5G mmWave Developer Kit
Labsheet Part IV

▮ List of laboratories

⚠ Please peruse the User Guide before using the developer kit.

Introduction

The 5G (5th generation mobile network) continues to be popular in 2022. With countries releasing new licenses for the FR2 frequency band one after another, operators also bid fiercely for their target bands. The FR2 frequency band includes n258(24.25-27.5 GHz), n257(26.5-29.5 GHz), n260(37-40 GHz), and n261(27.5-28.35 GHz). The FR2 is different from FR1, it can provide wider data bandwidth to satisfy high throughput and low latency features. However, it has a weakness, and it is the short wavelength that may contribute to higher path loss. To overcome this weakness, beamforming is the key technology to solve the mmWave application. In fact, beamforming has already been adopted in many applications such as FWA, Low Earth Orbit (LEO) Satellite, ADAS, ADAS, and more.

The mmWave development is an inevitable trend in the coming years and the market size will explode in growth. The mission is obvious, to develop and train talents. For the development of mmWave, the next generation of engineers will play a key role, and it is essential that engineering graduates are prepared for the principle, practice, and advanced research of related mmWave technologies. But, the reality is that the cost of mmWave relevant components is very expensive and difficult to demonstrate practical operating applications. The TMYTEK Developer Kit is a complete and affordable mmWave training tool for lecturers, professors, and researchers. It provides complete mmWave components as well as ready-made practical classes. It is not only a great entry-level kit for mmWave teaching, but also extends to advanced research with other options like Software Defined Radio (SDR), Arduino, and Up/Down Converter.

What's included

- 5G FR2 Beamformer - BBoard ×1
- Signal Soure - PLO ×1
- Power Detector ×1
- 5G FR2 Array Antenna ×1
- 28 GHz COCO Antenna ×1
- 20 GHz-40 GHz Amplifier ×1
- 40 GHz RF Cable ×4
- 10 GHz-40 GHz Combiner/Splitter ×1

BBoard
n257 beamformer.

Signal Source PLO
26.5-29.5 GHz. 8 steps.

Power Detector
0.1-40 GHz.
35 dB Dynamic Range.

Array Antenna
n257. 15 dBi gain.

COCO Antenna
27-29 GHz. 7 dBi gain.

Amplifier
20-40 GHz. 15 dB gain.

RF Cables
Up to 40 GHz.

Power Combiner/ Splitter
10-40 GHz. 1.2 dB loss.

Figure 1. List of Developer Kit

◼ Lab 7 - Measure the channel gain at the receiver?

1. Significance

For wireless communication systems, the specification of the first stage at the receiver will dominate the signal quality so using the LNA at the front-end of the receiver to reduce the noise is a common architecture. Referring to the architecture of the BBoard, it consists of four channels and each channel integrates a Power Amplifier (PA) for transmitter and a Low Noise Amplifier (LNA) for receiver. To achieve effective beamforming, You must be able to adjust precisely the gain among all channels.
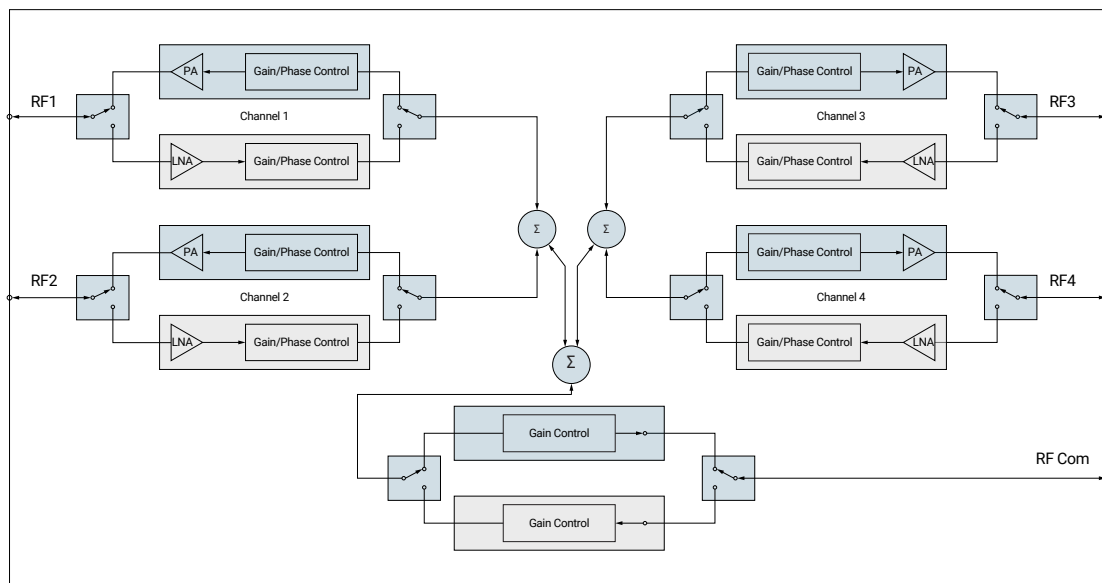

Figure 2. Architecture of beamformer

2. Aim

To understand how to switch between Tx and Rx mode on BBoard, how to adjust and measure each RF channel gain, and what is the difference between each gain stage . After the experiment, you can experience the linearity of each channel gain and the difference among them, and try to calibrate it if needed.

