UNIVERSE OF LAB 5

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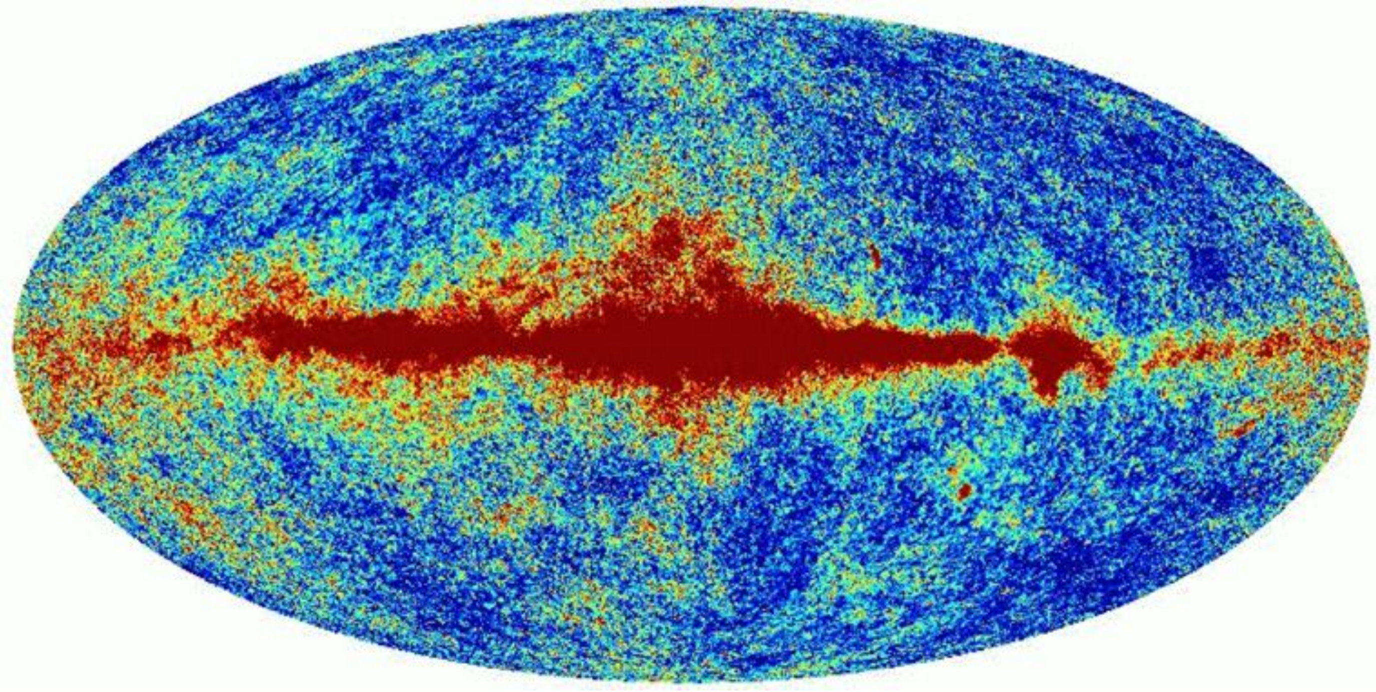
HELLOO

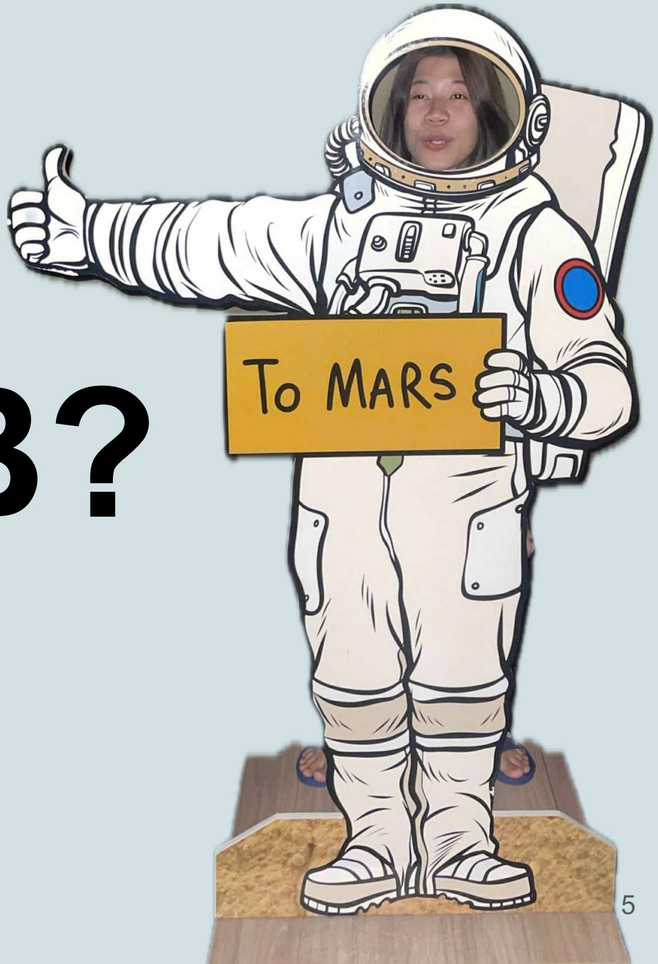
This is our team

The Cosmic Microwave Background (CMB)



What is the CMB?

The Oldest Light in the Universe



CMB

- The "**afterglow**" or leftover light from the Big Bang.

Why
is it important?

Why?

