

AT-RF3030

RF EDUCATION EXPERIMENT SYSTEM

Manual For Experiment



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EXPERIMENT

1. Theory and Experiment of VCO and Detector

I. Objective

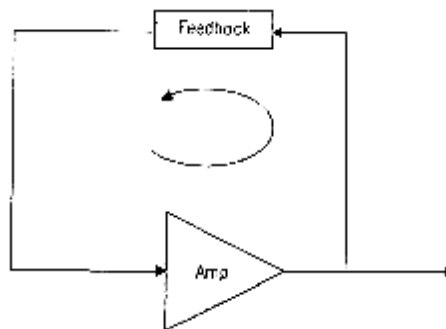
To measure frequency and output power changes according to the variation in the tuning voltage of an AT-RF3030-1(VCO) module with an AT-RF3030-24 (Coaxial Detector) and to comprehend the basic principle of the VCO.

II. Theory

1. VCO (Voltage Controlled Oscillator)

The VCO is an abbreviation for the Voltage Controlled Oscillator. The VCO is an oscillator which can control output frequency ($f_1 \sim f_2$) within a certain range by changing the tuning voltage (V_{tune}) in addition to the bias voltage (VCC) applied to the VCO. Here, the oscillation means that energy is concentrated in a specific frequency region due to the electric or structural resonance. An oscillator used for a signal source of microwave generates excellent oscillations in purpose, but the oscillation in other circuit means the electric components undesirably caused at more than a specific level. In particular, the oscillation should be removed from circuits having gains such as an amplifier, a frequency or a frequency doubler.

The oscillation is based on a concept of feedback. When a loop using an output signal as an input is formed, the output signal is fed back to the input and becomes bigger with having gains. As shown in [Fig.1-1], if the amplified signal is fed back, the signal grows bigger and bigger.



[Fig.1-1] Feedback Loop

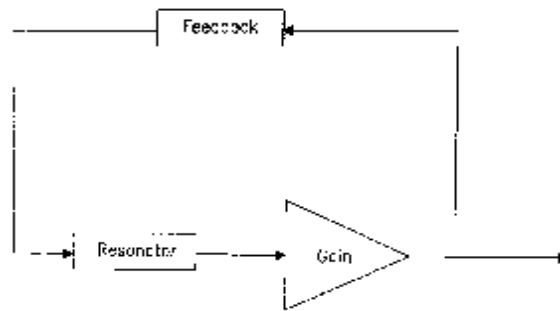
The oscillation is initiated by a transient phenomenon or noise at the first step, and gradually approaches the stable phase. An active element is required to obtain gains during the oscillation, and a negative resistance is also required. IMPACT, Gunn diode or the like is used for a single port, and FET or transistor in addition to a passive element is used for the port so that the input port has a negative resistance.

Colpitts or Hartley oscillator having a lumped element is used in the low microwave frequency range. In this case, a resonator is used for the input or output in order to increase the stability.

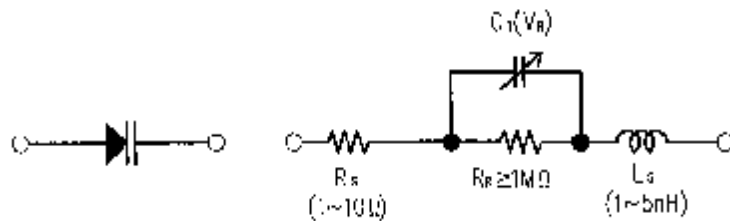
That is, the oscillator can stably operate by an insertion of a resonator and the selective feedback of a certain frequency as shown in [Fig.1-2].

As shown above, it is the resonator that determines the frequency. The resonance implies a selectivity of a certain frequency, so the resonance frequency can change by adjusting the property of the resonator.

Operating Temperature Range	-40 to +70 degrees C
Storage Temperature Range	-55 to +125 degrees C
Vcc Voltage, Vdc	+12
Vtune Voltage, Vdc	+20



[Fig.1-2] Oscillator Circuit



(a) Symbol

(b) Reverse Bias Equivalent Circuit

[Fig.1-3] Varactor Diode

That can be achieved by using a varactor diode as shown in [Fig.1-3].

The varactor (varactor = variable + capacitor) diode is manufactured from semiconductors, and it is a variable capacitor having variable C_T values according to applied voltages. When the diode is reverse biased, at both sides of the p-n junction is formed a space charge region, which forms a depletion region.

The width of the depletion region is controlled by the reverse bias, and the transition capacitance C_T is generated by isolated space charges. As the voltage of the reverse bias increases, the width of the depletion region also increases, which results in the decrease of the transition capacitance

Basically, the resonance frequency changes according to the inductance (L) and the capacitance (C). Therefore, adjusting the inductance (L) or capacitance (C) can change the property of the resonance part. The resonance frequency is easily changed by changing either of them without changing both. More general and common method is to change the capacitance of the resonance part. When the capacitance of the varactor diode changes due to the voltage change applied to the varactor diode, the resonance frequency of the resonance part changes, which eventually leads to the change of the oscillation frequency. The VCO (Voltage Controlled Oscillator) is made based on this principle.

The VCO can be changed by the voltage, but it has problems that it is weak for external impacts such as the temperature change or voltage instability. That is, the desirable oscillation frequency is not fixed but fluctuated, so the system can not operate in normal condition because the source signal is fluctuated. Therefore, various techniques are required to increase the frequency stability of the VCO. A series of the procedures is called the locking, in short.

The PLL (Phase Locked Loop) is a circuit combination method used in RF for fixing the frequency source against the external impacts. The VCO is usually regarded as a part of the PLL, but, strictly speaking in terms of RF, the PLL is a powerful tool and methodology for smoothly fixing and changing the frequency of the

VCO.

[Fig. 1- 4] shows a specification of the **SZ-COM • V6009001 2350VCO** used as the VCO.



Contact Assignments	
1.RF Out	
2.Vcc	
3.Vtune	
All other contacts are Ground	

Item	MIN	TYP	MAX
Frequency (MHz)	1250	----	2360
Power Output (dBm)	+8	----	+13
Harmonics (dBc)	----	-20	-12
SSB Phase Noise (dBc/Hz)			
@ Offset = 100kHz	----	-115	-110
Pushing (MHz/V)	----	1	1.5
Pulling (MHz)	----	+20	+30
Tuning Voltage (Vdc)	----	0	+20
Tuning Sensitivity (MHz/V)	----	60	----
Supply Votage (Vdc)	----	+12	----
Supply Current (mAdc)	----	30	----
Output Power @ Vtune = 0 and 20 V	+8	----	----
Tuning Port Capacitance (pF)	----	47	----
3dB Modulation Bandwidth (kHz)	----	300	----

[Fig.1-4] Specification of the VCO (**SZ-COM • V6009001 2350VCO**)

2. Diode Power Detector

Power is defined as a consumed amount of energy per unit time.

It is hard to measure the voltage and current of the microwave, so usually the power is measured. The power of the microwave can be divided into three levels.

Low power: $\sim 1\text{mW}$ (0dBm or lower)

Intermediate power: $1\text{mW} \sim 10\text{W}$ (0 \sim 40dBm)

High power: $10\text{W} \sim$ (40dBm or higher)

A power meter is necessary to detect the power of the microwave. The power meter can be divided into a calorimeter, bolometer or microwave diode type.

When the power is low, a bolometer type is used because error caused by the temperature increase of water may be large, The bolometer is inserted to the wave guide and the microwave is absorbed. Then the power is obtained from the resistance value after equilibrating the changed resistance by means of the bridge circuit. Commercial power meters have this configuration.

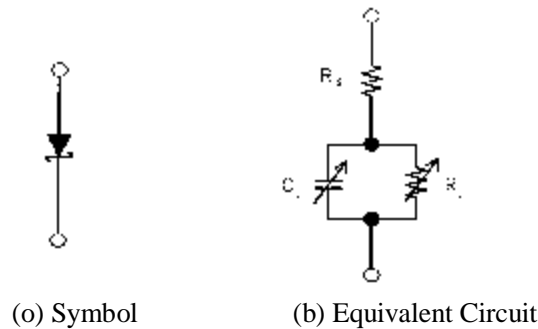
Using a calorimeter, the power is measured from the temperature change of water by absorbing the microwave to water. Various methods are required to increase the sensitivity, and it is useful for the power measurement higher than a few Watts.

A diode power detector converting the power of microwave into the proportional DC voltage is used for

the low power measurement of a few mW to a few hundreds mW according to the diode capacity.

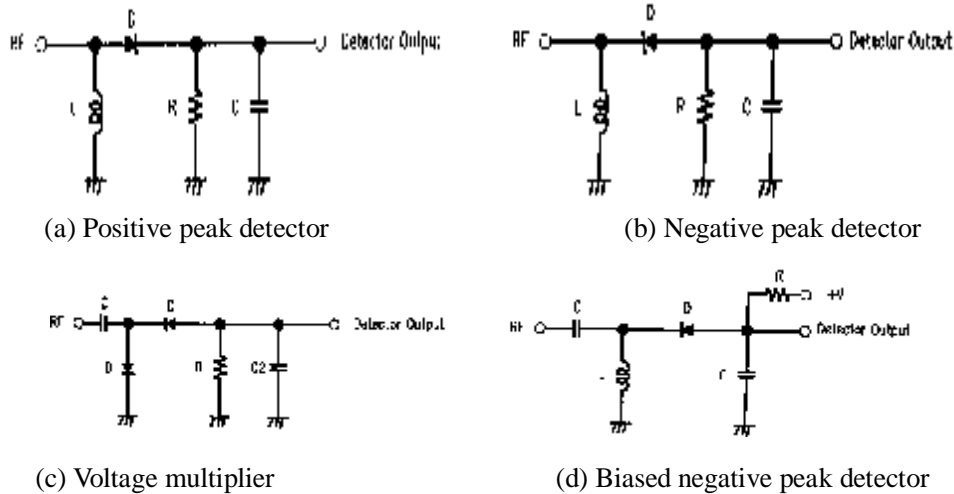
The Shcottony barrier diode is commonly used for the detector. Hereafter, it will be abbreviated as the SBD (Shcottony Barrier Diode) for convenience. One big difference exists between the SBD and the common diode. The general diode is formed by the junction of p-type and n-type semiconductors (p-n conjunction), but the SBD is formed by the junction of metal (tungsten, platinum or chrome) and a semiconductor (n-type). It shows a similar characteristic for the rectification with the p-n junction, but there is a big difference inside. The p-n junction diode has both majority and minority carriers for transporting charges, but the SBD has only majority carriers. As a result, high-speed operation is possible and it is widely used in radio frequency region. One of the important characteristics of the SBD is that reverse and forward voltages are low. The reverse voltage is lower than that of the p-n junction diode by one order of magnitude, and the forward voltage is about half of that of the p-n junction diode.

[Fig.1-5] shows the SBD equivalent circuit at radio frequency region. It comprises a serial resistor R_s , a non-linear junction resistor R_j , and a non-linear junction capacitance C_j , and the R_s and C_j values should be small when the SBD is used for a detector and a mixer.



[Fig. 1-5] Shcottony Barrier Diode

[Fig. 1-6] shows four types of the detector circuit used most frequently.



