國立臺灣大學電機資訊學院電信工程學研究所

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Master Thesis

K-頻段輻射計量測及近場成像

K-band Radiometer Measurement and Near-Field Imaging

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國立臺灣大學碩士學位論文
口試委員會審定書

K-頻段輻射計量測及近場成像
K-band Radiometer Measurement and Near-Field Imaging

本論文係蔡昱墩君（R02942089）在國立臺灣大學電信工程學研究所完成之碩士學位論文，於民國 106 年 02 月 06 日承下列考試委員審查通過及口試及格，特此證明

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中文摘要

本論文係依據普朗克黑體輻射定律，使用 K 頻段輻射計量測物體產生之雜訊功率。第一章介紹輻射計基本原理，第二章敘述輻射計之天線及接收機中頻及射頻模組量測結果，並計算天線解析度及接收機等效雜訊溫度。第三章第一節敘述接收機連接 20 dB 導波管天線為一輻射計，量測 50Ω 負載、吸收體、鋁板及人手之雜訊功率，並計算物體之雜訊溫度。第二節則敘述接收機連接 85 cm 碟形天線為一輻射計，並安裝於二維平面掃描器，量測 1.38 公尺距離之近場物體 18 公分 × 18 公分所計算之雜訊功率，量測數值經 Visual Basic 程式控制及量測，並以 MATLAB 程式顯示物體之成像，量測物體包含吸收體、20 dB 增益天線之輻射低功率以及發熱之陶瓷電阻。

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Abstract

In this thesis, a K-band radiometer is developed to measure the noise power coming from an object based on Plank's blackbody radiation law. The basic radiometer theory is briefly introduced in Chapter 1. The measured results of a 85 cm dish antenna, IF and RF stages of a receiver are presented in Chapter 2 to give the antenna spatial resolution and receiver noise temperature. In Sec. 3.1 of Chapter 3, the receiver is connected with a 20 dB horn antenna as a radiometer to measure the noise power of four different objects to calculate their noise temperatures. In Sec. 3.2.2, a radiometer is developed to connect the receiver and a 85 cm dish antenna. The radiometer is mounted on a 18 cm × 18 cm scanner as a near-field imaging system to measure the noise power from the test object at 1.385 m distance. The recorded result and image are controlled through a personal computer using Visual Basic and MATLAB programs. The near-field imaging several objects includes a low-power antenna, absorber and heated ceramic resistors.

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Chapter 1 Basic Theory

The objective of radiometer is to passively measure the noise power generated by the object brightness, to be explained in Sec. 1.1, in microwave region. Radiometer hardware basically consists of an antenna and a low noise with high gain receiver as illustrated in Fig. 1.1. The antenna is to collect the object radiation. The receiver is used to amplify the antenna received noise then detect and integrate the measured noise power. There are few radiometer parameters involved. They include spatial resolution, integration time, and temperature resolution, which is also the radiometer sensitivity. These terminologies will be discussed later in Chapter 2.

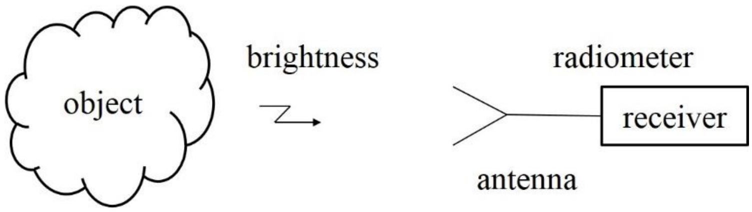

Fig. 1.1 Radiometer consists of an antenna and a receiver.

1.1 Brightness and Brightness Temperature

All natural objects whose temperatures are above absolute 0°K can emit electromagnetic energy. They also absorb and scatter the electromagnetic energy incident on them. In thermal equilibrium, a perfect absorber that absorbs all the incident energy and does not reflect is called a blackbody. According to Kirchhoff's law of radiation, a perfect absorber emits the energy as the same as it absorbs. The radiation from a blackbody source is given by Planck's law as [1]

$$B_{rad} = \frac{2hf^3}{c^2}\frac{1}{e^{hf/kT}-1}. \tag{1.1}$$

In (1.1) $c = 3\times10^8$ m/s is the speed of light. f is frequency in Hz. h = 6.63$\times$10^{-34} J$\times$

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s is Planck's constant. k = 1.38×10^{-23} J is Boltzmann's constant. T in K is the absolute temperature of the blackbody. B_{rad} in W m^{-2} Hz^{-1} is the radiation emitted by the blackbody and is also called brightness or brightness spectral density.

For microwaves in K-band from 18 GHz to 26 GHz, hf is much smaller than kT, therefore, one can use the first two terms of the Taylor series expansion approximation as

$$e^{hf/kT} - 1 \simeq \frac{hf}{kT} \tag{1.2}$$

or the Rayleigh-Jeans approximation to give (1.1) as

$$B_{rad} = \frac{2k}{\lambda^2} T \tag{1.3}$$

where λ is the wavelength. When the object is not a blackbody, it partially reflects the incident energy. The measured brightness is smaller than that given in (1.3). Therefore the brightness temperature T_B is defined as $T_B \equiv eT$ [2] where e is the object emissivity with $0 \le e \le 1$ and depends on the body material. The object brightness B_{rad} is then given as

$$B_{rad} = \frac{2k}{\lambda^2} T_B = \frac{2k}{\lambda^2} eT. \tag{1.4}$$

It indicates the brightness temperature distribution $T_B(\theta,\phi)$ measured by a microwave radiometer can give a spatial description of the object observed in microwave region. This work has been developed in radio astronomy for years [3].

1.2 Equivalent Noise Temperature and Noise Figure

Planck's blackbody radiation law can also be applied to electronic circuits. The following description is referred from [4]. The electronic components generate energy which is called thermal noise. Considering a resistor at physical temperature of T K, the

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electrons in the resistor are in random motion, with a kinetic energy that is proportional to the temperature. This energy produces a random voltage across the resistor given by

$$V_n = \sqrt{\frac{4hfR}{e^{hf/kT} - 1}}. \tag{1.5}$$

V_n in (1.5) is the root mean square value of random voltage spectrum in Volt Hz^{-1}. R is the resistance in Ω. By using (1.2) with f in K-band, (1.5) can be simplified as

$$V_n = \sqrt{4kTR}. \tag{1.6}$$

This noisy resistor has the maximum power transfer when its load is matched to a resistor with the same value. The power spectrum delivered to the load is

$$P_n = \frac{V_n^{\ 2}}{4R^2} R = kT. \tag{1.7}$$

Since the above noise power is independent of frequency, it has a power spectral density being constant with frequency. The noise power is then directly proportional to the bandwidth and given as

$$P_n = kTB \tag{1.8}$$

where B is the operational bandwidth. The noisy resistor is called a white noisy resistor.

For an arbitrary noisy source or network where noise power (thermal or nonthermal) is not strongly dependent of frequency over the bandwidth of interest, it can be characterized with an equivalent noise temperature as

$$T_e = \frac{N_o}{kB}. \tag{1.9}$$

In (1.9), N_o is the noise power delivered to a matched load.

Consider a lossy network having power loss of L and it matches with source and load resistors at temperature T as shown in Fig. 1.2. The loss factor L is given by $L = 1/G > 1$ with G being the power gain. Since the entire system is in thermal equilibrium at the

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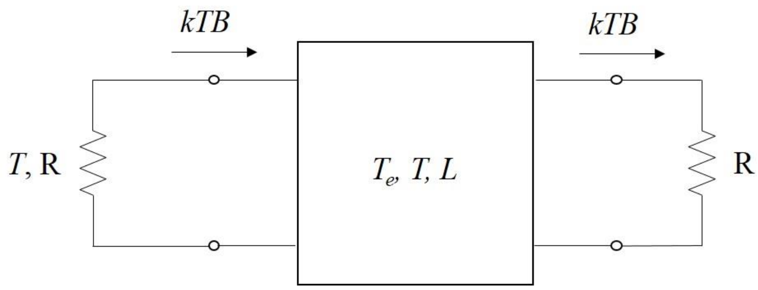

Fig. 1.2 A lossy network with matched source and load.

temperature *T*, the output noise power must be $N_o = kTB$ and is given as

$$N_o = kTB = GkTB + GN_{added} \tag{1.10}$$

where N_{added} is the noise generated by the lossy network. From (1.10)

$$N_{added} = k\left(L-1\right)TB = kT_eB. \tag{1.11}$$

$T_e = \left(L-1\right)T$ in (1.11) shows that the lossy network has an equivalent noise temperature T_e which is proportional to its loss and is embedded in the output noise power.

A common characterization used to characterize a noisy network is noise figure *F*, which is defined as [4]

$$\begin{aligned} F &= \frac{S_i / N_i}{S_o / N_o} = \frac{S_i N_o}{S_o N_i} = \frac{GkB\left(T_o + T_e\right)}{GkT_oB} \\ &= 1 + \frac{T_e}{T_o} \end{aligned} \tag{1.12}$$

Where *B*, *G*, and T_e are the bandwidth, power gain and equivalent noise temperature of the network. S_i and N_i are the input signal power and noise power. S_o and N_o are the output signal power and noise power. Note the input noise power is defined from a matched resistor under the situation of $T_o = 290\,\text{K}$.

Once the network consists of several cascaded components, (1.12) can be given as

$$F_{cas} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1G_2} + \cdots \tag{1.13}$$

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where F_{cas} is the overall noise figure. F_1, F_2, F_3, G_1, and G_2 are the noise figure and gain of each component. The form of the overall equivalent noise temperature T_{cas} is then

$$T_{cas} = T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1 G_2} + \cdots \tag{1.14}$$

where T_{e1}, T_{e2} and T_{e3} are the equivalent noise temperature of each component. For a cascaded system with high gain in each component, F_{cas} and T_{cas} are dominated by the characteristics of the first stage.

1.3 Antenna

The purpose of radiometer antenna is to effectively collect the brightness radiating from the observed object temperature. It connects to a radiometer receiver to measure the noise power.

1.3.1 Antenna Temperature

When an antenna points toward an object with the spatial distribution of brightness temperature $T_B(\theta,\phi)$ given by (1.4), its received power spectrum P_r in WHz^{-1} is given by [1]

$$P_r = \frac{1}{2}\int \frac{2k}{\lambda^2} T_B(\theta,\phi) A_r(\theta,\phi)\, d\Omega \tag{1.15}$$

where

$$\begin{gathered} \int A_r(\theta,\phi) d\Omega = \lambda^2 \\ \frac{A_r(\theta,\phi)}{A_{rm}} = P_a(\theta,\phi). \end{gathered} \tag{1.16}$$

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In (1.16), $A_r(\theta,\phi)$ is the receiving antenna cross section and $A_{rm} = \frac{\lambda^2}{4\pi} G_a$ is the maximum receiving antenna cross section with G_a being the antenna gain. $P_a(\theta,\phi)$ is the normalized receiving antenna radiation power pattern. The factor $\frac{1}{2}$ is because the antenna receives only one polarization and the integral is overall the solid angle. Given the operation bandwidth B, the normalized received power against the background can then be written as

$$P_r = k\frac{\int T_B(\theta,\phi) P_a(\theta,\phi) d\Omega}{\int P_a(\theta,\phi) d\Omega} B = kT_a B \tag{1.17}$$

where T_a is called the antenna temperature. The antenna output power P_r is usually expressed in terms of its antenna temperature T_a. It is obvious that the antenna received noise power is an integral of the object brightness temperature seen by the antenna multiplying the antenna radiation power pattern over the observation range. This thesis then uses this equation to give the image of the observed object brightness temperature $T_B(\theta,\phi)$ by having the antenna radiation pattern to be a delta function at a certain direction (θ_0,ϕ_0). In our experiment, a parabolic dish antenna with 85 cm diameter is used.

For a realistic antenna with dissipative loss, the antenna received power is reduced by the antenna efficiency η_{rad}, which is the ratio of the antenna output power to the input power. The received object brightness temperature will also be reduced by the factor of η_{rad}. Note the thermal noise is generated by the antenna loss can be modeled as a lossless antenna with a loss of $L = 1/\eta_{rad}$. The resulted antenna noise temperature T_A is given by [5]

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$$T_A = \frac{T_a}{L} + \frac{(L-1)T_p}{L} = \eta_{rad} T_a + (1-\eta_{rad}) T_p \tag{1.18}$$

where T_p is the antenna physical temperature. Hence the antenna noise temperature T_A is a linear combination of the antenna temperature T_a related to the observed object brightness temperature $T_B(\theta,\phi)$ and the thermal noise generated by the antenna loss.

1.3.2 Spatial Resolution

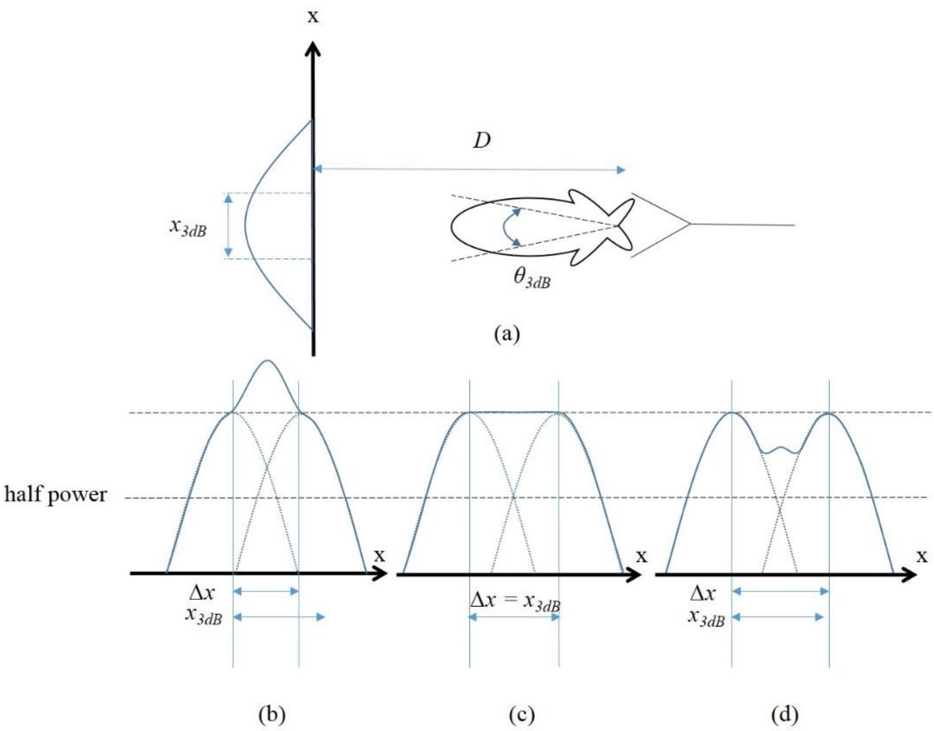

Fig. 1.3 Spatial resolution on x-axis by moving (a) an antenna with Δx to give two (b) unresolved, (c) just resolved, and (d) resolved patterns.

Consider an antenna points to an object as shown in Fig. 1.3 (a) and the distance between antenna and object is *D*. The curve on the x-axis represents the magnitude of the antenna main beam projection. θ_{3dB} is half power beamwidth and x_{3dB} is the projected width corresponding to θ_{3dB} with a distance of *D*. The spatial resolution along x-axis is

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given by

$$x_{3dB} = 2D \tan \frac{\theta_{3dB}}{2} \tag{1.19}$$

If the antenna is moved by Δx, which is smaller than x_{3dB}, as shown in Fig. 1.3 (b), peaks of the original pattern (dotted lines) cannot be distinguished in the combined pattern (solid line), which is called the unresolved pattern. Once Δx is greater than x_{3dB}, as shown in Fig. 1.3 (d), two peaks can be distinguished from the combined pattern and they are resolved. For Δx is equal to x_{3dB}, as shown in Fig. 1.3 (c), two patterns are just resolved. x_{3dB} is then called the spatial resolution of the antenna along x-axis.

In our experiment, the parabolic dish antenna is moved in a planar scanner. The antenna spatial resolution in x-direction is then determined by θ_{3dB} in θ-direction. Similarly, one can define the antenna spatial resolution y_{3dB} in cross x-direction (or y-direction).

1.4 Receiver

Once the object radiating noise power or antenna temperature is received by the antenna, the receiver then provides a very high gain about 100 dB with a low noise figure. The noise power level for an object at 290 K observed by a receiver with bandwidth of 30 MHz is about $N_o = k \times 290\ \text{K} \times 30\ \text{MHz} \simeq 1.2 \times 10^{-10}$ mW = -99.2 dBm based on (1.8). The receiver amplification is provided over the RF and IF stages and the noise figure is determined by the receiver RF stage.

Fig. 1.4 (a) shows the block diagram of the receiver used in this thesis. The RF stage consists of a broad band low noise amplifier (LNA) and a bandpass filter to extract the lower sideband of the signal after LNA. The local oscillator provides a sinusoidal output,

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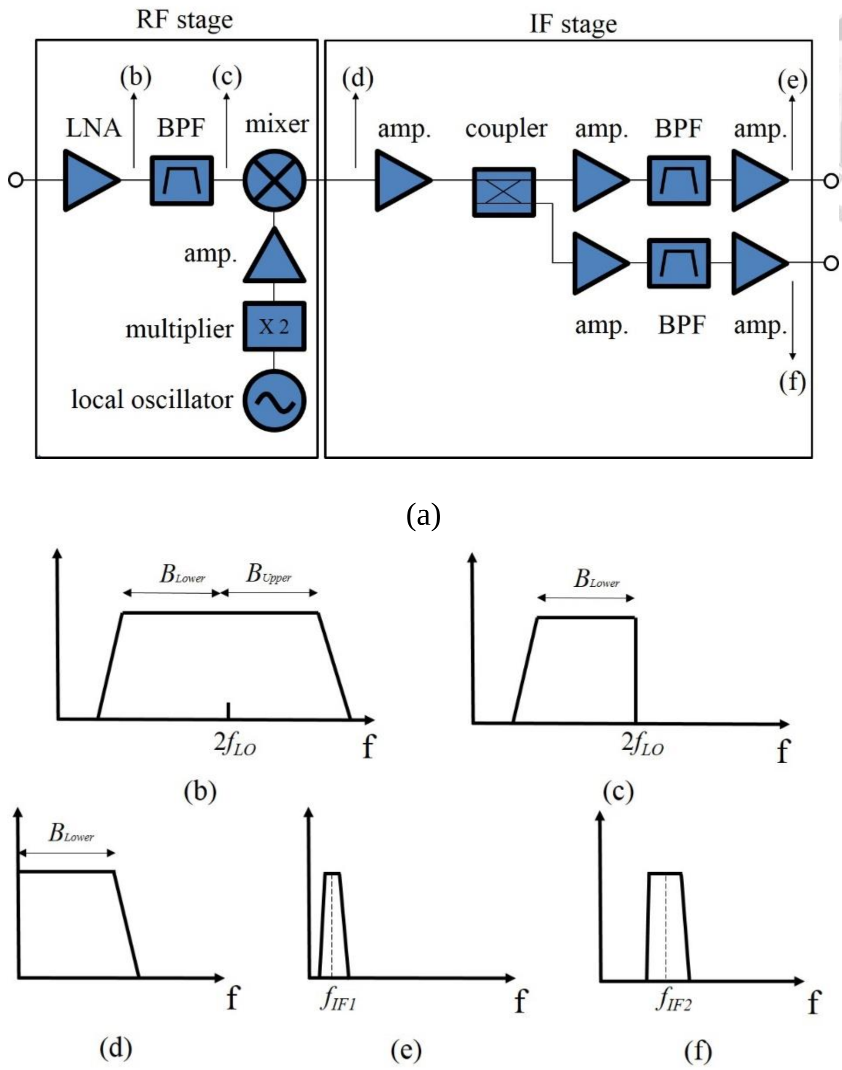

Fig. 1.4 (a) Receiver block diagram with (b)~(f) corresponding to each operational spectrum.

whose frequency f_{LO} = 9.825 GHz is doubled by a frequency multiplier and then amplified by an amplifier. A mixer is used to down convert the frequency from RF band to IF band. In IF stage, an IF amplifier increases the signal from the RF stage. A coupler offers a pair of signal paths and the signal in each path is amplified and filtered to f_{IF1} and f_{IF2} frequencies. This receiver was used for the ROCSAT-1 communication experiment [6] as a beacon receiver with f_{IF1} = 150 MHz and a communication receiver for f_{IF2} = 1.2 GHz. The corresponding RF frequency channels are 19.5 GHz and 18.45

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GHz.