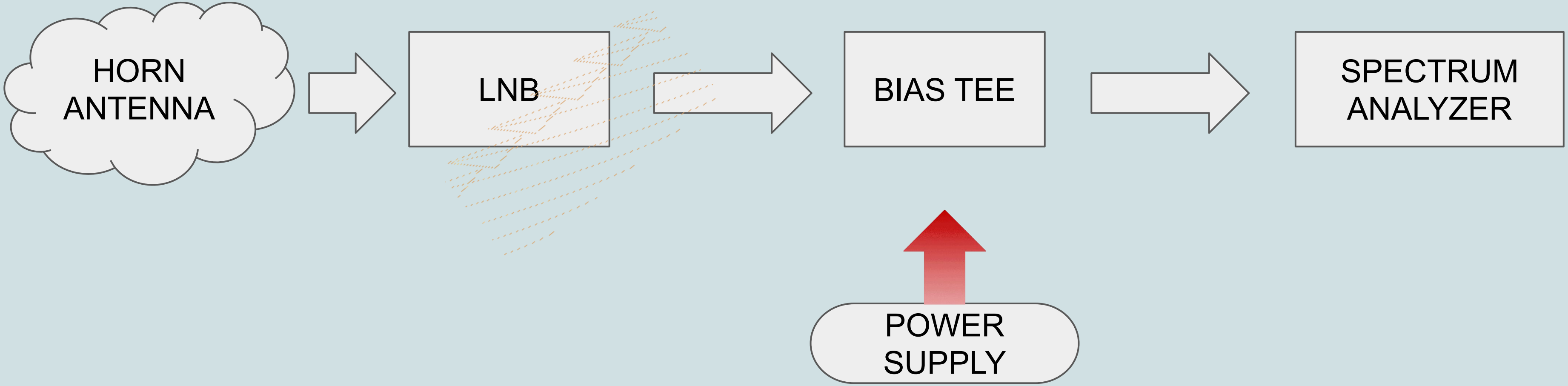
- The single greatest source of information about the early universe.

- It's our **only window** into the universe at just 380,000 years old.

Let’s quickly travel back to the early universe, through **FOUR** main stages.

Big Bang → Opaque "Fog" → CMB is Released → First Stars & Galaxies

BLOCK DIAGRAM



So what is the function of each part?

HORN ANTENNA

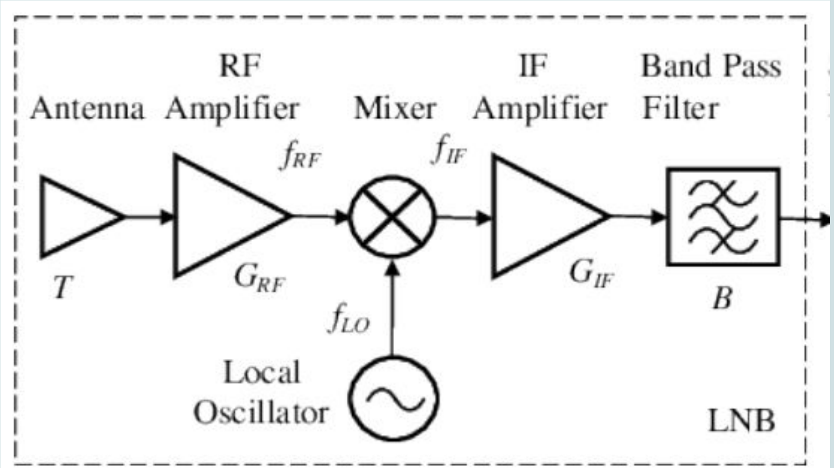
- A high-precision

- Directional measurement around 11 GHz microwave radiation from targeted sky sections

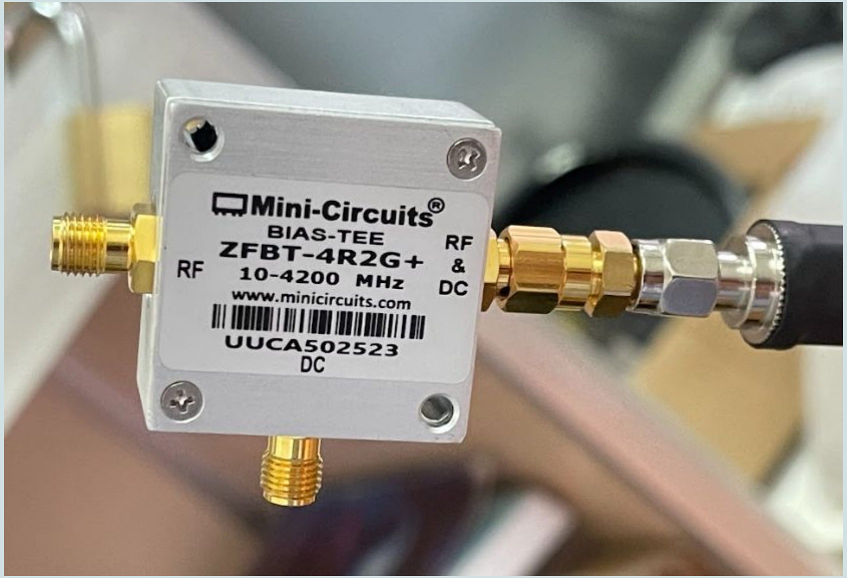
- Ensuring minimal noise contamination from ground and atmospheric sources.

LNB

- Input: 11.2 - 11.7 GHz
- Local: 10.25 GHz
- DC Input: +12V to +24V

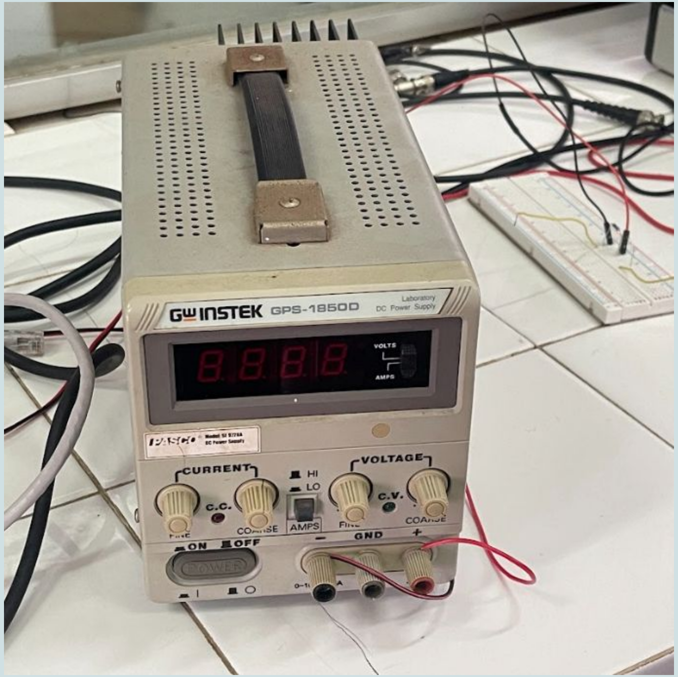


BIAS T

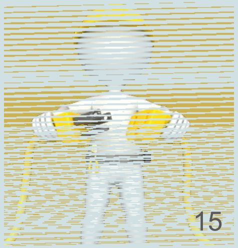


Function of the Bias Tee:
- Providing DC power to the LNB
- Separating RF signals and DC power