[Fig. 1-6] Basic Configuration of Power Detector

(a) is a positive peak detector which can obtain a positive (+) output. If the amplitude modulation is not used the radio frequency signal input to the circuit, the detector output is DC voltage proportional to the high-frequency signal level and the output voltage is positive.

(b) is a negative peak detector where a reverse diode is arranged unlike (a). Therefore, a negative detector output is obtained as the output.

(c) is a voltage multiplier which uses two diodes in the circuit. The circuit can obtain the output twice larger than the (b) detector.

(d) is a biased negative peak detector where a portion having an IF-VF characteristic of better linearity is selectively operated by flowing small DC bias to the diode. This detector can increase the measuring

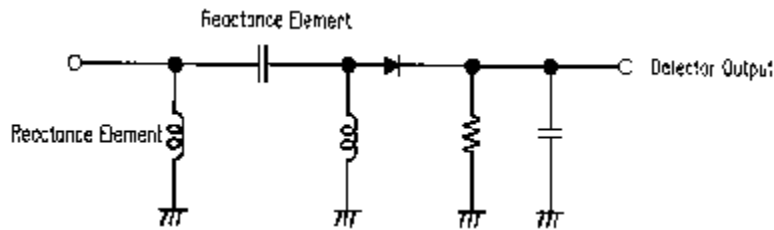
sensitivity when the high-frequency signal level is low.

In case of the actual detector, the input power should be transported to the key element of the detector, diode without loss. To increase the detector efficiency, the impedance matching is very important. An L, C or stub is used at input terminal for matching, or an inductor for DC return can be used as a part of the matching element. If the impedance matching is not done properly, the sensitivity of the detector is decreased so that accurate measurements are hardly expected.

3. Impedance matching of detector

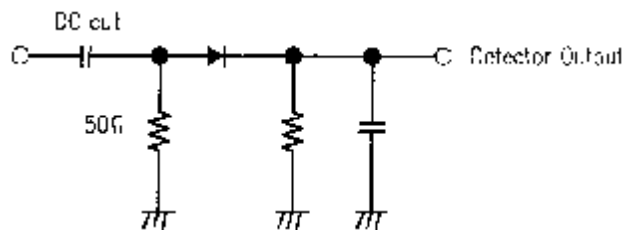
The detector is a circuit for converting AC power to the proportional DC voltage. In addition, it requires transporting of the input power to the diode, the key element of the circuit without loss. The input impedance matching is of great importance in increasing the detector efficiency.

If the target for detecting is determined so that the frequency band is narrow and the efficiency and sensitivity are required, the matching circuit is formed by using reactance elements (distributed line such as L, C, stub or the like). As shown in the figure, the inductor used for DC return may be used a part of the matching circuit. In addition, when the circuit connected to the input is not open DC circuit, a capacitor for isolating the DC may be necessary.



[Fig. 1-7] Matching Using Narrow-band Reactance Elements

If a broad-band detector is required for the broadband, the circuit is formed by inserting resistors in parallel. In this case, the impedance matching should be done by adjusting the resistance in a manner that the impedance is as close to 50~ as possible. With this circuit, the input signal power is partially consumed so that the sensitivity of the detector is decreased for the broadband. Therefore, an amplifier is often used at the input terminal of the detector.



[Fig. 1-8] Matching Using Broad-band Resistors

In case of the detector, not only the circuit for converting the fore mentioned frequency to the DC voltage, but also the circuit for handling the detector output signal is also important, If the input signal level has a low value like minus a few tens dBm, the detector output also has a value lower than a few mV. Therefore, the signal amplification at the output terminal is necessary.

In this case, when various fine properties such as offset voltage of the output terminal OP Amp are not calibrated, the detector efficiency is degraded due to the addition of undesirable voltage.

III. Measuring Instruments

Module Name	Item Name	Quantity
AT6030D	Digital Spectrum Analyzer	1
TPR3002-3C	Power	1
AT-RF3030-1	VCO	1
AT-RF3030-24	Coaxial Detector	1
Accessory	Banana—SMB	2
Accessory	SMA—SMA	1

※The frequency of VCO can be changed by controlling the V_{tune} voltage.

※Caution1: Take care not to apply higher voltage than rated voltage to the power supply of the AT-RF3030-1(VCO) module and the V_{tune} terminal. Higher voltage than the rated voltage can damage the circuit,

※Caution2: Apply the power to the circuit after completely connecting all the modules as always.

IV. Experimental Procedures

- (1) Connect all the lines to form a circuit as shown in [Fig. 1-9]



[Fig. 1-9] Output measurement of VCO

- (2) In order to supply the operational voltage V_{cc} and the tuning voltage V_{tune} to the AT-RF3030-1(VCO) module, set the V_{cc} and V_{tune} voltages of AT-RF3030-1(VCO) to 12 V and 0V, respectively.
- (3) Change the V_{tune} voltage of the AT-RF3030-1(VCO) module from 0V to 20V. Then, measure outputting frequency and power values with the AT6030D and record in <Table 1>.
- ※Caution: Higher voltage than rated voltage can damage the circuit. Take care not to apply higher voltage to the V_{cc} and V_{tune} terminal of the AT-RF3030-1(VCO) module.
- (4) Plot a graph by using results of <Table 1>. Keep these results because they are further used as basic data for all the experiments presented in this book.
- (5) Adjust the V_{tune} to some value, and then use AT6030D to observation frequency and two tuning wave.

V. Results

<Table 1> Output Measurement of VCO

V_{tune} (V)	Frequency[GHz]	Output Voltage[V]	Output Power[dBm]	Output Power [W]
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

※Note: Record frequencies [GHz]、 output voltage[V]、 output power (dBm)、 output power (W) with the reference of the output frequency table according to the tuning voltage V_{tune} in <Table 1>.

VI. Review

- (1) Explain the definition of the VCO and the principle of the oscillation.
- (2) Explain about V_{tune} which can control the VCO output frequency.
- (3) Explain the types of the detector and detecting methods.

2. Theory and Experiment of Circulator

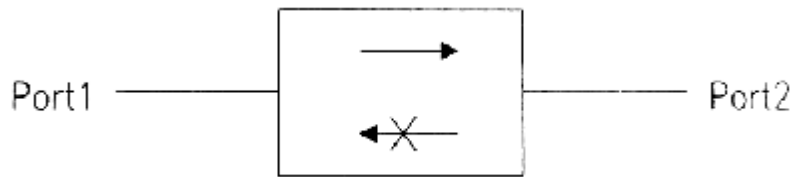
I. Objective

To comprehend the purpose and operational principle of a circulator by applying signal to each port with the AT-RF3030-3(Circulator) module.

II. Theory

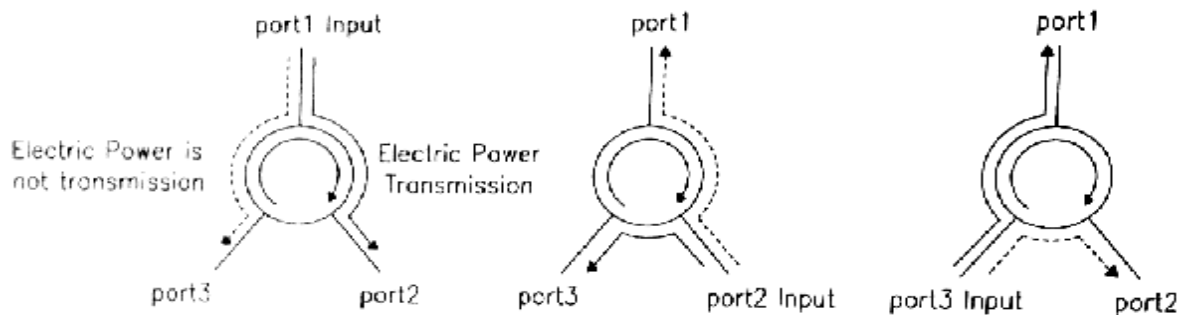
(1) Isolator and Circulator

An isolator is a circuit used for transporting signal without damping in one direction and isolating the progress in the other direction as shown in [Fig. 2-1]. It transports the signal from port 1 to port 2 with less than 3dB, but damps all the signals from port 2 to port 1. Commercial isolators have a insertion loss (transportation from port 2 to port 1) more than 15dB, and a reflective index of about 0~0.1.



[Fig.2-1] Operation of Isolator

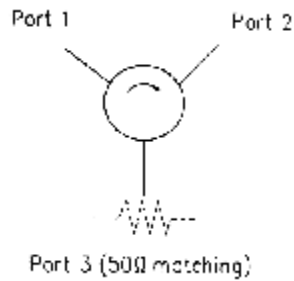
[Fig. 2-2] illustrates operation of the 3-port circulator which is a key element for forming the isolator.



[Fig. 2-2] Operation of 3-port Circulator

※A port means an input or output terminal of the microwave signal. A term of a terminal is used for low frequency circuits because just connecting two lines forms a connection. However, for the microwave, a term of a 'port' is separately used because a series connection of transmission lines (wave guides, coaxial cables or microstrip lines) is necessary for a complete transmission of a signal.

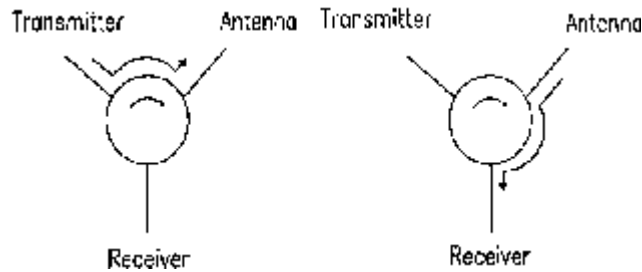
As shown in [Fig. 2-2], when the power is input to port 1, the power is transmitted to port 2 but not to port 3 by the operation of the circulator. That is, when the power is input to a certain port, the power is transmitted to either port of right and left ports and not to the other port. In other words, the signal is transmitted from port 1 to port 2, is transmitted from port 2 to port 3, and then transmitted again from port 3 to port 1. Reverse transmission of the signal is isolated due to the damping effect, (Note that only the reflected signal of port 2 is transmitted to port 3 when the signal is transmitted from Port 1 to Port 2, and no signals are transmitted to port 3 when there are no reflected signals at port 2) As three Cases shown in [Fig. 2-2], since the circulator transmits signals with having a direction by rotating in one direction, it originates from a circle. Rotating direction in a symbol represents the direction of the power transmission at each port.



[Fig. 2-3] Isolator Using Circulator

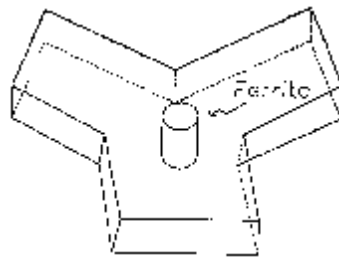
If a matching circuit of $50\ \Omega$ is connected to port 3 as shown in [Fig. 2-3], all the signals from port 2 are absorbed to port 3. Therefore, since even the reflected signal of port 2 is not transmitted to port 1, this circuit can be used as an isolator.

When the circulator is applied to the wireless communication system, it can be used as a duplexer by using one common antenna for transmitting and receiving. As shown in [Fig. 2-4], amplified transmitting signals are transmitted through the antenna in a clockwise direction, and the received signals by the antenna are transmitted to the receiver.

