5G mmWave Developer Kit
Labsheet Part II

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 3 - What is constructive and destructive interference in conduction?

1. Significance

Beamforming is a signal processing technique used in antenna arrays to implement a directional signal transmission or reception. The main architecture of the beamformer comprises multi-channel with built-in power amplifier (PA), low-noise amplifier (LNA), and phase shifter. Beamforming is about adjusting the phase of each channel to implement spatial selectivity.

When the peaks and valleys of the two channels are overlapped, we call it in-phase. If interference occurs, the two waves are combined and the result is maximum amplitude, this is called constructive interference.
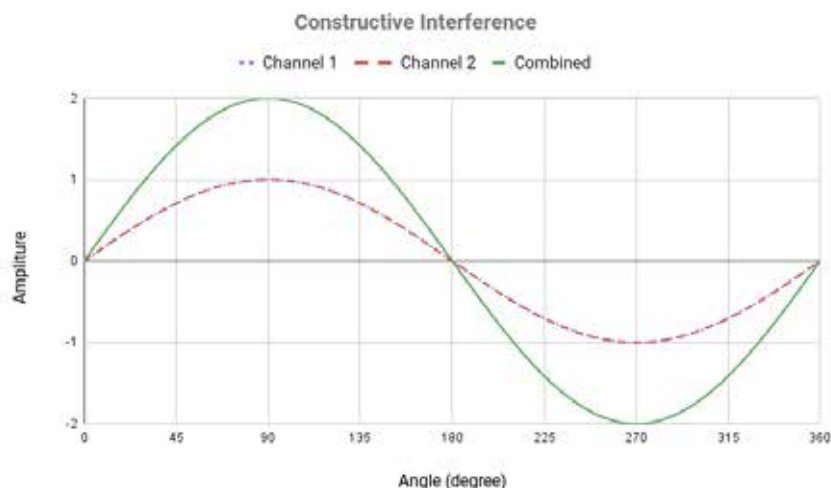

Figure 2. Constructive interference

Conversely, when the peaks and valleys of the two channels are inversed, we call it out of phase. If interference occurs, the combined waves would mutually cancel one another and result in minimum amplitude, this is called destructive interference.
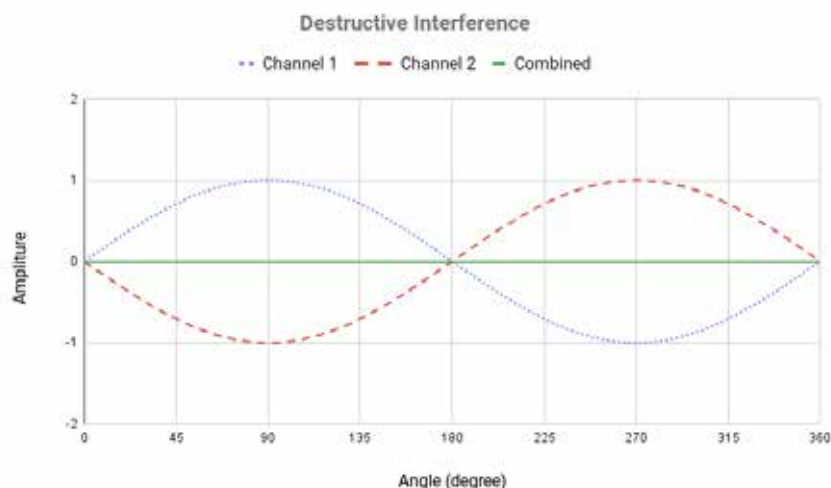

Figure 3. Destructive interference

2. Aim

In this experiment, you will understand the effect of the power combiner, practice phase adjustment, and monitor the change in power. After the experiment, you will be familiar with the foundation of constructive and destructive interferences. Finally, you can implement ways to in-phase among four channels.

3. Requirements

- 5G FR2 Beamformer - BBoard ×1
- Signal Soure - Phased-locked oscillator (PLO) × 1
- Power Detector ×1
- 40 GHz RF Cable ×4
- 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 COM port of BBoard via an RF cable.

b. Connect RF channels 1 & 2 of the BBoard to the power combiner with two RF cables.

c. Connect the combiner to the power detector using an RF cable as shown in Figure 4.