The receiver frequency allocation is presented in Fig. 1.4 (b)~(f) and the measured results will be given in the next Chapter. Fig. 1.4 (b) shows the LNA output spectrum, where B_{Lower} is the lower sideband and B_{Upper} is the upper sideband. Fig. 1.4 (c) shows the output spectrum of bandpass filter in RF stage, whose upper sideband is removed. Fig. 1.4 (d) shows the mixer output spectrum. Fig. 1.4 (e) and (f) show the output spectra of the IF stage for two paths at f_{IF1} and f_{IF2}.

1.5 Detection and Integration

To measure the observed noise power, a square-law detector is used through its property of diode nonlinearity. The diode output voltage is proportional to the receiver output power. From (1.9) and (1.18), the diode output voltage can be expressed as [2]

$$\begin{aligned} V &= kT_A BG_{rec} + kT_{rec} BG_{rec} \\ &= CP_{rec} \end{aligned} \tag{1.20}$$

In (1.20) T_A is the antenna noise temperature. T_{rec} is the receiver equivalent noise temperature. B and G_{rec} are the receiver bandwidth and power gain. C is the factor for the receiver measured output noise power to be given in Chapter 3.

Because T_A and T_{rec} are random signals, V presents extremely high fluctuation. Therefore, an integrator smooths the random signal by averaging in a specific time of τ. The longer integration time gives more smoothed value of V. It then needs more bandwidth to give more smoothed result. The temperature resolution or sensitivity of a radiometer is then given as [2]

$$\begin{aligned} \Delta T &= \frac{T_A + T_{rec}}{\sqrt{B\tau}} \\ &= \frac{T_{sys}}{\sqrt{B\tau}}. \end{aligned} \tag{1.21}$$

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As long as $1/\sqrt{B\tau}$ is large enough, the measured equivalent temperature after the integrator is close to T_{sys}. It is the summation of antenna noise temperature and receiver noise temperature. The object brightness temperature is embedded in the antenna noise temperature given by (1.17). Higher value of bandwidth and integration time will then increase the measurement accuracy.

In this thesis, the detection and integration is realized by using an Agilent U2000A power sensor. In the next Chapter, detail description of measured results of antenna and receiver will be presented to given receiver B, G_{rec}, T_{rec} and antenna η, spatial resolution, pointing direction (θ_0, ϕ_0) and gain G_a. Chapter 3 then gives noise power measurements of radiometer for several objects. The corresponded antenna noise temperature T_A and antenna temperature T_a will then be calculated.

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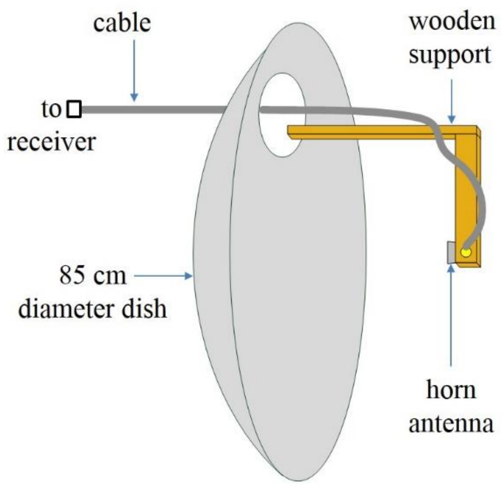
Chapter 2 Radiometer Measurements

In Chapter 1, (1.19) depicts that antenna spatial resolution corresponds to antenna beamwidth. In order to have a resolution in cm, antenna should have high gain with small 3dB beamwidth. In addition, receiver should have low noise figure in order to have low T_{rec}. This chapter will present the measurement results of antenna, RF stage and IF stage of receiver. The measured receiver result also gives the value of bandwidth B, determined by the IF stage, to calculate integration time. In addition, the measured antenna results give antenna main beam pointing angle, spatial resolution and efficiency.

2.1 Antenna Near-Field Measurement

In this thesis, a parabolic dish antenna with 85 cm diameter used in ROCSAT-1 experiment [6] is shown in Fig. 2.1 (a) to give a small spatial resolution. The wooden support is used to fix a horn antenna, Continental Microwave PA42-8, with about 8 dB gain. The horn is operated at TE_{10} mode with linear polarization in x-direction as shown in Fig 2.1 (b) and (d). Its frequency range is in K-band from 18 to 26.5 GHz.



(a)

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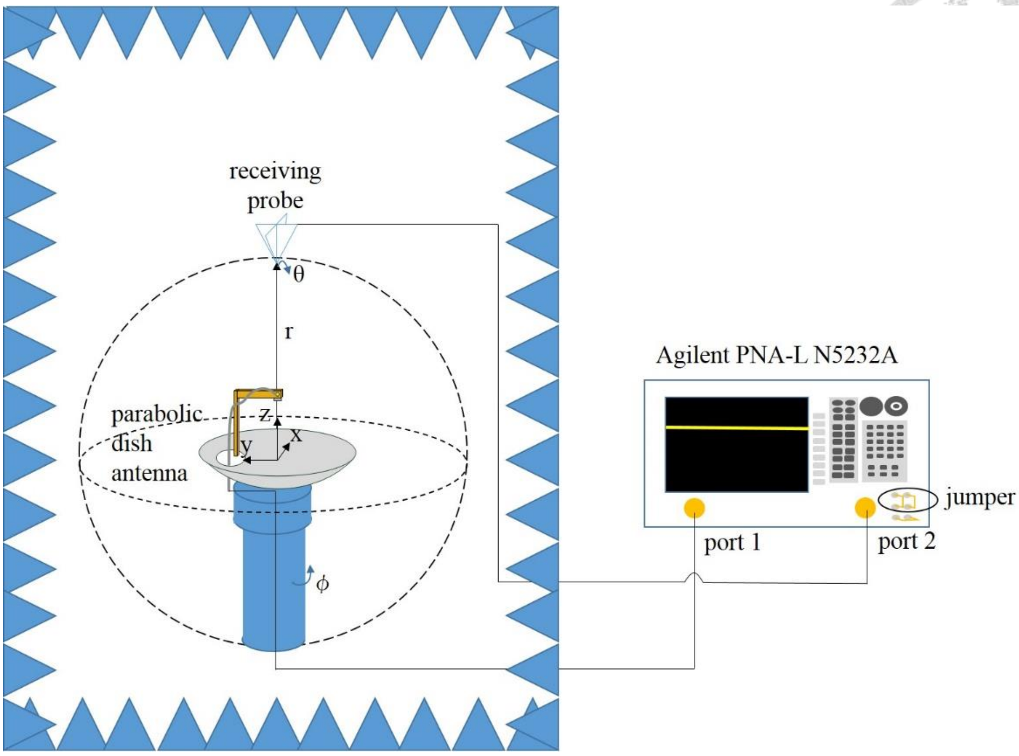

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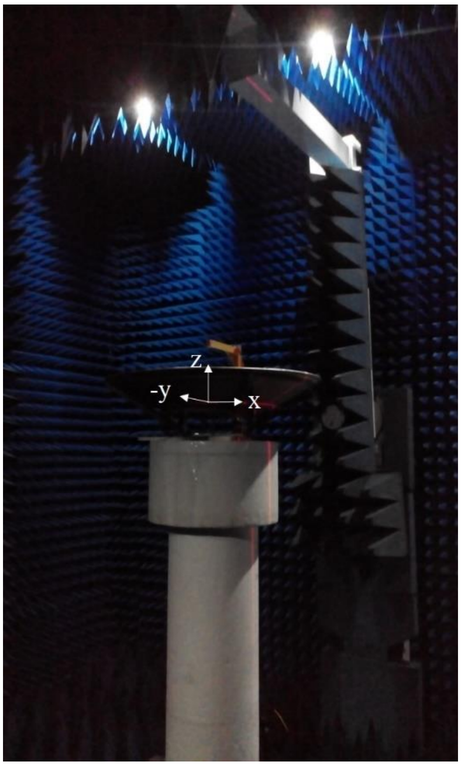
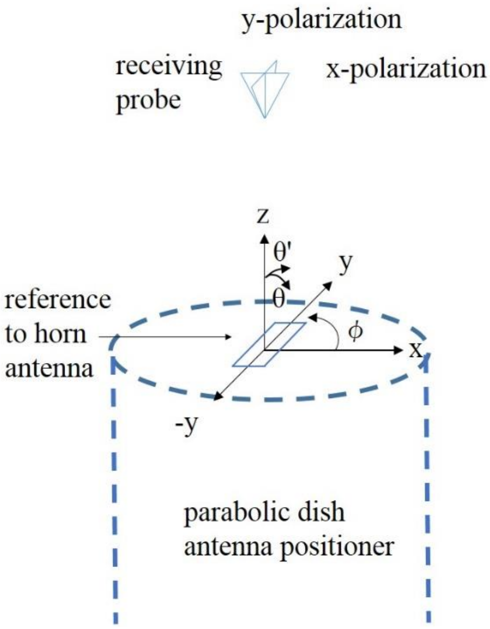


(c)



(d)

Fig. 2.1 (a) Dish antenna, (b) NSI2000 near-field antenna measurement arrangement, (c) its photograph and (d) coordination.

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Fig. 2.1 (b) and (c) is the NSI2000 [7] near-field antenna measurement arrangement and its photograph. A dual linear polarized log pyramidal receiving probe antenna, NSI-RF-DLP-03, at the top of an arm moved in θ-direction to give a circular trace in (x , z) plane in Fig. 2.1 (d). The range of θ is from $\theta = 0°$ to $165°$ and the radius r is 1.385 m. For each θ angle, the parabolic dish antenna is rotated in ϕ-direction to give a circular path in (x, y) plane. The range of ϕ is from $\phi = 0°$ to $360°$. The movement then gives two linear polarized near-field radiation patterns of the parabolic dish antenna on a spherical coordinate with radius of 1.385 m through switching the polarization of receiving probe at x- and y-directions. The moving step of θ- and ϕ-rotations is set at $0.6°$. The test frequency is set from 16 GHz to 20 GHz with a step of 0.5 GHz. An Agilent PNA-L N5232A is used to measure S_{21} values at the specified frequency between the receiving probe connected at port 2 and the parabolic dish antenna connected at port 1 at Fig. 2.1 (b). Note the two jumper at port 2 are properly changed to increase the receiver dynamic range by 15 dB [8].

Fig 2.2 and Fig. 2.3 show the measured x-polarized (or co-polarized) normalized S_{21} values given by the solid lines at frequencies of 18.45 GHz and 19.5 GHz. The distance of 1.385 m will be used later in the near-field imaging measurements for that between the parabolic dish antenna and the imaged object to be given in the next chapter. Both the amplitude patterns given in Fig 2.2 (a) and Fig 2.3 (a) indicate the parabolic antenna has a sharp tilted main beam by the solid lines at $\theta_0 = 7.8°$ and $\phi_0 = 171.6°$ for 18.45 GHz and $\theta_0 = 7.8°$ and $\phi_0 = 20.4°$ for 19.5 GHz. Since ϕ-direction corresponds to the rotation of parabolic dish antenna, the patterns at $\phi_0 + 180°$ given in Fig. 2.2 (b) and Fig. 2.3 (b) basically repeat the same x-polarization. The plots of maximum θ-profile are at ($\theta_0 = 7.8°$, $\phi_0 = 351.6°$) and ($\theta_0 = 7.8°$, $\phi_0 = 200.4°$) in Fig 2.2 (b) and Fig 2.3

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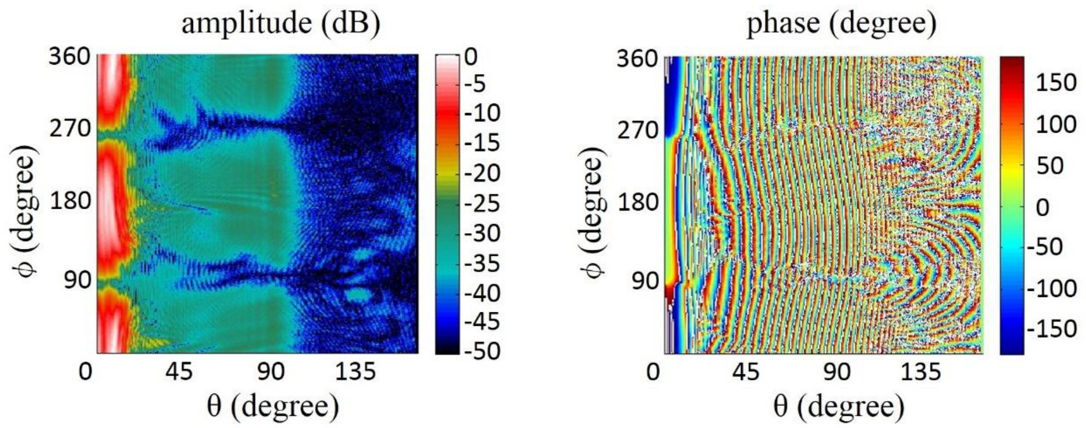
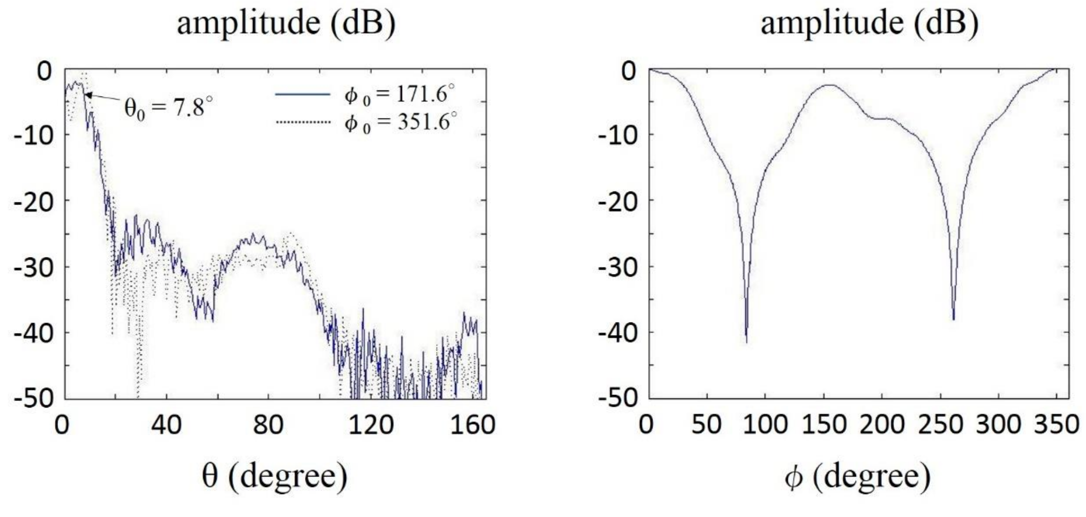
(b) to show that the peak tilt at $\theta_0 = 7.8°$ in (x, z) plane or at $x_0 = 138.5$ cm$\times$tan7.8° = 19 cm. The sharper beam also gives the 3dB beamwidth however the sampling angle of 0.6° may cause the small difference of two θ-profiles. The 3dB beamwidth in θ-direction is then about $\theta_{3dB} = 2.4°$ for 18.45 GHz and 19.5 GHz. These values give the spatial resolutions in x-direction given by (1.19) as $x_{3dB} = 2\times138.5\times\tan1.2° \simeq 5.8$



(a)



(b)

Fig. 2.2 Measured (a) x-polarized S_{21} patterns with (b) two θ - profiles with peaks at (θ_0 = 7.8°, ϕ_0 = 171.6°) and (θ_0 = 7.8°, ϕ_0 = 171.6°) and ϕ - profile for 18.45 GHz.

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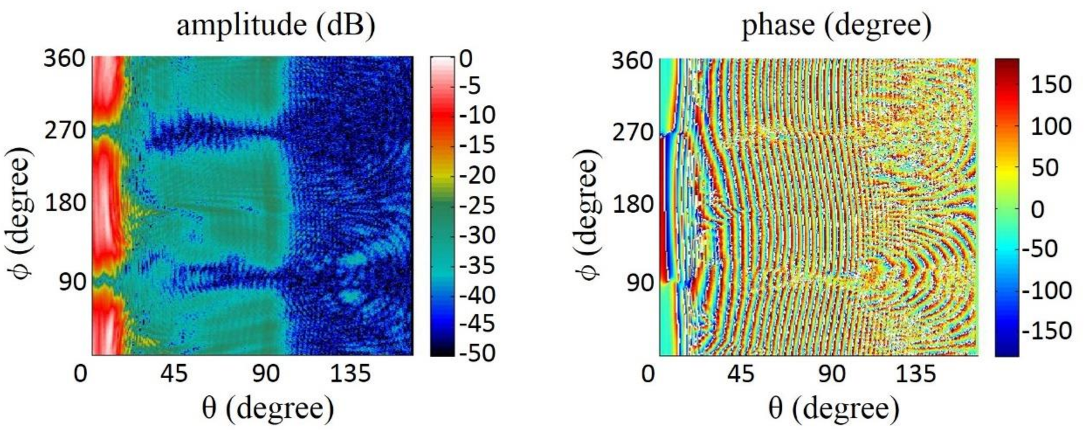
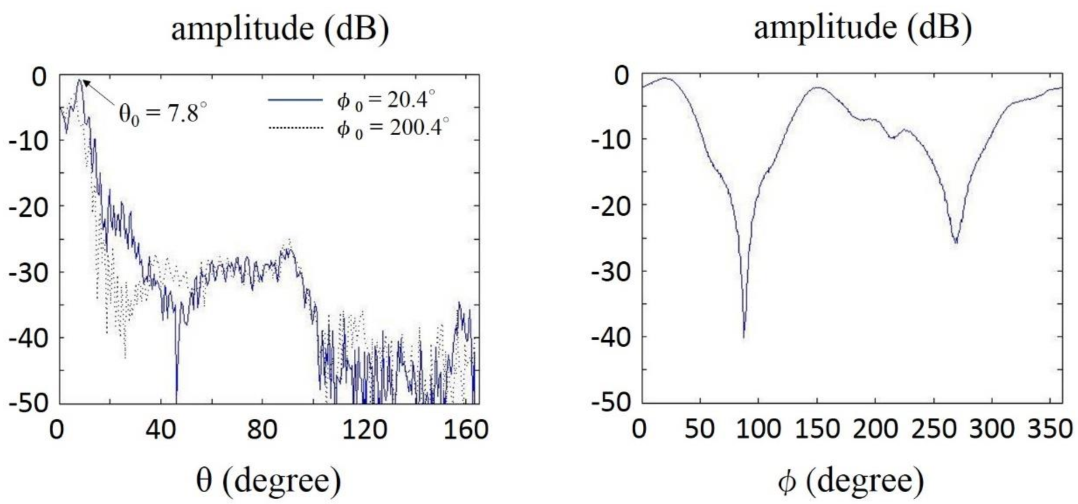


(a)



(b)

Fig. 2.3 Measured (a) x-polarized S_{21} patterns with (b) two θ - profiles with peaks at (θ_0 = 7.8°, ϕ_0 = 20.4°) and (θ_0 = 7.8°, ϕ_0 = 200.4°) and ϕ - profile for 19.5 GHz.

cm for 18.45 GHz and 19.5 GHz, respectively.