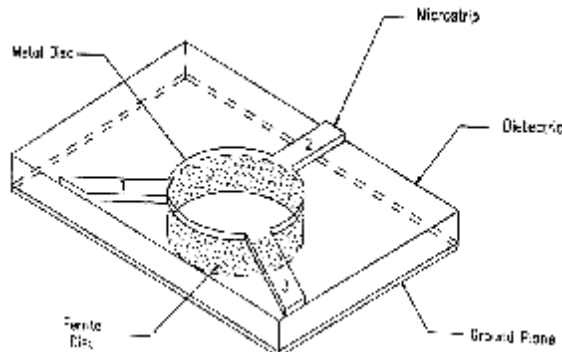


[Fig. 2-4] Duplexer Using Circulator

Circulator can be formed with using a waveguide as shown in [Fig. 2-5] (a), but the most commonly used circulator is a SMD (Surface Mount Device) type Ferrite circulator shown in [Fig. 2-5] (b). This circulator uses a soft magnetic ferrite which arranges its magnetic domain according to the external magnetic system. Each port is arranged with a 120° interval, and the basic structure is illustrated in [Fig. 2-5] (stripline type).



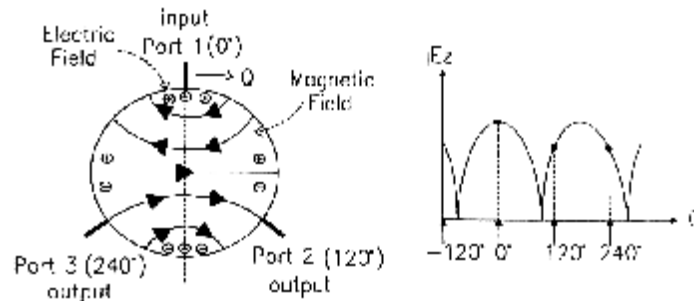
(a) Waveguide Circulator



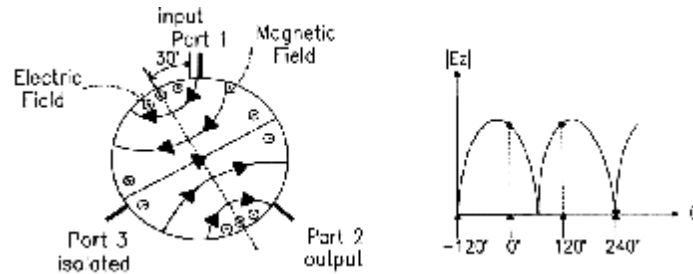
(b) Microstrip Circulator

[Fig. 2-5] Structure of Circulator

Ferrite is placed at the top and bottom of metal Plates having three ports, and a fixed magnet is located outside the ground metal plate. The fixed permanent magnet is used for causing the magnetization of ferrite, and only ferrite without a permanent magnet may be used. In an attempt to explain its operation, [Fig. 2-6] (a) illustrates a Case the power is input to port 1 out of 3 ports. Strip disk operates like a resonator so that the electric system exists perpendicular to the disk and the magnetic system on the surface of the disk. Therefore, Weaker signals than that of port 1 are identically detected at port 2 and port 3.



(a) Electric/Magnetic Field Resonance Pattern

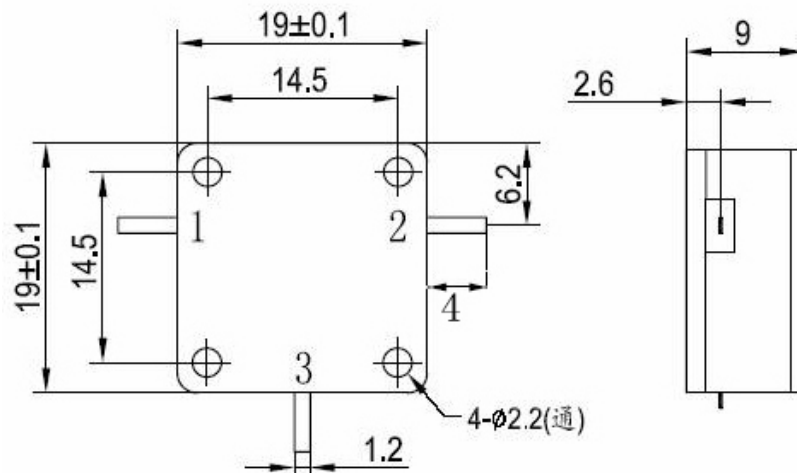


(b) 30° Rotation Electric Field/Magnetic Field Resonance Pattern

[Fig. 2-6] Operating Principle of Electric/Magnetic Resonance Pattern Circulator

When a DC magnetic system perpendicular to the ferrite disk is applied, the input plane moves about 30° in a counterclockwise direction so that the same signal as that applied at port 2 is detected at port 2. However, port 3 is placed at an intersection between (+) and (-) polarities of the electric system, that is a null point, so that the electric system can not form and no signals are detected at port 3. Even if port 2 and port 3 are used as the input ports, the power is detected only at one port as described above and it is isolated at the other ports, which plays a role as a circulator. In addition to the above stripline type of circulator, a microstrip or waveguide type circuit can form a circulator. Moreover, it can be applied in various ways by changing the shape of the middle metal plate in order to reduce the size of the entire circuit.

[Fig. 2-7] shows a specification of an element used in the circulator module.



Frequency (GHz)		Temperature (C)		Isolation Min. dB)	Loss Max. (dB)	VSWR	CW power (W)	Size inch) L*W*H
Min.	Max.	Min.	Max.					
1.8	2.2	-30	75	20	1	1.3	50	0.75*0.35*0.75

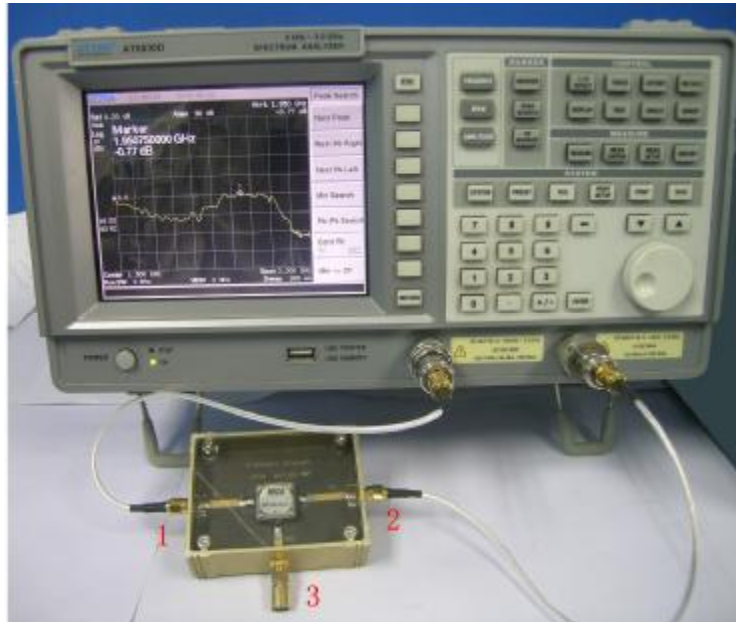
[Fig. 2-7] Specification of Circulator

III. Measuring instruments

Item	Module Name	Quantity
AT6030D	Spectrum Analyzer(tracking generator)	1
AT-RF3030-3	Circulator	1
Accessory	SMA—SMA	2
Accessory	SMA 50 Ω Load	1

IV. Experimental Procedures

- (1) Connect all the lines to form a circuit as shown in [Fig. 2-8]. (Connect 50 Ω Load to port 3 (P3) in order to use the AT-RF3030-3(Circulator) as an Isolator.)



- (2) Adjust the frequency of the AT6030D in $f_0=1500\text{MHz}$, Span=3000MHz, observing the frequency with AT6030D ,measuring the inserted $L \leq 3\text{dB}$ or not when $f = 1800\text{--}2200\text{MHz}$.
- (3)Connect port 2 and port 3 of the AT-RF3030-3(Circulator) module. Measure the inserted loss $L \geq 15\text{dB}$ of port 3 when $f=1800\text{--}2200\text{MHz}$, that is isolation of port 3 to port 1.
- (4)Because the ports of AT-RF3030-3(Circulator) module are different from each other, so measure the inserted loss in port 3 , port 1 and measure the isolation from port 1, port 2 when input from port 2 , port 3. Inserted loss and isolation must meet the Parameters above .

V. Review

- (1) Examine the types of ferrite, and list the microwave circuits using the irreversibility of ferrite.
- (2) Explain the principle of an isolator for the waveguide.
- (3) How would the result change if 50 Ω Load is not connected to P3 terminal or the SMA Short is connected?

3. Theory and Experiment of Directional Coupler

I. Objective

To comprehend the purpose and operational principle of the coupler by using the AT-RF3030-4(Directional Coupler) module.

II. Theory

Cross talk also exists in the low frequency region, but its effect is not significant because of the low frequency. As the frequency increases, each line becomes an antenna to radiate the electron wave energy and affects the neighboring lines. As such, an interaction between energy of lines is called coupling, and a coupler is made based on the coupling phenomenon. The coupling is controlled to the desired level by adjusting the interval and the length between the neighboring lines.

Main applications of the coupler are:

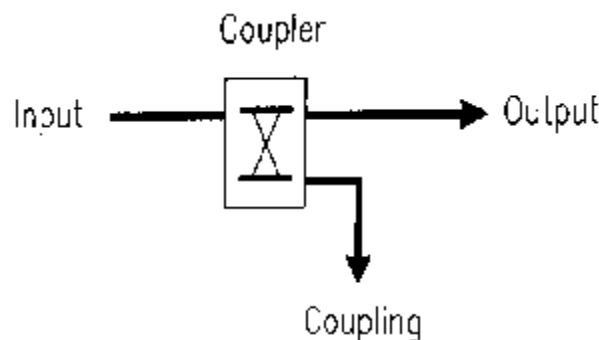
- 1) For power sampling
- 2) For power dividing

Power sampling means detecting a signal of very little amount from the original signal. When the properties of the actual signal needs to be checked from the line flowing an RF signal, the coupler is used for detecting the power without disturbing the flow of the signal.

With the detected power of little amount, the signal information, its properties or power level of its actual flow can be identified. In fact, it is commonly used to identify the power instead of the signal information or its properties.

For example, the detected power by a 30dB Coupler is -17dBm, it can be seen that actual power of $-17 + 30 = 13$ dBm are flowing through the circuit.

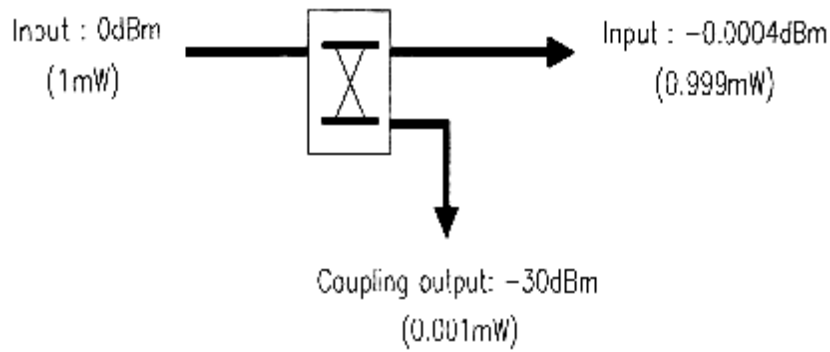
[Fig.3-1] shows a coupler for power sampling.