3. Requirements

- 5G FR2 beamformer - BBoard × 1
- Signal source - PLO × 1
- Power detector × 1
- 40 GHz RF cable × 1
- 10 GHz-40 GHz Combiner/Splitter × 1
- A personal computer with TMXLAB kit and LTC5596 GUI installed

4. Procedure

a. Utilizing the PLO and adding an attenuator as the source, and connecting it to the RF channels 1 port of BBoard.

b. Connect BBoard's RF com port to the power detector.

Figure 3. configuration of Lab 7

c. Switch BBoard to RX mode by pressing the button shows below in TMXLAB kit.

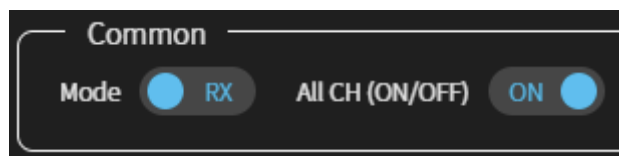
Figure 4. Switch BBoard to RX Mode

d. Adjust the TMXLAB kit for gain steps. There are two attenuators that can be adjusted in the TMXLAB kit, one is the common attenuator (coare adjustment) and another is the channel attenuator (fine adjustment). It is 1 dB per step for the common attenuator and 0.5 dB per step for the channel attenuator.
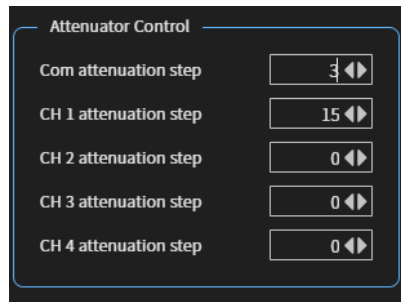

Figure 5. Attenuator control of TMXLAB Kit

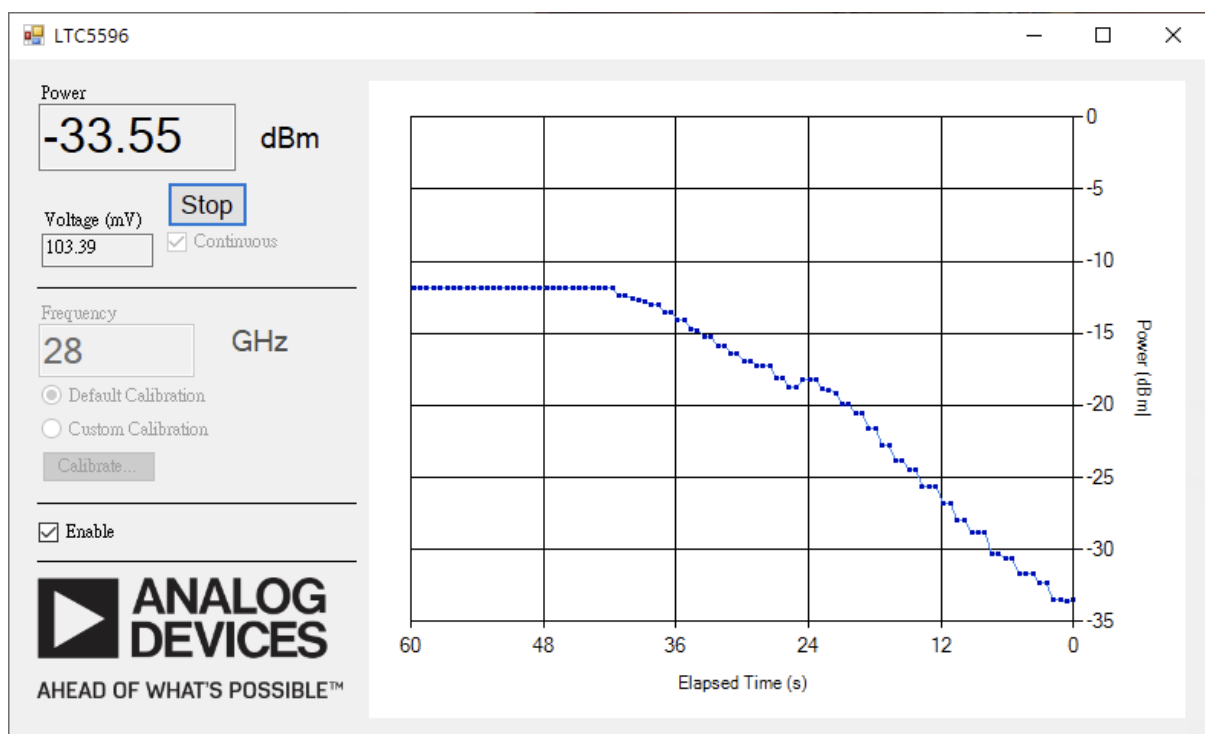e. Observe and record the detected power on the LTC5596 GUI for each gain step.

Figure 6. Measured power from LTC5596

f. Repeat steps a to e on all four BBoard RF channels.

