



# 5G mmWave Developer Kit

## Labsheet Part III

### List of laboratories

<b>Part I</b>	Lab 1. What is the link budget? Lab 2. What is channel gain?
<b>Part II</b>	Lab 3. What is constructive/destructive interference in conduction? Lab 4. What is constructive/destructive interference in radiation?
<b>Part III</b>	Lab 5. How is the beam steered? Lab 6. How is the beam pattern measured?
<b>Part IV</b>	Lab 7. How to measure the channel gain at the receiver? Lab 8. How to implement the in-phase at the receiver?



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 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 Cable ×4
- 10 GHz-40 GHz Combiner/Splitter ×1



Figure 1. List of Developer Kit

## Lab 5 - How is the beam steered?

### 1. Significance

Beamforming is necessary for millimeter-wave bands to overcome high path loss issues. The nature of the directivity of beamforming antenna requires the technique to manage the beam direction to achieve efficient communication performance.

Beamformer synthesizes the radiation patterns based on the constructive and destructive interference theory. Refer to the below equations on how to set the phase shifter of the beamformer to implement beam steering, where  $\Delta\phi$  is phase difference between two successive elements,  $d$  is the distance between the radiation elements, and  $\theta_s$  is the beam angle.

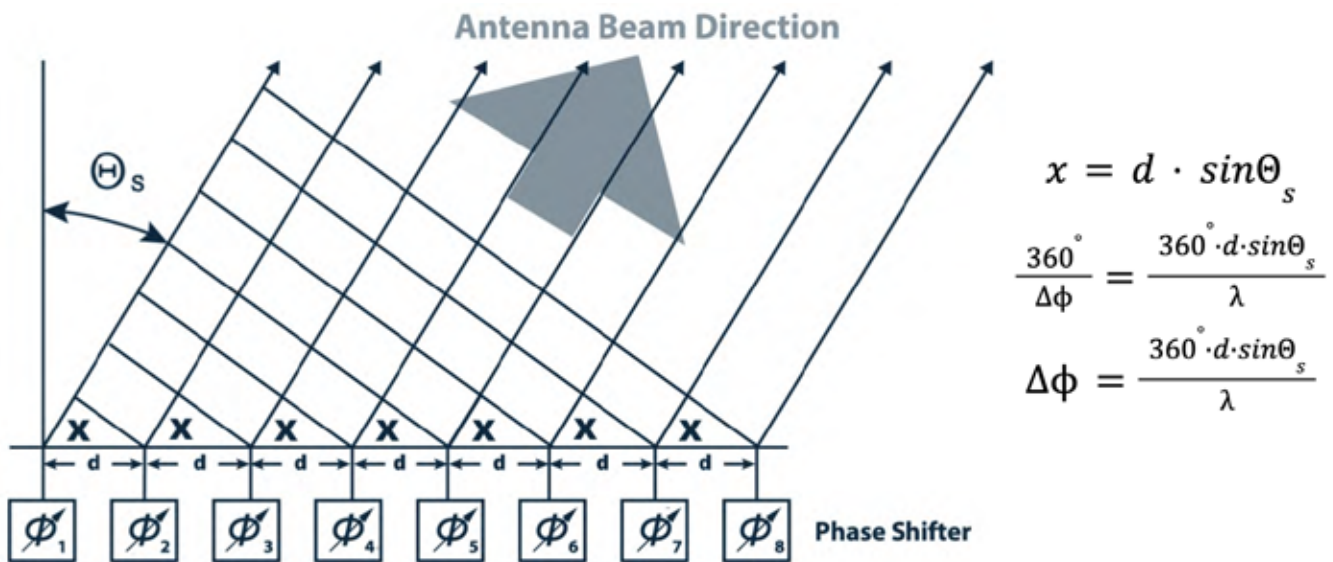


Figure 2. Beam steering by phase shifters

### 2. Aim

To understand the principles and the equations of beam steering and the relationship between array elements. You will learn how to steer the beam to the expected angle and experience how it works from the operation. Finally, you can try to steer quickly at different angles to cover a designated area.

### 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
- Protractor × 1

### 4. Procedure

- Measure the distance ( $d$ ) between the radiation elements of the array antenna as shown in Figure 3.