Figure 4. Configuration

d. Execute and run the TMXLAB kit to adjust the phase step. Keep channel 1 at step 0 and step through channel 2 from 0 to 63. There are 6 controlling bits within 360 degrees for the phase shifter so 1 step will shift 5.625 degrees.
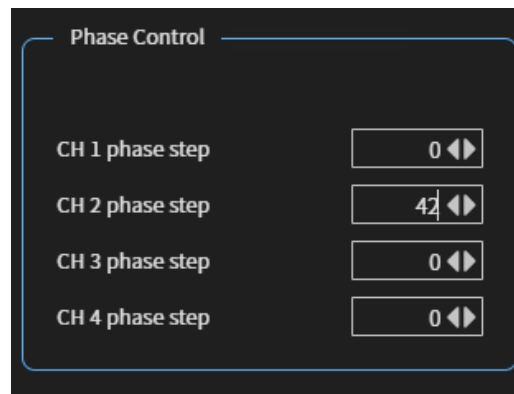

Figure 5. Phase control of TMXLAB kit

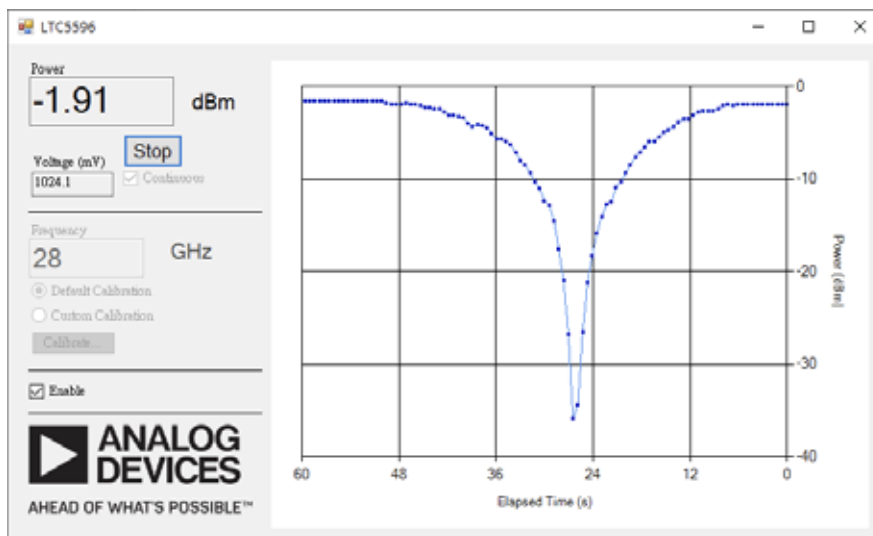e. Observe and record the detected power on the LTC5596 GUI after changing the phase step.

Figure 6. Measured power from LTC5596

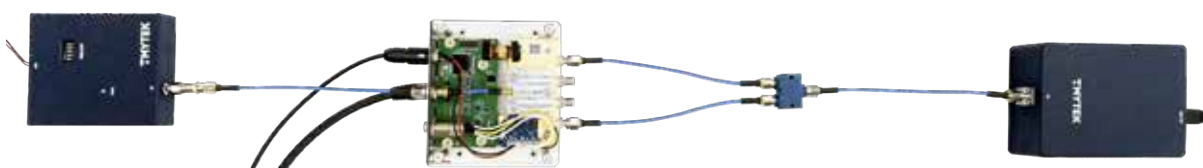f. Repeat steps b. to e. on channels 1&3 and 1&4 as shown in Figure 7.