5. Results

The test results are only for reference; they may differ depending on the developer kit or the conditions.

| Attenuator Step		Expected Attenuation	Power Readout				Differences		
Common	Channel		Channel 1	Channel 2	Channel 3	Channel 4	1 & 2	1 & 3	1 & 4
0	0	0.0	-11.42	-12.18	-12.35	-12.01	0.00	0.00	0.00
0	1	0.5	-11.93	-12.68	-12.79	-12.53	0.00	0.00	0.00
0	2	1.0	-12.32	-13.02	-13.19	-12.85	-0.29	-0.54	0.05
0	3	1.5	-12.68	-13.36	-13.53	-13.33	-0.27	-0.60	0.42
0	4	2.0	-13.19	-13.86	-14.03	-13.86	-0.21	-0.53	0.47
0	5	2.5	-13.69	-14.37	-14.54	-14.37	-0.25	-0.53	0.51
0	6	3.0	-14.37	-15.02	-15.04	-14.87	-0.25	-0.56	0.55
0	7	3.5	-14.87	-15.55	-15.72	-15.38	-0.28	-0.60	0.53
0	8	4.0	-15.38	-16.05	-16.22	-15.88	-0.23	-0.53	0.55
0	9	4.5	-16.05	-16.70	-16.78	-16.12	-0.18	-0.48	0.51
0	10	5.0	-16.39	-17.06	-17.23	-16.89	-0.26	-0.51	0.48
0	11	5.5	-16.89	-17.57	-17.74	-17.40	-0.22	-0.49	0.48
0	12	6.0	-17.57	-18.42	-18.14	-18.09	-0.21	-0.49	0.48
0	13	6.5	-18.24	-18.91	-19.08	-18.86	-0.22	-0.50	0.48
0	14	7.0	-17.90	-18.58	-18.81	-18.51	-0.22	-0.49	0.49
0	15	7.5	-18.41	-19.08	-19.42	-19.06	-0.22	-0.49	0.48
1	15	8.5	-19.42	-20.09	-20.43	-20.06	-0.12	-0.33	0.61
2	15	9.5	-20.09	-20.77	-21.07	-20.72	-0.17	-0.38	0.52
3	15	10.5	-21.10	-21.78	-22.11	-21.77	-0.14	-0.33	0.55
4	15	11.5	-22.45	-23.12	-22.89	-22.96	-0.16	-0.32	0.52
5	15	12.5	-23.46	-24.13	-24.30	-23.97	-0.20	-0.41	0.47
6	15	13.5	-24.13	-24.81	-24.98	-24.64	-0.22	-0.42	0.53
7	15	14.5	-25.18	-25.82	-26.15	-25.82	-0.11	-0.29	0.57
8	15	15.5	-26.43	-27.00	-27.33	-27.00	-0.20	-0.36	0.44
9	15	16.5	-27.67	-28.21	-28.51	-28.18	-0.18	-0.36	0.50
10	15	17.5	-28.51	-29.19	-29.14	-29.02	-0.12	-0.41	0.42
11	15	18.5	-29.98	-30.60	-30.87	-30.05	-0.15	-0.34	0.49
12	15	19.5	-30.22	-30.88	-31.21	-30.87	-0.16	-0.35	0.37
13	15	20.5	-31.37	-32.01	-32.22	-31.89	-0.16	-0.38	0.44
14	15	21.5	-32.05	-32.72	-32.99	-32.63	-0.17	-0.35	0.49
15	15	22.5	-33.23	-33.88	-34.07	-33.73	-0.16	-0.34	0.46