Power Supply

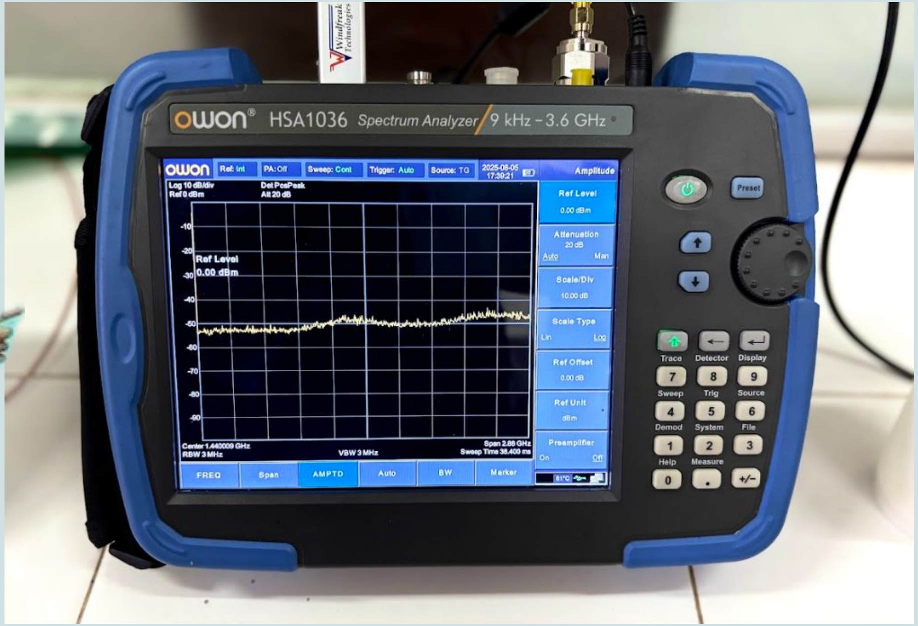


Function of the Power Supply:
The Power Supply provides stable DC power to the LNB via the Bias Tee

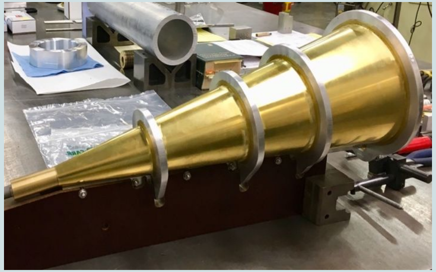


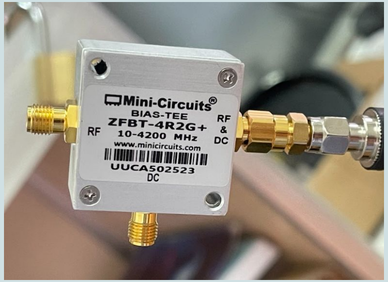
Spectrum analyzer

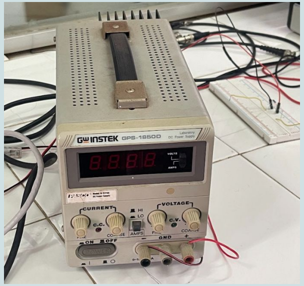
I'll talk later!!!

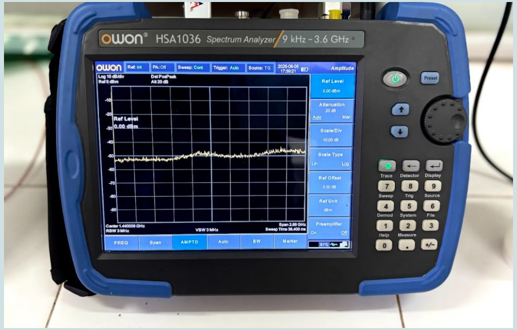


BLOCK DIAGRAM









HORN ANTENNA

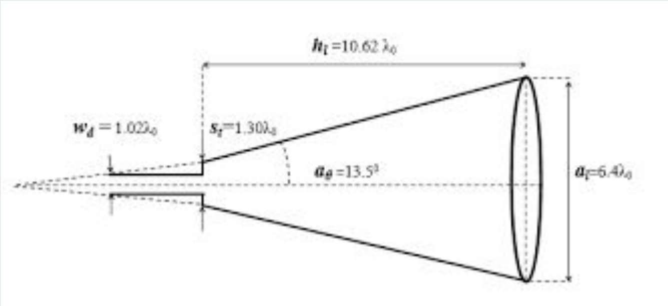
Why use a Horn Antenna to detect the CMB?

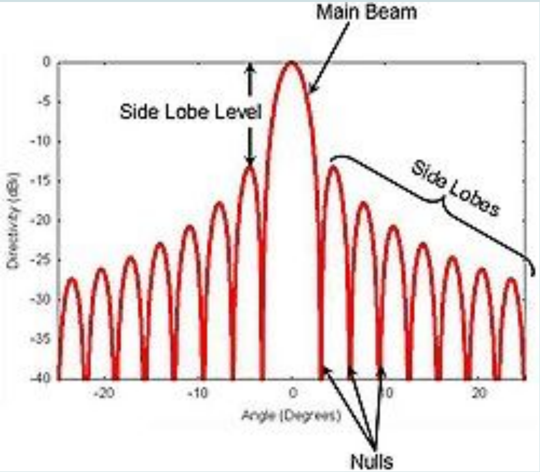
- A Horn Antenna is a **flared metal waveguide** used to collect or transmit waves
- CMB is **faint** (~2.725K), easily masked by ground and atmospheric noise
- Antenna focuses on microwave radiation from specific regions and **converts them into radio-frequency** signals, which are then amplified and measured by a **spectrum analyser** for us to observe.