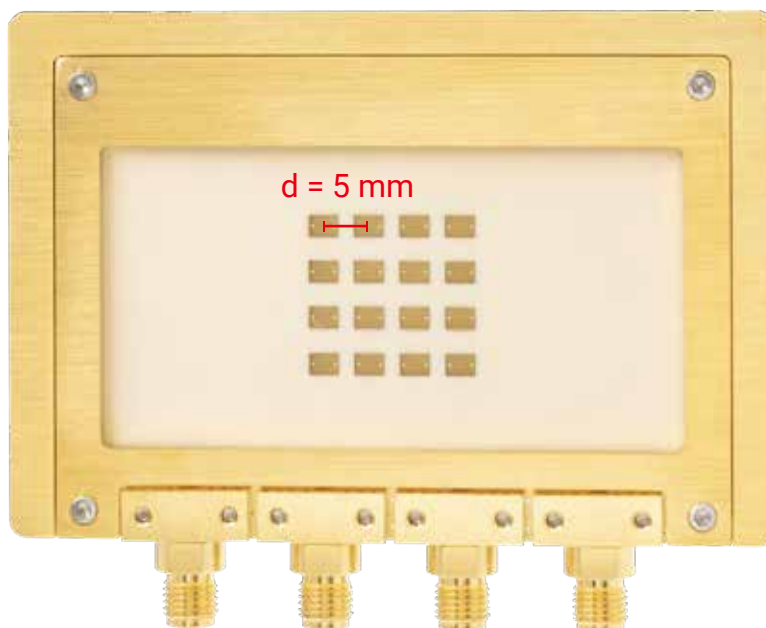


Figure 3. Array Antenna

- Assuming you want to steer the beam at 30 degrees, you can introduce the necessary parameters,  $\theta_s = 30^\circ$ ,  $\phi = 0^\circ$ , frequency = 28 GHz,  $d = 5$  mm, into the equation and acquire the phase difference between two successive elements, where  $\lambda = C / \text{frequency}$ , and  $C$  is the speed of light, 299,792,458 m/s.

$$\Delta\phi = \frac{360^\circ \cdot d \cdot \sin\theta_s}{\lambda}$$

$$\Delta\phi = (360^\circ \times 5 \times \sin 30^\circ) / (300/28) = 84^\circ$$

- c. According to the relationship of beam steering, you would know the corresponding phase set up in the four channels by using the equations below:

$$\text{Channel 1} = 0^\circ, \text{ phase step is } 0 \left( \frac{0}{5.625} = 0 \right)$$

$$\text{Channel 2} = \Delta\phi = 84^\circ, \text{ phase step is } 15 \left( \frac{84}{5.625} = 14.9333 \right)$$

$$\text{Channel 3} = 2 \times \Delta\phi = 168^\circ, \text{ phase step is } 30 \left( \frac{168}{5.625} = 29.8666 \right)$$

$$\text{Channel 4} = 3 \times \Delta\phi = 252^\circ, \text{ phase step is } 45 \left( \frac{252}{5.625} = 44.8 \right)$$

- d. Connect the 5G FR2 array antenna to the BBoard using the four right-angle adapters.
- e. Utilizing the PLO and adding an attenuator as the source, connect it to BBoard' s RF com port via an RF cable.
- f. Connect the 28 GHz COCO antenna to the input port of the amplifier.
- g. Supply a +12V DC to the amplifier from the DC power supply.
- h. Use the 40 GHz RF adapter to connect the output port of the amplifier and the power detector.
- i. Make sure there is at least a 50 cm distance between the 5G FR2 array antenna and the COCO antenna as shown in Figure 4.

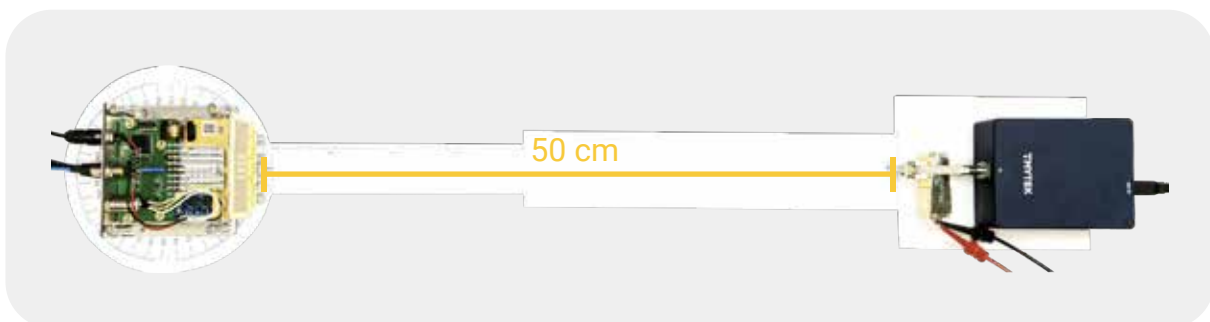


Figure 4. Configuration in Boresight Direction

- j. Execute and run the TMXLAB kit, key in the in-phase calibration using the zeroing table in Lab 3, and record the detected power on the LTC5596 GUI.

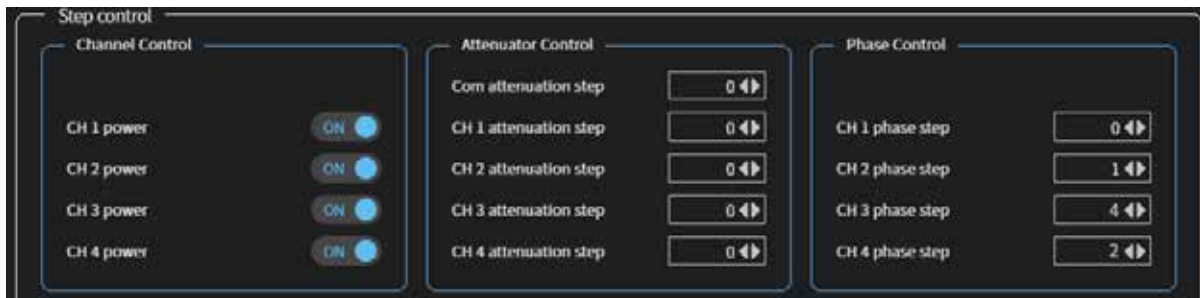


Figure 5. Phase Control for Boresight

- k. Rotate the BBoard 30 ° away from the horizontal line clockwise while maintaining the 50 cm distance, and record the detected power on the LTC5596 GUI.