Table 1. Test Results
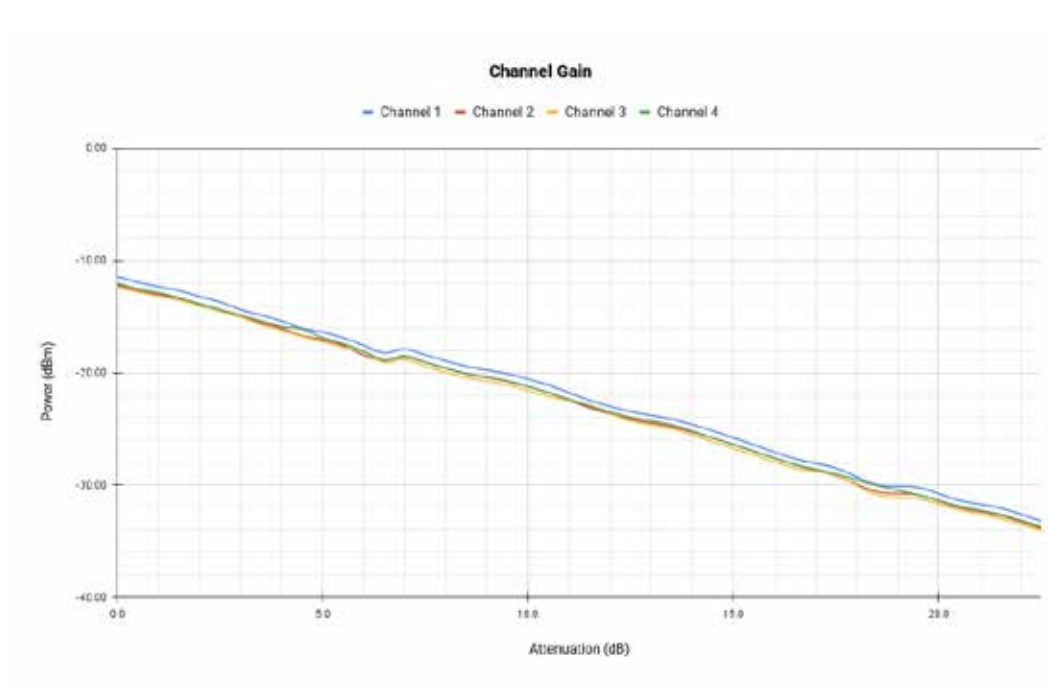
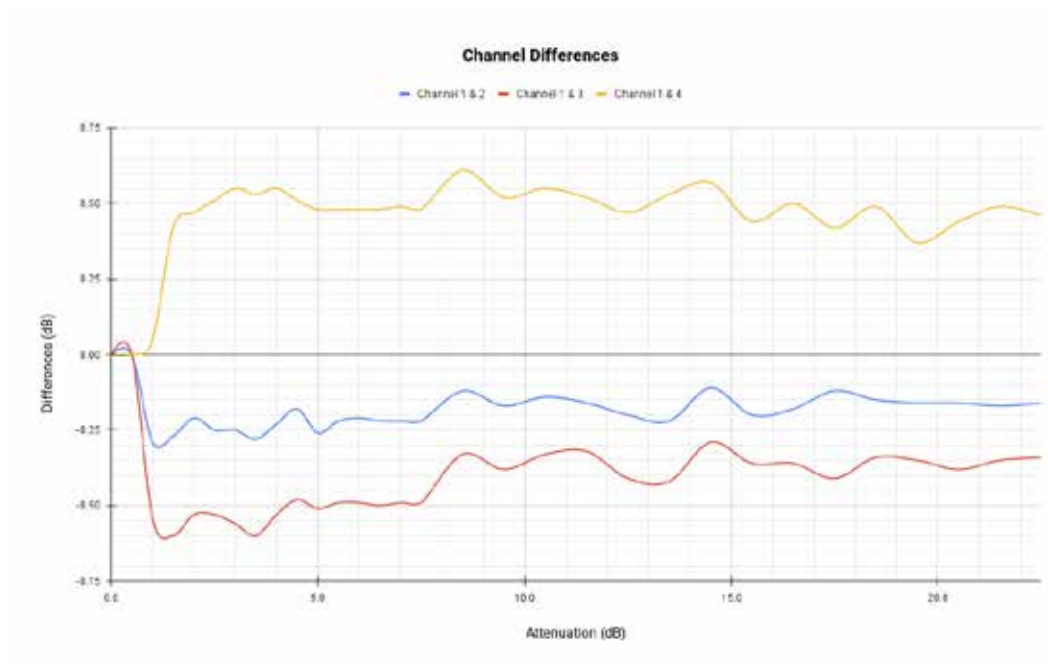Figure 7. The performance of attenuator among 4 RF channels

Figure 8. The channel difference among 4 RF channels

Calculate the link budget using results in Lab 1 and compare it against your results.
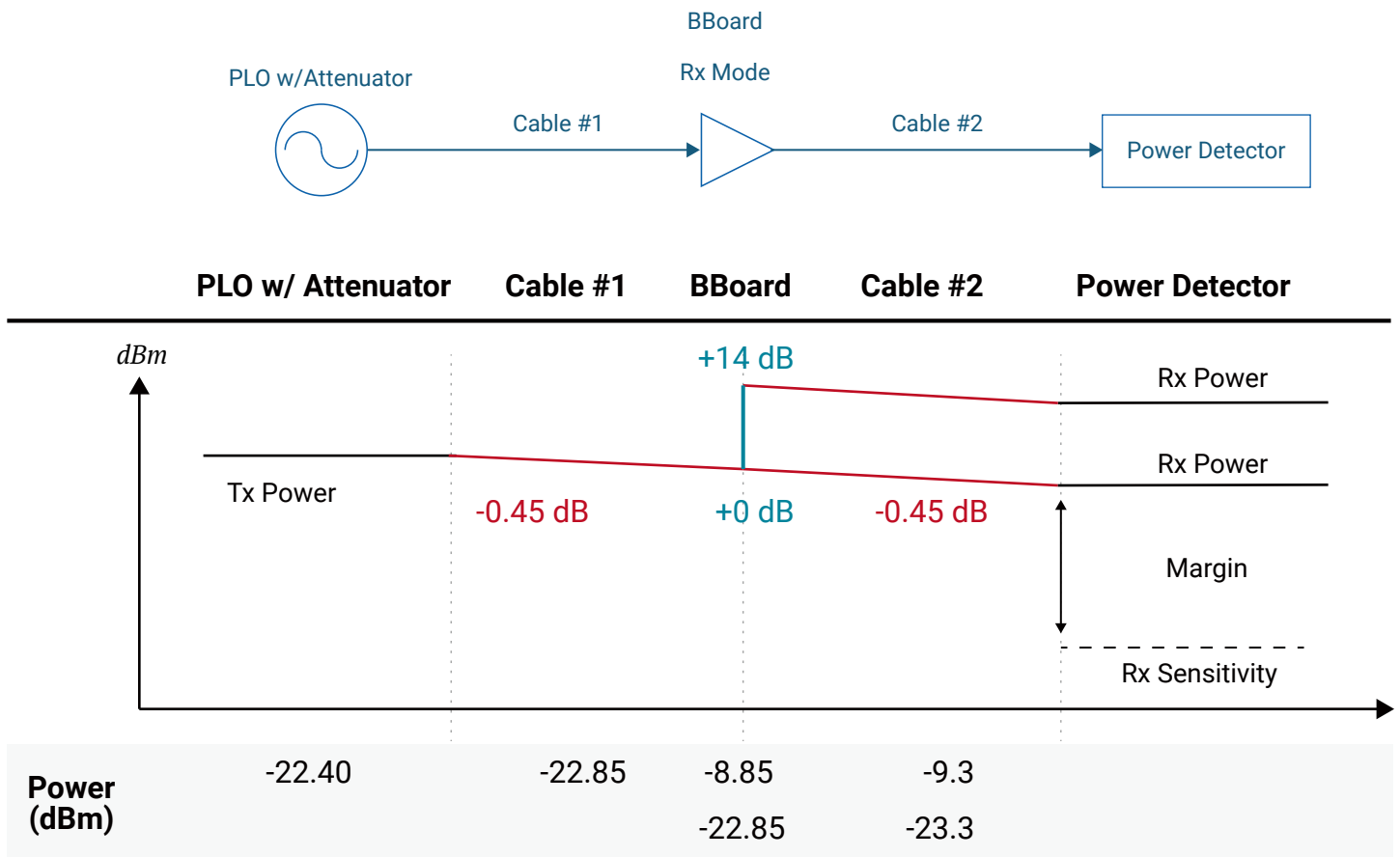