HORN ANTENNA

<u>The Potter Horn and its advantages:</u>

- modified horn antenna that has a **discontinuity in its flare**, **reducing noise** from surroundings.
- Producing a **narrow, clean beam** focused only on the sky and limits contaminants.
- Enabling for **accurate measurements** of the CMB across various angles without interference





HORN ANTENNA

Antenna types	Advantages	Limitations
Standard Horn	Simple, directional	Significant sidelobes - susceptible to ground and ambient noise, contaminates faint CMB data
Potter Horn	Ultra-low sidelobes, clean and narrow beam pattern, reduced off-axis noise	Precision manufacturing required
Parabolic Dish	Very high gain, narrow beam	Bulky, mechanically complex, sensitive to alignment issues, not ideal for rapid sky scans

Low noise block (LNB)

There are several types of LNB

3.40 to 4.20 GHz range

7.25 to 7.75 GHz range

10.70 to 12.75 GHz range

17.30 to 21.20 GHz range

LNB can also be customized to serve multiple purposes

Ref:

Low noise block (LNB)

- Small box mounted behind the horn antenna

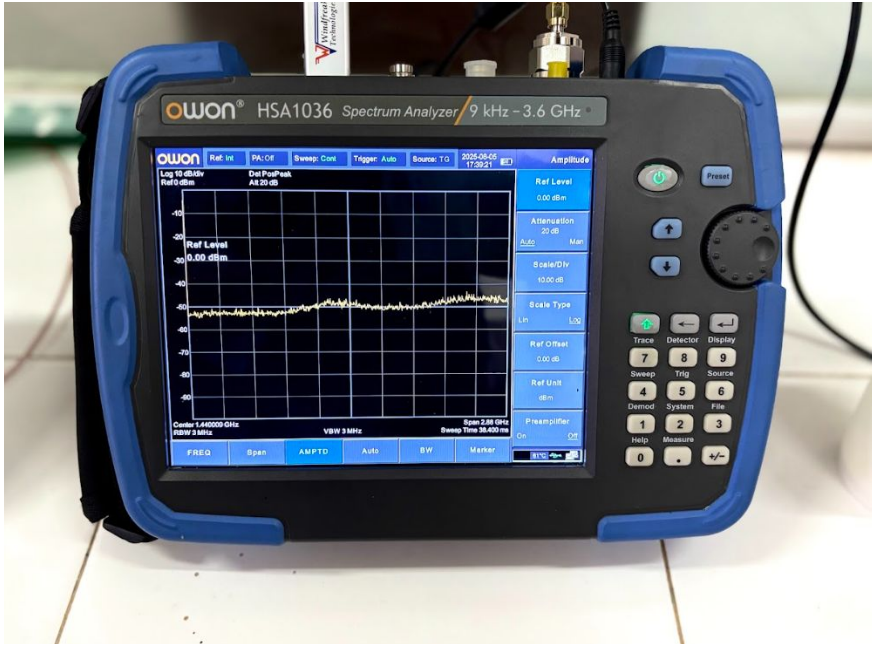
- Role:

  1. **Receives and amplifies** the 11.5 GHz signal
  2. **Down-converts** it to 1.2 GHz: mix the signal with a local oscillator to produce a more manageable Intermediate Frequency (IF)
  3. **Transfers** the converted signal to the next equipment

THE SPECTRUM ANALYZER

What is a spectrum analyzer?

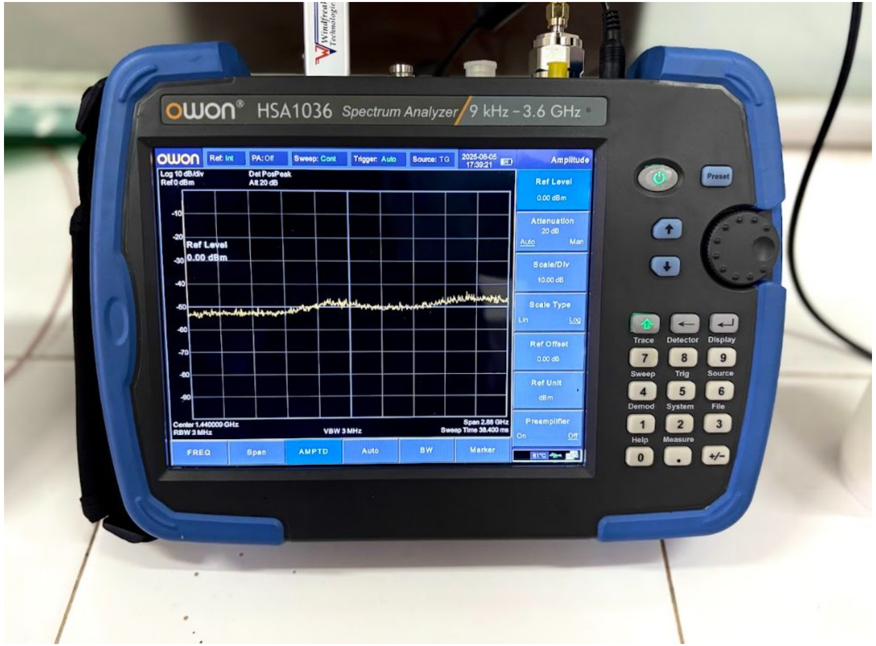
- A spectrum analyzer is an electronic measuring instrument used to analyze the spectral components of a signal in the frequency domain. Simply put, it shows the amplitude of different signals at various frequencies within a certain frequency range.



THE SPECTRUM ANALYZER

There are 3 types of spectrum analyzers:

- Swept Spectrum Analyzer (SA)
- Vector Signal Analyzer (VSA)
- Real-time Spectrum Analyzers (RSA)