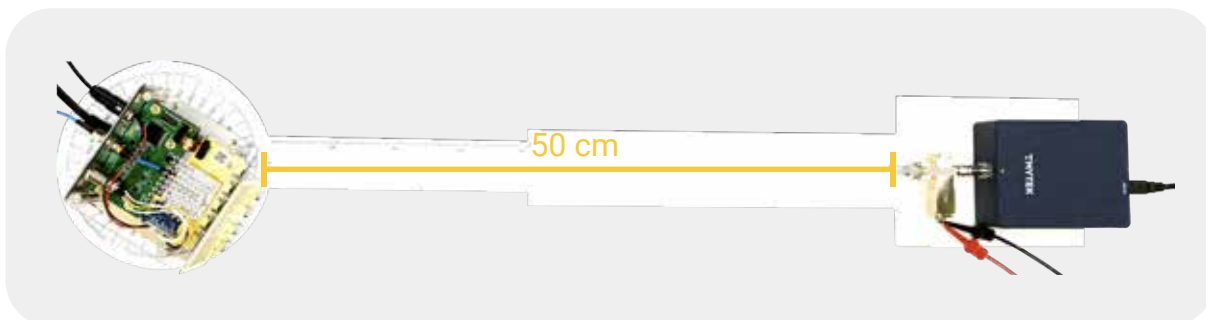


Figure 6. Move 30° away from the horizontal line

- l. Adjust the phase step of channels 2, 3, and 4 according to the result of step 2 and record the detected power on the LTC5596 GUI.

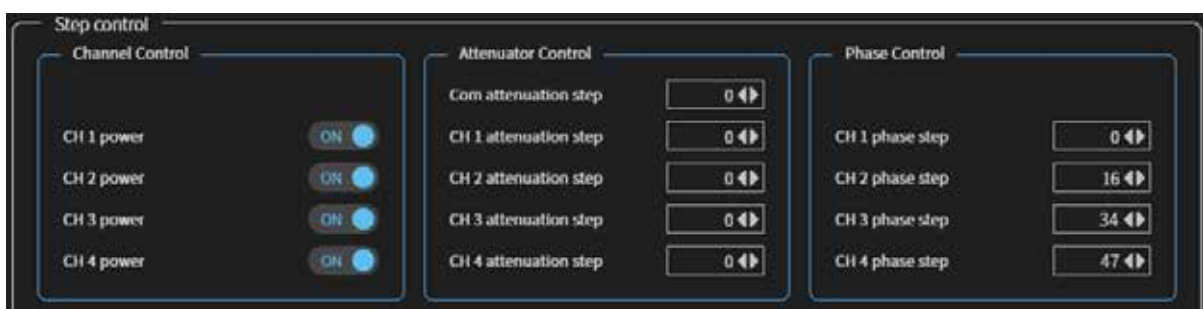


Figure 7. Phase Control for 30° Beam Steering

### 5. Results

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

The result of step j.:

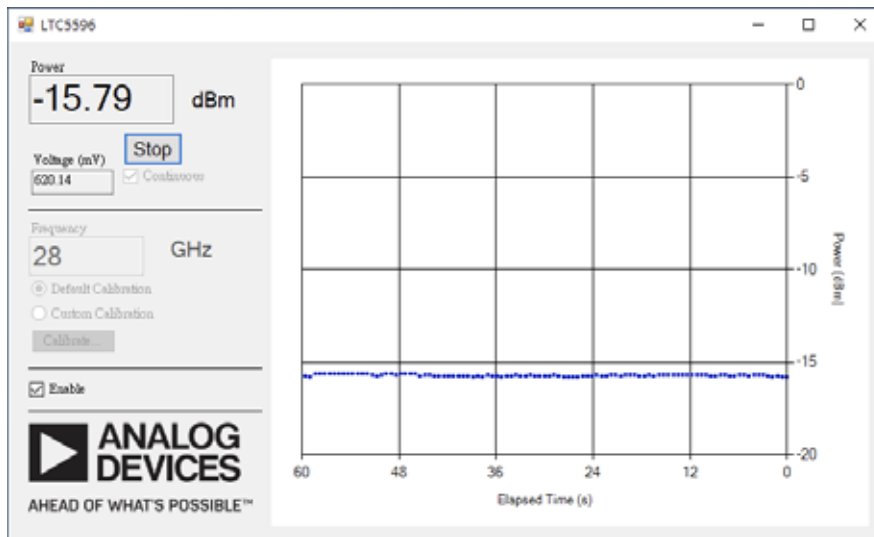


Figure 8. Measured power of step j.