Figure 7. Configuration

5. Results

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

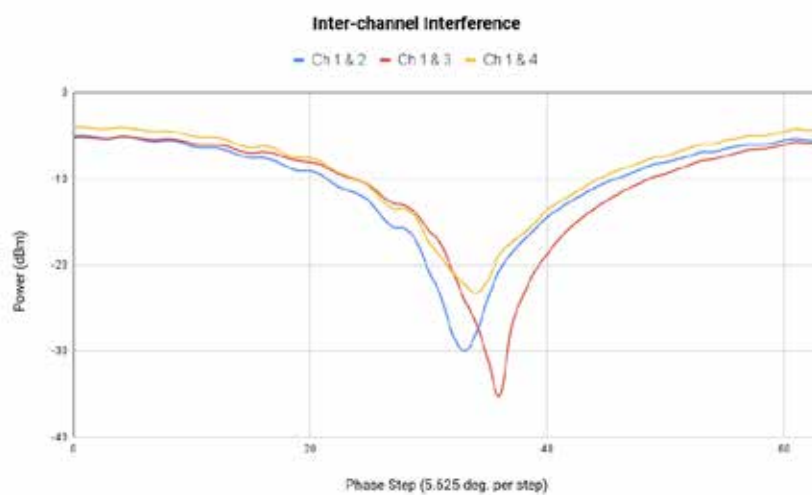| Phase Step	Fix #1, Adj #2	Fix #1, Adj #3	Fix #1, Adj #4
0	-5.05	-5.22	-4.02
1	-5.05	-5.22	-4.04
2	-5.23	-5.32	-4.21
3	-5.39	-5.39	-4.22
4	-5.16	-5.11	-4.04
⋮	⋮	⋮	⋮
31	-23.52	-17.47	-18.99
32	-27.94	-20.66	-20.84
33	-29.99	-23.98	-22.20
34	-27.98	-26.70	-23.26
35	-23.9	-30.9	-21.85
36	-20.56	-35.17	-18.7
37	-18.65	-27.2	-17.39
⋮	⋮	⋮	⋮
62	-5.56	-5.90	-4.39
63	-5.55	-5.72	-4.30

Table 1. Test results

Figure 8. Inter-channel interference

You should discover three phase-step combinations with maximum and minimum power in Table 1 and Figure 8. They represent the constructive and destructive interference results asTable 2.

	Maximum power @	Minimum power @
Ch1 & Ch2	1	33
Ch1 & Ch3	4	36
Ch1 & Ch4	0	34

Table 2. The maximum and minimum phase step

The procedure of recording the phase steps for both in-phase and out-of-phase is also known as phase calibration. The purpose is to find the phase offset among the channels and form the zeroing table as shown in Table 3. The main operation is to align the minimum power of three combinations at the same angle, to do so, simply move the phase step to achieve it. For example, you want to make the minimum power of the Ch 1 & 4 located at phase step 33, just move back 2 steps.