For the tilt angle of main beam in y-z plane and resolution in y-direction are determined from the y-polarized (or cross-polarized) normalized S_{21} patterns as shown in Fig. 2.4 and Fig. 2.5. Note θ -profile is now in -y-direction as the θ' - profile in (y, z) plane as shown in Fig. 2.1 (d). The plots of θ' -profile and ϕ -profile given in Fig. 2.4

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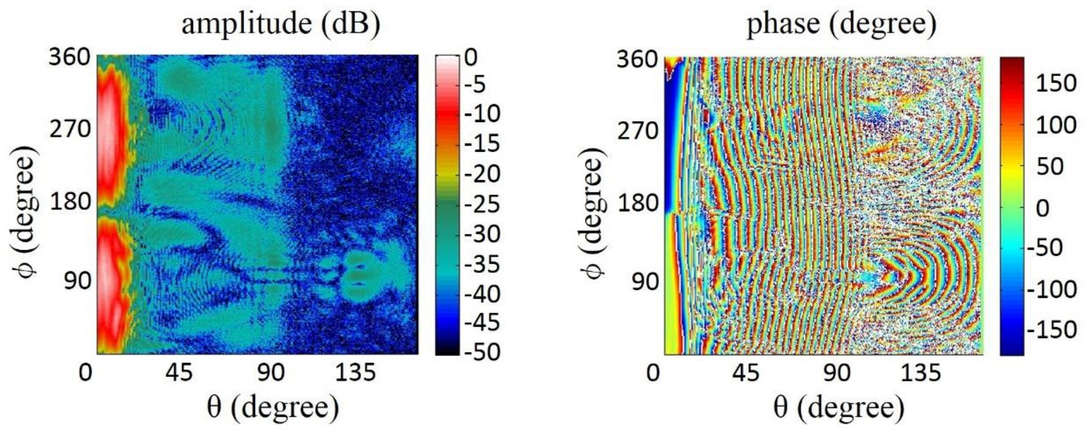
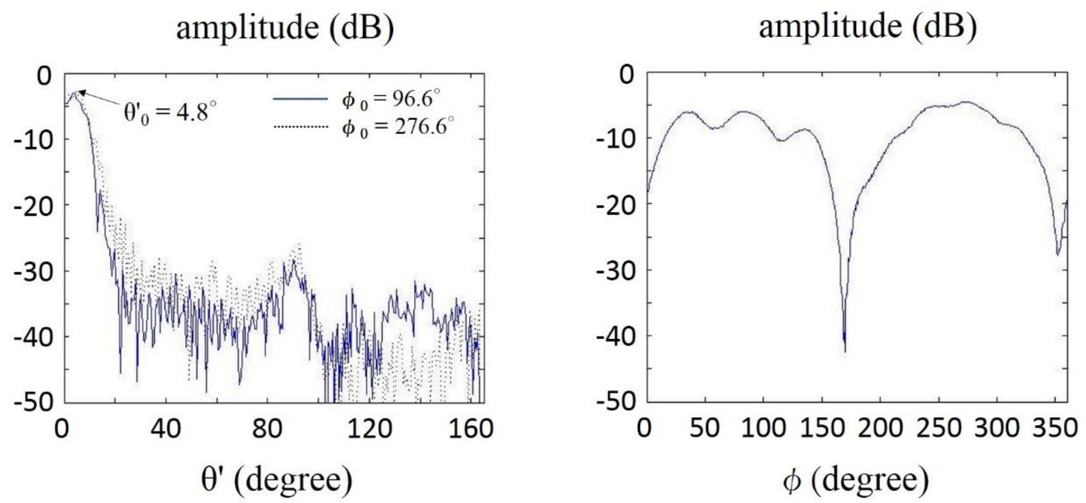
(b) and Fig. 2.5 (b) show that the peak tilts at about $\theta'_0 = 4.8°$ or $y_0 = -138.5$ cm$\times \tan 4.8° = -12$ cm for 18.45 GHz and 19.5 GHz. The corresponding 3 dB beamwidth $\theta'_{3dB} = 2.4°$ for 18.45 GHz and $\phi_{3dB} = 2.4°$ for 19.5 GHz. The corresponded spatial resolution in y-direction is $y_{3dB} = 2 \times 138.5 \times \tan 1.2° \simeq 5.8$ cm for 18.45 GHz and 19.5 GHz.



(a)



(b)

Fig. 2.4 Measured (a) y-polarized S21 patterns with (b) two θ- profiles with peaks at ($\theta_0 = 4.8°$, $\phi_0 = 96.6°$) and ($\theta_0 = 4.8°$, $\phi_0 = 276.6°$) and ϕ- profile for 18.45 GHz.

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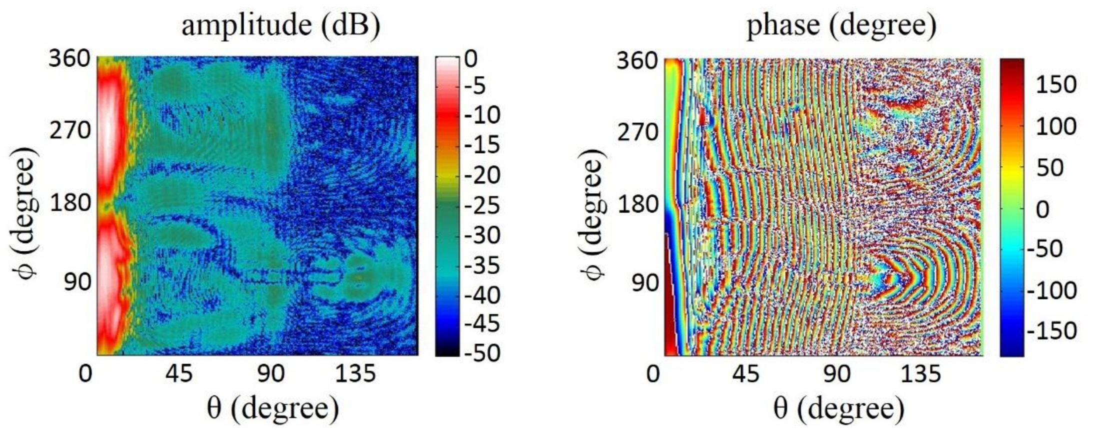
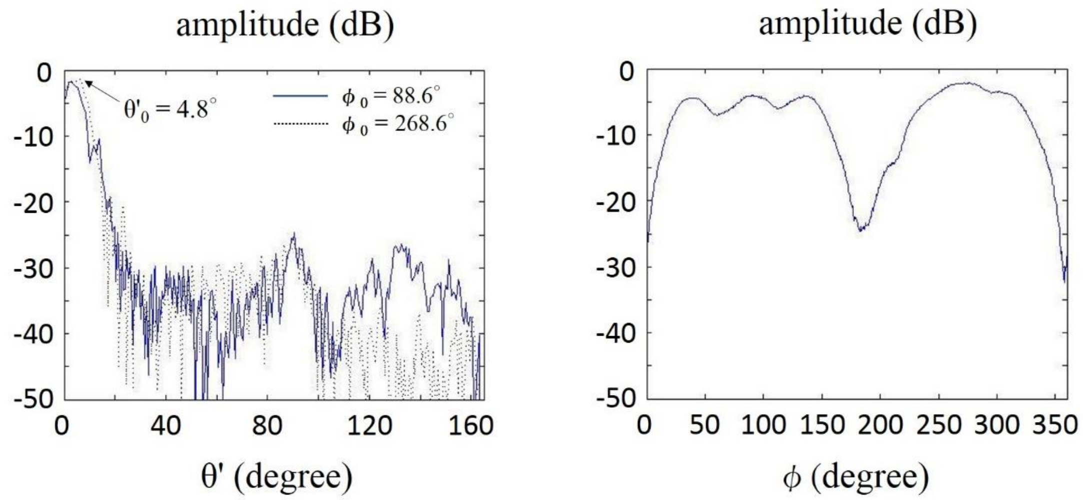


(a)



(b)

Fig. 2.5 Measured (a) y-polarized S21 patterns with (b) two θ - profiles with peaks at (θ'_0 = 4.8°, ϕ_0 = 88.6°) and (θ'_0 = 4.8°, ϕ_0 = 268.6°) and ϕ - profile for 19.5 GHz.

The measured gain G_a and efficiency η derived from near-field to far-field transformation are 40.14 dBi and 78.6 % for 18.45 GHz and 38.55 dBi and 49.72% for 19.5 GHz. The gain values are close to those of [6]. Table 2.1 summarizes the main beam pointing direction, beamwidth, spatial resolution, gain and efficiency of the 85 cm parabolic dish antenna.

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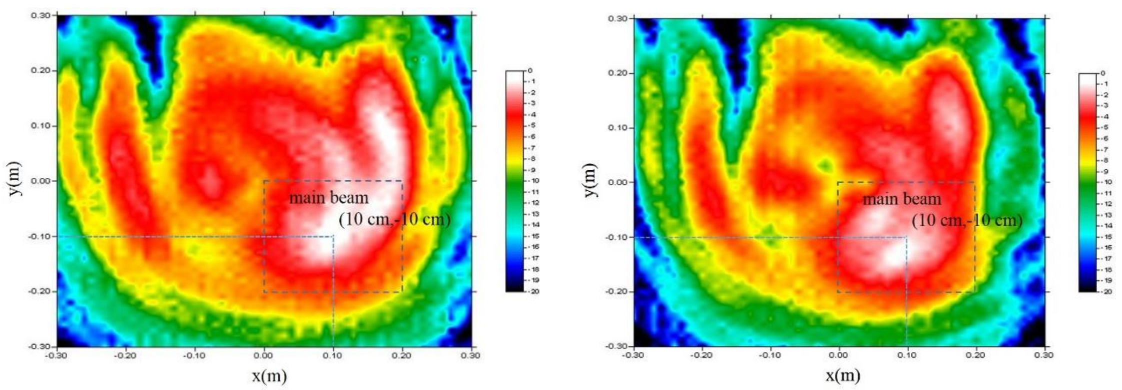
Frequency	18.45 GHz	19.5 GHz
Pointing direction @ r = 1.385 m	$\theta_0 = 7.8°, \theta'_0 = 7.8°$ or x_0 = 19 cm, y_0 = -12 cm	
Beamwidth @ r = 1.385 m	$\theta_{3dB} = 2.4°$	$\theta'_{3dB} = 2.4°$
Spatial resolution @ r = 1.385 m	x_{3dB} = 5.8 cm y_{3dB} = 5.8 cm	x_{3dB} = 5.8 cm y_{3dB} = 5.8 cm
Gain G_a @ far-field	40.14 dBi	38.55 dBi
Efficiency η @ far-field	78.6%	49.72%

Table 2.1 Measured results of parabolic dish antenna.

The main beam direction can also be verified from the holograms shown in Fig. 2.6 and the far field pattern shown in Fig. 2.7. Fig. 2.6 (a) and (b) show the measured x-polarized holograms at the distance of z = 1.385 m. The peak is shown close to x_o = 10 cm and y_0 = -10 cm which is close to the pointing direction given in Table 2.1. The color scale is in dB. The spatial resolution in x- and y-direction are about x_{3dB} = 5 cm and y_{3dB} = 5 cm. The dashed square with a range of 20 cm×20 cm will be the scanning range in the near-field imaging measurement to be presented in the next Chapter. The far



(a) (b)

Fig. 2.6 Measured x-polarized holograms at z = 1.385 m for (a) 18.45 GHz and (b) 19.5 GHz.

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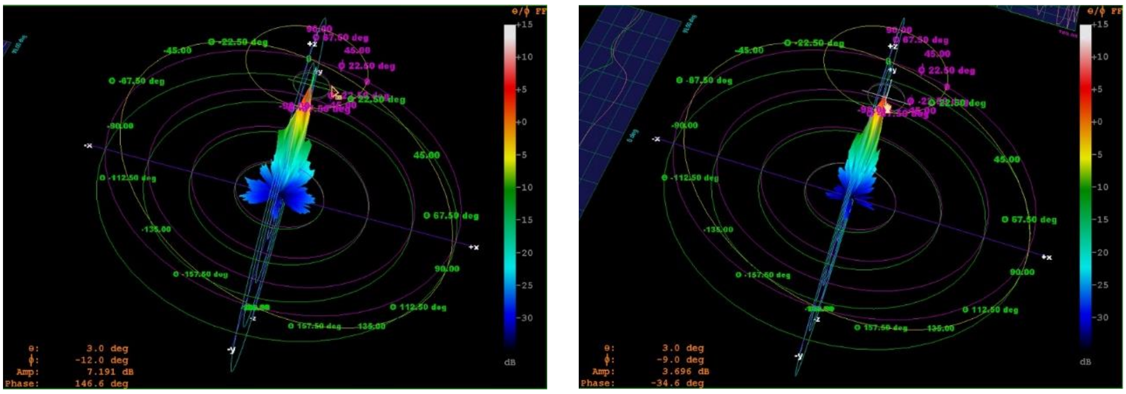
field pattern calculated from the measured near field data is shown in Fig. 2.7 for 18.45 GHz and 19.5 GHz. The pointing angles are at about (θ_0 = 3°, ϕ_0 = −7.5°) and (θ_0 = 3°, ϕ_0 = −5°). The beam pointing angles are close to that given in Table 2.1. The tilt of the main beam is due to the mislocations of horn antenna and back support of parabolic dish antenna as shown in Fig. 2.1 (c).



(a) (b)

Fig. 2.7 Measured far-field patterns at (a) 18.45 GHz and (b) 19.5 GHz.

2.2 Receiver Measurement

In this section, noise figure and power gain of receiver RF and IF stages are measured by an Agilent 4-port PNA N5222A. The two jumpers at port 2 of PNA are also properly changed to bypass the directional coupler to get 15 dB more power for the PNA receiver at port 2 as that given in Fig. 2.1 (b) [8].

2.2.1 RF Stage

The measurement arrangement for RF stage is shown in Fig. 2.8. The input and output ports of IF stage are terminated with $50\,\Omega$ terminations. Since the RF stage has input $P_{1dB} \simeq$ -30 dBm [9], a 30 dB attenuator is connected at the RF stage input to

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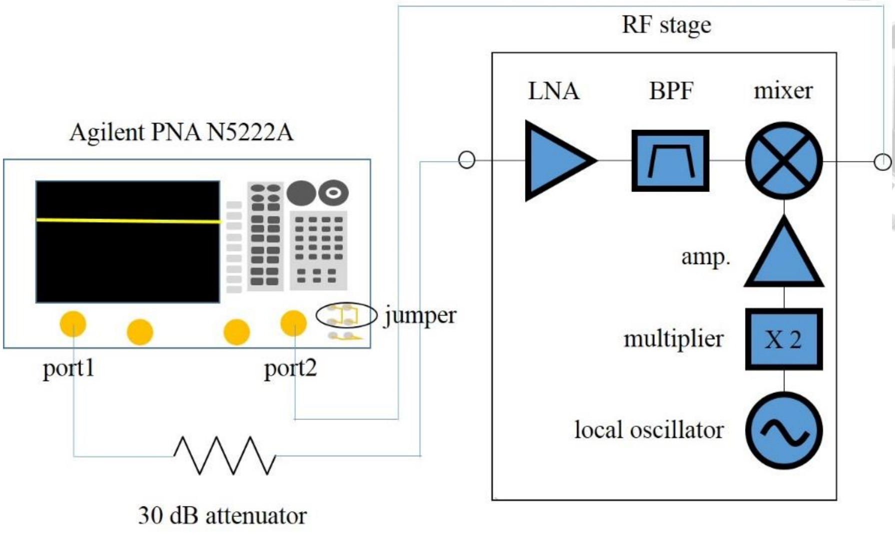

Fig. 2.8 RF stage measurement arrangement.

Frequency range	17.65 GHz to 19.64 GHz
Port 1 power level	-13 dBm
IF bandwidth	600 kHz
Noise bandwidth	1.2 MHz
Average value	400
Ambient temperature	293.6 K

Table 2.2 Setting values of PNA N5222A for RF stage measurement.

prevent the RF stage from saturation. It also improves the RF stage input match to accommodate the match requirement of (1.7). The receiver DC bias is at 12 V and 0.748 A. PNA N5222A is operated under the "noise figure converters" measurement class using the cold source method [10] to measure the conversion gain and noise figure.