The result of step k.:

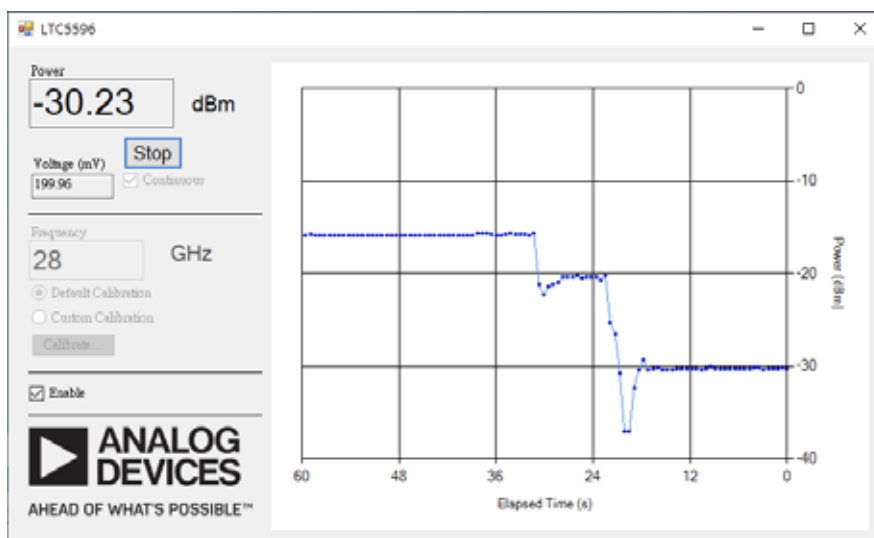


Figure 9. Measured power of step k.

The result of step I.:

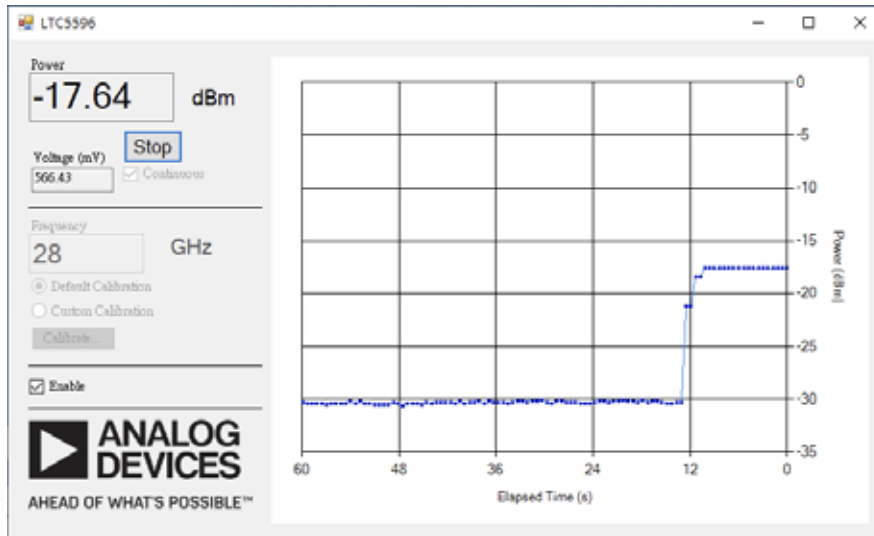


Figure 10. Measured power of step I.