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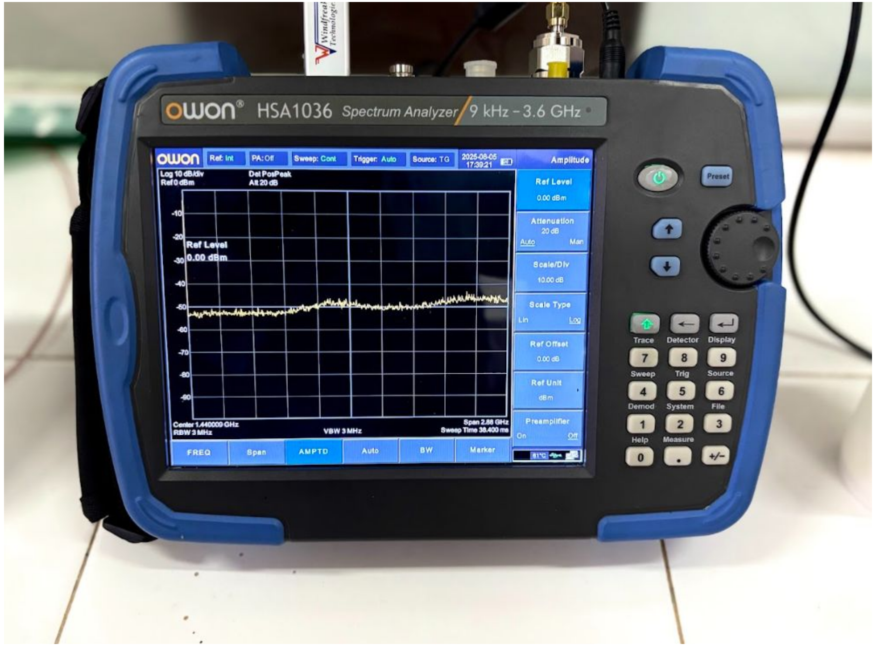
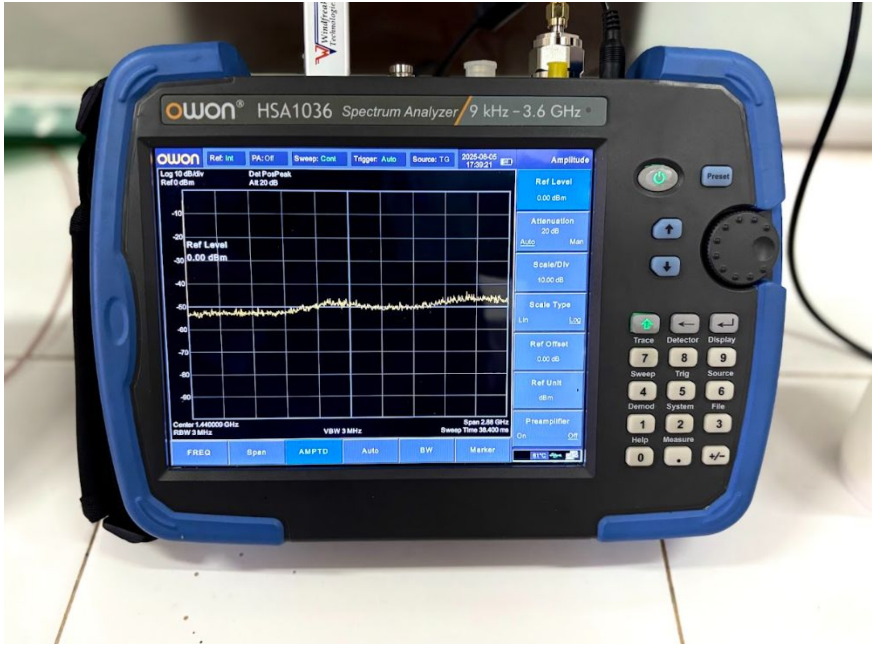
SA



THE SPECTRUM ANALYZER

What Does a Spectrum Analyzer Measure?

- Amplitude and Frequency
- Channel Power
- Adjacent Channel Power Ratio
- Occupied Bandwidth
- Harmonic Distortion
- Phase Noise
- Spurious Signals
- Intermodulation Distortion



THE SPECTRUM ANALYZER

How to Use a Spectrum Analyzer?

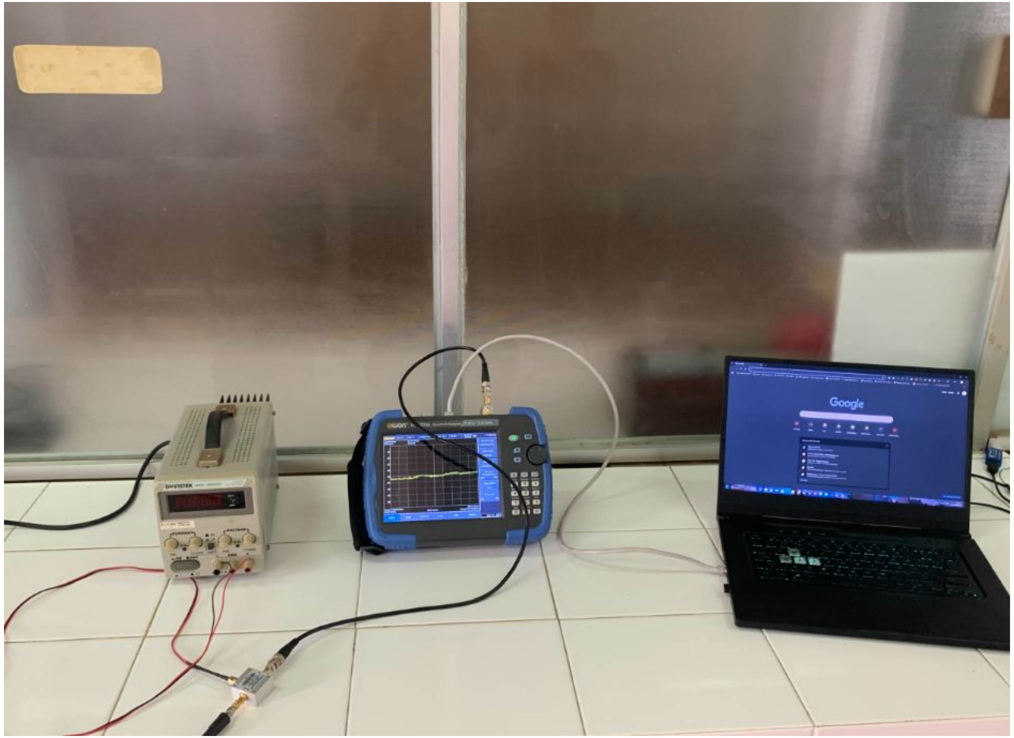
Using a spectrum analyzer involves setting a few basic parameters to accurately "view" the desired signal. Below are the steps and main control buttons:

THE SPECTRUM ANALYZER

How to Use a Spectrum Analyzer?

1. Connection

Connect the device under test to the RF INPUT port of the analyzer.



THE SPECTRUM ANALYZER

How to Use a Spectrum Analyzer?