Figure 9. Link Budget Calculation

■ Lab 8 - Implement the in-phase at the receiver?

1. Significance

The beamformer consists of multi-channels that integrate independ phase shifters per channel. You can control the beam direction to cover a target area by adjusting the phase shifter in these channels. In order to control the beam direction precisely , you must make sure these channels are in-phase. In general, you have to use a multi-ports Vector Network Analyzer (VNA) to measure the phase difference among these channels then make them in-phase.

2. Aim

In this experiment, you can study the principle of the in-phase, and realize in-phase using Developer kit really. You will replace the VNA with a power combiner to simulate how to in-phase as well as understand what is the interference. In order to finish the in-phase accurately, you must operate these actions in conduction.

3. Requirements

- 5G FR2 beamformer - BBoard × 1
- Signal source - PLO × 1
- Power detector × 1
- 10 GHz-40 GHz Combiner/Splitter × 1
- 40 GHz RF Cable × 4
- A personal computer with TMXLAB kit and LTC5596 GUI installed

4. Procedure

a. Utilizing the PLO and adding an attenuator as the source and connecting it to the combiner port of the combiner/splitter.

b. Use two RF cables and connect to RF channel 1 & 2 of the BBoard to the splitter ports of the combiner/splitter.

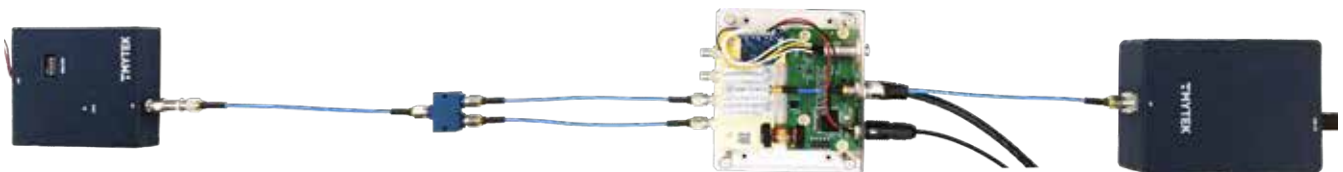c. Use the last one RF cable to connect it to BBoard's RF com port to the power detector as shown in Figure 10.

Figure 10. Configuration of Lab 8

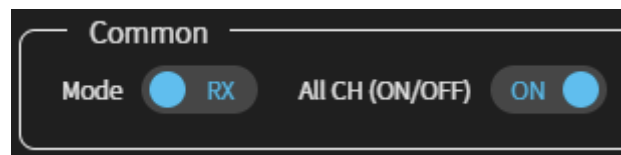d. Switch the operation mode into the receiver from the TMXLAB kit as shown in Figure 11.