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



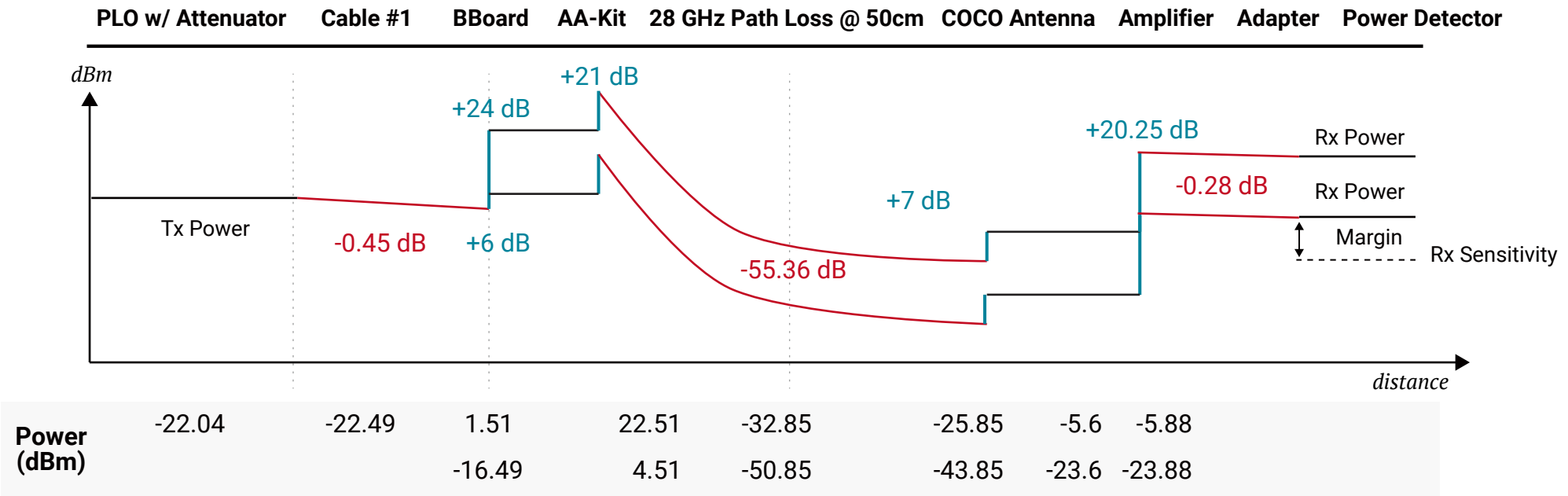
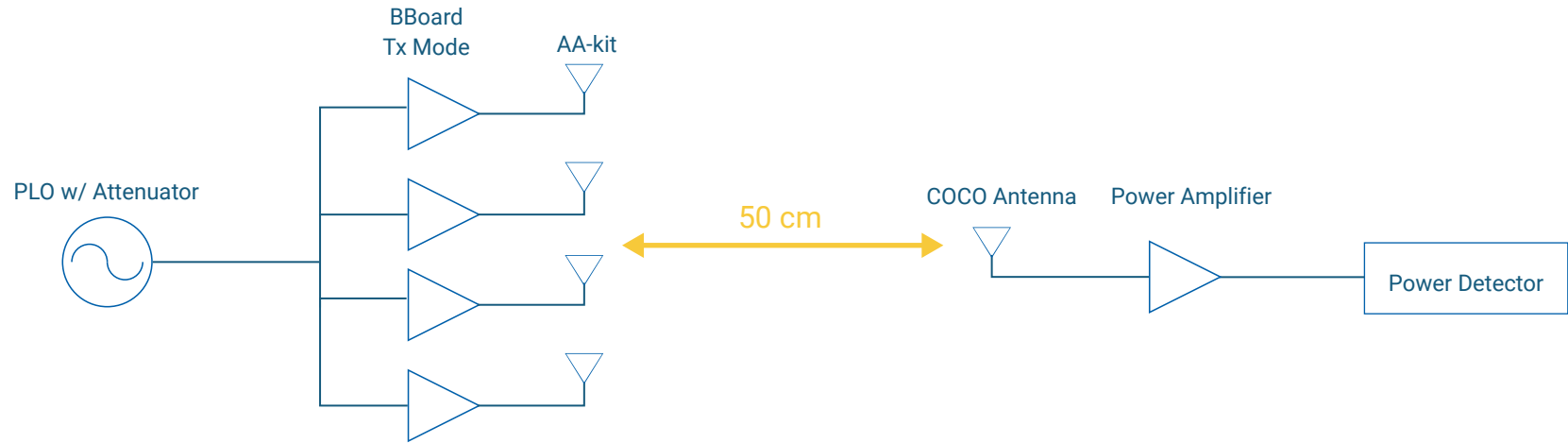


Figure 11. Link budget calculation

## ■ Lab 6 - How the beam pattern is measured?

### 1. Significance

To evaluate the performance of the mmWave antenna, you need to scan the beam pattern of the antenna and measure parameters including the gain, 3 dB beamwidth. In general, you must put the device under test (DUT) in the Compact Antenna Test Range (CATR) and utilize a controllable gimbal to change the angle and direction of the beam to execute the relevant measurements. The beam pattern under polar coordinates is a common indicator for mmWave antennas. It exhibits the main lobe and side lobes and of character the main lobe.

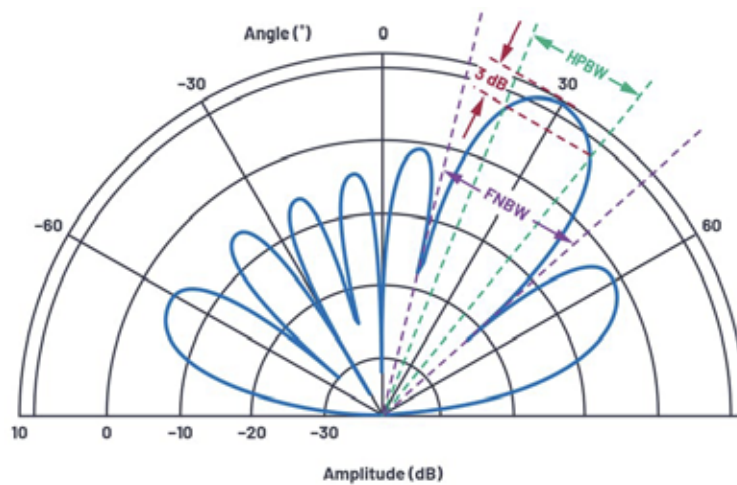


Figure 12. Beam Pattern

(Source: Analog Devices 2020. Phased Array Antenna Patterns—Part 1: Linear Array Beam Characteristics and Array Factor)

### 2. Aim

In this experiment, you will simulate how to measure the mmWave antenna in CATR, and draw the beam pattern. By using a simple fixture that integrates a ruler and a protractor to replace the CATR, you will learn how to draw the beam pattern via Microsoft Excel or equivalent software.