The setting values of PNA are given in Table 2.2. The frequency range is from 17.65 GHz to 19.64 GHz to give the IF frequency range from 10 MHz to 2 GHz. The input signal power level is -13 dBm to make sure that the RF stage and the PNA receiver at port 2 are operated in linear range. The local oscillation frequency of the RF stage is 19.65 GHz. The setting values of PNA noise bandwidth and average value are properly

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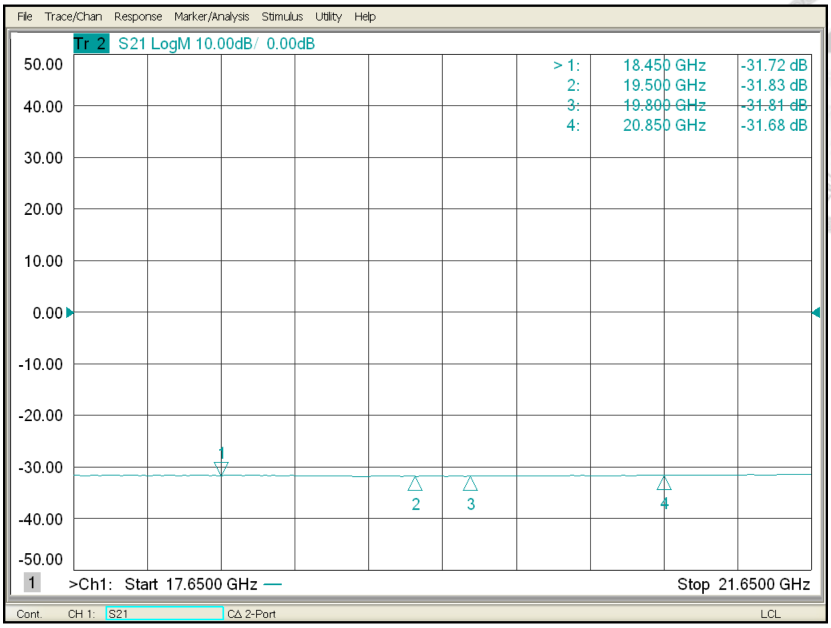
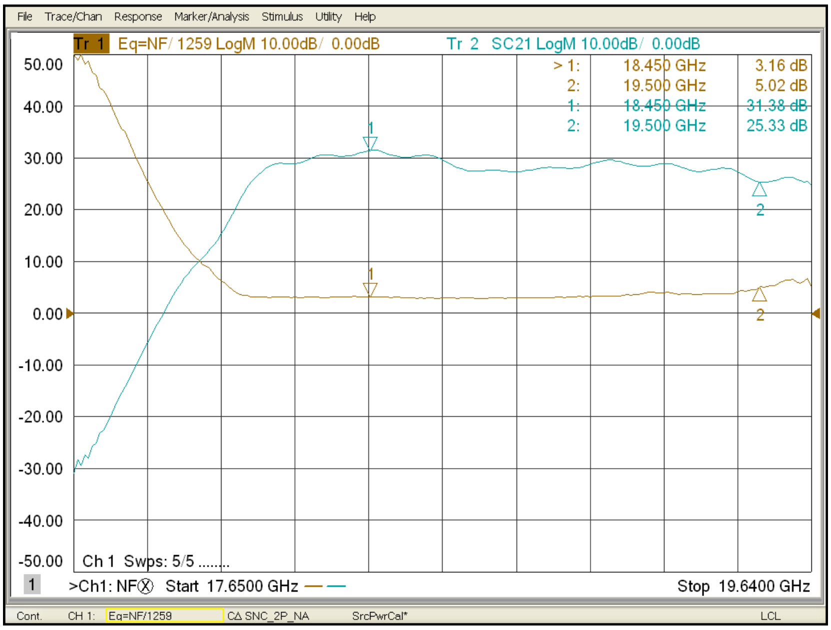


(a)



(b)

Fig. 2.9 Measurement results of (a) a 30 dB attenuator and (b) noise figure and conversion gain of RF stage.

given in Table 2.2 to smooth the measured noise figure value based on (1.21).

Fig. 2.9 (a) shows the measured attenuation of 30 dB attenuator is 31.8 dB. This value is used to compensate the measured conversion gain and noise figure as shown in

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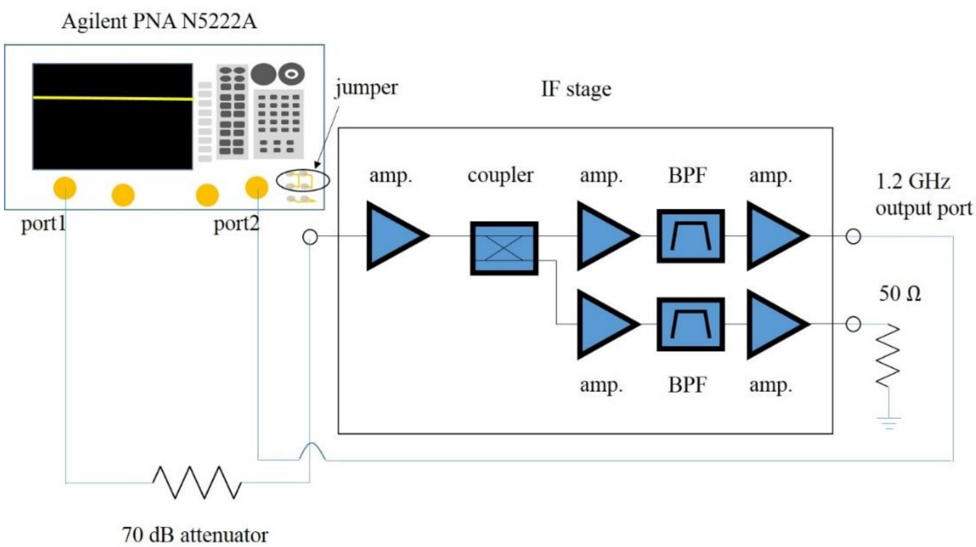
Fig. 2.9 (b). The noise figure is about 3.16 dB and 5.02 dB for 18.45 GHz and 19.5 GHz, respectively. The conversion gain is about 31.38 dB and 25.33 dB for 18.45 GHz and 19.5 GHz, respectively. Measured results of noise figure and conversion gain are shown in Table 2.3. The equivalent noise temperature T_{RF} of RF stage is calculated from measured noise figure using (1.12).

Frequency	18.45 GHz	19.5 GHz
Noise figure	3.16 dB	5.02 dB
Conversion gain	31.38 dB	25.33 dB
T_{RF}	310.34 K	631.29 K

Table 2.3 Measurement results of noise figure and conversion gain of RF stage.

2.2.2 IF Stage

As shown in Fig. 2.10, a 70 dB attenuator is connected between the port 1 of PNA N5222A and the input port of IF stage since the IF stage has input $P_{1dB} \simeq$ -61dBm [9]. The PNA is operated under the "noise figure cold source" measurement class and its setting values are shown in Table 2.4. The frequency range is from 10 MHz to 2 GHz.



(a)

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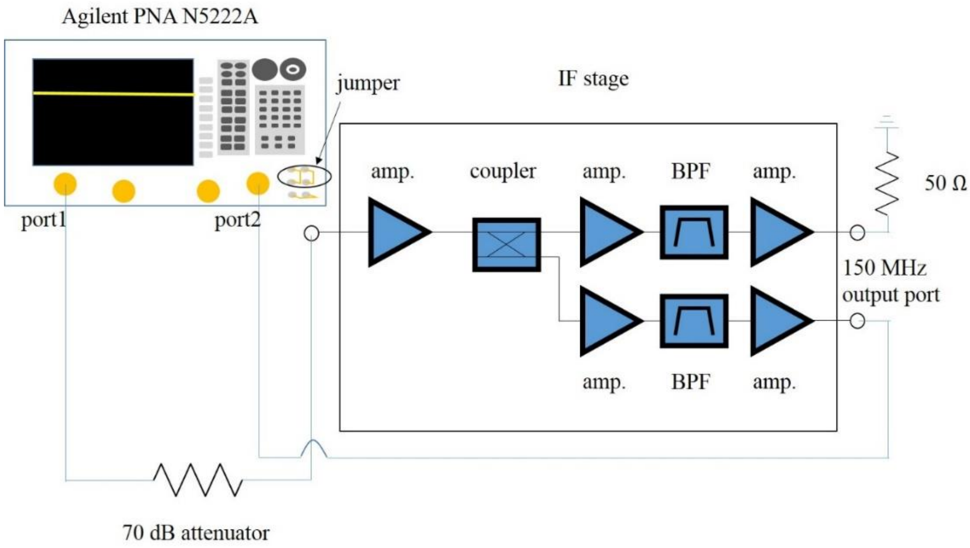

(b)

Fig. 2.10 IF stage measurement arrangements for (a) 1.2 GHz and (b) 150 MHz.

Frequency range	10 MHz to 2 GHz
Port 1 power level	-13 dBm
IF bandwidth	5 kHz
Noise bandwidth	1.2 MHz
Average value	400
Ambient temperature	293.5 K
Sweep average for noise figure	4

Table 2.4 Setting values of PNA 5222A for IF stage measurement.

Frequency	1.2 GHz	150 MHz
Noise figure	6.87 dB	12.58 dB
Gain	68.16 dB	70.01 dB
3 dB bandwidth	104.03 MHz	35.697 MHz
T_{IF}	1120.58 K	4962.89 K

Table 2.5 Measurement results of IF stage.

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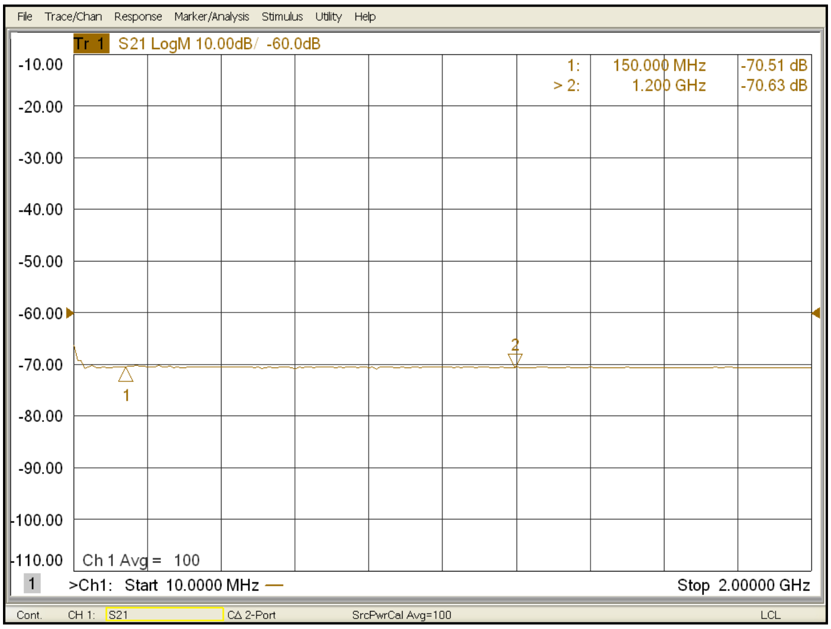
The input signal power level is -13 dBm to ensure that the IF stage and the PNA receiver at port 2 are operated in linear region. The setting values of noise bandwidth and average value are the same as those in RF stage except the sweep average is 4 to smooth the noise figure values.

Measured results are shown in Fig. 2.11. Fig. 2.11 (a) is the measured attenuation of 70.5 dB of a 70 dB attenuator to compensate the measured gain and noise figure. The measured values of noise figure in Fig. 2.11 (b) and (c) are given with a multiplication factor of $1/11220184.54$ due to compensating the 70 dB attenuator given as

$$10^{\frac{70.5}{10}} = 11220184.54. \tag{2.1}$$

Measured results of noise figure, gain and bandwidth of the IF stage for 1.2 GHz and 150 MHz are given in Table 2.5. The equivalent noise temperature T_{IF} is calculated from measured noise figure using (1.12). For 1.2 GHz channel, results of IF stage are NF = 6.87 dB, G = 68.16 dB and B = 104.03 MHz. For 150 MHz channel, results of IF stage are NF = 12.58 dB, G = 70.01 dB and B = 35.697 MHz.



(a)

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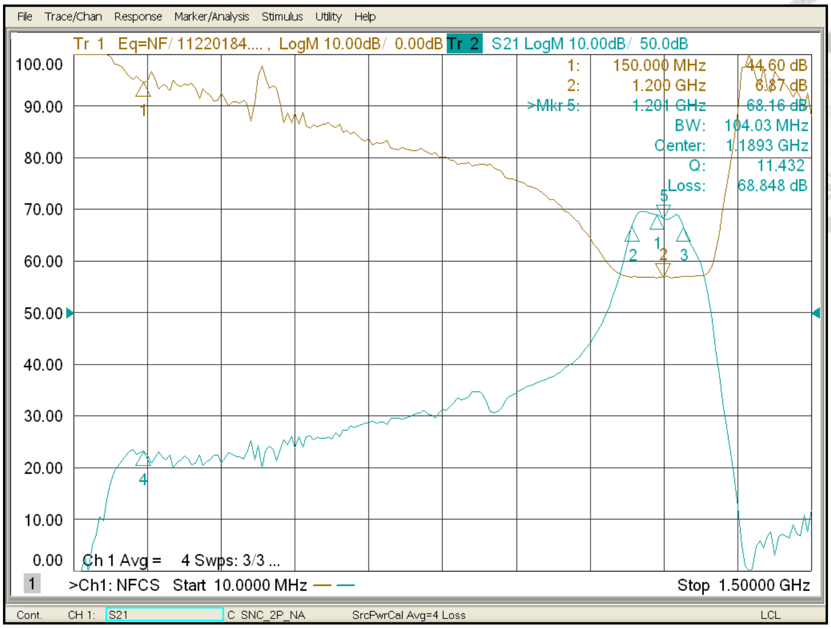
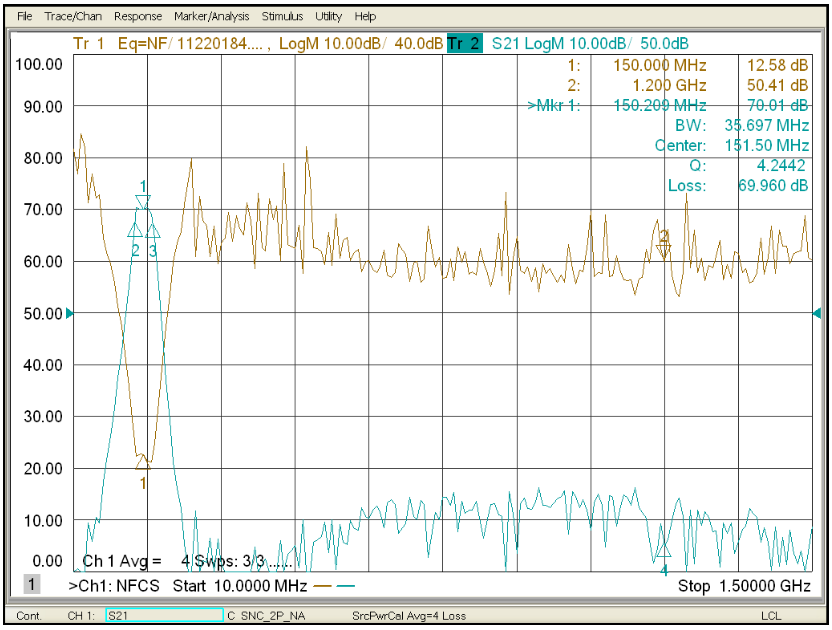


(b)



(c)

Fig. 2.11 Measured results of (a) a 70 dB attenuator, noise figure and gain of IF stage at (b) 1.2 GHz and (c) 150 MHz.

2.2.3 Receiver

To ensure the receiver and the PNA port 2 receiver are operated in linear region, receiver input power should to be below -106 dBm. This value is given by considering

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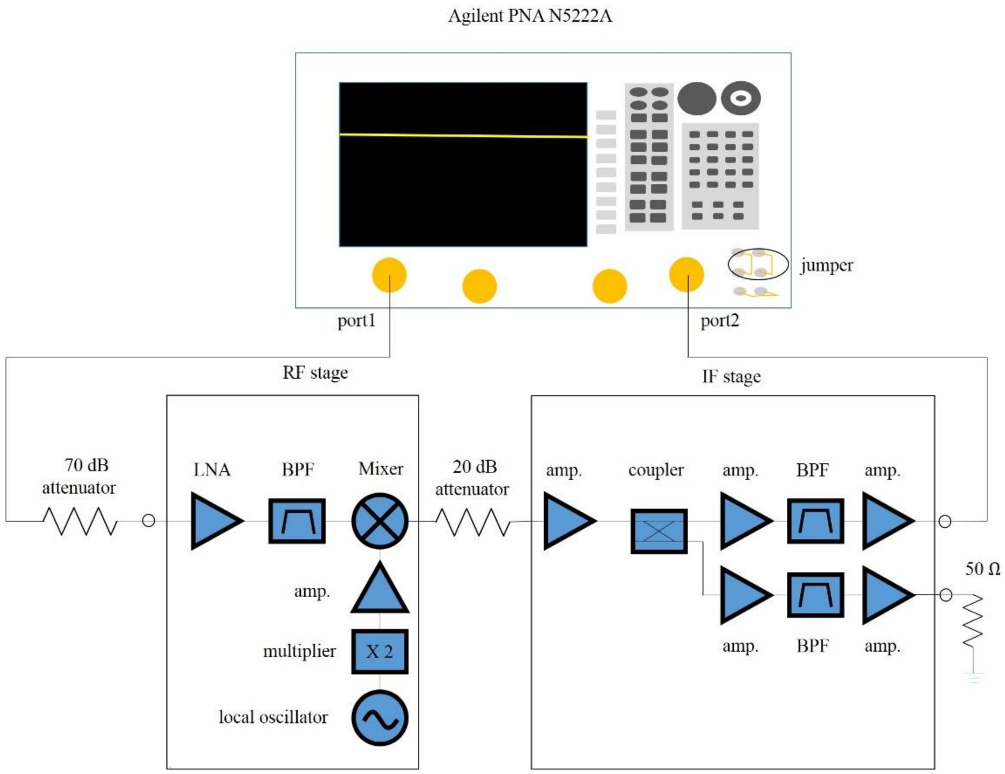
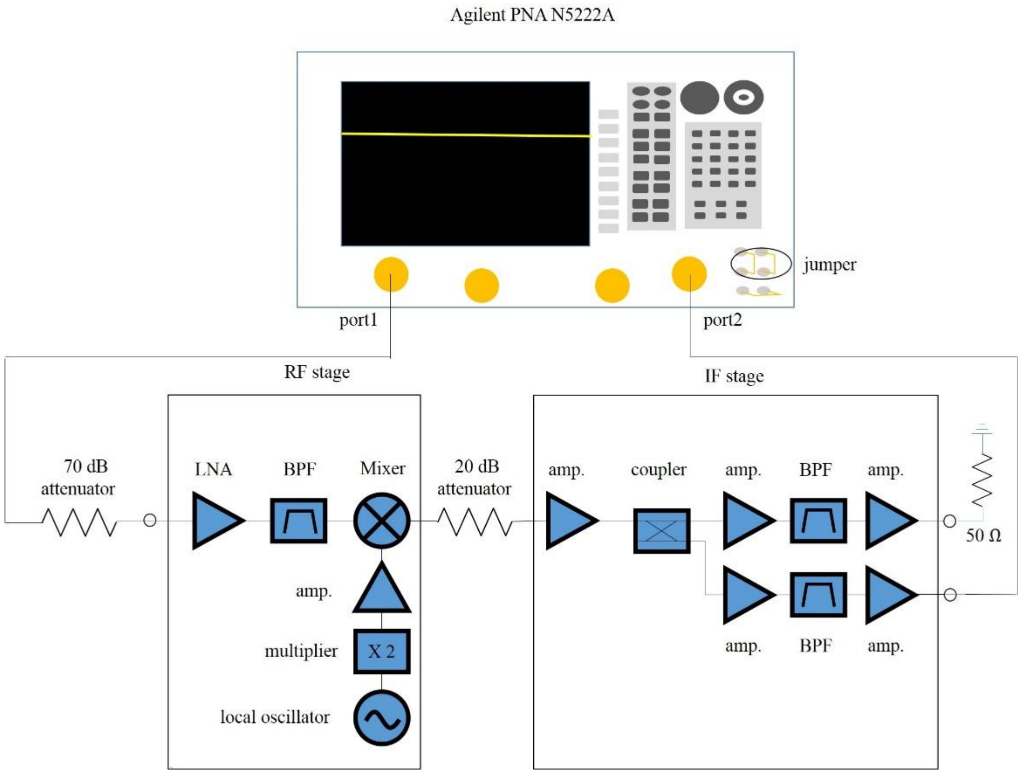


(a)



(b)

Fig. 2.12 Measurement arrangements of receiver for (a) 18.45 GHz and (b) 19.5 GHz.