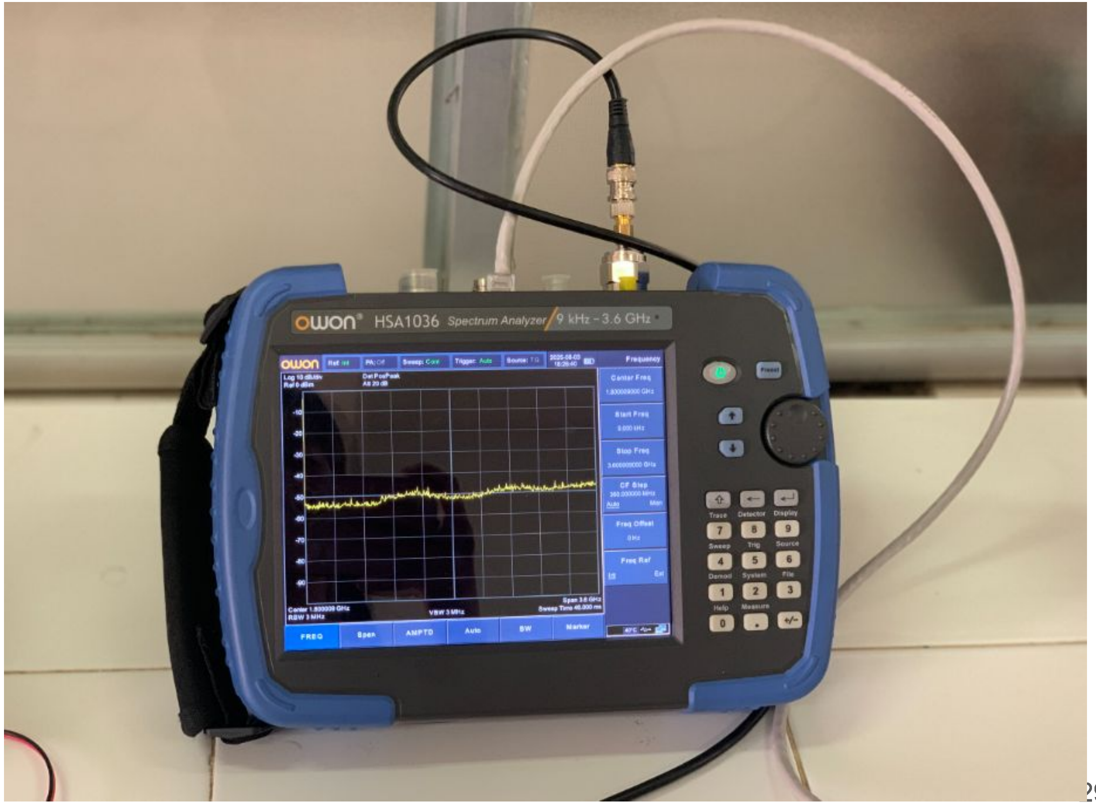
2. Setup

Centre Frequency: 1.2 GHz

Reference Level:

0 dBm

Bandwidth (RBW): 500 MHz

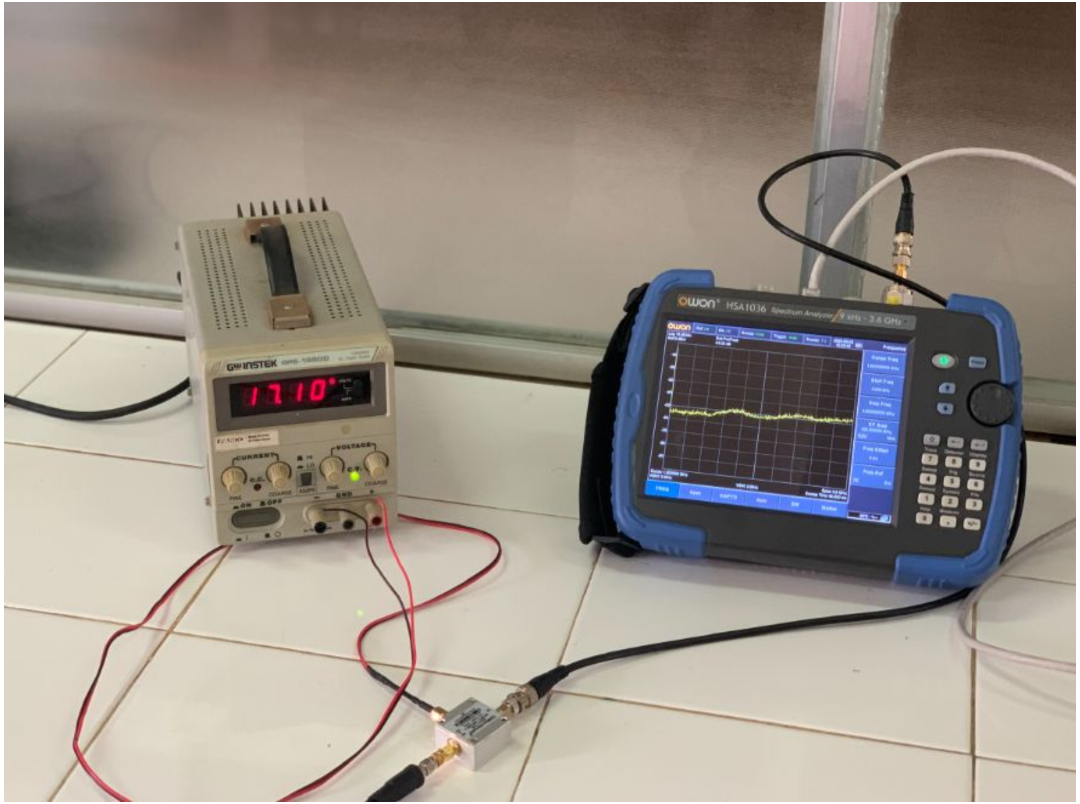


THE SPECTRUM ANALYZER

How to Use a Spectrum Analyzer?