### 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
- Protractor × 1

#### 4. Procedure

- a. Connect the 5G FR2 array antenna to BBoard using the four right-angle adapters.
- 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. Provide a +12 V DC to the amplifier from the DC power supply.
- e. Use the 40 GHz RF adapter to connect the output port of the amplifier and power detector.
- f. Make sure there is at least a 50 cm distance between the 5G FR2 array antenna and the COCO antenna.

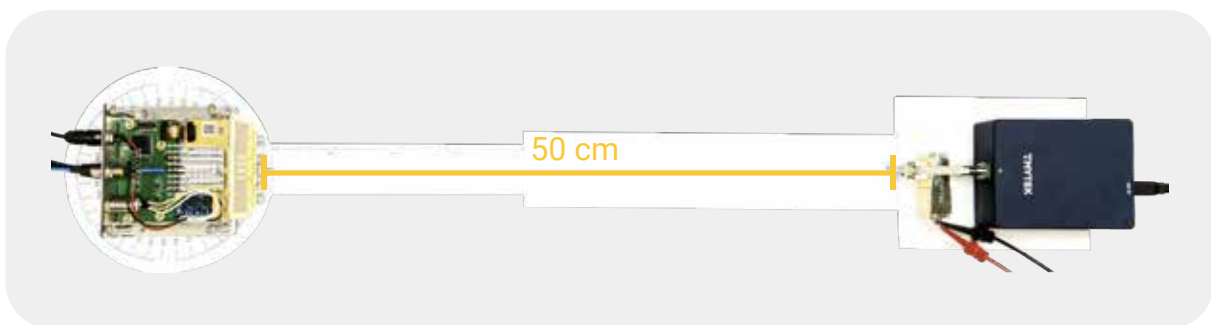


Figure 13. Configuration

- g. Execute and run the TMXLAB kit and key in the in-phase calibration using the zeroing table in Lab 3, and record the detected power on the LTC5596 GUI.



Figure 14. Phase Control for Boresight

h. Rotate the BBoard from  $-90^\circ$  to  $90^\circ$  in  $5^\circ$  increments away from the horizontal line while maintaining the 50 cm distance, and record the detected power on the LTC5596 GUI separately as shown in Figure 15.