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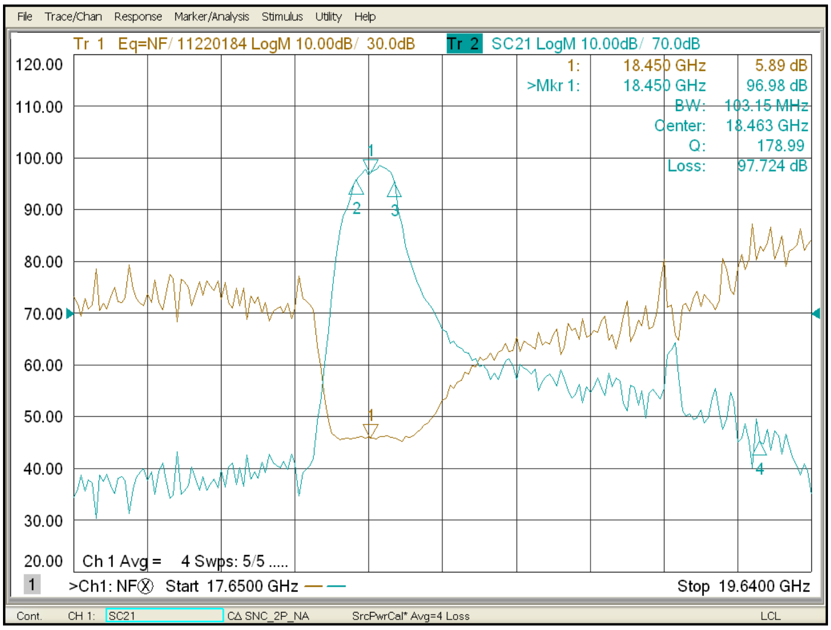
the summation of the input P_{1dB} = -30 dBm of the RF stage, the input P_{1dB} = -61 dBm of the IF stage and additional 15 dB gain of the Agilent 5222A port 2 receiver by changing two jumpers. Since this power level is less than the noise power of -93.8 dBm at 290 K with B = 104.03 MHz, a 70 dB attenuator is connected before the RF stage and a 20 dB attenuator is connected between the RF stage and the IF stage as shown in Fig. 2.12. In the measurement, the 70.5 dB attenuation is compensated for noise figure as given in (2.1). More detail to compensate the 20 dB attenuator will be discussed later.

The setting values of PNA are shown in Table 2.6. Measured receiver results are shown in Fig. 2.13 and Table 2.7. For 1.2 GHz channel, NF = 5.89 dB to give T_{rec} =

Frequency	18.45 GHz	19.5 GHz
Port 1 power level	-10 dBm	-16 dBm
IF bandwidth	600 KHz	10 MHz
Noise bandwidth	1.2 MHz	1.2 MHz
Average value	400	400
Ambient temperature	293.6 K	293.6 K
Sweep average	4	4

Table 2.6 Setting values of PNA5222A for receiver measurement.



(a)

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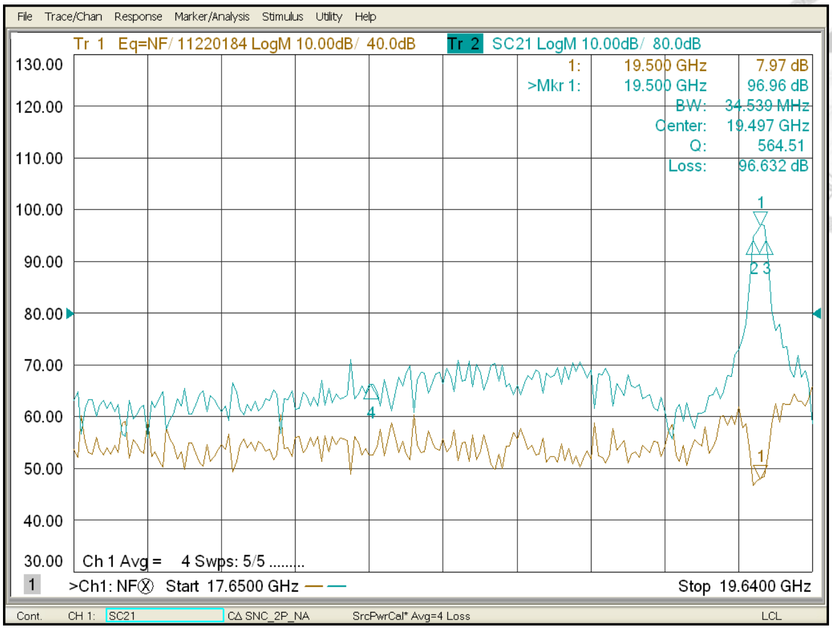

(b)

Fig. 2.13 Measurement results of receiver noise figure and gain for (a) 18.45 GHz and (b) 19.5 GHz.

Frequency	18.45 GHz	19.5 GHz
Noise Figure	5.89 dB	7.97 dB
Gain G_{rec}	96.98 dB	96.96 dB
3dB bandwidth B	103.15 MHz	34.539 MHz
T_{rec}	835.64 K	1527.18 K

Table 2.7 Receiver measurement results.

835.64 K using (1.12), G_{rec} = 96.98 dB and B = 103.15 MHz. For 150 MHz, NF = 7.97 dB to give T_{rec} = 1527.18 K , G_{rec} = 96.96 dB and B = 34.539 MHz.

As described earlier the noise figure measurement in Fig. 2.12 includes a 20 dB attenuator connected between the RF stage and the IF stage and it is included in the results of Table 2.7. The following procedure is then given to compensate or subtract its effect on the receiver noise figure.

Shown in Fig. 2.14, each component has power gain G_i and noise figure NF_i. Attenuation 1 represents a 70 dB attenuator and attenuator 2 represents a 20 dB

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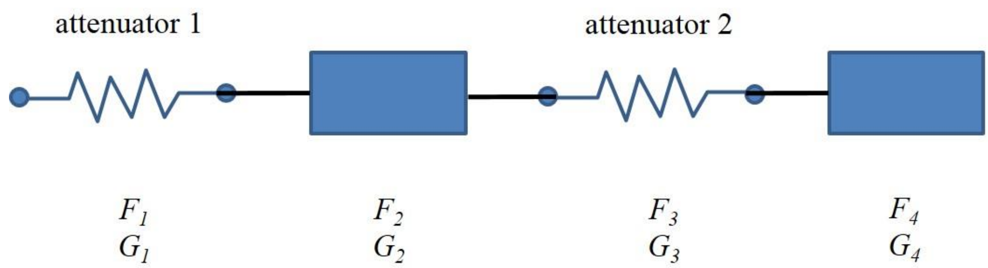

Fig. 2.14 Arrangement to compensate two attenuators 2 for the noise figure measurement.

attenuator. The second and forth components represent the RF stage and the IF stage. The overall noise figure F_{cas} is given by (1.13) as

$$\begin{aligned} F_{cas} &= F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} \\ &= F_1 + \frac{F_2}{G_1} - \frac{1}{G_1} + \frac{F_3}{G_1 G_2} - \frac{1}{G_1 G_2} + \frac{F_4}{G_1 G_2 G_3} - \frac{1}{G_1 G_2 G_3} \\ &= F_1 + \frac{F_2}{G_1} - L_1 + \frac{F_3}{G_1 G_2} - \frac{1}{G_1 G_2} + \frac{F_4}{G_1 G_2 G_3} - \frac{L_3}{G_1 G_2}. \end{aligned} \tag{2.2}$$

Since noise figure of a attenuator equals to its loss given by $F_1 = L_1 = \frac{1}{G_1}$ and $\frac{F_3}{G_1 G_2} = \frac{L_3}{G_1 G_2}$, (2.2) can be written as

$$F_{cas} G_1 = F_2 - \frac{1}{G_2} + \frac{F_4}{G_2 G_3}. \tag{2.3}$$

With one more measurement with a different attenuator 2, additional (2.3) can be written as

$$F_{cas}' \, G_1 = F_2 - \frac{1}{G_2} + \frac{F_4}{G_2 G_3'}. \tag{2.4}$$

Subtracting (2.3) by (2.4) gives

$$\frac{F_4}{G_2} = \frac{\left(F_{cas} - F_{cas}'\right) G_1 G_3 G_3'}{G_3' - G_3}. \tag{2.5}$$

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Subtracting (2.5) by (2.3) gives

$$F_2 - \frac{1}{G_2} = F_{cas}G_1 - \frac{\left(F_{cas} - F_{cas}'\right)G_1G_3'}{G_3' - G_3}. \tag{2.6}$$

Adding (2.5) and (2.6) then gives

$$F_2 + \frac{F_4 - 1}{G_2} = \frac{G_1G_3'F_{cas}'\left(1 - G_3\right) + G_1G_3F_{cas}\left(G_3' - 1\right)}{G_3' - G_3}. \tag{2.7}$$

If attenuator 2 has a large attenuation to give $G_3 \ll 1$ and $G_3' \ll 1$, (2.7) can be approximated as

$$F_2 + \frac{F_4 - 1}{G_2} = \frac{G_1\left(G_3'F_{cas}' - G_3F_{cas}\right)}{G_3' - G_3}. \tag{2.8}$$

The left term before the equal sign is the overall noise figure of stage 2 and stage 4 by compensating the effect of attenuators 2. However, the noise figure or T_{rec} in Table 2.7 include the additional effect of the 20 dB attenuator.

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Chapter 3 Noise Power and Near-Field Imaging Measurements

In this chapter, the measured parabolic dish antenna and receiver are integrated as a radiometer mounted on a two-dimensional scanner to give near-field imaging of several objects. In Sec. 3.1, the receiver is connected to a 20 dB horn antenna to measure the noise power values of four different objects. A program written using Visual Basic performs the measurements. Sec. 3.2 then describes the near-field imaging measurements. Resulted images are displayed by a program using MATLAB. Both programs are given in the appendixes.

3.1 Noise Power Measurements

The measurement arrangement is shown in Fig. 3.1 (a). A horn antenna with 20 dB gain is connected at the receiver input to collect the brightness radiating from the observed objects. An Agilent U2000A power sensor [11] is connected at receiver output to detect and integrate the received noise power. A personal computer controls the integration time and record the noise power through a USB interface. The program is written using Visual Basic with the graphical user interface as shown in Fig. 3.1 (b).

The measurement procedure is given as the following.

(1) Click the selection listing and choose USB port.

(2) Click ON to connect the personal computer with the power sensor.

(3) Click Initialize and Zero to reset and calibrate power sensor when the receiver is power off.

(4) Click Status and VISA Read to receive the message to ensure the connection is

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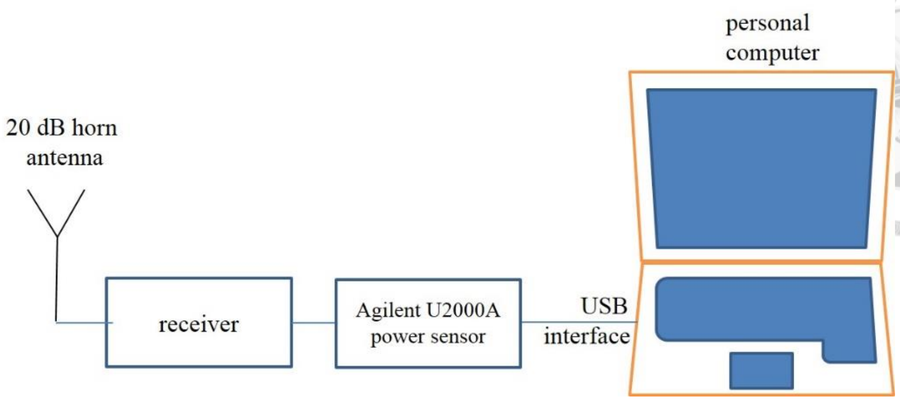
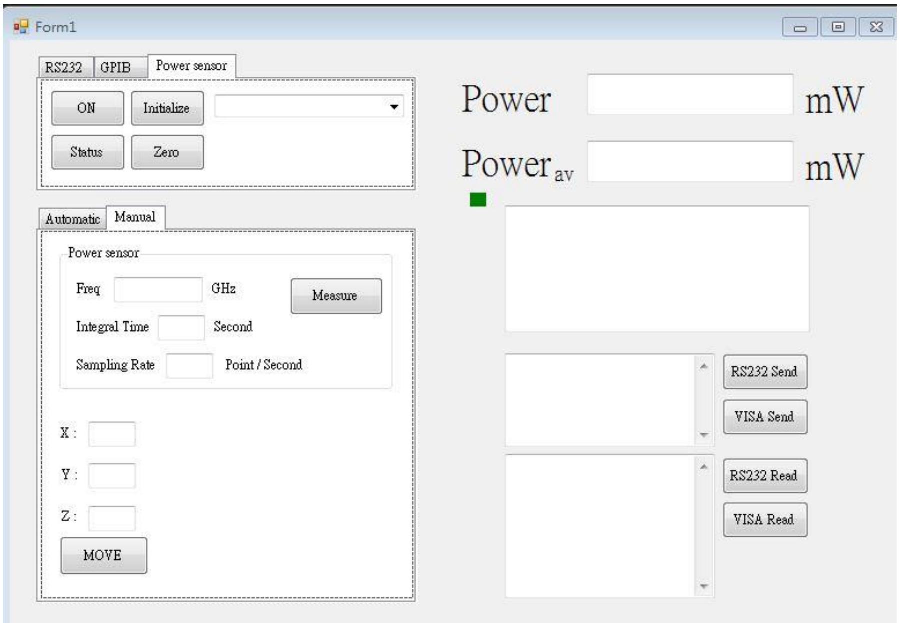


(a)



(b)

Fig. 3.1 (a) Measurement arrangement and (b) its graphical user interface.

done.

(5) Enter the operation frequency and integration time then click Measure. The first and averaged power values are displayed on the screen.

Fig. 3.2 (a)-(c) show the photographs of three different objects sensed by the receiver and a 20 dB horn antenna. They are an absorber, an aluminum plate and a hand. Fig. 3.2 (d) shows the photograph of a $50\,\Omega$ load connected at the receiver input for reference.

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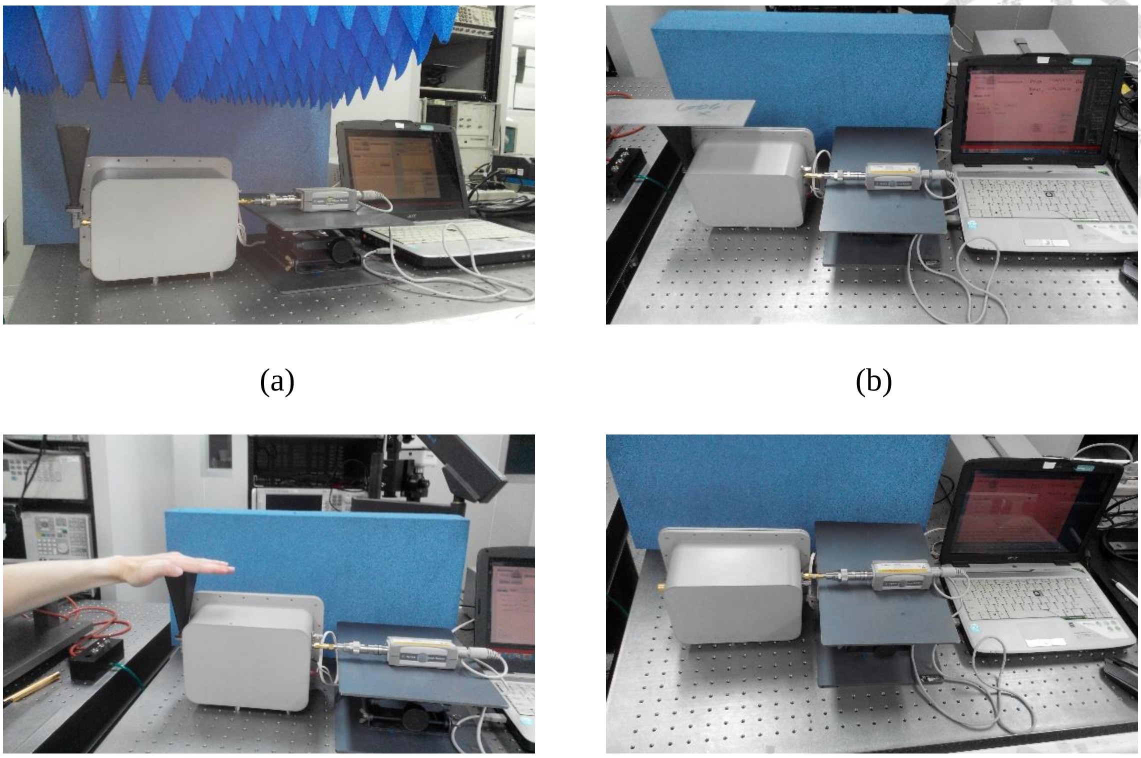

(a) (b)

(c) (d)

Fig. 3.2 Photographs of noise power measurement including (a) an absorber, (b) an aluminum plate, (c) a hand and (d) a 50Ω load.

The integration time is set at 40 seconds and each object are measured 5 times. Measurement results are listed in Table 3.1 with the receiver for four observed objects. The noise power given by 18.45 GHz is higher than that of 19.5 GHz because its bandwidth is about 3 time, or about 5 dB wider with about the same receiver gain G_{rec}. Noise power measured from aluminum plate is the lowest and human hand has the largest

IF frequency	18.45 GHz		19.5 GHz	
Absorber	2.516 mW	4 dBm	1.150 mW	0.61 dBm
Aluminum plate	2.395 mW	3.79 dBm	0.674 mW	-1.7 dBm
Hand	2.557 mW	4.07 dBm	1.171 mW	0.69 dBm
50Ω load	2.518 mW	4.01 dBm	1.148 mW	0.6 dBm

Table 3.1 Measurement results of noise power for four objects.

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noise power. This is because aluminum plate has low emissivity and temperature of human hand is higher than others. The measurement results of absorber and $50\,\Omega$ load are very close as expected.