[Fig.3-1] Power Sampling

It should be noted that if a 30 dB coupler samples 1/1000 of the actual power, the actual power would be decreased by 1/1000. However, since a decrease of 1/1000 can be assumed to be negligible, it will not significantly affect on the signal. If the decreased power is too small to detect the accurate signal state by means of -30 dB, other coupler that can detect greater power such as -20 dB (1/100) or -13 dB (1/20) coupler can be used. In this case, the decrease can be bigger than that of -30 dB, so detecting proper power according to the condition is preferable.

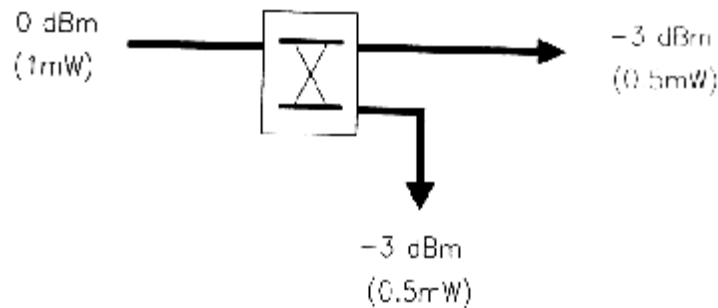
[Fig.3-2] illustrates 30 dB coupler.



[Fig.3-2] 30dB Coupler

Another application of the coupling is a power divider. A power divider means a coupler not used for identifying the signal property or the power level by sampling a small amount of power, but for coupling the desired amount of power when the large amount of power is needed. In addition, when the power is coupled by means of the power divider, the loss of power in actual signal lines will be greater. As such, it is used not for sampling power, but for dividing power.

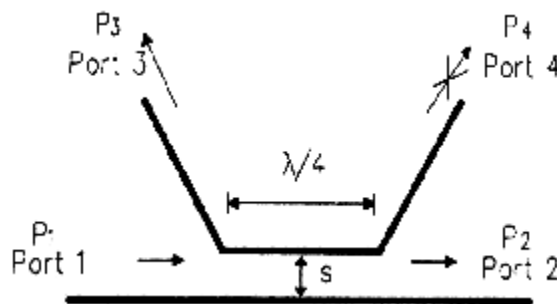
[Fig.3-3] illustrates a power divider.



[Fig.3-3] Power Divider

Both the power sampling and the power dividing have a same principle, but they can be divided to the power sampler and the power divider according to their application. The power level used for coupling is different according to a fact that a small portion of the signal is sampled or the power is used to be divided.

[Fig.3-4] represents a simplified structure and principle of a directional coupler. An interval s between two neighboring lines is such an important design variable which determines the coupling amount of the directional coupler that the coupling amount can be determined by adjusting the s interval. The coupler has generally four ports, where some ports transmit signal but the others don't.



[Fig.3-4] Transmission Principle of Directional Coupler

When the power is input to port 1, it proceeds to port 2 along the microstrip transmission line. A portion of it proceeds with coupled to port 3, and ideally, the power is not coupled to port 4 so that no signals are detected. With this property, the coupler can have a direction. Coupling coefficient, transmission coefficient, isolation coefficient or directivity is used for representing the electric property of the directional coupler, (Generally, a 10dB-coupler means a coupler having a coupling coefficient of 10 dB.) Coupling coefficient

can be defined as follows.

$$\text{Coupling Coefficient} = -10\log_{10}(P_3/P_1) \text{ [dB]}$$

The coupling coefficient represents the electric coupling level from port 1 to port 3, and the transmission coefficient represents the transmitted level to port 2. The isolation coefficient represents the output to port 4, which is hardly detected for actual signal.

$$\text{Transmission Coefficient} = -10\log_{10}(P_2/P_1) \text{ [dB]}$$

$$\text{Isolation Coefficient} = -10\log_{10}(P_4/P_1) \text{ [dB]}$$

The following directivity represents the difference between the power desired for coupling and the power not desired for coupling.

$$\begin{aligned} \text{Directivity} &= \text{Isolation coefficient [dB]} - \text{Coupling coefficient [dB]} \\ &= -10\log_{10}(P_4/P_1) \text{ [dB]} \end{aligned}$$

The directional coupler shows the same properties even if its input and output is changed. That is, if the signal is input to port 2, it directly is transmitted to port 1. A portion of it is coupled to port 4, and port 3 is isolated. '-' is used with each coefficient in order to obtain positive values for convenience.

III. Measuring Instruments

Item Name	Module Name	Quantity
AT6030D	Spectrum Analyzer(tracking generator)	1
AT-RF3030-4	Directional Coupler	1
Accessory	SMA—SMA	2
Accessory	50 Ω load	2

IV. Experimental Procedures

- (1) Connect all the lines to form a circuit as shown in [Fig.3-5].



[Fig.3-5] Directional Coupler Experiment

- (2) Adjust the center frequency of the AT6030D $f_c=1500\text{MHz}$, SPAN=3000MHz, use cable connecting the input and output port of AT6030D, and then Calibration.
- (3) Connect the AT-RF3030-4(Directional Coupler) module as figure above, observing the Spectrum of AT6030D and measuring the inserted loss.

- (4) Connect exchanging the port 2 and port 3 of the AT-RF3030-4(Directional Coupler) module, that is the port 2 of the AT-RF3030-4(Directional Coupler) module to the input of the AT6030D, the port 3 of the AT-RF3030-4(Directional Coupler) module with $50\ \Omega$ load , and then measuring the Coupling Coefficient C of the AT-RF3030-4(Directional Coupler) module.
- (5) Connect exchanging the port 3 and port 4 of the AT-RF3030-4(Directional Coupler) module, that is the port 4 of the AT-RF3030-4(Directional Coupler) module to the input of the AT6030D, the port 3 of the AT-RF3030-4(Directional Coupler) module with $50\ \Omega$ load , and then measuring the isolation Coefficient I of the AT-RF3030-4(Directional Coupler) module, and directivity $D=I-C$.

V. Results

※Note: If unused ports are not matched, the reflected signal may flow back to other ports, which leads to inaccuracy in the measurements.

<Table 2-1> Characteristics of Directional Coupler

Frequency [GHz]	Coupling Coefficient	Transmission Coefficient	Isolation Coefficient	directivity
	$P_1[\text{dBm}] - P_3[\text{dBm}]$ = [dB]	$P_1[\text{dBm}] - P_2[\text{dBm}]$ = [dB]	$P_1[\text{dBm}] - P_4[\text{dBm}]$ = [dB]	$P_3[\text{dBm}] - P_4[\text{dBm}]$ = [dB]
1.4				
1.5				
1.6				
1.7				
1.8				
1.9				
2.0				

Example) Coupling Coefficient = $-(P_3 [\text{dBm}] - P_1 [\text{dBm}]) = -10\log_{10}(P_3/P_1) [\text{dB}]$.

VI. Review

- (1) What is the average coupling coefficient [dBm] of the used coupler in the rage of 1.7GHz-I.9GHz?
In other words, which decibel [dB] Coupler is it?
- (2) What kind of problems are caused when the unused ports for the measurement are not matched?
- (3) How much signals are detected from port 1, 2 and 3 when the signal having a frequency of 1.5GHz and a power of 10 dBm is used for port 4 shown in [Fig.3-4]? Calculate referring to <Table 2-1>.
- (4) Find and explain an example of the application circuit using a directional coupler.

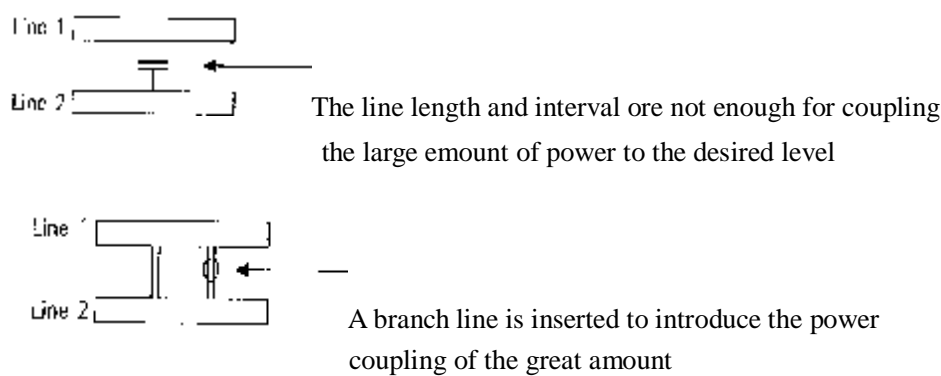
4. Theory and Experiment of Branch Line Coupler

I. Objective

To comprehend the operational principle and purpose of Branch Line Coupler using AT-RF3030-20 (Branch Line Coupler) module.

II. Theory

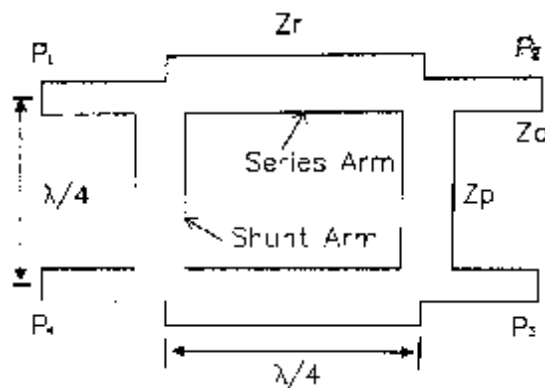
When a large amount of power is coupled for using as a divider, the line length and interval are not enough for coupling the large amount of power to the desired level. Therefore, in case of the coupler for power dividing, a branch line is inserted to introduce the power coupling of the great amount. A coupler using the above method is called a Branch Line Coupler. [Fig.4-1] is a comparison of a Directional Coupler and a Branch Line Coupler.



[Fig.4-1] Directional Coupler and Branch Line Coupler

When explaining the Coupling, the lines are spatially separated so that it is explained by a concept of the Capacitance. More specifically, the coupling is a comprehensive meaning for referring to the electric/magnetic power transmission between two lines, and implies that the direct signal transmission using lines can be included. Therefore, in case of the power transmission between two separate lines, to connect lines for transmitting the power or to transmit by spatial jumping does not make any difference in terms of the coupling. If a direct connection is performed using a branch line, it increases the capacitance value so that a branch line coupler is the same as a directional coupler.

[Fig.4-2] shows a 90° Branch-Line Coupler.



[Fig.4-2] 90° Branch Line Coupler

90° Branch-Line Coupler is frequently used as an equally dividing couple having a coupling of 3dB. By using this, a coupler having a relatively high coupling can be made easily. Branch Line Coupler has an advantage of simple design, but also has a disadvantage of large circuit size because it is made using a

transmission line.

90° Branch-Line Coupler basically operates as follows. If all the ports of 90° Branch-Line Coupler in [Fig.4-2] are matched, when the signal is input to port 1, port 2 and port 3 show an output having a phase transition of 90°, while there is no output in port 4. 90° Branch Line Coupler has both vertical/horizontal symmetry, and the output port and the isolation port are placed at the opposite side and at the top/bottom of the input port, respectively. That is, it operates in a fully symmetric structure, which shows the output in port 1 and port 4 and no output in port 3 when the signal is input to port 2.