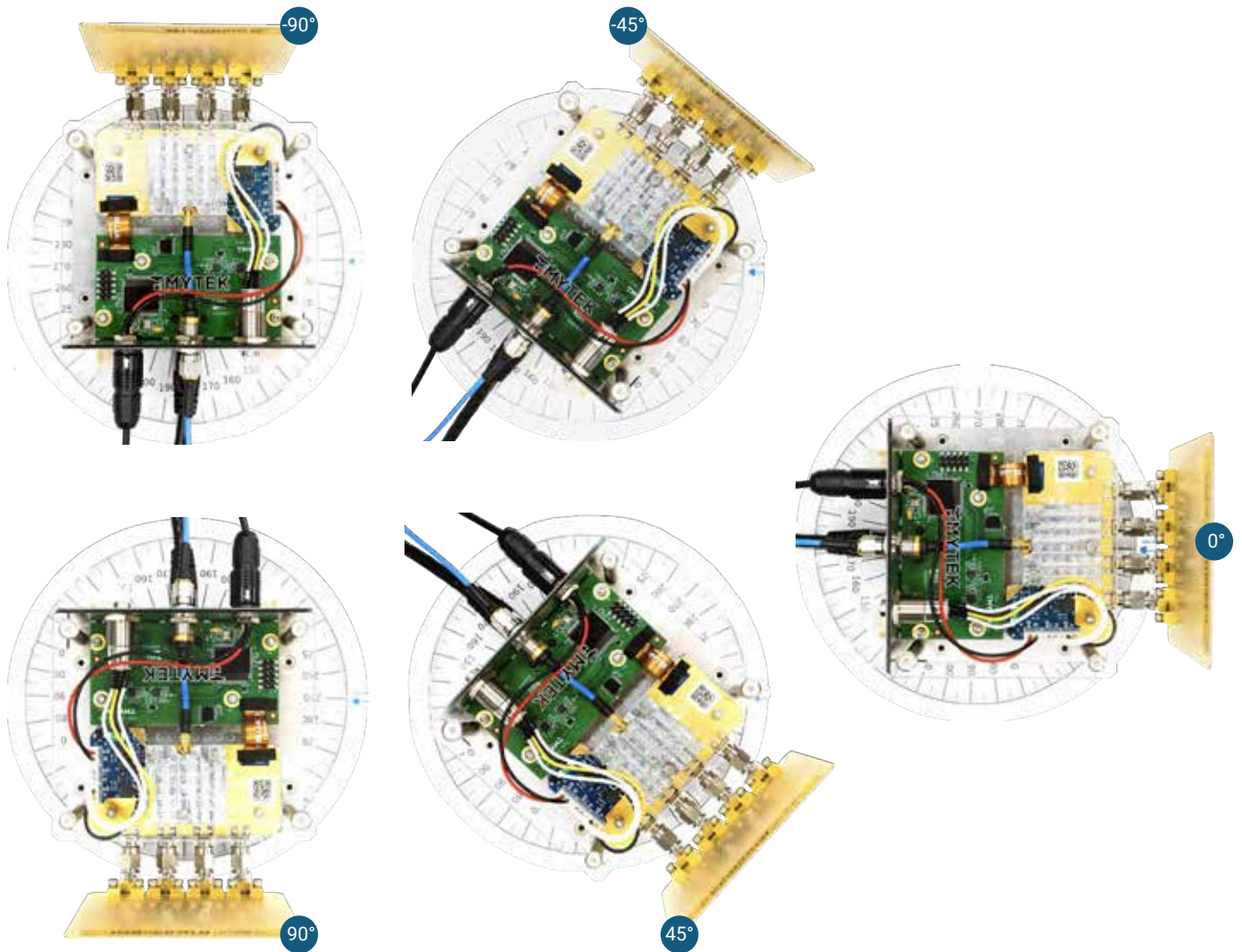


Figure 15. Move the BBoard from  $-90^\circ$  to  $90^\circ$

### 5. Results

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

Angle (°)	Power (dBm)	Angle (°)	Power (dBm)	Angle (°)	Power (dBm)	Angle (°)	Power (dBm)
-180	-40.00	-90	-36.62	90	-34.50	180	-40.00
-175	-40.00	-85	-28.90	85	-32.00	175	-40.00
-170	-40.00	-80	-27.80	80	-32.50	170	-40.00
-165	-40.00	-75	-31.25	75	-37.10	165	-40.00
-160	-40.00	-70	-27.59	70	-37.10	160	-40.00
-155	-40.00	-65	-32.75	65	-37.10	155	-40.00
-150	-40.00	-60	-27.53	60	-30.10	150	-40.00
-145	-40.00	-55	-24.01	55	-27.10	145	-40.00
-140	-40.00	-50	-19.83	50	-23.20	140	-40.00
-135	-40.00	-45	-18.92	45	-19.80	135	-40.00
-130	-40.00	-40	-15.35	40	-19.20	130	-40.00
-125	-40.00	-35	-18.90	35	-19.80	125	-40.00
-120	-40.00	-30	-22.40	30	-25.00	120	-40.00
-115	-40.00	-25	-24.30	25	-25.70	115	-40.00
-110	-40.00	-20	-17.20	20	-18.50	110	-40.00
-105	-40.00	-15	-13.40	15	-13.80	105	-40.00
-100	-40.00	-10	-8.10	10	-8.60	100	-40.00
-95	-40.00	-5	-5.73	5	-5.85	95	-40.00
		0	-4.85	0	-4.85		

Table 1. Test results. Use the minimum power detector value to fill in the remaining angles (Highlighted in yellow)

Only results from -90° to 90° were measured, so you need to fill other angles with a minimum value to plot the pattern with a correct angle. For example, the minimum value of the power detector is about -37.1 dBm, therefore you can simply key -40 into them, as shown in Table 1.

In Microsoft Excel or equivalent software, you can plot the beam pattern under polar coordinates using a Radar chart. But be careful, you must sort the results sequentially to satisfy and form a semi-circle or the beam pattern may be incorrect, as shown in Figure 16.