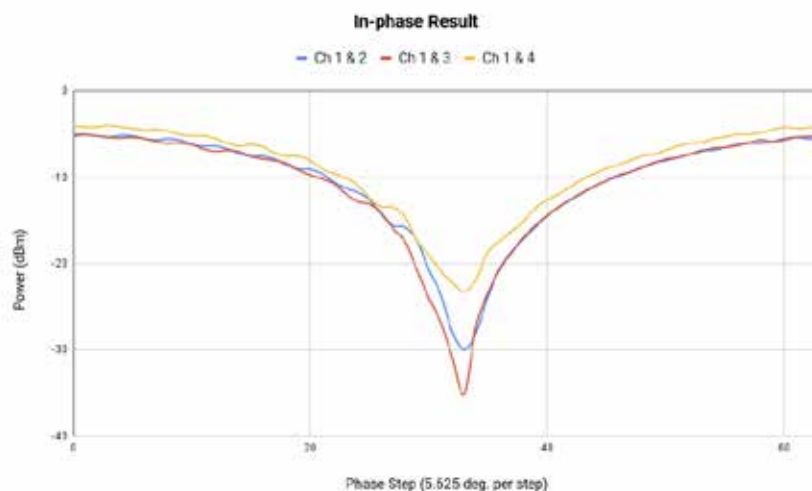|	Zeroing
Ch1	0
Ch2	1
Ch3	4
Ch4	2

Table 3. Zeroing result

Figure 9. In-phase among 4 RF channels

Assuming that you have already completed the in-phase calibration using the above table, calculated the link budget using results in Lab 1, and compared it against your results.
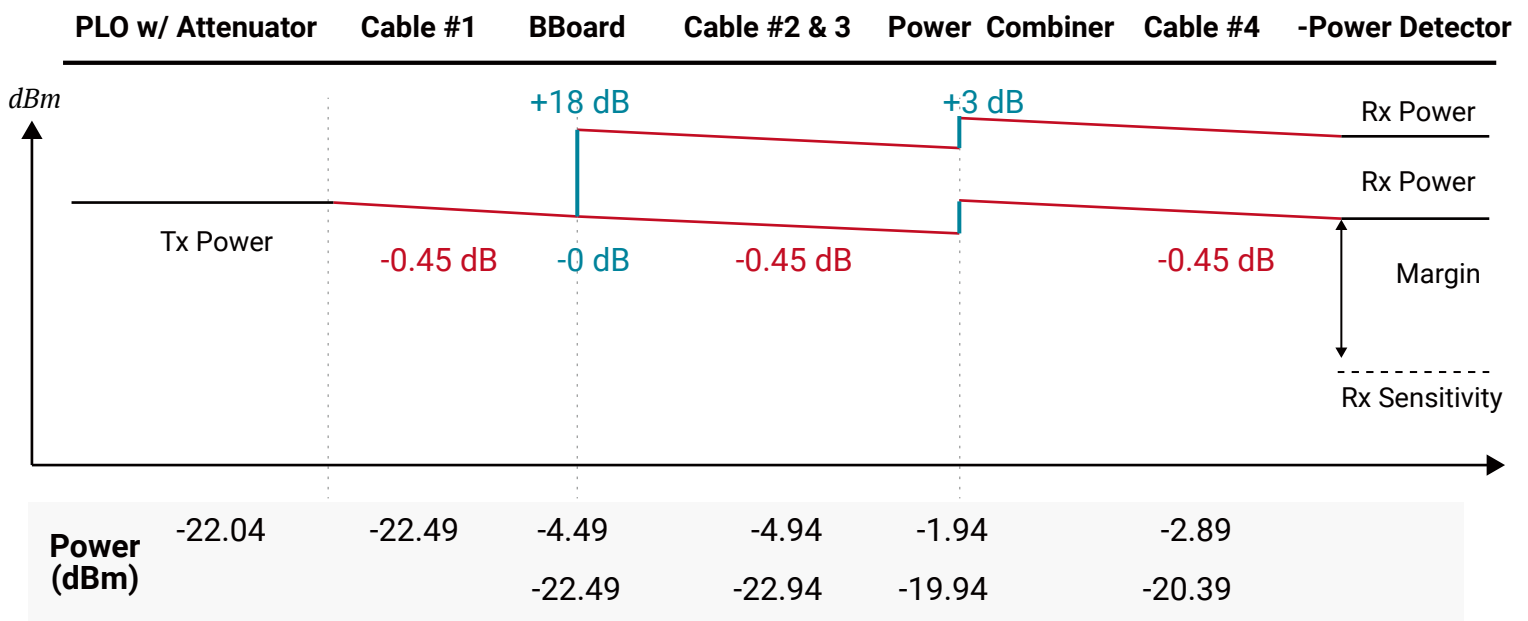

Figure 10. Link Budget Calculation
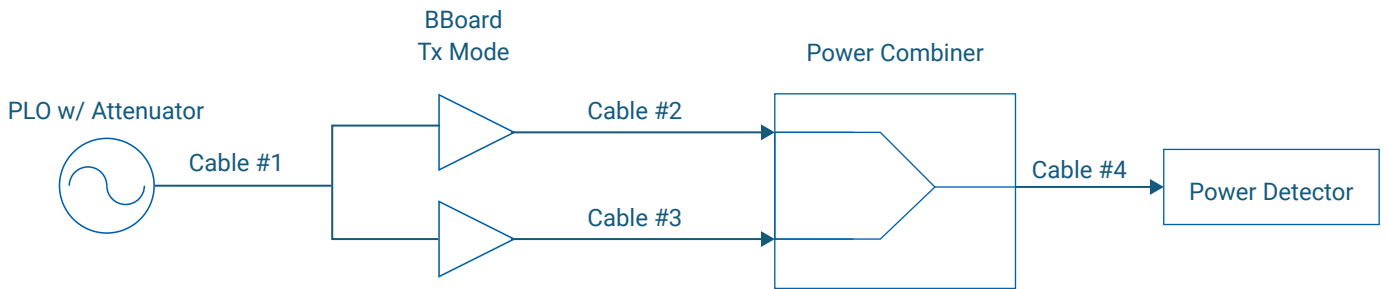
	PLO w/ Attenuator	Cable #1	BBoard	Cable #2 & 3	Power Combiner	Cable #4
Power (dBm)	-22.04	-22.49	-4.49	-4.94	-1.94	-2.89
			-22.49	-22.94	-19.94	-20.39

Lab 4 - What is constructive and destructive interference in radiation?