The coupling is determined by a Shunt Arm to Series Arm ratio, where the impedance can be determined by the following equation.

$$\frac{P_2}{P_3} - \left(\frac{Z_p}{Z_o} \right)^2 \left(\frac{Z_o}{Z_r} \right)^2 = \left(\frac{Z_o}{Z_p} \right)^2 + 1$$

For a commonly used 3dB Coupler,

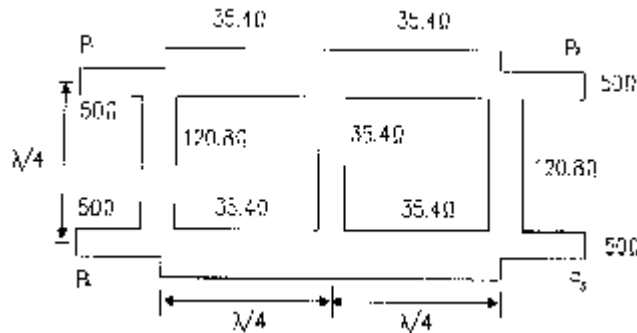
because $P_2=P_3$ in $\frac{P_2}{P_3} = \left(\frac{Z_p}{Z_o} \right)^2$, $Z_p=Z_o$.

Therefore, the right-hand side of $\left(\frac{Z_o}{Z_r} \right)^2 - \left(\frac{Z_o}{Z_p} \right)^2 + 1$ becomes 2, so that $Z_r = Z_o / \sqrt{2}$.

If $Z_o=50$ is used as a basis, $Z_p=50$ and $Z_r=35.4$. Branch Line Coupler can be easily formed with the simple equation by means of various transmission lines such as Stripline. Microstrip Line or the like (In case of Microstrip Line, the characteristic impedance of 50 Ω plays a standard role, so that the line width becomes broader at an impedance lower than 50 Ω, and narrower at an impedance higher than the value.)

Branch Line Coupler has a disadvantage of having a narrow available frequency band. With a basic 2-Arm configuration shown in [Fig.4-2], it properly operates in the band width of about 10% of the main frequency.

Adding one Shunt Arm in a manner that the overall shape is like a combination of two 90° Branch-Line Couplers is required in order to broaden the band width. [Fig.4-3] shows a broadband 3dB Coupler. By using this multiple shapes, the operational band width can be expanded up to 25% of the main frequency, but the physical size becomes larger. As a result, a minimization by bending the line of each Arm to form a bent shape is necessary.



[Fig.4-3] Broadband Branch 90° Branch Line Coupler

III. Measuring Instruments

Item	Module Name	Quantity
AT6030D	Spectrum Analyzer(tracking generator)	1
AT-RF3030-20	Branch Line Coupler	1
Accessory	SMA—SMA	2
Accessory	50 Ω Load	2

IV. Experimental Procedures

- (1) First, adjust the frequency of the AT6030D in $f_c=1500\text{MHz}$, SPAN=3000MHz. Connect the input and output of the AT6030D Spectrum Analyzer with cable and calibrate it. Then, measure the refer voltage P_1 measure observing the frequency with AT6030D, measuring the inserted $L \leq 3\text{dB}$ or not when $f = 1800\text{--}2200\text{MHz}$.



[Fig.4-4] Branch Line Coupler Experiment

- (2) Connect all the lines to form a circuit as shown in [Fig.4-4]. Use cable connecting the port 1 of the AT-RF3030-20(Branch Line Coupler) and the output of the AT6030D, port 2 to the input of the AT6030D, port 3 and port 4 with $50\ \Omega$ Load. Now it can obtain relation curve between the output voltage P_2 of port 2 and frequency, so the inserted loss $L=P_2-P_1$.
- (3) Connect exchanging port 2 and port 4 of the AT-RF3030-20(Branch Line Coupler), measure the relation curve between the output voltage P_4 of port 4 and frequency, so the inserted loss $L=P_4-P_1$, the asymmetry of this two ways is P_2-P_4 .
- (4) Connect exchanging port 4 and port 3 of the AT-RF3030-20(Branch Line Coupler), measure the relation curve between the output voltage P_3 of port 3 and frequency, so the isolation $I=P_3-P_1$.
- (5) In common, the signal input from the port 3, output from the port 2 and port 4, without signal from port 1. Because the port 2 and port 4 are near very much, $P_2=P_4=P_1-3\text{dB}$, so the Branch Line Coupler has another name of 3dB bridge.

V. Review

- (1) What is the average coupling (dB) of the used coupler in the rage of 1.7GHz-1.9GHz? In other words, which decibel (dB) Coupler is it? In addition, what is the available frequency range of the coupler at the instance?
- (2) What kind of problems are caused when the unused ports for the measurement are not matched?
- (3) How much signals are detected from port 1 and 3 when the signal having a frequency of 1.5GHz and a power of 10 dBm is input to port 2 shown in [Fig.4-4]?
- (4) Explain how the output signals of port 2, 3 and 4 would change if the input signal is connected to port 1?
- (5) Explain the definition and principle of the Branch Line Coupler.
- (6) Find and explain the example of an application circuit using the Branch Line Coupler.

5. Theory and Experiment of Hybrid Ring Coupler

I. Objective

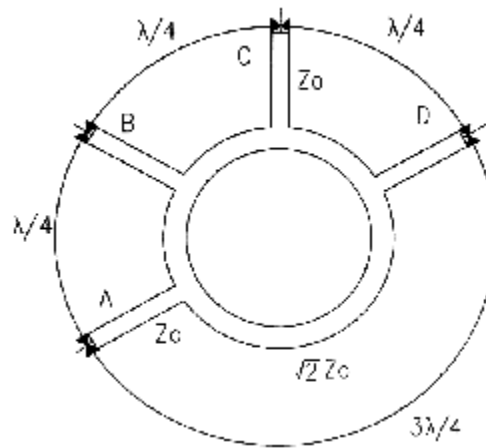
To comprehend the operational principle and purpose of Hybrid Ring Coupler using AT-RF3030-9(Hybrid Ring Coupler) module.

II. Theory

The hybrid ring coupler is a coupler also known as the rat race coupler. Basically, it is used for the half-power divider as the 90° Branch-Line Coupler, but the difference from it is having a phase difference of 180° for the signal power.

The 90° Hybrid Coupler, described above, is used for a divider or combiner having a phase difference of 90° , while the Hybrid Ring coupler is used when having a phase difference of 180° .

[Fig.5-1] shows the external appearance of the Hybrid Ring Coupler circuit.



[Fig.5-2] Hybrid Ring Coupler

As shown in the figure, all the intervals between ports A-B, B-C, and C-D are $\lambda/4$, while only that between ports A-D is $3\lambda/4$. It will be explained how the input and output relationship of each port is defined due to this configuration.

When a signal is input to C, a wave propagating about $5\lambda/4$ from C in the clockwise direction and a wave propagating about $\lambda/4$ from C in the counterclockwise direction reach B. In addition, because these two waves have same phase, they are output with combined with each other. Also at D, like at B, two waves propagating in the clockwise and the counterclockwise directions are output with combined with each other. At A, a wave propagating λ from C in the clockwise direction and a wave propagating $\lambda/2$ from C in the counterclockwise directions are reached. These two waves have opposite phase so that they cancel each other. Therefore, A becomes an isolation port, where no output is detected. Accordingly while A is a negligible port the circuit has a symmetric arrangement of B and D ports from C point of view. That is, the power input to C is equally divided to B and D with having same phase.

When a signal is input to A, a wave propagating about $3\lambda/4$ from A in the counterclockwise direction and a wave propagating $\lambda/4$ from A in the clockwise direction reach B. These two waves have same phase so that they are output at B with combined with each other. From the A point of view, D is located at a position which is separated $3\lambda/4$ from A both in the clockwise and the counterclockwise directions, so that two waves having same phase are combined and output. At C, a wave propagating $\lambda/2$ from A in the clockwise direction and a wave propagating λ from A in the counterclockwise direction are reached. These two waves have opposite phase. Therefore, C becomes an isolation port where no output is detected. Therefore, while C is a negligible port, the circuit has a symmetric arrangement of B and D ports from A point of view. The

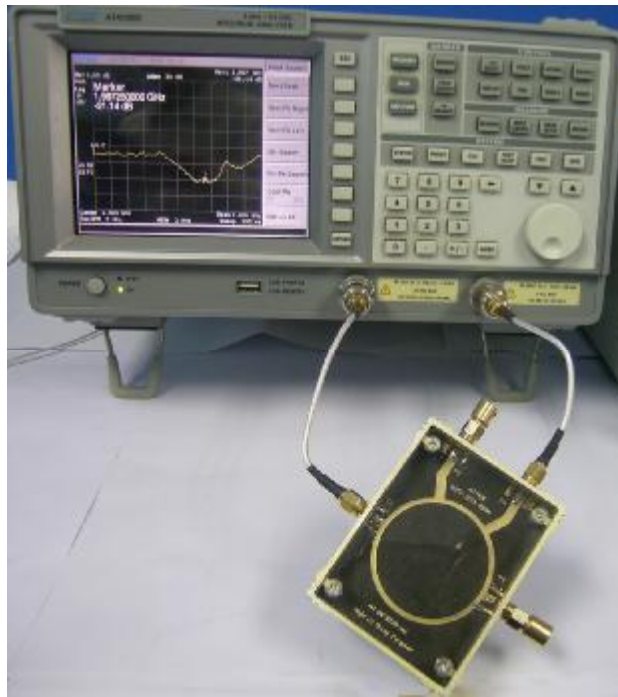
power input to A is equally divided to B and D, not as equally divided to B and D with having same phase as the input signal is applied to C. Instead, it is equally divided to B and D with having opposite phase. As such, characteristic of the Hybrid Ring Coupler is explained in brief. In fact, matching of each port is also an important factor, so the literatures should be referred for the detailed design method.

III. Measuring Instruments

Item Name	Module Name	Quantity
AT6030D	Spectrum Analyzer(tracking generator)	1
AT-RF3030-9	Hybrid Ring Coupler	1
Accessory	SMA—SMA	2
Accessory	50 Ω load	2

IV. Experimental Procedures

- (1) Connect the input and output of the AT6030D Spectrum Analyzer with cable and calibrate it. Then, Obtain the refer voltage P_1 .
- (2) Connect all the lines to form a circuit as show in [Fig.5-3].



[Fig.5-3] Hybrid Ring Coupler Experiment

- (3) Connect the port 1 of the AT-RF3030-9(Hybrid Ring Coupler) module to the output of the AT6030D, the port 2 of the AT-RF3030-9(Hybrid Ring Coupler) module to the output of the AT6030D, the port 3 and port 4 with 50 Ω load, measure the input voltage P_2 . Then, Connect the port 4 of the AT-RF3030-9(Hybrid Ring Coupler) module to the input of the AT6030D, the port 2 and port 3 with 50 Ω load, measure the input voltage P_4 , together, it can measure the P_3 .