Figure 11. Switch BBoard to RX

e. Operate the TMXLAB kit to adjust the phase step. Keep channel 1 at step 0 and just change channel 2 from 0 to 63 step by step. There are 6 controlling bits within 360 degrees for the phase shifter so 1 step will shift 5.625 degrees.
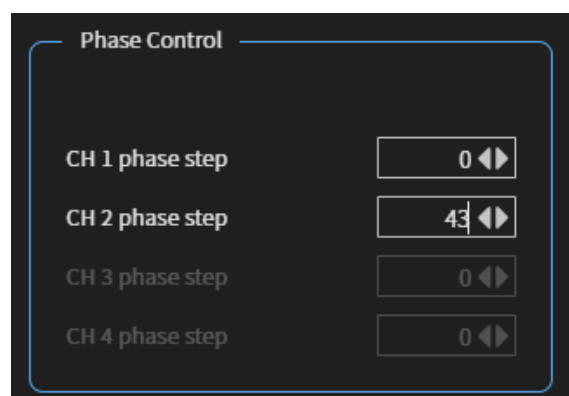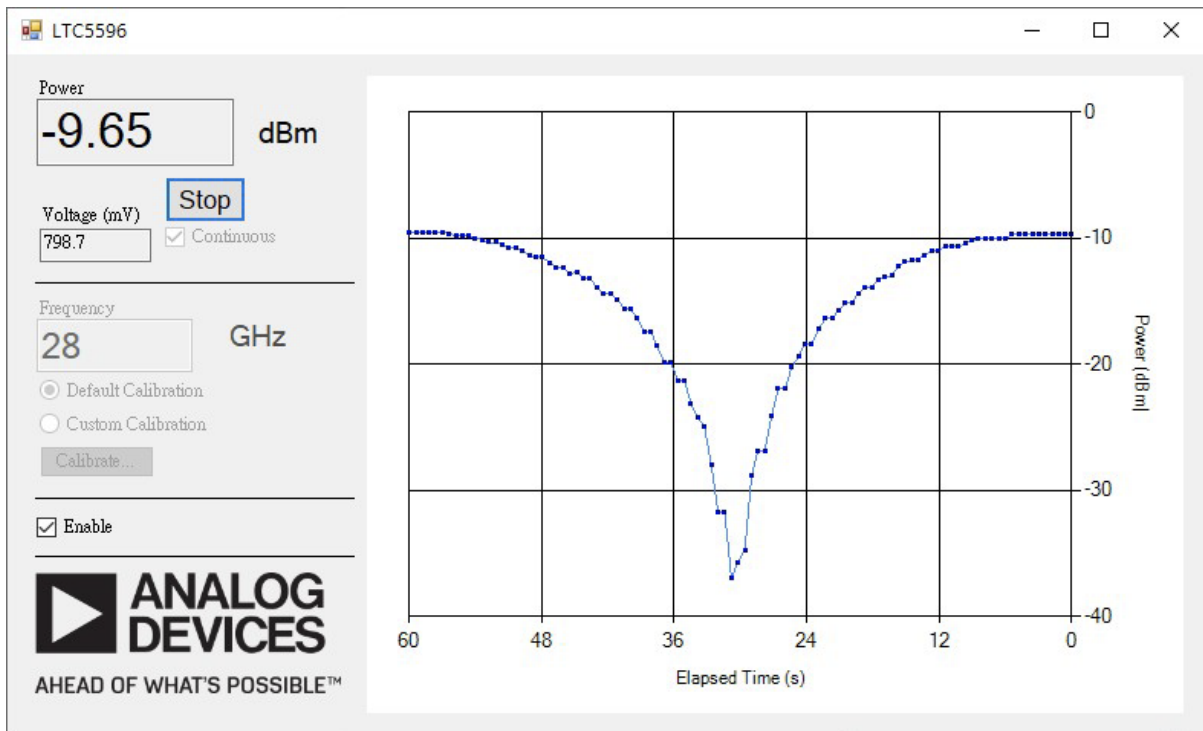

Figure 12. Phase control of TMXLAB Kit

f. Observe and record the detected power on the LTC5596 GUI after changing phase step.
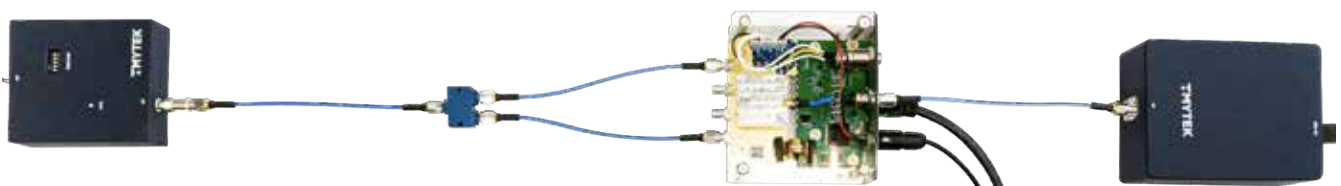

g. Repeat steps b to f on 1&3 and 1&4 channels.

Figure 13. Configuration of Lab 8

5. Results

The test results are only for reference; they may differ depending on the developer kit or the conditions.