Using (1.20), the noise temperature of the $50\,\Omega$ load can be calculated as the reference with its physical temperature and measured results of receiver noise temperature, bandwidth and gain given in Table 2.7. Calculated noise power values for $50\,\Omega$ load are 9.04 dBm (assuming $T_{50\Omega} = T_p = T_a = T_A$ = 292.5 K) using (1.20) ($k(T_a + T_{rec})BG_{rec}$ = $1.38\times10^{-23}\times($ 292.5 + 835.64 $)\times 103\times10^{6}\times10^{9.7}\times10^{3}$ = 8.04 mW = 9.05 dBm) for 18.45 GHz and 6.34 dBm ($1.38\times10^{-23}\times($ 292.5 + 1527.18 $)\times 34.5\times10^{6}\times10^{9.7}\times10^{3}$ = 4.34 mW = 6.38 dBm) for 19.5 GHz. The values are higher than measured results of 50Ω load given in Table 3.1. The measured noise power values for 50Ω at 2.518 mW and 1.148 mW give equivalent noise temperatures T_{sys} = 353.46 K (N_{sys}/kBG_{rec} = $\frac{2.518\times10^{-3}}{1.38\times10^{-23}\times103\times10^{6}\times10^{9.7}}$) for 18.45 GHz and T_{sys} = 481.12 K (= $\frac{1.148\times10^{-3}}{1.38\times10^{-23}\times34.5\times10^{6}\times10^{9.7}}$) for 19.5 GHz. These measured noise temperature values are smaller than those of $T_a + T_{rec}$ giving before. To calculate the factors in (1.20), the factor values of measured noise power to calculated noise power C = 0.313 (= 2.518 / 8.04) and C = 0.264 (= 1.148 / 4.34) for 18.45 GHz and 19.5 GHz. Therefore the measured noise temperature values of hand are given as 311 K = 38°C $\left(=\frac{2.557\times10^{-3}}{0.313\times1.38\times10^{-23}\times103\times10^{6}\times10^{9.7}}-835.64\right)$ and 332 K = 59°C $\left(=\frac{1.171\times10^{-3}}{0.264\times1.38\times10^{-23}\times34.5\times10^{6}\times10^{9.7}}-1527.18\right)$ for 18.45 GHz and 19.5 GHz.

Similarly the measured noise temperature values of aluminum plate are given as 238 K $\left(=\frac{2.395\times10^{-3}}{0.313\times1.38\times10^{-23}\times103\times10^{6}\times10^{9.7}}-835.64\right)$ and -457 K $\left(=\frac{0.674\times10^{-3}}{0.264\times1.38\times10^{-23}\times34.5\times10^{6}\times10^{9.7}}-1527.18\right)$

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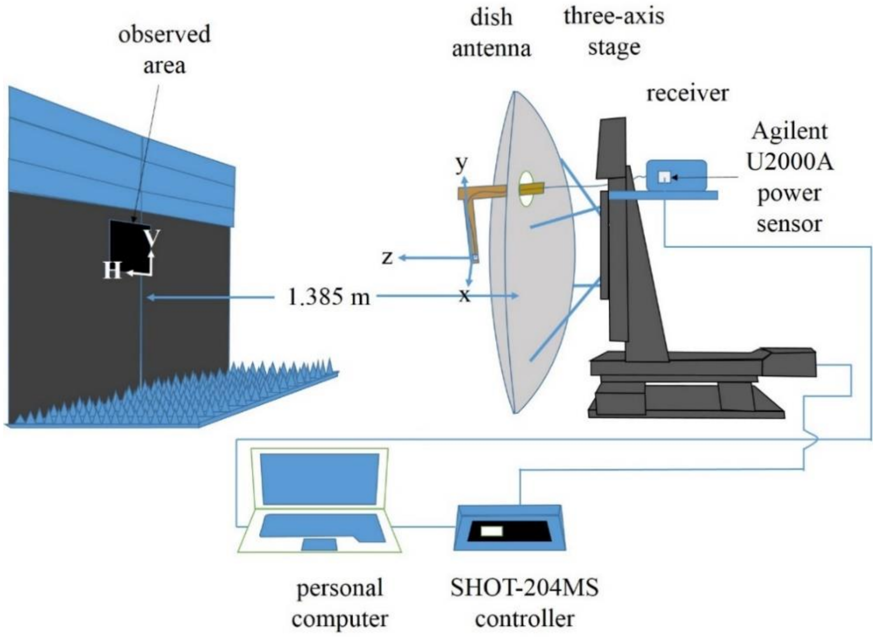
for 18.45 GHz and 19.5 GHz. The calculated noise temperature of aluminum at 19.5 GHz is less than 0 K is not reasonable due to the multi-scattering of aluminum plate and horn antenna. The measured noise temperature values of absorbers are similar to those of 50Ω loads. The temperature resolution given by (1.21) is 0.018 K ((T_a + T_{rec}) $/\sqrt{B\tau}$ = (292.5 + 835.64) $/\sqrt{103\times10^6\times40}$) for 18.45 GHz and 0.049 K ((292.5 + 1527.18) $/\sqrt{34.5\times10^6\times40}$) for 19.5 GHz.

As the objects move about few centimeters away from the 20 dB horn antenna, the values of measured noise power are the same. One reason is that the background noise may dominate the antenna noise temperature T_a due to wide antenna beamwidth. Note that the contrast between absorber and aluminum plate at 19.5 GHz is higher than that of 18.45 GHz. The near-field measurements given in the next section is then performed at this frequency.

3.2 Near-Field Imaging Measurements



(a)

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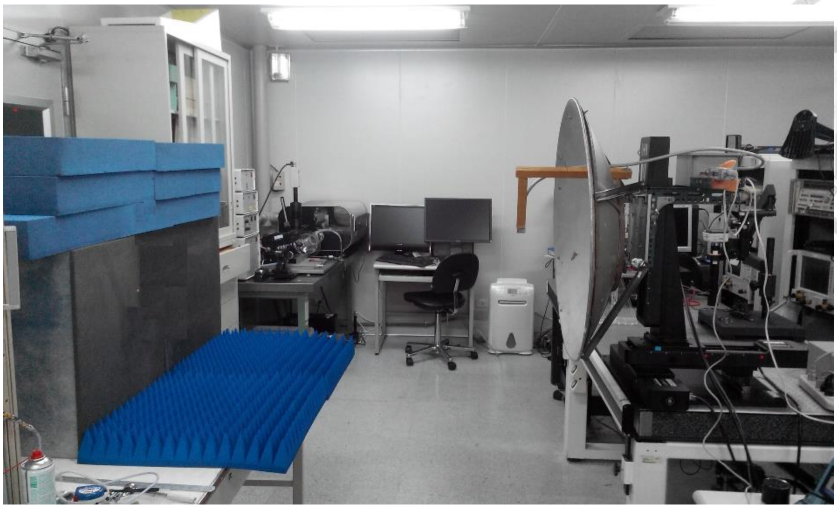

(b)

Fig. 3.3 (a) Measurement arrangement and (b) its photograph.

In this section the parabolic dish antenna and receiver including the power sensor are mounted on a Sigma Koki three-axis stage [12] as shown in Fig. 3.3 (a) and (b). The observed object is located about 1.385 m from the dish antenna tilt angle about $30°$ from the vertical (V) direction in Fig. 3.3 (a). The three-axis stage moves in vertical and horizontal (H) directions for 18 cm $\times$ 18 cm facing to the observed plane. The cable connected between dish horn and receiver has 2.23 dB loss at 19.5 GHz. Later in Sec. 3.2.2 the LNA in RF stage will be connected to the dish horn directly to reduce the effect by cable loss. The power sensor is connected at the receiver 150 MHz output port. Absorber piles are located as the background with 120 cm $\times$ 90 cm area.

The radiometer moves with its scanning area facing to the observed area as depicted in Fig. 3.4 (a). The dashed-line square marked by H-axis and V-axis is the area corresponding to the physical center of the dish antenna. X-axis and y-axis are the axes corresponding to Fig. 2.6 (b) with about $30°$ tilt angle due to the attachment of the dish antenna mounting plate to the three-axis stage. The solid square represents the plane mapped to the estimated main beam of dish antenna as explained in Sec. 2.1. Its center is

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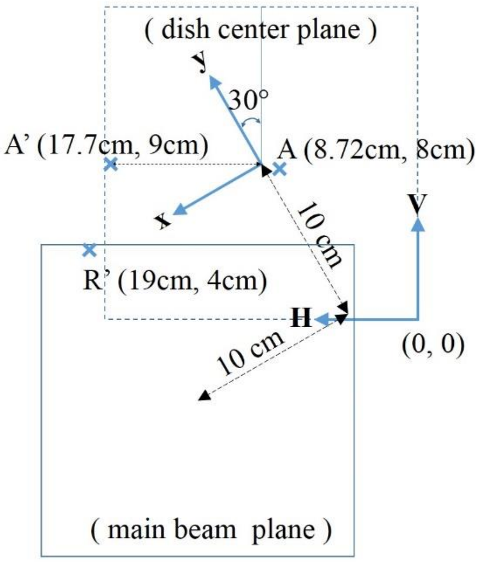
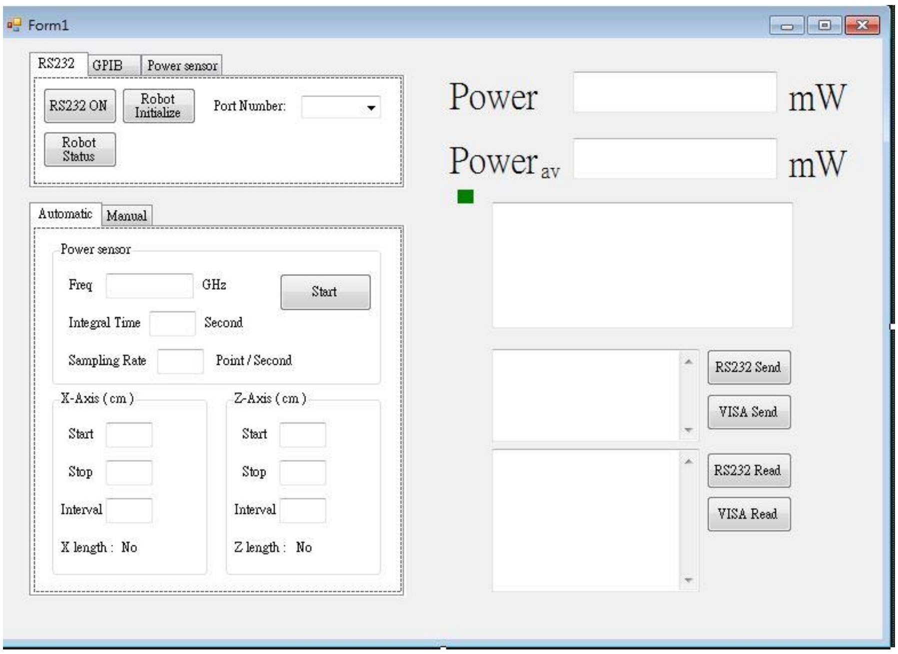


(a)



(b)

Fig. 3.4 (a) Observed planes and (b) graphical user interface.

at about x = 10 cm and y = -10 cm as given in Fig. 2.6 (b).

A personal computer is used to control SHOT-204MS controller moving the three-axis stage in a raster scan, integrate the power sensor reading values and record the averaged noise power. The program given in Sec. 3.1 is then revised to include the control

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of three-axis stage. The related graphical user interface is shown in Fig. 3.4 (b). The measurement procedure is given as the following.

(6) Repeat steps 1 to 4 as those given in Sec. 3.1.

(7) Select the port number and click RS232 ON.

(8) Click Robot Status and receive the character "R" to ensure the connection is done.

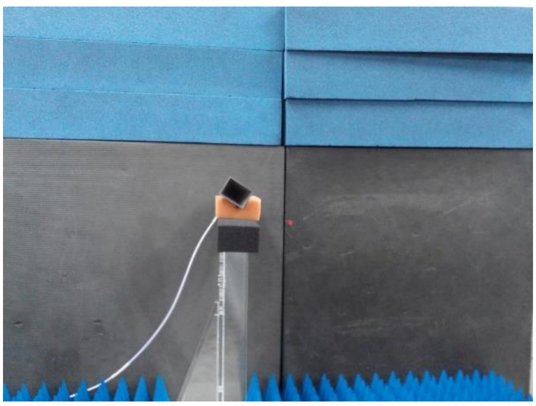
(9) Click Robot Initialize to initialize the stage.

(10) Enter operation frequency, integration time, start position, stop position and interval number then click Start to begin the measurement.

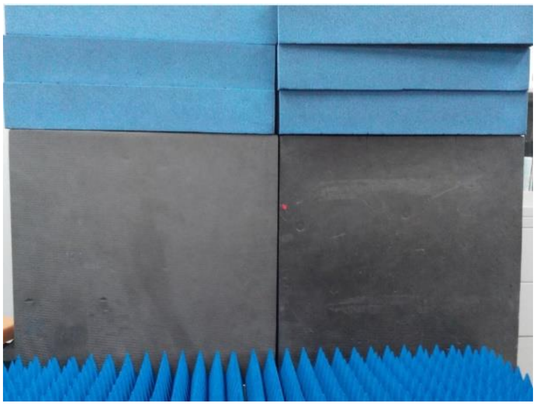
3.2.1 Cable behind LNA Case

In this section, the cable of 2.23 dB loss at 19.5 GHz is located between the dish horn and the receiver. The observed object is placed at point A in Fig. 3.4 (a). The scanning area is 18 cm × 18 cm in a raster scan with a step of 1cm. The operating frequency is19.5 GHz and the integration time is 12 second. Four different objects are observed and their photographs are as shown in Fig. 3.5 (a)-(d).

Fig. 3.5 (a) is a 20 dB gain horn antenna excited with Hewlett Packard 8320A source connected through a 60 dB attenuator and a 2.5 dB loss cable to give a low-power about -72.8 dBm. The 20 dB horn antenna and is tilted to match the polarization of the dish



(a)



(b)

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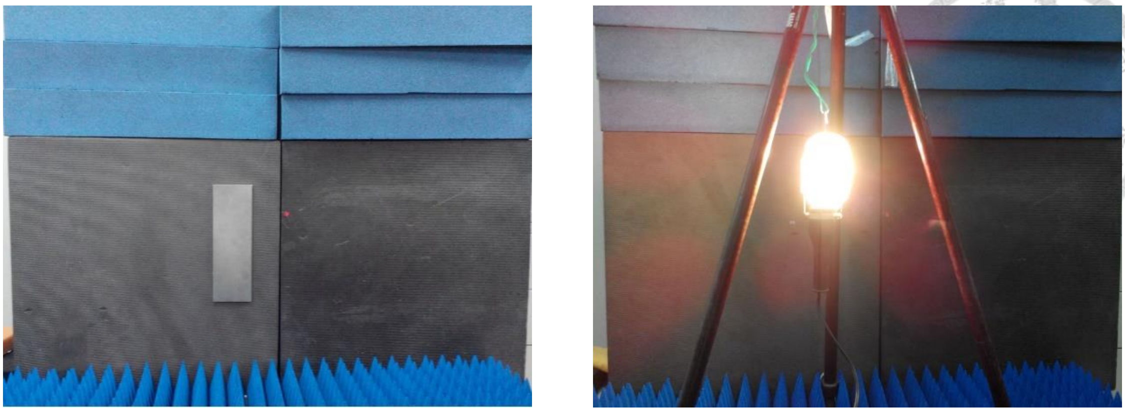
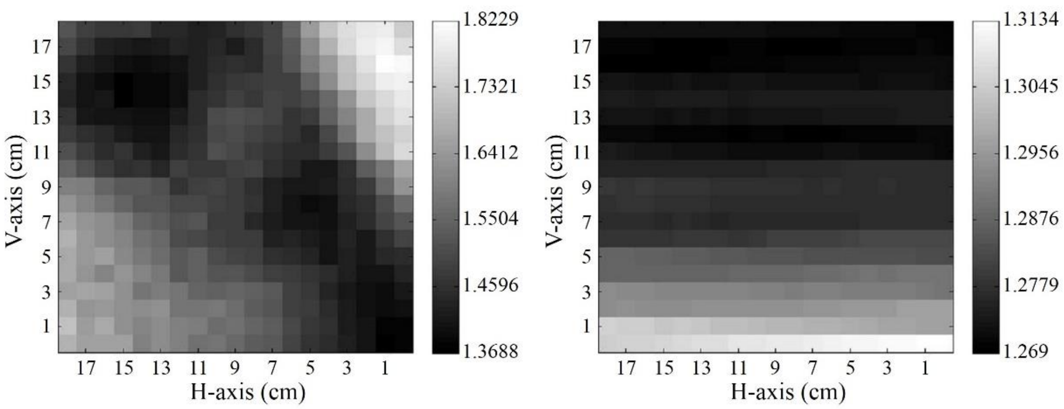


(c) (d)

Fig. 3.5 Photographs of four objects including (a) an excited horn antenna, (b) absorber piles, (c) an aluminum plate and (d) a 250W lamp.



(a) (b)

Fig. 3.6 Imaging results of (a) a low-power excited horn antenna and (b) absorber plies.

horn. Fig. 3.5 (b) is absorber piles and Fig. 3.5 (c) shows an aluminum plate. Fig. 3.5 (d) is a 250W lamp and its temperature is about 200°C. The resulted images are presented with gray scale in Fig. 3.6 using a display program written by MATLAB.

Shown in Fig. 3.6 (a) of a low-power indicates the radiometer gives a brighter image at the upper right side. This is because the antenna is placed near point A (8.72 cm, 8cm) as illustrated in Fig. 3.4 (a). The largest measured power is close to 1.8 mW assumed to be the noise power to give about equivalent noise temperature T_{sys} = 754.35 K.

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Considering the factor of 0.264 given in Sec.3.1, the noise power is 6.82 mW (1.8 mW / 0.264) to give equivalent noise temperature of T_{sys} = 2857.4 K. To subtract the receiver noise temperature of T_{rec} = 1527.18 K, the equivalent noise temperature is T_a = 1330.21 K. The measured lowest noise power is about 1.4 mW to give about equivalent noise temperature of T_{sys} = 586.7 K. Similarly by considering the factor, the noise power is 5.3 mW to give T_{sys} = 2222.42 K and T_a = 693.24 K.

Fig. 3.6 (b) is the image of absorber piles. The noise power values around 1.29 mW to give equivalent noise temperature of T_{sys} = 541 K are lower than the lowest temperature given in Fig. 3.6 (a). By considering of the factor of 0.264, the noise power is 4.89 mW to give T_{sys} = 2047.8 K and T_a = 520.62 K.The upper side is colder than the lower side. This is because the scanning starts from the right lower corner. The absorber gradually turns into thermodynamic equilibrium to the surrounding temperature to give about measured noise power to be 1.27 mW. By considering the factor of 0.264, the noise power is 4.81 mW to give T_{sys} = 2016 K and T_a = 488.9 K ($\simeq 216°C$) to be compared with the results in Fig. 3.10 (b) in Sec. 3.2.2.

Fig. 3.7 (a) has the similar imaging result as Fig. 3.6 (b) because the brightness temperature of aluminum plate is low and it also reflects the surrounding brightness temperature. The imaging result of a 250W lamp depicts that it seems to be warmer at the upper side with about of measured noise power of 1.28 mW. However, the measured noise power values are close to those of the absorber piles. Note the 2.23 dB loss cable connected before the receiver increases the receiver noise figure (and noise temperature T_{rec}) to increase the object noise temperature. Based on this reason, the receiver noise power is reduced by placing the LNA before the cable and measurements are repeated.