<Table 5-1>

Frequency [GHz]	P1	P2		P3		P4	
	Input power [dBm]	Output voltage [V]	Output power [dBm]	Output voltage [V]	Output power [dBm]	Output voltage [V]	Output power [dBm]
1.8							
1.9							
2.0							
2.1							

2.2							
2.3							
2.4							

- (4) Connect the other ports of the AT-RF3030-9(Hybrid Ring Coupler) module to the output of the AT6030D, repeat step (3), and obtain the level of the relation isolation port.

V. Review

- (1) What is the average coupling of the used coupler in the range of 1.85GHz-2.4GHz? In other words, which decibel (dB) Coupler is it? In addition, what is the available frequency range of the coupler at the instance?
- (2) What kind of problems are caused when the unused ports for the measurement are not matched?
- (3) How much signals are detected from ports 2, 3 and 4 when the signal having a frequency of 1.8GHz and a power of 10 dBm is input to port 1 shown in [Fig.5-3]? Calculate the value referring to <Table 5-1>.
- (4) Explain how the output signals of ports 1, 3 and 4 would change if the input signal is connected to port 2?
- (5) Explain the definition and principle of the Hybrid Ring Coupler.
- (6) Find and explain the example of an application circuit using the Hybrid Ring Coupler.

6. Theory and Experiment of Attenuator

I. Objective

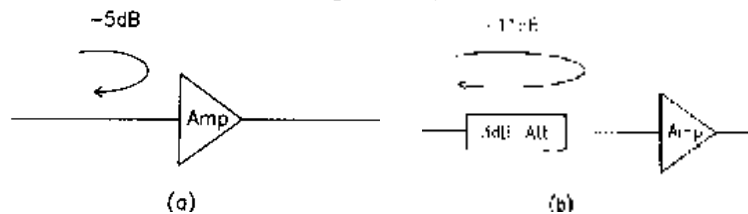
To comprehend the operational principle and purpose of Attenuator using AT-RF3030-7(Attenuator) module.

II. Theory

In brief, the attenuator can be defined as a device for reducing amplitude of the electric signal. Because the attenuator only reduces the signal amplitude without changing the signal waveform, all the input/output impedances of the attenuator should be matched with the characteristic impedance of the transmission lines. The attenuator is mainly used for three purposes in a circuit that is the level control, the stability improvement, and the matching improvement. Here, if one of the stability or the matching is improved, the other also improved together. In addition to the control of power level, the attenuator is also used for the output terminal of the oscillation circuit the LO input terminal of the mixer, the output terminal of IF, or the output terminal of the amplifier.

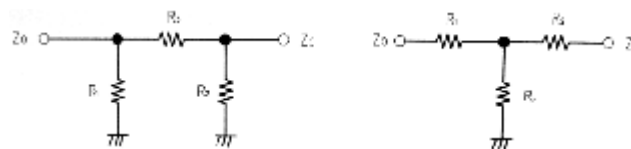
The oscillation circuit is affected more or less by the load connected to the its output. Here, the attenuator is used for reducing the effect of the load so as to improve the stability of the frequency and the output level in the oscillation circuit. In general, the attenuator of a few dB is commonly used.

In the mixer, it is used for improving the matching with Lo (Local Oscillation Circuit) and IF (Intermediate Frequency Circuit). For example, if an attenuator of 3 dB is connected to a port having bad characteristic of return loss, the return loss is improved by 6 dB.



[Fig.6-1] improving Return Loss by Attenuator

As shown in (a) of [Fig.6-1], if a 3 dB attenuator is connected to the input terminal of the amplifier having the return loss of 5 dB, the return loss is improved to 11 dB added by 6 dB. As such, by inserting in a circuit where the impedance matching is difficult, the attenuator is also used for the matching improvement through forced reducing the reflective wave. [Fig.6-2] shows the appearance and the circuit configuration of T and π -type fixed attenuator.



[Fig.6-2] π -type, T-type attenuator

When the attenuated value by an attenuator is L (dB), the resistance considering the matching can be calculated by the following equations.

π -type	T-type
$R_3 = \frac{Z_0}{2} = (10^{\frac{L}{10}} - 1) \times 10^{-\frac{L}{20}}$ $R_1 = R_2 = \frac{1}{\frac{10^{\frac{L}{10}} + 1}{Z_0(10^{\frac{L}{10}} - 1)} - \frac{1}{R_3}}$	$R_3 = \frac{2Z_0 10^{\frac{L}{20}}}{10^{\frac{L}{10}} - 1}$ $R_1 = R_2 = \frac{10^{\frac{L}{10}} + 1}{10^{\frac{L}{10}} - 1} Z_0 - R_3$

For example, the 3dB attenuator has the following calculated values. ($Z_0 = 50 \Omega$).

π -type: $R_1 = R_2 = 296.5 \Omega$, $R_3 = 17.6 \Omega$

T-type: $R_1 = R_2 = 8.6 \Omega$, $R_3 = 141.9 \Omega$

III. Measuring Instruments

Item Name	Module Name	Quantity
AT6030D	Spectrum Analyzer(tracking generator)	1
AT-RF3030-7	T/ π Attenuator	1
Accessory	SMA—SMA	2

IV. Experimental Procedures

- (1) Adjust the center frequency of the AT6030D to $f_c=1500\text{MHz}$, SPAN=3000MHz. Connect the input and output of the AT6030D Spectrum Analyzer with cable and calibrate it. Then, measure the reference level P_1 .
- (2) Connect the T-type attenuator of the AT-RF3030-7 (T/ π Attenuator) module. Connect all the lines to form a circuit as shown in [Fig.6-3]. Measure the accessing level P_2 , so the attenuated value $A= P_1- P_2$. (Record the input signal [dBm] - output signal [dBm] in the attenuated value <table 6-1>.)



[Fig.6-3] T-type attenuator Experiment

- (3) Connect the π -type attenuator of the AT-RF3030-7 (T/ π Attenuator) module. Connect all the lines to form a circuit as shown in [Fig.6-4]. Measure the accessing level P_2 , so the attenuated value $A= P_1- P_2$. (Record the input signal [dBm] - output signal [dBm] in the attenuated value in <table 3-1>.)



[Fig.6-4] Π -type attenuator Experiment

V. Results

<Table 6-1> Characteristics of T-type and Π -type attenuators

Frequency [GHz]	Input Signal		T-type Attenuator			Π -type Attenuator		
	Voltage [V]	[dBm]	Voltage [V]	[dBm]	Attenuator Value [dB]	Voltage [V]	[dBm]	Attenuator Value [dB]
1.5								
1.6								
1.7								
1.8								
1.9								

VI. Review

- (1) What is the average attenuated value of the used attenuator in the range of 1.7GHz-1.9GHz? In other words, which decibel (dB) attenuator is it?
- (2) Explain the definition and principle of the attenuator.
- (3) Design a 10dB T-type Attenuator.

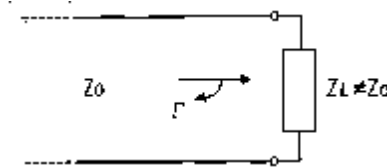
7. Theory and Experiment of Matched, Unmatched

I. Objective

To measure the reflected power in an unmatched circuit (AT-RF3030-5) whose one end is terminated by a certain load, and to learn how to match it by means of the $\lambda/4$ converter and the parallel stub (AT-RF3030-6).

II. Theory

1. Unmatching and Reflection



[Fig.7-1] Reflection in Transmission Lines

As shown in [Fig.7-1], when the characteristic impedance Z_0 is different from the impedance of the load connected to the terminal, part of the incident wave is reflected at the load and the standing wave is generated in the transmission lines.

The voltage reflection coefficient is

$$\Gamma = \frac{V_r}{V_i} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Where, V_r is the amplitude of the reflected voltage, and V_i is the amplitude of the incident voltage.

In this case, the ratio of the incident power to the reflected power is

$$|\Gamma|^2 = \frac{P_r}{P_i}$$

Where, P_r is the power of the reflected wave, and P_i is the power of the incident wave.

When the load at the terminal of the transmission line is same with the characteristic impedance, the transmission line is called matched. In this case, the reflection does not occur and all the incident power is transmitted to the load. That is, if $Z_L = Z_0$, $\Gamma = 0$ and $P_r = 0$.

Problems caused by the reflection are as follows.

- Generating the standing wave in the transmission line
- Loss of the transmitting power
- Possible oscillation due to the circuit instability
- Damage of sensitive elements
- Causing arc discharge in the high-power circuit
- Undesirable interference with other signal

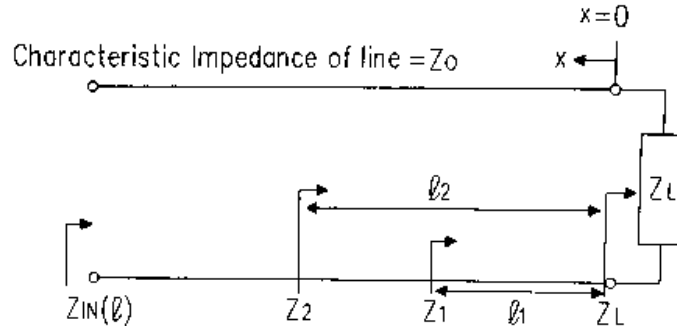
As described above, when the reflection occurs, system performance is degraded and many problems are caused. Therefore, it is very important to protect the element and minimize the reflection by matching the load in the input/output lines transmitting the microwave energy in the system.

2. Impedance Matching

When the light proceeds in the air and encounters a medium, part is penetrated and the other is reflected. In the same manner, when the electromagnetic wave proceeds along the line having the characteristic impedance Z_0 and encounters the transmission line having different impedance or the circuit, part is

transmitted and the other is reflected. As such, a certain condition should be satisfied in order to transmit the maximum power to the load without generating the reflective wave. A case where the condition is satisfied is called the impedance matching. When the characteristic impedances are same, there occurs no reflections regardless of structures of the line or circuit. That is, when the coaxial line and the microstrip line, each having a characteristic impedance of 50Ω are connected, there is no reflection.

(1) Impedance change according to the length of the transmission line



[Fig.7-2] Load Impedance Change according to the length of Transmission Line

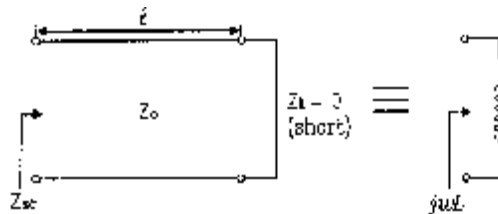
As shown in [Fig.7-2], when observing a certain load with connected by the transmission line, it can be seen that the impedance varies according to the length of the transmission line. The load at $x=0$ is Z_L , but as x increases to l_1, l_2 , $Z_L \neq Z_1 \neq Z_2 \neq Z_{IN}$. Even if the load impedance Z_L is pure resistance, Z_2, Z_3 are complex numbers. (Combined type of the resistance and the capacitance or the inductance components) In other words, the impedance can be changed to the desired value by adding the transmission line to the load and adjusting its length. For reference, such change of the impedance is repeated every $\lambda/2$ of the line length.