1. Significance

Beamforming is the technique used for radiative transmission to overcome and satisfy mmWave applications. The signal is converted to electromagnetic waves to communicate. Over the air, the signal wave will be affected by different factors, for example, weather, building, various materials, etc. may cause absorption, multipath fading, reflection, and propagation effects. Therefore, understanding the effect of the environment is also an important task for wireless communication, especially for mmWave.

2. Aim

By replacing the cables in Lab 3 with an antenna, you are about to dive into the fundamental theories of beamforming. You will discover the radiative effects using OTA (Over-the-air) operations and analyze the difference between the two test results. After that, you will realize why most wireless communication is tested by conduction in the mass production phase.

3. Requirements

- 5G FR2 beamformer - BBoard × 1
- Signal source - PLO × 1
- Power detector × 1
- 5G FR2 array antenna ×1
- 28 GHz COCO antenna × 1
- 20 GHz-40 GHz amplifier × 1
- 40 GHz RF adapter × 1
- 40 GHz RF cable × 1
- A personal computer with TMXLAB kit and LTC5596 GUI installed
- DC power supply × 1
- Ruler × 1

4. Procedure

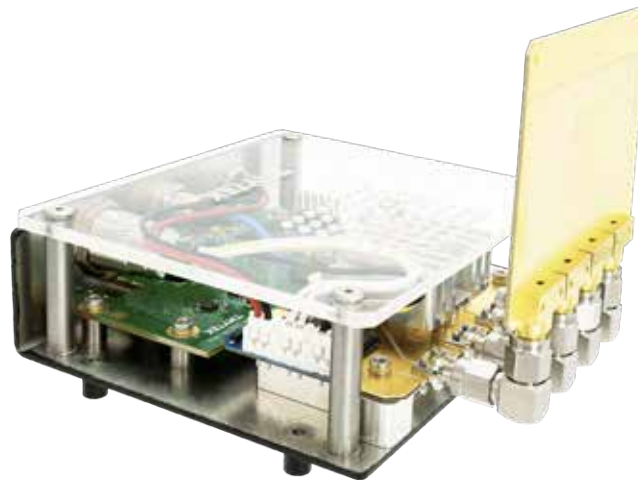a. Connect the 5G FR2 array antenna to the BBoard using the four right-angle adapters.

Figure 11. Connect array antenna to the BBoard

b. Utilizing the PLO and adding an attenuator as the source and connecting it to BBoard's RF com port via an RF cable.

c. Connect the 28 GHz COCO antenna to the input port of the amplifier.

d. Use the 40 GHz RF adapter to connect the output port of the amplifier and power detector.

e. Provide a +12V DC to the amplifier from the DC power supply.

f. Make sure there is at least a 50 cm distance between the 5G FR2 array antenna and the COCO antenna as shown in Figure 12.
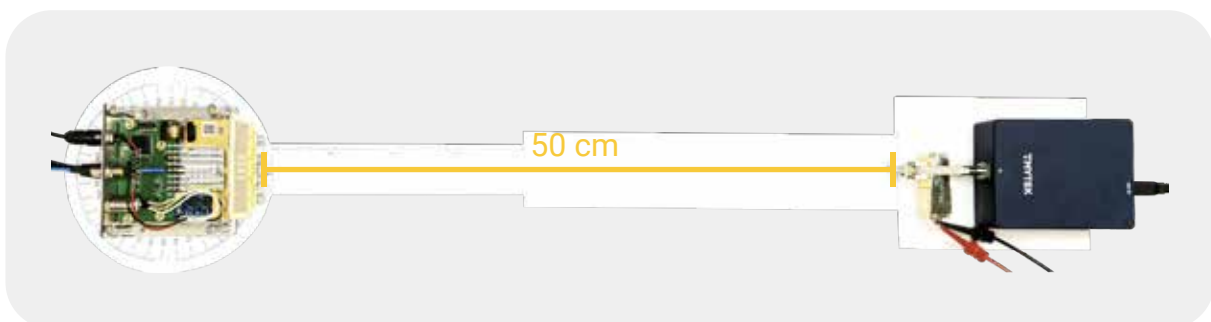