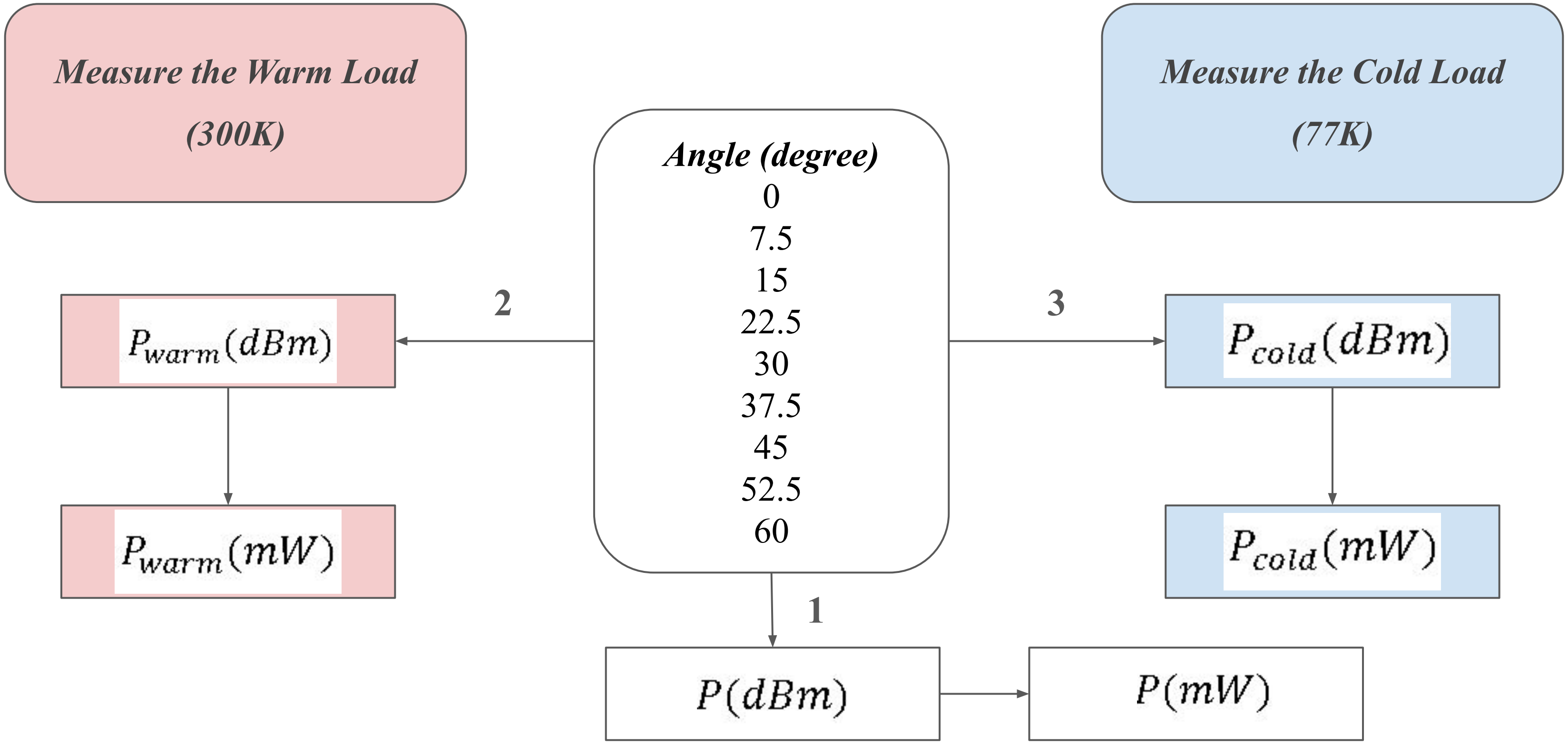
3. Reading the Results

Use the Marker function to move to the peak of the signal and accurately read its frequency and amplitude.



Measuring procedure

$$P(mW) = 10^{\frac{P(dB)}{10}}$$



Calibration Calculation

Step 1: Convert Power (dBm) into linear scale (mW)

Frequency range measured: 0.7GHz - 1.2GHz

Freq(Hz)	0 degree					
	dBm			mW		
701523662	-61.13	-62.59	-62.04	0.0000007709034691	0.0000005508076964	0.0000006251726928
702356996	-59.98	-61.63	-52.89	0.00000100461579	0.00000068706844	0.000005140436516
703190329	-52.67	-63.16	-56.54	0.000005407543229	0.000000483058802	0.0000022181964
704023662	-57.34	-60.48	-56.42	0.000001845015419	0.0000008953647655	0.000002280342072
704856996	-59.79	-56.02	-57.15	0.000001049542429	0.000002500345362	0.000001927524913
705690329	-54.26	-56.11	-66.32	0.000003749730022	0.000002449063242	0.0000002333458062
706523662	-60.61	-56.92	-62.53	0.0000008689604293	0.000002032357011	0.0000005584701947
707356996	-64.86	-59.35	-57.6	0.0000003265878322	0.000001161448614	0.000001737800829
708190329	-61.69	-57.36	-55.99	0.0000006776415076	0.000001836538343	0.000002517676928
709023662	-59.8	-58.68	-60.63	0.000001047128548	0.000001355189412	0.0000008649679188
709856996	-59.78	-60.9	-53.74	0.000001051961874	0.0000008128305162	0.000004226686143
710690329	-57.31	-59.87	-59.07	0.000001857804455	0.00000103038612	0.000001238796587
711523662	-56.32	-57.3	-60.3	0.000002333458062	0.000001862087137	0.0000009332543008
712356996	-55.08	-61.99	-54.7	0.000003104559588	0.0000006324118514	0.000003388441561
713190329	-61.02	-57.45	-63.51	0.000000790678628	0.000001798870915	0.0000004456562484
714023662	-66.32	-55.88	-61.48	0.0000002333458062	0.000002582260191	0.0000007112135137
714856996	-54.6	-60.57	-57.68	0.000003467368505	0.0000008770008211	0.000001706082389
715690329	-53.38	-61.84	-61.8	0.000004591980128	0.0000006546361741	0.00000066069344 8
716523662	-62.74	-59.95	-58.72	0.0000005321082593	0.000001011579454	0.000001342764961
717356996	-57.06	-54.99	-56.99	0.00000196788629	0.000003169567463	0.0000019998 6187
718190329	-62.1	-57.29	-58.08	0.0000006165950019	0.000001866379691	0.000001555965632

Collected data from 3 runs

Data converted to mW

Take the average of the data from the three runs

0.000002529965927	0.000002423180433	0.000002454756176
0.000002469300845		

Then take the final average

Calibration Calculation

Step 1: Convert Power (dBm) into linear scale (mW)