(2) Impedance of Short or Open Transmission Line

When the load at the terminal of the transmission line is shorted or opened, the overall impedance becomes the capacitive or inductive load according to the length of the transmission line. As shown in [Fig.7-3], when the impedance Z_{sc} is measured at a point of length l away after shorting the terminal of the transmission line having a characteristic impedance of Z_0 , $Z_{sc} = jZ_0 \cdot \tan(l) (=j \omega L)$.

However, the length l should be $0 < l < \lambda/4$ and $= 2\pi/\lambda$.

That is, Z_{sc} can play a role of an inductor ($L = Z_0 \cdot \tan(l)/\omega$). As such, an element which has an inductance component by using the transmission line is called the distributed constant element.

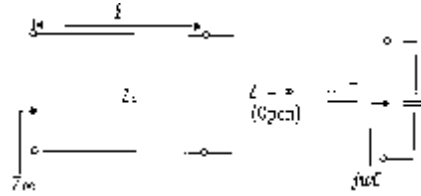


[Fig.7-3] Impedance of Short Transmission Line

In the same manner, as shown in [Fig.7-4], when the impedance Z_{oc} is measured at a point of length l

away after opening the terminal of the transmission line, $Z_{oc} = \frac{-j}{\omega C} = -j Z_0 \cdot \cot(l)$. That is, Z_{sc} can

play a role of a capacitor($C=1/(Z_0 \cdot \cot(\ell))$).

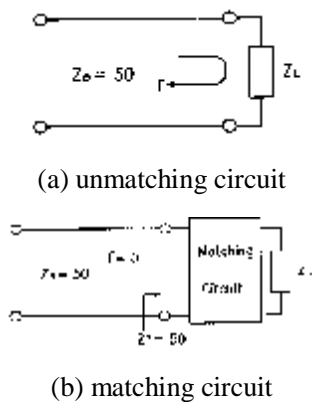


[Fig.7-4] Impedance of Open Transmission Line

(3) Impedance Matching Using Stub

As shown in [Fig.7-5], if the characteristic impedance $Z_0=50$ when the load impedance is $Z_L = R_L + jX_L$ the reflection occurs. In this case, if setting $Z_T = 50$ by inserting a matching circuit as shown in Fig. (b), $Z_T = Z_0$ So that the reflection coefficient becomes $r' = 0$ and the matching is done. The matching circuit uses lumped and distributed constant elements, and also may use the complex form of the two elements. The distributed constant element has small loss and its size can be reduced, while it is difficult to find an element having a desired value.

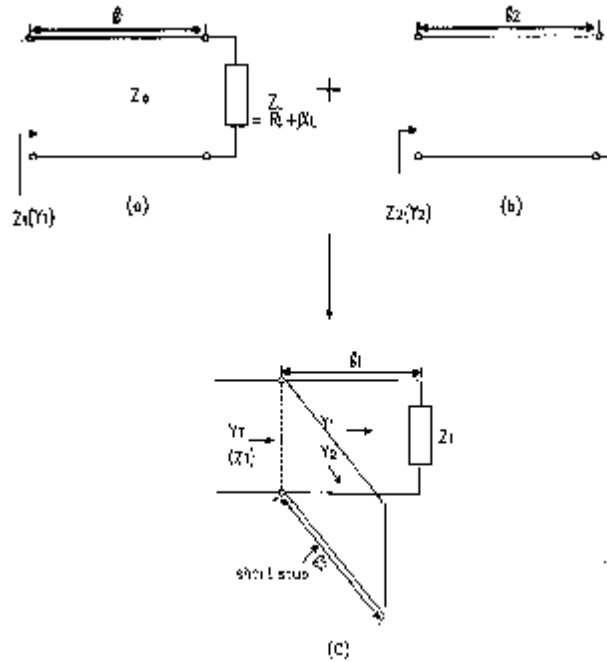
For an instance of matching, adjust the length of the transmission line so that a new impedance of $50 + jX_L'$ can be obtained by adding a transmission line when $Z_L = R_L + jX_L$. Then, if $-jX_L'$ is connected again to the circuit in serial, the overall impedance becomes $Z_T = 50 + jX_L' - jX_L' = 50$ and the matching is possible. Because connecting the circuit in serial has a practical difficulty, generally the matching is done by connecting in parallel.



[Fig.7-5] Matching/Unmatching Circuit

Now, the design method for a matching circuit shown in (b) of [Fig.7-5] by using the transmission line will be explained. When the load impedance of the circuit for matching with Z_0 is $Z_L = R_L + jX_L$, connect the transmission line as shown in (a) of [Fig.7-6] and adjust the length ℓ in such a way that the admittance Y_1 becomes $Y_1 = 1/Z_1 = 1/50 + jB_1$.

Independently, as shown in Fig.(b), adjust the length ℓ_2 in such a way that the admittance Y_2 of the transmission line having a short (or open) terminal becomes $Y_2 = 1/Z_2 = -jB_1$.



[Fig.7-6] Matching Using Stub

Connect Fig. (a) and (b) in parallel as shown in Fig. (c). As such, the transmission line connected in parallel (as a distributed constant element) is called a stub. In this case, the overall admittance Y_T is

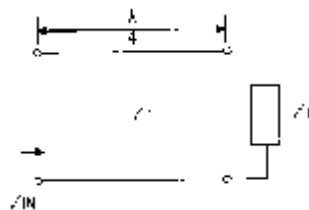
$$Y_T = Y_1 + Y_2 = \left(-\frac{1}{50} + jB_1\right) + (-jB_1) = \frac{1}{50}$$

Therefore, the overall impedance Z_T becomes

$$Z_T = \frac{1}{Y_T} = 50 (= Z_0)$$

and the matching is possible. Matching with this method is called the parallel stub matching. (But, it has a disadvantage of having very narrow bandwidth.)

(4) Matching Using $\lambda/4$ transmission line



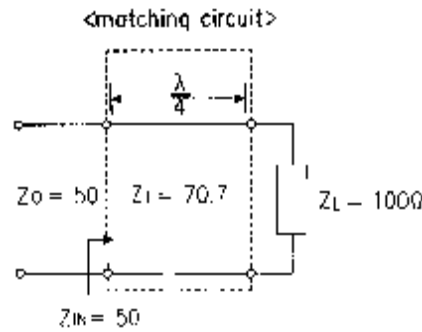
[Fig.7-7] Impedance of $\lambda/4$ Transmission Line

As shown in [Fig.7-7], if the load impedance Z_L is connected by a transmission line having a length of $\lambda/4$, the overall impedance Z_{IN} is

$$Z_{IN} = \frac{Z_1^2}{Z_L}$$

By using this property, the resistive load can be matched. Here, Z_1 means the impedance of the $\lambda/4$ transmission line. For matching Z_{IN} to Z_0 , Z_1 is determined by

$$Z_1 = \sqrt{Z_{IN} \cdot Z_L}$$



[Fig.7-8] Matching Using $\lambda/4$ Transmission Line

If $Z_L=100\ \Omega$, for matching the line of $Z_0=50\ \Omega$, Z_1 is determined by

$$Z_1 = \sqrt{50 \cdot 100} = 70.7$$

That is, if the characteristic impedance of the $\lambda/4$ line is $Z_1=70.7\ \Omega$, the overall impedance is matched to $Z_{IN}=50\ \Omega$.

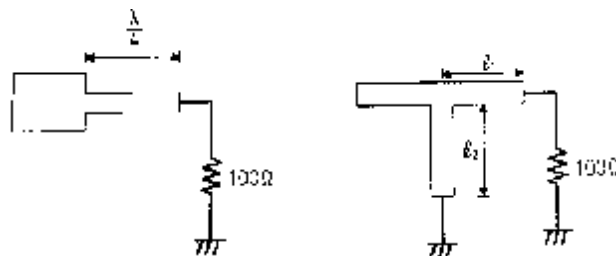
Verifying the result, when $Z_1=70.7\ \Omega$, Z_{IN} becomes

$$Z_{IN} = \frac{70.71^2}{100} = 50$$

and the circuit is matched.

Such a method is called matching using the $\lambda/4$ transmission line. In order to match an arbitrary complex number load instead of the resistive load, connect another transmission line first to convert the complex number to the resistive load as shown in [Fig.7-2], then perform the $\lambda/4$ matching. (However, it has a disadvantage that the bandwidth becomes very narrow.)

[Fig.7-9] shows an example of matching by means of the microstrip transmission line.



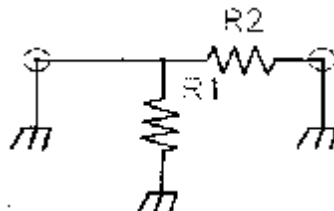
Quarter wave Transformer

Short Stub

[Fig.7-9] Matching Circuit Using Microstrip Transmission Line

(5) Resistance Impedance Transformer

The circuit shown in [Fig.7-10] is a input/output matching circuit using the resistor. This circuit can be assumed that the minimum amount of attenuation is achieved by performing an appropriate matching from inserting the attenuator between different impedance terminals. The characteristic of the resistance impedance transformer is that it can match the broadband from the DC to the ultrahigh frequency. As a result, it can be mainly used for the calibration of a measuring instrument which requires the wide frequency range. However, it can be used in the broadband, while the insertion loss becomes larger because it uses the resistor.



[Fig.7-10] Broadband Resistance Impedance Transformer

[Fig.7-10] is a modified type of the π -type attenuator, and the resistors symmetrically arranged in the π

-type attenuator are removed. Because the input and output impedance of the matching element are not symmetric, two resistors positioned at both sides should not be symmetric.

III. Measuring Instruments

Item	Module Name	Quantity
AT6030D	Spectrum Analyzer(tracking generator)	1
AT-RF3030-5	Unmatched Load	1
AT-RF3030-6	Matched Load	1
AT-RF3030-23	microstrip line	1
Accessory	SMA-SMA	2

IV. Experimental Procedures

- (1) Adjust the frequency of the AT6030D on some point of $f_c=100\text{MHz}-3000\text{MHz}$, SPAN=0MHz, Connect the input and output of the AT6030D Spectrum Analyzer with cable and calibrate it.
- (2) Connect all the lines to form a circuit as shown in [Fig.7-11].That is, connect the output of the AT6030D to the input of the AT-RF3030-23(microstrip line) module, connect the output of the AT-RF3030-23(microstrip line) module to the AT-RF3030-6(Matched Load), connect the output of the slider to the input of the AT6030D, move the slider, and then, observe the changes of the Spectrum line, and measure the VSWR of the AT-RF3030-6(Matched Load).



[Fig.7-11] connect the matched load

- (3) Repeat the step (2), measure the VSWR when the open and short of the load.
- (4) Change the AT-RF3030-6(Matched Load) to the AT-RF3030-6(Unmatched Load), and then, repeat the steps (2), (3). The two measure methods are same, just the VSWR of the AT-RF3030-6(Unmatched Load) is bigger. When the VSWR is more than 5, measure with the method of the double the minimum, obtain the index d at two times the minimum distance between two points and waveguide wavelength, and then, calculate the VSWR as following formula,

$$VSWR = \sqrt{1 + \frac{1}{\sin^2\left(\frac{pd}{lg}\right)}}$$

V. Review

- (1) Identify the relationship between F and the return loss. ($-20\log\Gamma = \text{Return Loss [dB]}$)
- (2) Describe advantages and disadvantages of matching by comparing the stub matching with the

matching using the $\lambda/4$ transmission line.