50 cm

Figure 12. Configuration

g. Execute and run 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. To ensure the result is reasonable, you must turn off channels 3 and 4 due to the array antenna connection.

Figure 13. TMXLAB Kit

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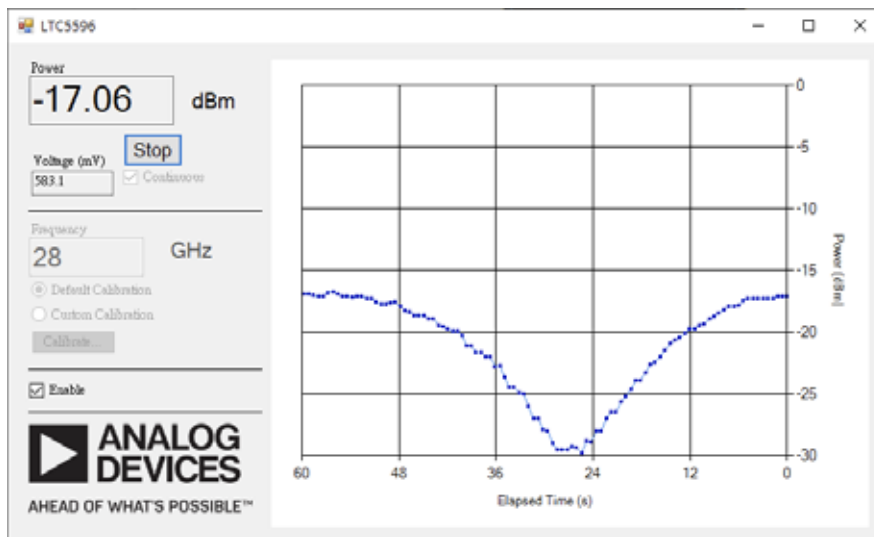

Figure 14. Measured power from LTC5596

i. Repeat steps g. to h. on channels 1&3 and 1&4.

5. Results

Phase Step	Fix #1, Adj #2	Fix #1, Adj #3	Fix #1, Adj #4
0	-15.29	-13.77	-15.98
1	-15.62	-13.65	-16.01
2	-15.63	-13.72	-16.13
3	-15.46	-13.83	-16.27
4	-15.63	-13.61	-16.13
⋮	⋮	⋮	⋮
31	-29.71	-24.83	-29.11
32	-29.36	-27.31	-31.59
33	-28.53	-28.98	-32.14
34	-27.38	-31.32	-32.98
35	-27.24	-34.78	-34.07
36	-26.31	-32.66	-32.77
37	-24.93	-32.61	-30.9
⋮	⋮	⋮	⋮
62	-15.63	-14.35	-16.30
63	-15.43	-14.31	-16.13

Table 4. Test results
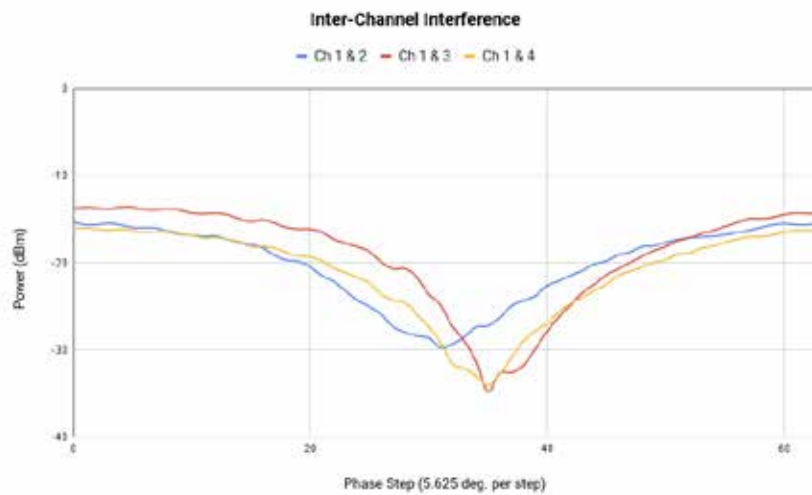
Figure 15. Inter-channel interference