Angle (θ)	Final power average (mW)
0	0.0000002469300845
7.5	0.0000002475789403
15	0.0000002377286943
22.5	0.0000002469300845
30	0.0000002461826078
37.5	0.0000002497409805
45	0.0000002447273283
52.5	0.0000002415812118
60	0.0000002486978391

Calibration Calculation

Step 2: Calculate Receiver Noise Temperature

$$T_{rec} = \frac{(T_{warm} * P_{cold}(mW) - T_{cold} * P_{warm}(mW))}{P_{warm}(mW) - P_{cold}(mW)}$$

where T_{rec} is the Receiver Noise Temperature

T_{warm} is the Temperature of the warm load (300K)

T_{cold} is the Temperature of the cold load (77K)

$P_{cold}(mW)$ is the measured Power of the cold load

$P_{warm}(mW)$ is the measured Power of the warm load

Calibration Calculation

Step 2: Calculate Receiver Noise Temperature

T_{warm}	300K
T_{cold}	77K
P_{cold}	0.0000007718
P_{warm}	0.000002442455405

$\longrightarrow T_{rec} = 26.02\text{K}$

Calibration Calculation

Step 3: Calculate the system Gain

$$G = \frac{P_{warm}\,(dB)}{T_{warm} + T_{rec}}$$

where G is the system Gain (mW/K)

$\longrightarrow$ G = $7{,}49 \times 10^{-9}$ mW/K

Calibration Calculation

Step 4: Calculate the Antenna Temperature

$$T_{ant}(\theta) = \frac{P(\theta)\ (mW)}{G} - T_{rec}$$

where $P(\theta)\ (mW)$ is the Power of each angle θ (0-60 degree)

$T_{ant}(\theta)$ is the Antenna Temperature for each angle θ (K)

Calibration Calculation

Step 4: Calculate the Antenna Temperature

Angle (θ)	**P(θ) (mW)**	$T_{ant}(\theta)$ **(K)**
0	0.0000002469300845	6.94
7.5	0.0000002475789403	7.03
15	0.0000002377286943	5.71
22.5	0.0000002469300845	6.94
30	0.0000002461826078	6.84
37.5	0.0000002497409805	7.32
45	0.0000002447273283	6.65
52.5	0.0000002415812118	6.23
60	0.0000002486978391	7.18

Calibration Calculation

Step 5: Temperature vs. Airmass plotting

Airmass: the amount of atmosphere that CMB has to passed through at a given observational angle

$$\text{Airmass} = \sec(\theta) = 1/\cos(\theta)$$

θ = 0 degree (zenith angle) → Airmass = 1

θ = 60 degree → Airmass = 2

Calibration Calculation

Step 5: Temperature vs. Airmass plotting

Airmass	$T_{ant}(\theta)$(K)
1	6.94
1.008628961	7.03
1.03527618	5.71
1.0823922	6.94
1.154700538	6.84
1.260472414	7.32
1.414213562	6.65
1.642679632	6.23
2	7.18

Calibration Calculation

Step 5: Linear fit the data points
Comparing with the equation

$$T_\theta = T_s + T_A \sec\theta$$

where T_θ corresponding to the antenna temperature T_{ant}

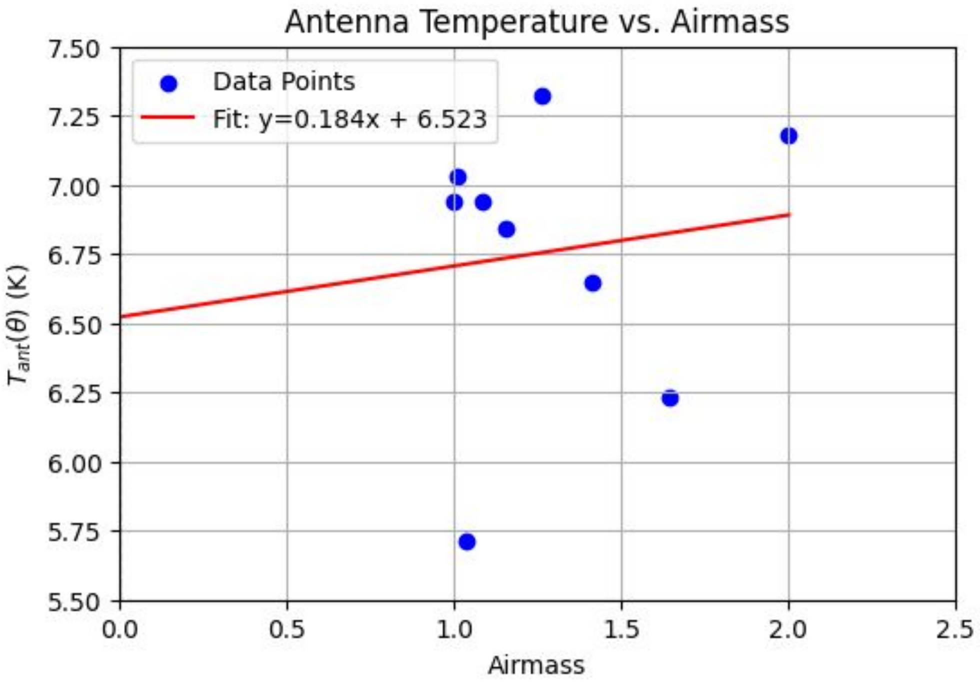
T_A is the atmospheric temperature contribution

T_s is the sky signal temperature (CMB temperature)

We have: Slope = the atmospheric temperature contribution = 0.184
y-intercept = CMB temperature = 6. 523K

Calibration Calculation

Step 5: Linear fit the data points
Find the slope and y-intercept



Error Sources

The most precise measurement of CMB temperature is 2.725K by NASA's COBE (Cosmic Background Explorer) satellite.

Comparing to our result, the error is:

$$\%E = \frac{6.523 - 2.725}{2.725} * 100\% = 139.4\%$$

painly large error :(

Error Sources

1. Unsuitable weather condition (cloudy)
2. Standard laboratory equipment (compare to NASA's COBE)
3. Interference from other radio sources (ground pickup, satellites, etc)
4. Receiver noise temperature
5. Calibration offsets in the calibration procedure

Thank you for your attention!