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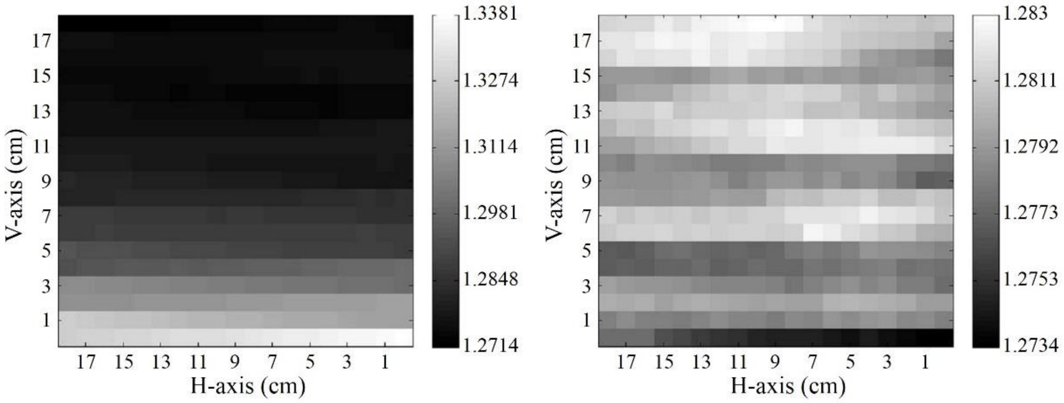
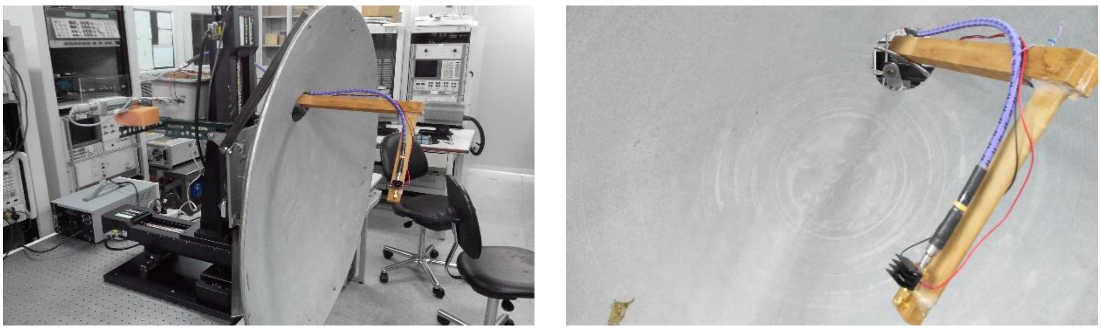


(a) (b)

Fig. 3.7 Imaging results of (a) aluminum plate and (b) 250W lamp.

3.2.2 Cable after LNA Case



(a) (b)

Fig. 3.8 (a) The LNA is connected after the dish horn and (b) its larger view.

The cable of 2.23 dB loss is replaced with another cable having 1.36 dB loss. The LNA is removed from receiver and connect after the feed horn of dish antenna as shown in Fig. 3.8. The observed object is shown in Fig. 3.9 (a) a 20 dB horn antenna with input power of -74.53 dBm at 19.5 GHz slightly smaller than that in Fig. 3.5 (a). Note it is shifted to the left side of H-axis and placed at the point A’ (17.7 cm, 9 cm) in Fig. 3.4 (a). The integration time is 5 second. Fig. 3.9 (b) shows the imaging result. The measured noise power values are smaller than those given in Fig. 3.6 (a). The resulted image is tilted to the left lower side because the horn antenna is shifted to point A’. The largest and

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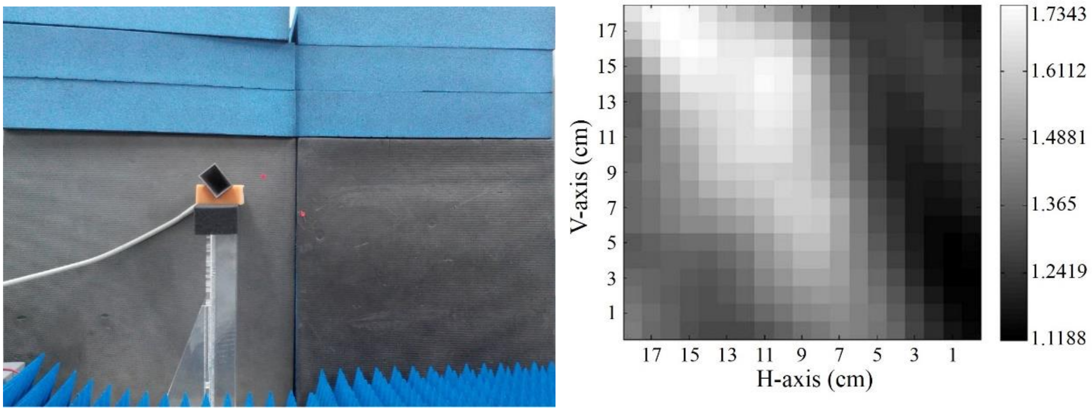
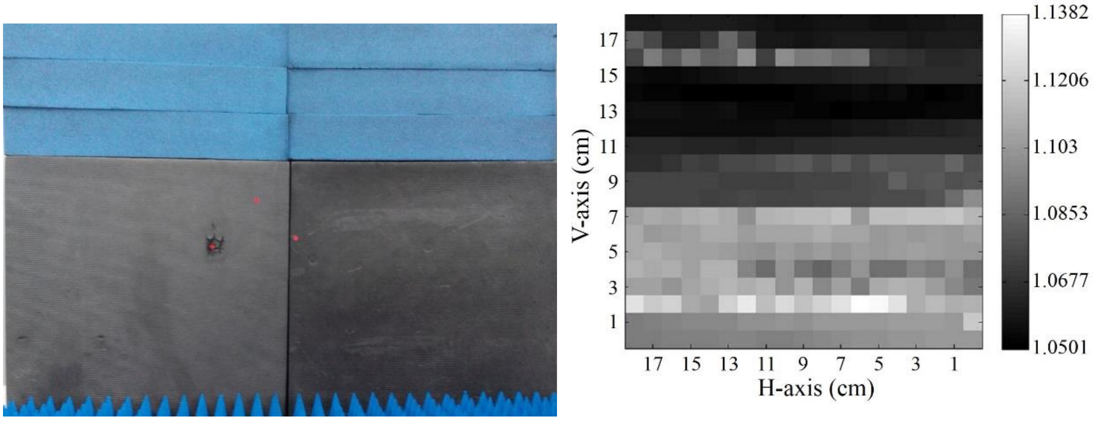


(a) (b)

Fig. 3.9 (a) A 20 dB horn antenna and (b) its imaging result.



(a) (b)

Fig. 3.10 (a) Absorbers piles and (b) imaging result.

lowest measured power are close to 1.7 mW and 1.1 mW to give T_{sys} = 2698.65 K and T_{sys} =1746.19 K, and T_a = 1171.47 K and T_a = 219 K by considering the same factor of 0.264. The dynamic range of T_a is three times more than that in Fig. 3.6 (a) with LNA inside the receiver.

Fig. 3.10 shows the observed absorber piles and imaging result. Integration time is 12 seconds and the temperature resolution is about 0.09 °K with T_{sys} = 1819.68 K by considering the factor of 0.264. Comparing with Fig. 3.6 (b), the measured noise power is lower with further variation, because the receiver noise figure is lower by the moving

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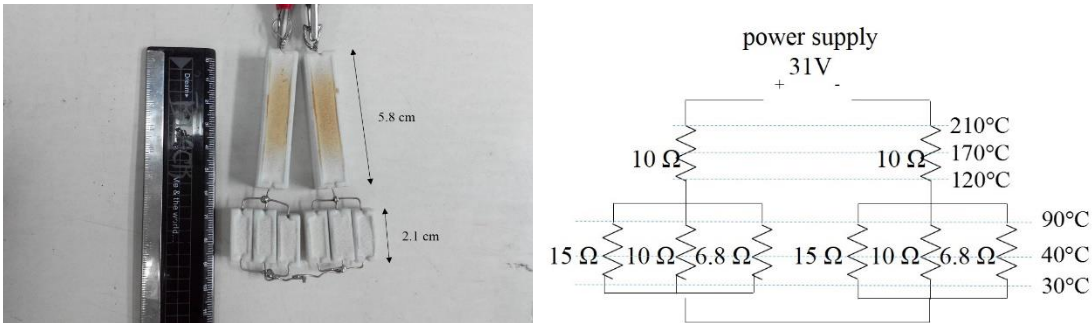
LNA before the cable. Measured noise power values in Fig. 3.10 (b) are close to the measured results of 1.15 mW of the absorber given in Table 3.1. The largest and lowest measured power are close to 1.14 mW and 1.05 mW to give T_{sys} = 1809.68 K and 1666.81 K and corresponding T_a = 282.5 K and 139.63 K. The values of T_a are much reasonable comparing with those in Fig. 3.6 (a).

Fig. 3.11 (a) shows an additional object with heated ceramic resistors. The dimension of long resistor is 5.8 cm×1.3 cm×1.3 cm and the short one is 2.1 cm×0.8 cm×0.8 cm. Resistors are arranged as shown in Fig. 3.11 (b) and biased with 31 V. Temperatures on surface of resistors are measured with an IR sensor and given in Fig. 3.11 (b). The long resistor have larger temperature than that of short resistor.

Fig. 3.12 (a) shows the ceramic resistors are placed at the position R' (19 cm, 4 cm) given in Fig. 3.4 (a). The integration time is 12 second and the imaging result is given in Fig. 3.12 (b). The largest and lowest measured power are close to 1.4 mW and 1.2 mW. By considering the factor of 0.264, they correspond to T_{sys} = 2222.42 K and 1904.93 K and T_a = 695.24 K(≃422.24°C) and 377.75 K (≃104.75°C). T_a



(a) (b)

Fig. 3.11 (a) Photograph of ceramics resistors and (b) its circuit with IR measured temperature values.

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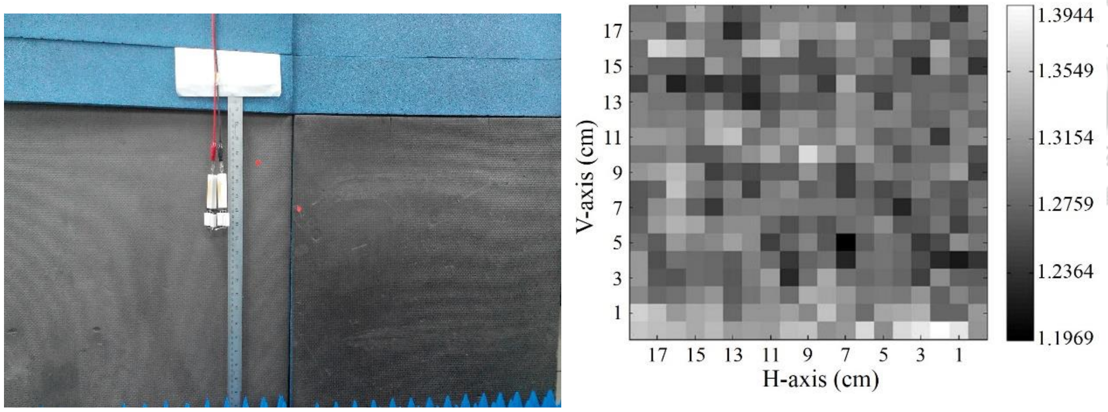

(a) (b)

Fig. 3.12 (a) Heated ceramic resistors and (b) imaging result.

values are shown in close agreement to those in Fig. 3.11 (b). Temperatures at 210°C = 483 K and 90°C = 363 K. Since because the spatial resolution of dish antenna is not short enough to separate the resistor. The imaging result in Fig. 3.12 (b) looks like a random distribution. Comparing with the dynamic range of measured power values in Fig. 3.9 (b) and Fig. 3.12 (b), 0.2 mW for resistors is smaller than 0.62 mW for horn antenna.

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Chapter 4 Conclusion

In this thesis, a K-band radiometer including a dish antenna with few centimeter resolution and a low noise figure and high gain receiver measures the observed object noise temperature in a near-field imaging system. An automatic measurement program is written using Visual Basic program and the near-field image is presented using MATLAB program.

Based on the measured results in Chapter 2, the main beam of dish antenna is tilted about x = 10 cm and y = -10 cm around the dish center. The receiver has about G_{rec} = 96.98 dB, NF = 3.16 dB and B = 103.15 MHz for 18.45 GHz and G_{rec} = 96.96 dB, NF = 5.02 dB and B = 34.539 MHz for 19.5 GHz. In Chapter 3, the receiver connected with a 20 dB horn antenna provides the noise power values of four different objects with 50Ω, absorber, aluminum plate and human hand. The differentiation of T_a of object is observable as it is attached to the antenna. The near-field imaging system of serval objects about 1.385 m away from a 85 cm dish antenna with about 40dB gain can identify the noise temperature of objects. The noise power of the absorber is the lowest case. The noise power of ceramic resistors provide larger value to give a random distribution. The power of a low-power antenna is assumed to be the noise power to give the largest case and the image can be observed.

Main future work of this thesis is the calibration of the Y-factor of this total power radiometer and the image process to reduce the antenna effect and object distance. More studies may include to reduce the antenna size with higher gain to reduce the receiver noise temperature, and to develop a radiometry array using this type and other types of radiometer architectures.

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Appendices

1.1 Measurement Program Using Visual Basic

```
Imports System.IO.Ports
Imports System.Text
Imports System.Drawing
Imports System.Collections
Imports System.ComponentModel 'CancelEventArgs
Imports System.Windows.Forms
Imports System.Data
Imports System.IO
Imports NationalInstruments.NI4882
Imports NationalInstruments.VisaNS



Public Class Form1
    Private mbSession As MessageBasedSession
    Private GpibDevice As Device
    '宣告一個委派類別，並宣告符合函式參數有一個，而其型態是字串
    Delegate Sub SetTextCallback(ByVal InputString As String)
    Dim Rtime As Integer = 500 ''判斷 MOTO 是否 Ready 的時間
    Dim Gtime As Integer = 100 '指令 G 後的時間
    Dim motorscale As Integer = 1000        'step 的比例

    '****************************************************************
    '表單的 Load 事件中先將所有的通訊埠先列出來
    '將通訊埠排序，並將第一個通訊埠設為預設值
    '****************************************************************
    Private Sub Form1_Load(sender As Object, e As EventArgs) Handles MyBase.Load
        '取得系統所有可使用的 serialport
        For Each sp As String In SerialPort.GetPortNames
            CMBcom.Items.Add(sp)
        Next
        CMBcom.Sorted = True        '排序
        CMBcom.SelectedIndex = 0 '第一個是預設選項
        CMBcom.DropDownStyle = 2 '不讓使用者在此輸入資料
        Call RS232BTOFF()
        '取得 VISA bus
        Dim resources() As String =
ResourceManager.GetLocalManager().FindResources("?*")
        Dim s As String
```


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```
        For Each s In resources
            CMBvisa.Items.Add(s)
        Next
        CMBvisa.Sorted = True        '排序
        CMBvisa.SelectedIndex = 0 '第一個是預設選項
        CMBvisa.DropDownStyle = 2 '不讓使用者在此輸入資料
        '關閉致能傳送
        Call VISABTOFF()
    End Sub

    '************************************************************
    '『開啟通訊埠』按鈕的 Click 事件
    '此事件將設定通訊埠參數，並開啟通訊埠
    '************************************************************
    Private Sub BTNrs232on_Click(sender As Object, e As EventArgs) Handles
BTNrs232on.Click
        Call SerialPortSetUp()
        If Not RS232.IsOpen Then
            RS232.Open()      '開啟通訊埠
            Call RS232BTON()
            MsgBox("通訊埠已開啟")
        Else
            RS232.Close()
            MsgBox("通訊埠已關閉")
            End
        End If
    End Sub

    '************************************************************
    '傳送測試
    '************************************************************
    Private Sub BTNsend_Click(sender As Object, e As EventArgs) Handles
BTNrs232send.Click
        RS232.Write(TXBsend.Text & vbCrLf)
        RS232.Write("G:" & vbCrLf)
        TimeDelay(100)              '延遲時間
    End Sub

    '************************************************************
    '時間延遲函式
    '延遲參數單位為毫秒(ms)
    '************************************************************
    Private Sub TimeDelay(ByVal DT As Integer)
        Dim StartTick As Integer
        StartTick = Environment.TickCount() '開始計數前的 Tick
        Do
            If Environment.TickCount() - StartTick >= DT Then Exit Do
```


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```
        Application.DoEvents()   '處理佇列中的訊息
    Loop
End Sub

'**************************************************************
'讀取 RS232 緩衝區字元
'**************************************************************
Private Sub BTNread_Click(sender As Object, e As EventArgs) Handles BTNrs232read.Click
    TXBread.Text = TXBread.Text + RS232.ReadExisting()
End Sub

'**************************************************************
'手動移動 X,Y,Z 軸
'**************************************************************
Private Sub BTNmove_Click(sender As Object, e As EventArgs) Handles BTNmove.Click
    BTNmove.Enabled = False
    Dim xstep As Integer                 'X 軸
    xstep = motorscale * Val(TXBx.Text)
    Dim ystep As Integer                 'Y 軸
    ystep = motorscale * Val(TXBy.Text)
    Dim zstep As Integer                 'Z 軸
    zstep = motorscale * Val(TXBz.Text)
    RS232.Write("A:W+P" & xstep & "+P" & ystep & "+P" & zstep & vbCrLf)
    RS232.Write("G:" & vbCrLf)
    TimeDelay(100)
    Call motorask(Rtime)
    Call displaylocation()
    BTNmove.Enabled = True
End Sub
'**************************************************************
'自動移動量測 in X,Z 軸
'**************************************************************
Private Sub BTNauto_Click(sender As Object, e As EventArgs) Handles BTNauto.Click
    BTNauto.Enabled = False
    'X 軸
    Dim xstart As Double = motorscale * Val(TXBxstart.Text)
    Dim xstop As Double = motorscale * Val(TXBxstop.Text)
    Dim xsteplength As Double = 0
    If (Val(TXBxpn.Text) = 1) Then
    Else
        xsteplength = (xstop - xstart) / (Val(TXBxpn.Text) - 1)
    End If
    'Z 軸
    Dim zstart As Double = motorscale * Val(TXBzstart.Text)
    Dim zstop As Double = motorscale * Val(TXBzstop.Text)
```