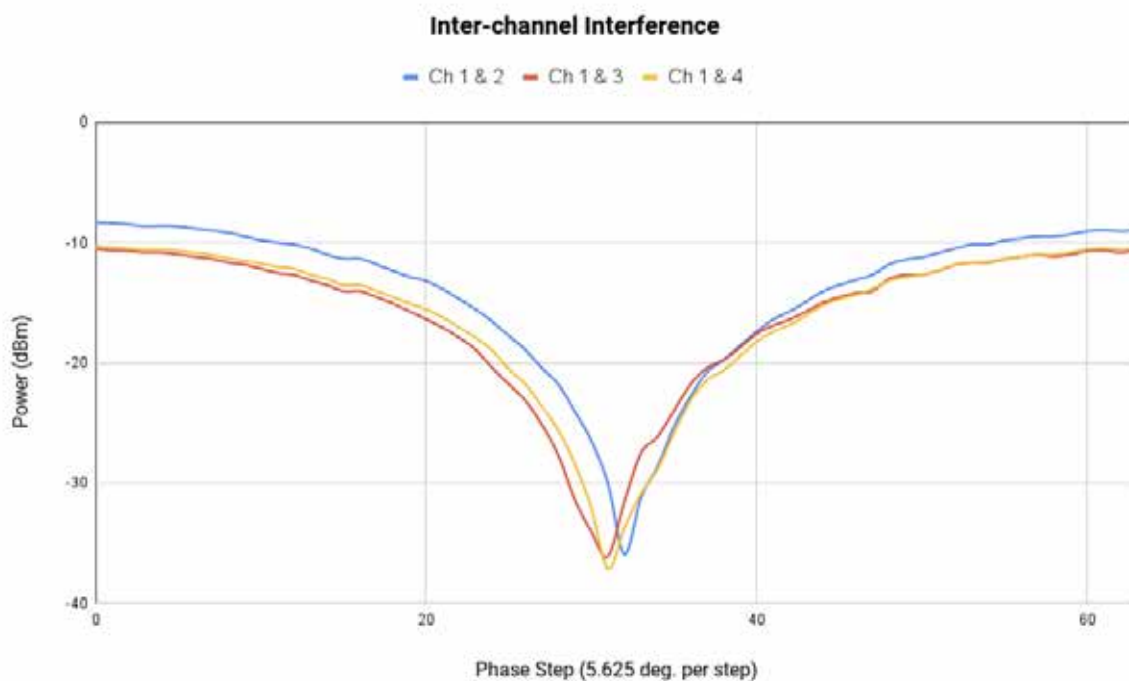| Phase Step	Fix #1, Adj #2	Fix #1, Adj #3	Fix #1, Adj #4
0	-8.31	-10.50	-10.33
1	-8.37	-10.66	-10.34
2	-8.47	-10.71	-10.50
⋮	⋮	⋮	⋮
28	-21.78	-27.67	-25.60
29	-24.04	-31.37	-28.41
30	-26.49	-34.06	-32.06
31	-30.03	-36.07	-37.10
32	-35.91	-31.54	-33.72
33	-31.22	-27.50	-30.87
34	-28.63	-26.15	-28.85
⋮	⋮	⋮	⋮
62	-9.06	-10.83	-10.56
63	-8.98	-10.66	-10.50

Table 2. Test results

Figure 14. Inter-channel interference

List out the maximum and minimum power in three combinations independently. You would experience constructive and destructive interference.

To in-phase purpose, you just need to let three combinations overlap as close as possible. Move forward or backward the phase step to finish in-phase processing. Sometimes, the relationship of the maximum and minimum step among three combinations may not be symmetrical. So you can use the minimum step to finish it. It is because the effect of the destructive interference is more obvious than the constructive interference.