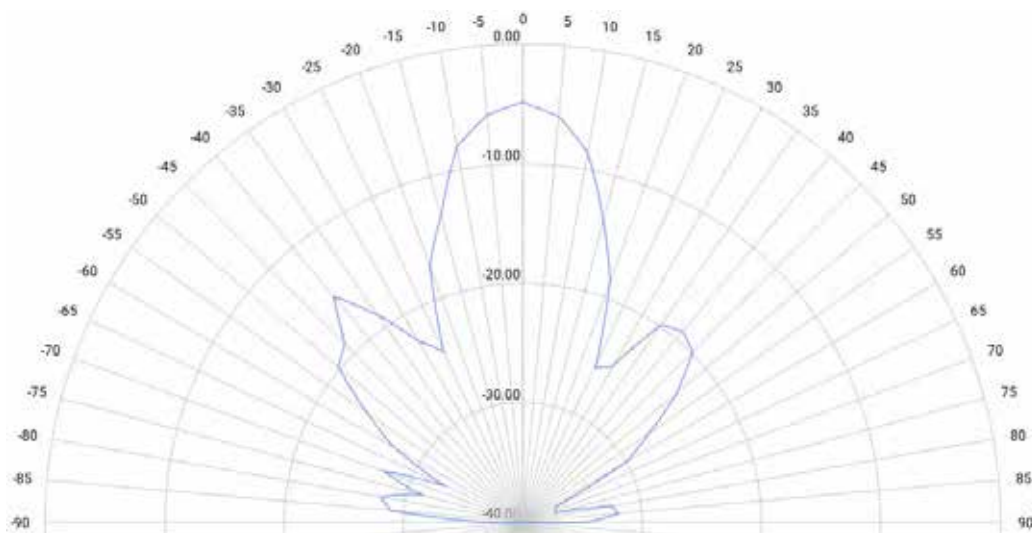
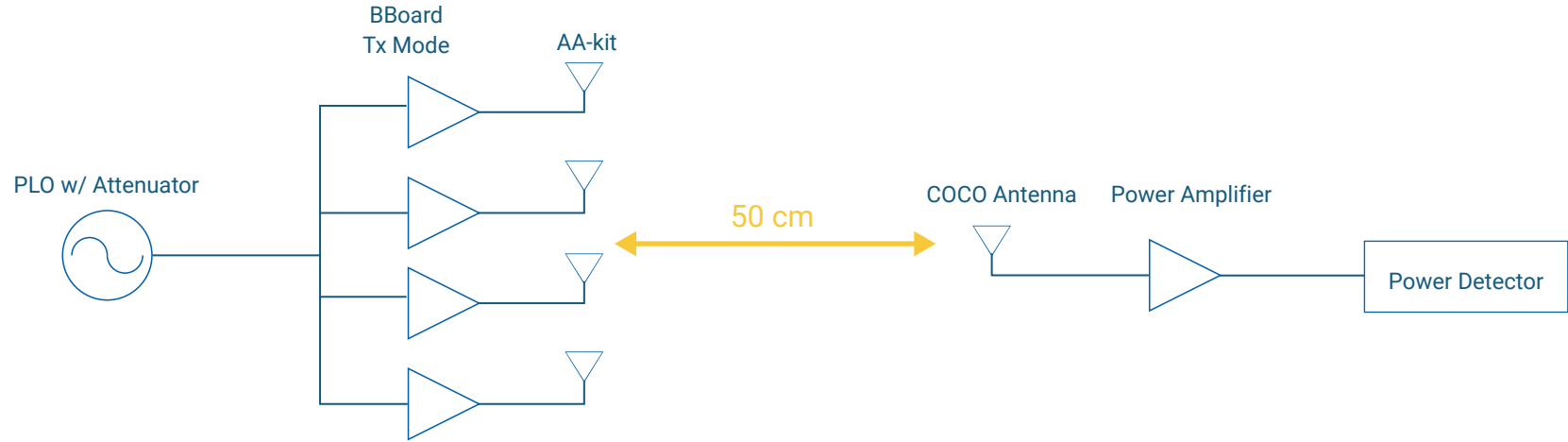


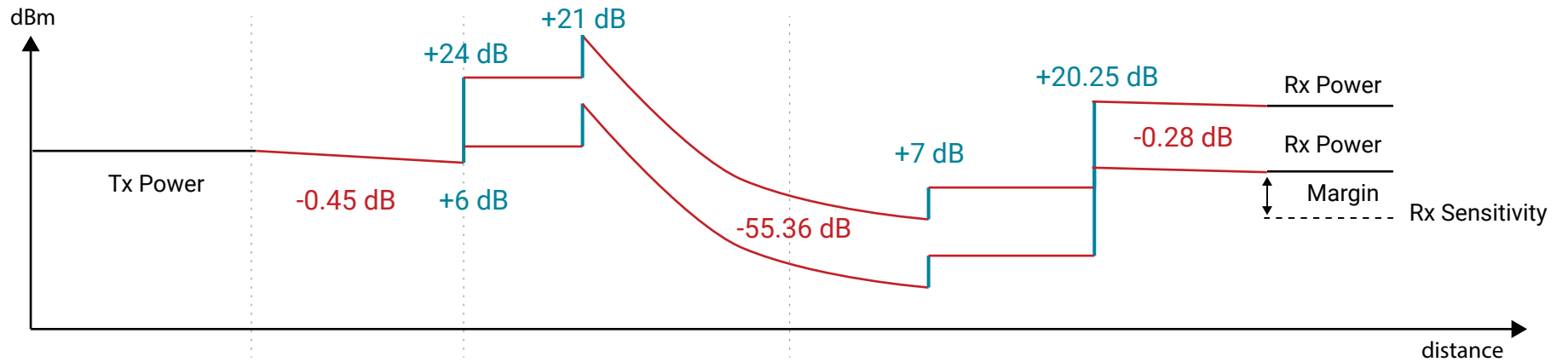
Figure 16. Measured Beam Pattern

For this result, the power unit is dBm and different from CATR. It is because you are using the absolute value from the power detector and cannot calibrate and quantify the test setting and environment like CATR.

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



**PLO w/ Attenuator    Cable #1    BBoard    AA-Kit    Path Loss @ 50cm    COCO Antenna    Amplifier    Adapter    Power Detector**



<b>Power (dBm)</b>	-22.04	-22.49	1.51	22.51	-32.85	-25.85	-5.6	-5.88
			-16.49	4.51	-50.85	-43.85	-23.6	-23.88

Figure 17. Link budget calculation