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```
        Dim zsteplength As Double = 0
        If (Val(TXBzpn.Text) = 1) Then
        Else
            zsteplength = (zstop - zstart) / (Val(TXBzpn.Text) - 1)
        End If
        Dim flage As Integer = 1
        LBLxlength.Text = xsteplength / motorscale
        LBLzlength.Text = zsteplength / motorscale
        TXBread.Clear()
        TXBsend.Clear()
        Dim mode As String = CMBrate1.SelectedItem.ToString
        Dim unit As String = CMBpunit.SelectedItem.ToString
        Dim freq As Double = Val(TXBfreq.Text)
        Dim t As Double = Val(TXBintegralt.Text)
        If t <= 0 Or t > 41.9 Then
            MsgBox("time must be 0 < t <= 41.9")
            Return
        End If
        If (Not CheckKeyIn()) Then
            Return
        ElseIf (Int((xsteplength)) <> (xsteplength)) Or (Val(TXBxpn.Text) <= 0) Then
'判斷移動間格 X 是否符合格式
            MsgBox("xsteplength 錯誤,必須是整數",)
            Return
        ElseIf (Int((zsteplength)) <> (zsteplength)) Or (Val(TXBxpn.Text) <= 0) Then
'判斷移動間格 Z 是否符合格式
            MsgBox("zsteplength 錯誤,必須是整數",)
            Return
        Else
            Call RBintial()
            Call motorask(Rtime)
            Call displaylocation()
            If (Val(TXBxlocation.Text) <> 0 Or Val(TXBzlocation.Text) <> 0) Then
                MsgBox("motor 初始化座標錯誤,檢查 motor 並重新操作",)
                Return
            End If
            LBL.BackColor = Color.Red
            Dim data As String = CreatTXT(freq, t, mode, unit)
            Call SetSensorUnit_LV()
            Dim i As Double = xstart
            Dim j As Double = zstart
            For j = zstart To zstop Step zsteplength
                If (flage > 0) Then
                    For i = xstart To xstop Step xsteplength
                        Call AbsMv(i, j)
                        Call SensorMs(freq)
                        Call SensorMsAp(freq, t)
                        Call WriteTXT(data, i, j)
```


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```
                        If (xsteplength = 0) Then
                            Exit For
                        End If
                    Next
                    flage = -1 * flage
                Else
                    For i = xstop To xstart Step -xsteplength
                        Call AbsMv(i, j)
                        Call SensorMs(freq)
                        Call SensorMsAp(freq, t)
                        Call WriteTXT(data, i, j)
                        If (xsteplength = 0) Then
                            Exit For
                        End If
                    Next
                    flage = -1 * flage
                End If
                If (zsteplength = 0) Then
                    Exit For
                End If
            Next
        End If
        LBL.BackColor = Color.Green
        BTNauto.Enabled = True
    End Sub
    '*****************************************************************
    '讀取 moto 狀態
    '****************************************************
    Private Sub BTNrbstatus_Click(sender As Object, e As EventArgs) Handles
BTNrbstatus.Click
        BTNrbstatus.Enabled = False
        RS232.Write("!:" & vbCrLf)
        TimeDelay(1000)
        BTNrbstatus.Enabled = True
        ''***************************************************************
        ''讀取回傳訊號(非 DataReceived)
        ''***************************************************************
        'TXBread.Text = TXBread.Text + "***************" & vbCrLf +
RS232.ReadExisting()
        ''使 TXBread 自動往下捲
        'TXBread.SelectionStart = TXBread.TextLength
        'TXBread.ScrollToCaret()
    End Sub

    '********************************************************
    '通訊埠物件的 DataReceived 事件程式
    '當有資料超過 ReceivedBytesThreshold 屬性設定值會引發此事件
    '接收的程式可以寫在此事件程序中
```


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```
'處理資料的部份必須另外以委派(Delagate)類別予以處理，否則將會產生錯誤
'**************************************************
Private Sub RS232_DataReceived(sender As Object, e As SerialDataReceivedEventArgs) Handles RS232.DataReceived
    '在此範圍內，不能直接將結果指定給 TXBread 控制項的 Text 屬性
    '原因是事件的引發在不同的執行緒
    If e.EventType <> SerialData.Chars Then Exit Sub '判斷接收的資料是否為字元
    Dim inData As String = RS232.ReadExisting '取得字串
    DisplayText(inData)   '顯示資料
End Sub
'****************************************************
'委派副程式
'處理上述通訊埠的接收事件
'由於欲將資料顯示到接收文字框中，因此必須檢查是否由另外的 Thread
'所呼叫的，若是，則必須先建立委派物件
'Invoke 用於在擁有控制項基礎視窗控制代碼的執行緒上執行委派
'**************************************************
Private Sub DisplayText(ByVal comData As String)
    '如果呼叫 TXBread 的是另外的執行緒，傳回 True
    If TXBread.InvokeRequired Then
        '利用委派型別建立委派物件，並指定委派的函式
        Dim d As New SetTextCallback(AddressOf ShowString)
        '用大括號 {} 括住初始值，藉以初始化陣列的值。
        Me.Invoke(d, New Object() {comData})   '以指定的引數清單叫用函式
    Else   '相同的執行緒
        ShowString(comData)     '將收到的資料填入接收文字框中
    End If
End Sub

'************************************************
'顯示資料的函式
'************************************************
Private Sub ShowString(ByVal comData As String)
    TXBread.Text += comData     '將收到的資料入接收文字框中
End Sub
Private Sub BTNrbinitialize_Click(sender As Object, e As EventArgs) Handles BTNrbinitialize.Click
    BTNrbinitialize.Enabled = False
    Call RBintial()
    MsgBox("initialization complete",)
    BTNrbinitialize.Enabled = True
End Sub
Private Sub BTNgpibon_Click(sender As Object, e As EventArgs) Handles BTNgpibon.Click
    Try
```


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```
                Cursor.Current = Cursors.WaitCursor
                'GpibDevice.DefaultBufferSize = 9192
                GpibDevice = New Device(CInt(NUDboardid.Value), CByte(NUDgpib.Value))
            Catch ex As Exception
                MessageBox.Show(ex.Message)
            Finally
                Cursor.Current = Cursors.Default
            End Try
        End Sub
        Private Sub BTNgpibstatus_Click(sender As Object, e As EventArgs) Handles BTNgpibstatus.Click
            Try
                Cursor.Current = Cursors.WaitCursor
                GpibDevice.Write("*IDN?" & vbCrLf)
                TXBread.Text = TXBread.Text + GpibDevice.ReadString() & vbCrLf
                GpibDevice.Write("*CONF?" & vbCrLf)
                TXBread.Text = TXBread.Text + GpibDevice.ReadString() & vbCrLf
            Catch ex As Exception
                MessageBox.Show(ex.Message)
            Finally
                Cursor.Current = Cursors.Default
            End Try
        End Sub
        Private Sub BTNvisaon_Click(sender As Object, e As EventArgs) Handles BTNvisaon.Click
            Dim usb As String = CMBvisa.SelectedItem.ToString
            Try
                mbSession = CType(ResourceManager.GetLocalManager().Open(usb), MessageBasedSession)
                MsgBox("connection complete")
            Catch exp As InvalidCastException
                MessageBox.Show("Resource selected must be a message-based session")
            Catch exp As Exception
                MessageBox.Show(exp.Message)
            Finally
                System.Windows.Forms.Cursor.Current = Cursors.Default
            End Try
            Call VISABTON()
        End Sub

        Private Sub BTNvisastatus_Click(sender As Object, e As EventArgs) Handles BTNvisastatus.Click
            System.Windows.Forms.Cursor.Current = Cursors.WaitCursor
            Try
                TXBread.Text = TXBread.Text + mbSession.Query("*IDN?") & vbCrLf
                TimeDelay(1000)
                TXBread.Text = TXBread.Text + mbSession.Query("CONF?") & vbCrLf
```


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```
            Catch exp As Exception
                MessageBox.Show(exp.Message)
            Finally
                System.Windows.Forms.Cursor.Current = Cursors.Default
            End Try
        End Sub
        Private Function ReplaceCommonEscapeSequences(ByVal s As String) As String
            Return s.Replace("\n", vbLf).Replace("\r", vbCr)
        End Function
        Private Function InsertCommonEscapeSequences(ByVal s As String) As String
            Return s.Replace(vbLf, "\n").Replace(vbCr, "\r")
        End Function
        Private Sub BTNpzero_Click(sender As Object, e As EventArgs) Handles BTNpzero.Click
            Dim MsgResult As Integer
            MsgResult = MessageBox.Show("確認 Power Sensor 輸入端的訊號源為 OFF")
            mbSession.Write("CAL:ZERO:TYPE INT")
        End Sub
        Private Sub BTNnisaread_Click(sender As Object, e As EventArgs) Handles BTNnisaread.Click
            TXBread.Text = TXBread.Text + mbSession.ReadString() & vbCrLf

        End Sub
        Private Sub BTNnisasend_Click(sender As Object, e As EventArgs) Handles BTNnisasend.Click
            mbSession.Write(TXBsend.Text)
        End Sub
        Private Sub BTNmanual_Click(sender As Object, e As EventArgs) Handles BTNmanual.Click
            BTNmanual.Enabled = False
            LBL.BackColor = Color.Red
            Call SetSensorUnit_LV()
            Dim freq As Double = Val(TXBf.Text)
            Dim t As Double = Val(TXBt.Text)
            If t <= 0 Or t > 41.9 Then
                MsgBox("time must be 0 < t <= 41.9")
                Return
            End If
            Call SensorMs(freq)
            Call SensorMsAp(freq, t)
            TXBav.Text = TXBav.Text + TXBavpower.Text & vbCrLf
            LBL.BackColor = Color.Green
            BTNmanual.Enabled = True
        End Sub
        'average powermeasurment
        Sub SensorMsAp(ByRef freq As Double, ByRef t As Double)
            Dim rate As Double
            If CMBrate2.SelectedIndex = 0 Then
```


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```
            rate = 24.7
        Else
            rate = 49.3
        End If
        Dim numavg As Integer = t * rate
        If numavg > 1024 Then 'numavg shouldn't be set larger than 1024
            numavg = 1024
        End If
        mbSession.Write("FREQ " & freq & "GHz" & ";AVER:COUN " & numavg)
'refer to "Keysight U2000 Series USB Power Sensors Operating And Service Guide"
Table 3-5
        TimeDelay(50)
        mbSession.Write("READ?")
        TimeDelay(t * 1000)
        Dim unit As String = CMBpunit.SelectedIndex
        If unit = 1 Then
            TXBavpower.Text = Val(mbSession.ReadString()) * 1000
        Else
            TXBavpower.Text = Val(mbSession.ReadString())
        End If
        TXBav.Text = TXBav.Text + TXBavpower.Text & vbCrLf
    End Sub
    'power measurment
    Sub SensorMs(ByRef freq As Double)
        mbSession.Write("FREQ " & freq & "GHz" & ";AVER:COUN 1") 'refer to
"Keysight U2000 Series USB Power Sensors Operating And Service Guide" Table 3-5
        TimeDelay(50)
        mbSession.Write("READ?")
        Dim unit As String = CMBpunit.SelectedIndex
        If unit = 1 Then
            TXBpower.Text = Val(mbSession.ReadString()) * 1000
        Else
            TXBpower.Text = Val(mbSession.ReadString())
        End If
    End Sub
    '詢問 motor 動作狀態
    Sub motorask(time As Integer)
        Do Until TXBread.Lines(TXBread.Lines.Length.ToString() - 2) Like "R"
            RS232.Write("!:" & vbCrLf)
            TimeDelay(time)
        Loop
    End Sub
    '自動下移選單
    Sub checkdown()
        TXBread.SelectionStart = TXBread.TextLength
        TXBread.ScrollToCaret()
    End Sub

    Private Sub BTNvisainitialize_Click(sender As Object, e As EventArgs) Handles
```


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```
BTNvisainitialize.Click
            System.Windows.Forms.Cursor.Current = Cursors.WaitCursor
            Try
                  mbSession.Write("*CLS;*RST;CONF:POW:AC 0dbm,4,(@1)")
                  TimeDelay(1000)
                  mbSession.Write("UNIT:POWER W")
            Catch exp As Exception
                  MessageBox.Show(exp.Message)
            Finally
                  System.Windows.Forms.Cursor.Current = Cursors.Default
            End Try
      End Sub
      'show the current location
      Sub displaylocation()
            TXBread.Clear()
            RS232.Write("Q:" & vbCrLf)
            TimeDelay(1000)
            Dim s As String = TXBread.Text
            Dim aryS() As String = s.Split(",")
            TXBxlocation.Text = Val(aryS(0)) / motorscale
            TXBzlocation.Text = Val(aryS(2)) / motorscale
      End Sub
      'set up power sensor measurement unit and level
      Sub SetSensorUnit_LV()
            Dim unit As String = CMBpunit.SelectedIndex
            If unit = 0 Then
                  Label24.Text = "dbm"
                  Label25.Text = "dbm"
                  mbSession.Write("UNIT:POWER dbm")
            Else
                  Label24.Text = "mW"
                  Label25.Text = "mW"
                  mbSession.Write("UNIT:POWER W")
            End If
            Dim level As String = CMBplevel.SelectedIndex
            If level = 0 Then
                  mbSession.Write("POW:AC:RANG 0") 'sets to lower power range (-
60dbm ~ -7dbm)
            Else
                  mbSession.Write("POW:AC:RANG 1") 'sets to upper power range (-
7dbm ~ 20dbm)
            End If
      End Sub
      'Robot intial
      Sub RBintial()
            RS232.Write("H:W" & vbCrLf)
            TimeDelay(1000)
            Call motorask(500)
      End Sub
```


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```
'開啟 RS232 相關按鍵
Sub RS232BTON()
    BTNrs232on.Text = "RS232 OFF"
    BTNmove.Enabled = True
    BTNauto.Enabled = True
    BTNrbstatus.Enabled = True    '
    BTNrbinitialize.Enabled = True
    BTNrs232send.Enabled = True
    BTNrs232read.Enabled = True
End Sub
'關閉 RS232 相關按鍵
Sub RS232BTOFF()
    BTNrs232on.Text = "RS232 ON"
    BTNmove.Enabled = False
    BTNauto.Enabled = False
    BTNrbstatus.Enabled = False    '
    BTNrbinitialize.Enabled = False
    BTNrs232send.Enabled = False
    BTNrs232read.Enabled = False
End Sub
'serialport 初始化參數
Sub SerialPortSetUp()
    RS232.PortName = CMBcom.SelectedItem.ToString     '欲開啟的通訊埠
    RS232.BaudRate = 9600                              '通訊速度
    RS232.Parity = System.IO.Ports.Parity.None                    '同位
位元檢查設定
    RS232.DataBits = 8                                 '資料位元設定值
    RS232.StopBits = StopBits.One                      '停止位元設定值
    RS232.ReceivedBytesThreshold = 1                   '設定引發事件的門
檻值
End Sub
'檢查輸入是否為空
Function CheckKeyIn() As Boolean
    If ((TXBfreq.Text = "") Or (TXBintegralt.Text = "") Or (TXBxstart.Text = "")
Or (TXBxstop.Text = "") Or (TXBxpn.Text = "") Or (TXBzpn.Text = "") Or
(TXBzstop.Text = "") Or (TXBzstart.Text = "")) Then
        MsgBox("設定不可為空")
        Return 0
    Else
        Return 1
    End If
End Function
'開啟 VISA 相關按鍵
Sub VISABTON()
    BTNvisaon.Enabled = False
    BTNvisastatus.Enabled = True
    BTNvisainitialize.Enabled = True
```


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```
            BTNpzero.Enabled = True
            BTNmanual.Enabled = True
            BTNnisasend.Enabled = True
            BTNnisaread.Enabled = True
        End Sub
        '關閉 VISA 相關按鍵
        Sub VISABTOFF()
            BTNvisaon.Text = "VISA ON"
            BTNvisastatus.Enabled = False
            BTNvisainitialize.Enabled = False
            BTNpzero.Enabled = False
            BTNmanual.Enabled = False
            BTNnisasend.Enabled = False
            BTNnisaread.Enabled = False
        End Sub
        '移動絕對座標
        Sub AbsMv(ByRef x As Double, ByRef z As Double)
            '重複確認座標
            For i = 0 To 2
                If (Val(TXBxlocation.Text) <> x / motorscale Or Val(TXBzlocation.Text)
<> z / motorscale) Then
                    RS232.Write("A:W+P" & x & "+P" & 0 & "+P" & z & vbCrLf)
                    RS232.Write("G:" & vbCrLf)
                    TimeDelay(Gtime)
                    motorask(Rtime)
                    Call displaylocation()
                Else
                    Return
                End If
            Next
            MsgBox("請檢查 motor 座標")
        End Sub
        'creat a TXT form
        Function CreatTXT(ByVal freq As Double, ByVal itime As Double, ByVal mode As
String, ByVal unit As String) As String
            Dim xpoint As Integer = Val(TXBxpn.Text) + 1
            Dim zpoint As Integer = Val(TXBzpn.Text) + 1
            Dim xstart As Double = Val(TXBxstart.Text)
            Dim zstart As Double = Val(TXBzstart.Text)
            Dim xstop As Double = Val(TXBxstop.Text)
            Dim zstop As Double = Val(TXBzstop.Text)
            Dim saveFileDialog1 As New SaveFileDialog()
            saveFileDialog1.Filter = "文字檔(*.txt)|*.txt"
            saveFileDialog1.Title = "Save an Image File"
            If (saveFileDialog1.ShowDialog() = DialogResult.OK) Then
                Dim streamwriter As System.IO.StreamWriter =
My.Computer.FileSystem.OpenTextFileWriter(saveFileDialog1.FileName, True)
                Dim dt As String
```


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```
            dt = Now()
            streamwriter.WriteLine(dt)
            streamwriter.WriteLine("Freq: " & freq & "GHz     IntegralTime: " & itime & "(Sec)    SamplingRate: " & mode)
            streamwriter.WriteLine("XPointNumber      ZPointNumberXstart(cm)    Zstart(cm)      Xstop(cm)      Zstop(cm)")
            streamwriter.WriteLine(xpoint & Chr(9) & Chr(9) & zpoint & Chr(9) & Chr(9) & xstart & Chr(9) & Chr(9) & zstart & Chr(9) & Chr(9) & xstop & Chr(9) & Chr(9) & zstop)
            streamwriter.WriteLine()
            streamwriter.WriteLine("Power in " + unit)
            streamwriter.Close()
            Return saveFileDialog1.FileName
        End If
        Return ""
    End Function
    'write data in TXT
    Sub WriteTXT(ByRef data As String, ByRef i As Integer, ByRef j As Integer)
        Dim streamwriter As New StreamWriter(data, FileMode.Append)
        streamwriter.WriteLine(Val(TXBavpower.Text))
        streamwriter.Close()
    End Sub
End Class
```


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1.2 Imaging Program Using MATLAB

```
clear;
clc;
fid = fopen('filename.txt');


% parameters in the file
[DATA] = textscan(fid,'%f %f %f %f %f %f','headerLines',3);
xpoint=DATA{1,1};
zpoint=DATA{1,2};
xstart=DATA{1,3};
zstart=DATA{1,4};
xstop=DATA{1,5};
zstop=DATA{1,6};


% data in the file
[DATA] = textscan(fid,'%f','headerLines',3);
maxvalue= max(DATA{1,1}); % be used in colorbar
minvalue= min(DATA{1,1}); % be used in colorbar
img = zeros(xpoint,zpoint);
fclose(fid);


%permuted data from DATA to img
t=1;            % tick of DATA
flage=1;        %flage of loop
for i= 1 : zpoint
    flage = flage*(-1);
    for j = 1 : xpoint
        if flage == -1
             img(i,j) =DATA{1,1}(t,1);
        else
            img(i,xpoint+1-j) = DATA{1,1}(t,1);
        end
        t = t+1;
    end

end


%output figure result
figure;
imagesc(img); %show image
shading flat;%remove grid lines
colormap(gray)% add gray scale
```


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```
% set up for output figure cursor
set(gca,'XTickLabel',{'1','3','5','7','9','11','13','15','17'});
set(gca,'XDir','reverse');
set(gca,'YTickLabel',{'1','3','5','7','9','11','13','15','17'});
set(gca,'YDir','normal');
xlabel('H-axis (cm)');
ylabel('V-axis (cm)');
step=(maxvalue-minvalue)/5;
colorbar('Ytick',minvalue:step:maxvalue); %colorbar set up
```


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