	Maximum power @	Minimum power @
Ch1 & Ch2	0	32
Ch1 & Ch3	0	31
Ch1 & Ch4	0	31

Table 3. The maximum and minimum phase step

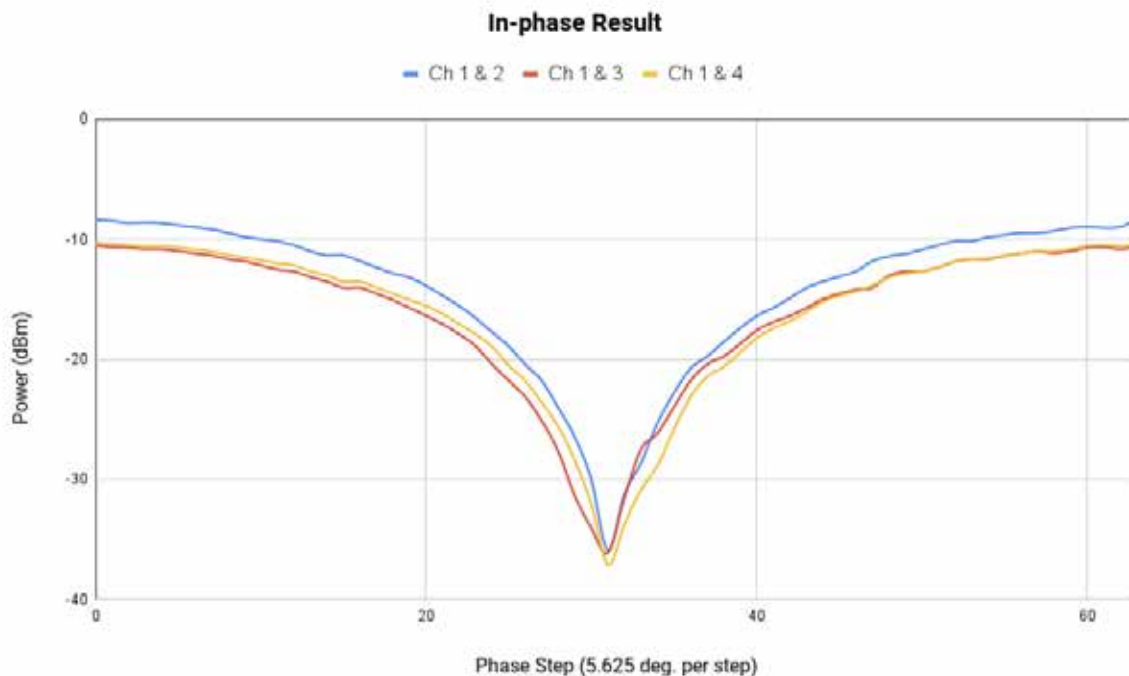|	Zeroing
Ch1	0
Ch2	63
Ch3	0
Ch4	0

Table 4. Zeroing result

Figure 15. In-phase among 4 RF channels

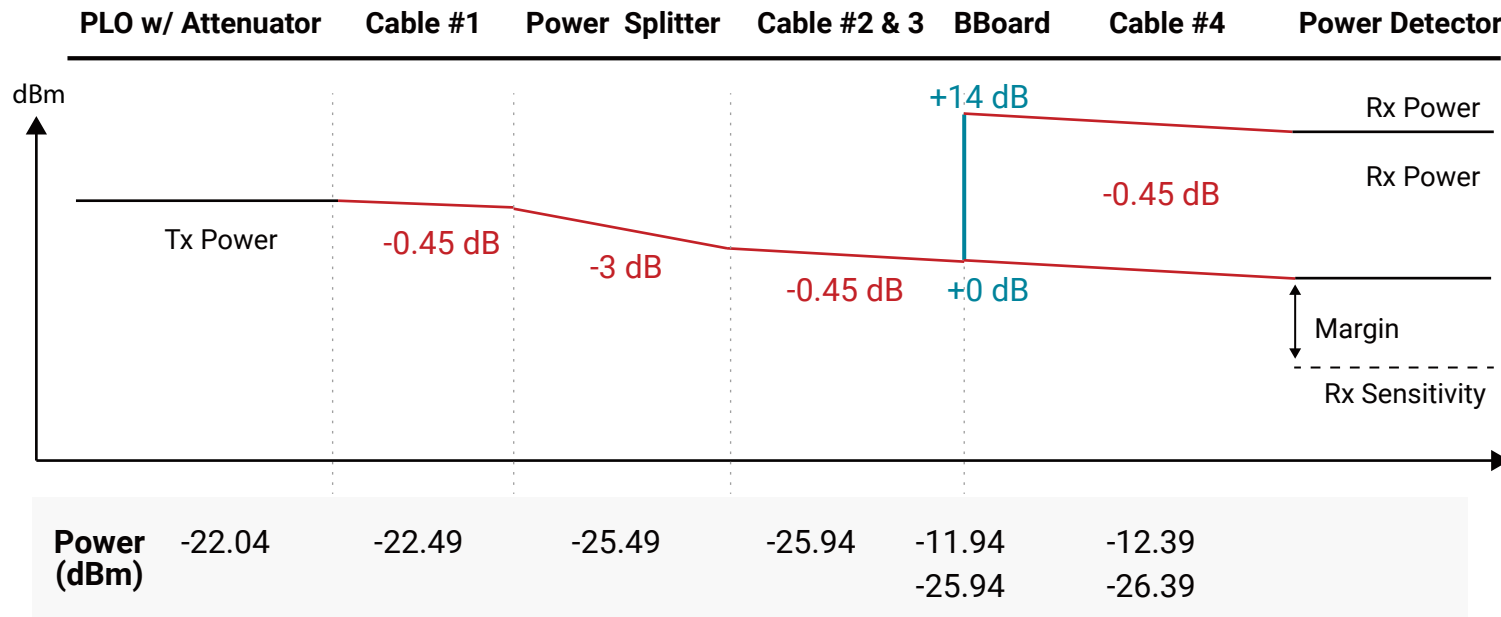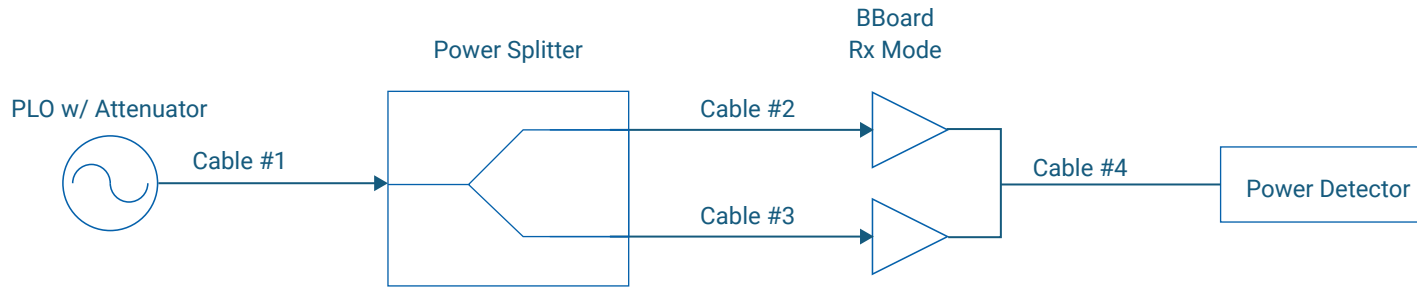Assume you already completed the in-phase calibration using the above table and then calculate the link budget using results in Lab 1 and compare it against your results.

Figure 16. Link Budget Calculation

	PLO w/ Attenuator	Cable #1	Power Splitter	Cable #2 & 3	BBoard	Cable #4	Power Detector
Power (dBm)	-22.04	-22.49	-25.49	-25.94	-11.94 -25.94	-12.39 -26.39	