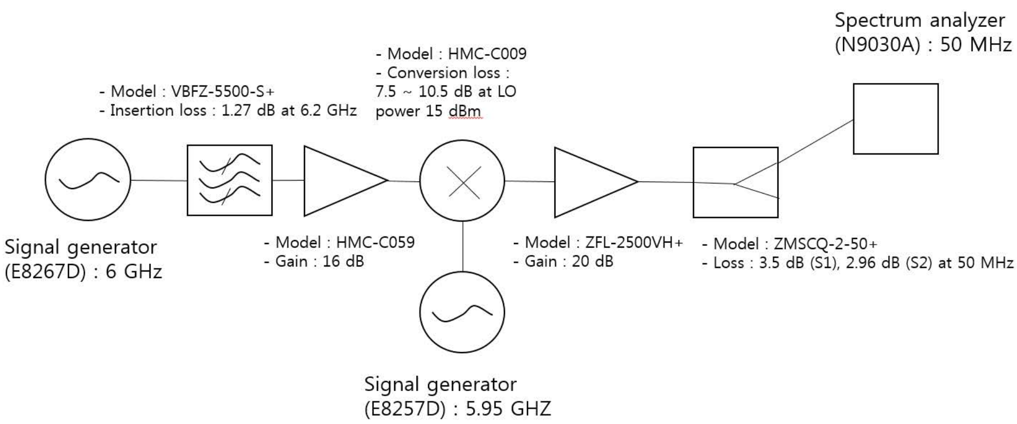

Figure 5: The diagram of the down conversion RF system. The model name and a short description is shown.

Model	VBFZ 5500-S+	HMC C059	HMC C009	ZFL 2500VH+	ZMSCQ 2-50+	Total
Gain/Loss (dB)	-1.3	+16	-10.5→-7.5	+20	-3.5	23.7

Table 3: The gain or loss of each component and the gain of the entire system. Those values are described in detail in their data sheet.

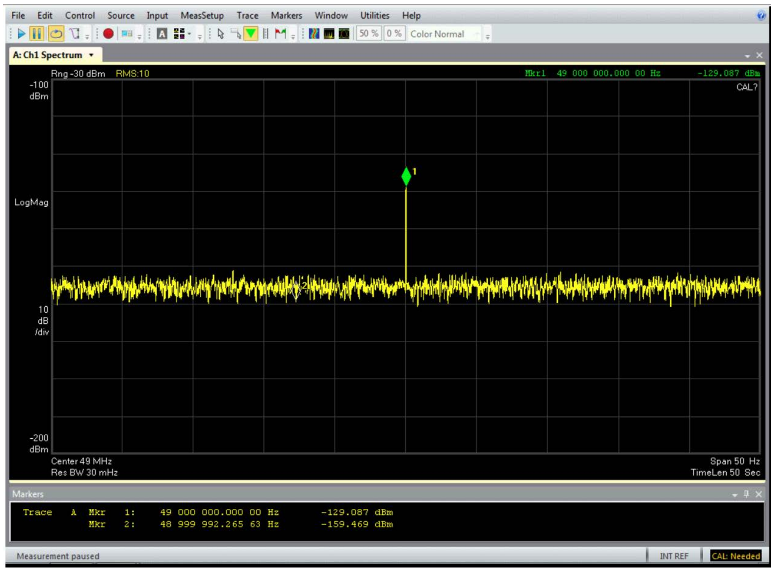

Figure 6: The screen shot of the signal analyzer : the input power is - 160 dBm. The measured output power is -129.087 dBm.

3 Conclusion

In the axion cavity experiment, the RF signal which is extreamly weak should be handled at room temperature. The RF signal processing system has been designed. Each individual component and the whole system have been tested. The gain or loss of each component matches well with data sheets. The entire RF processing system has been tested with a very weak signal (-160 dBm) and the gain of the whole system (25 dB) matches well with the expected value (23.73 dB).

References

[1] https://www.hittite.com/content/documents/data_sheet/hmc-c059.pdf

[2] https://www.hittite.com/content/documents/data_sheet/hmc-c009.pdf