	Maximum power @	Minimum power @
Ch1 & Ch2	0	31
Ch1 & Ch3	4	35
Ch1 & Ch4	0	35

Table 5. The maximum and minimum phase step

As instructed in Lab 3, you may also locate the maximum and minimum power position as shown in Table 5. Compare to Lab 3 results, you can see that the power range and distribution are different from Lab 3. The dynamic range is significantly narrower than conduction, and the destructive interference also occurs in different phase steps. The test results may change if you perform this experiment at a different location. The main reason is the signal wave would be affected by the environment. You can also try placing various materials like glass, a mirror, metal, or plastic in the transmission path and observe the changes.

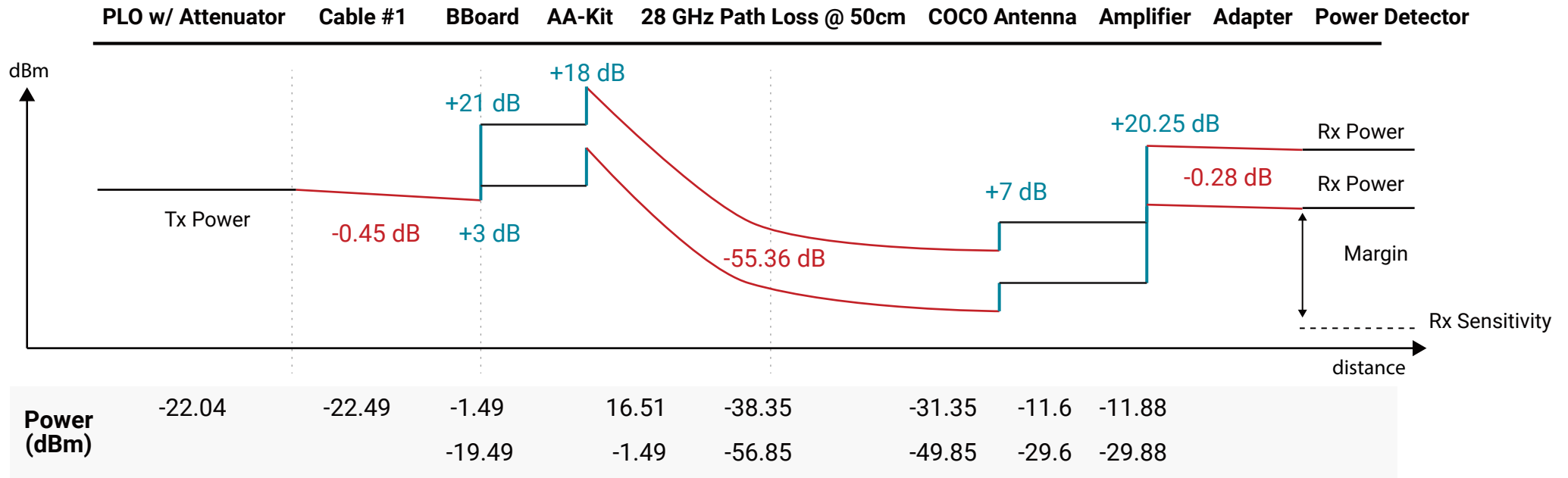Assuming that you have already completed the in-phase calibration using the zeroing table in Table 3, calculated the link budget using results in Lab 1, and compared it against your results.

Figure 16. Link budget calculation

	PLO w/ Attenuator	Cable #1	BBoard	AA-Kit	28 GHz Path Loss @ 50cm	COCO Antenna	Amplifier	Adapter	Power Detector
Power (dBm)	-22.04	-22.49	-1.49	16.51	-38.35	-31.35	-11.6	-11.88	
			-19.49	-1.49	-56.85	-49.85	-29.6	-29.88	