- (3) When the load impedance is $50\ \Omega$, matching using the $\lambda/4$ transmission line is tried. What is the characteristic impedance and length of the $\lambda/4$ transmission line? (Here, the frequency is 1 GHz and the relative dielectric constant ϵ_r is 1.)
- (4) Calculate the load resistance (expected to be $100\ \Omega$) by using the measured reflection return loss Γ . What is the accuracy, and what is the reason if the accuracy is not good?
- (5) $10\log_{10}P$ is used in a calculation for converting the power to value in dB, and $20\log_{10}P$ is used for converting the return loss to value in dB. Why are the coefficients used in these equations different?

8. Theory and Experiment of Measuring

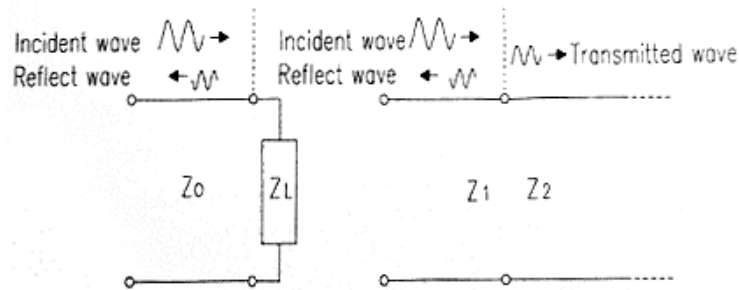
Standing Wave Ratio

I. Objective

To comprehend the reflected wave and the standing wave by measuring the reflection coefficient and wavelength and the standing wave formed in the transmission line when a terminal of the microstrip line is short, open, or matched.

II. Theory

When the transmission line is infinitely placed as shown in [Fig.8-1] (a), only the traveling wave exists in the line when a microwave signal is applied. Or, all the incident waves are transmitted to the load and only the traveling wave exists in the line when the characteristic impedance Z_0 (normally a line of 50Ω is used for the microwave) and the load impedance Z_L of the transmission line are same ($Z_L = Z_0$) as shown in figure (b). Such a state is called a matching state.



[Fig.8-1] Electric Wave in Matched Transmission Line

However, if the load impedance and the characteristic impedance of the line are not same ($Z_L \neq Z_0$) as shown in [Fig.8-2] (a), a part is reflected and the other part is transmitted to the load. It is same when a transmission line of the characteristic impedance Z_1 is connected to an infinite transmission line of different impedance Z_2 as shown in figure (b), which is called a mismatched state.

In a mismatched circuit, the ratio of incident wave to reflected wave of the voltage, that is the voltage reflection coefficient Γ (Gamma) is

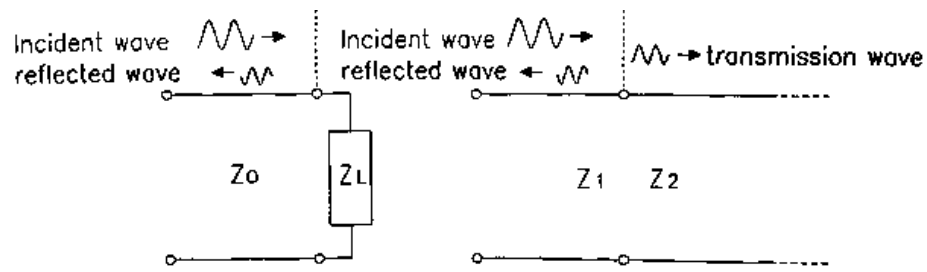
$$\Gamma = \frac{V_r}{V_i} = \frac{Z_L - Z_0}{Z_L + Z_0} \quad \left(= \frac{Z_L - Z_0}{Z_L + Z_0} \right)$$

Where, V_r is size of the reflected voltage, V_i size of the incident voltage, Z_0 the characteristic impedance of the line, and Z_L the load impedance.

Here, the ratio of incident power to reflected power is

$$|\Gamma|^2 = \frac{P_r}{P_i}$$

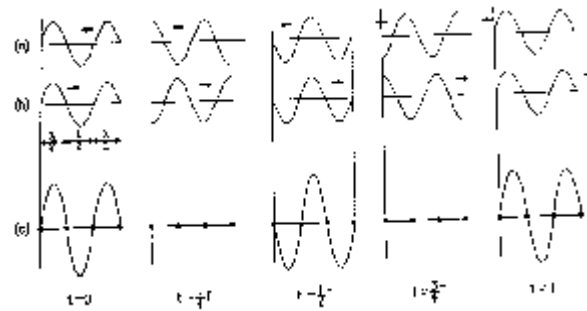
where P_r is power of the reflected wave and P_i indicates power of the incident wave.



[Fig.8-2] Electric Wave in Mismatched Transmission Line

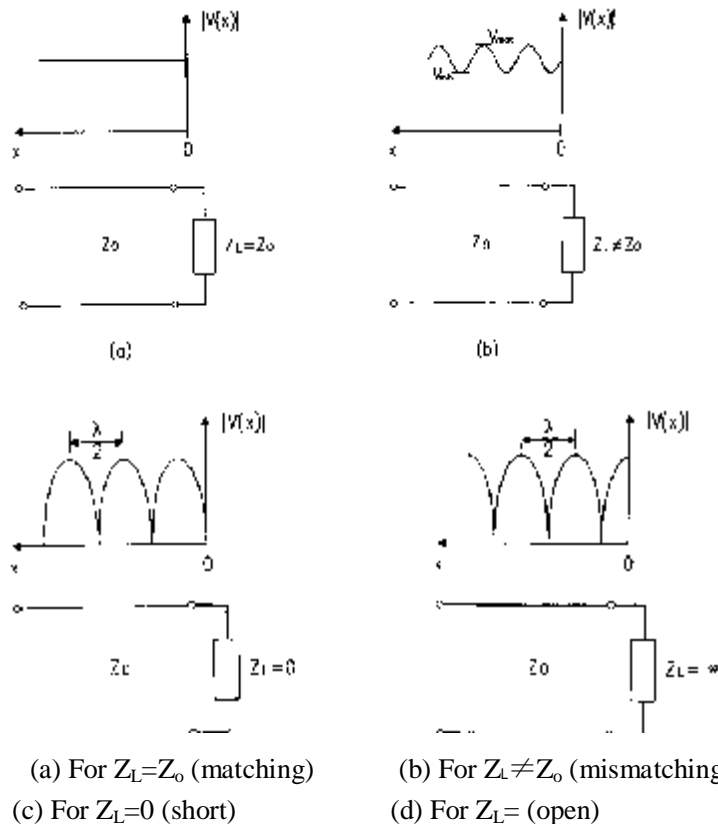
The incident and the reflected waves simultaneously exist in the line, but actually, they are observed as a mixed form. [Fig.8-3] shows a process forming the standing wave from mixing two waves in a case of perfect reflection, which is $\Gamma = -1$ due to the short of the load.

In the figure, (a) is the reflected wave, (b) is the incident wave, and (c) is a waveform resulting from mixing the reflected and incident waves. As time goes on, the size changes but intersections with x-axis are fixed.



[Fig.8-3] Generating Process of Standing Wave from Incident and Reflected Waves

As such, a waveform, which seems to stand still by mixing the incident and reflected waves while they simultaneously exist in the transmission line, is called the standing wave.



(a) For $Z_L = Z_0$ (matching) (b) For $Z_L \neq Z_0$ (mismatching)
(c) For $Z_L = 0$ (short) (d) For $Z_L = \infty$ (open)

[Fig.8-4] Effective Value Change of Standing Wave in Transmission Line

When the load impedance and the characteristic impedance of the transmission line are matched, the voltage size of the standing wave occurring in the line is constant as shown in [Fig.8-4] (a). However, when the line and the load are mismatched as shown in (b) the incident and the reflected waves simultaneously exist in the transmission line and the standing wave occurs by mixing two waves. The standing wave has a period of $\lambda/2$, and the difference between the maximum and the minimum points of the wave becomes larger as the reflection larger. Not illustrated in the figure, but the standing wave can also occur for the current.

The ratio of maximum to minimum of the standing wave is called VSWR (Voltage Standing Wave Ratio, ρ) and defined as follows.

$$VSWR = \rho = \frac{V_{\max}}{V_{\min}} = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (VSWR=1 \sim \infty)$$

In general, SWR (Standing Wave Ratio) means VSWR (Voltage Standing Wave Ratio) and is a real number value having no unit. Or, the size of the reflection coefficient can be known from the VSWR value.

$$|\Gamma| = \frac{VSWR-1}{VSWR+1} \quad (\Gamma=-1 \sim 1)$$

In fact, SWR is a same phenomenon as the reflection coefficient, known as the degree of reflection of the load. Matched load has a reflection coefficient of 0 and VSWR of 1. The standing wave is mainly expressed as a non-dimensional number and has a value from 1 to ∞ . Often, VSWR is expressed in dB as follows.

$$VSWR [dB] = 20 \log_{10} VSWR$$

The reflection coefficient $\Gamma = -1$ when the load is short as shown in (c), while $\Gamma = 1$ when the load is open as shown in (d). In both cases, the perfect reflection occurs and the VSWR value becomes ∞ . For the short, the voltage in the load becomes minimum (at a position of $x=0$), while it becomes maximum for the open.

The standing wave occurring in the line is repeated in the microstrip line with a period of half of the guided wavelength ($\lambda_g/2$). Therefore, the guided wavelength can be obtained by measuring the interval between the minimum or maximum values, which can be used for obtaining the wavelength of That is, the frequency of the incident microwave can be calculated. If the frequency is known, the effective dielectric constant of the microstrip line can be obtained from the guided wavelength. That is,

$$\lambda_0 = \frac{c \text{ (speed of light)}}{f} = \frac{3 \times 10^8}{f} [m]$$

$$\epsilon_{eff} = \left(\frac{\lambda_0}{\lambda_g} \right)^2$$

<Example 8-1> When the interval between the maximum (or minimum) values of the measured voltage is 54 mm, calculate the followings.

- ① What is the guided wavelength λ_g (wavelength in the microstrip line)?
- ② What is the wavelength λ_0 in free space ?
- ③ In such a case, what is the frequency f ?

① $\lambda_g = 2 \times 54 \text{ mm} = 108 \text{ mm}$

② $\lambda_0 = \lambda_g \times \sqrt{\epsilon_{eff}}$

For the Duroid 6002 substrate having a characteristic impedance of 50Ω .

The effective dielectric constant $\epsilon_e 2.387 (\approx 2.4)$.

$$\lambda_0 = 2 \times 54 \text{ mm} \times \sqrt{2.387} = 167 \text{ mm} = 0.167 \text{ m}$$

$$\textcircled{3} \quad \frac{c(\text{speed of light})}{\lambda_0(\text{wavelength})} = \frac{3 \times 10^8}{0.167} = 2 \times 10^9 \text{ Hz} = 2 \text{ GHz}$$

III. Measuring instruments

Item	Module Name	Quantity
AT6030D	Digital Spectrum Analyzer	1
AT-RF3030-23	microstrip line	1
Accessory	SMA 50 Ω Load	1
Accessory	SMA Short	1
Accessory	SMA Open	1
Accessory	SMA-SMA	2

IV. Experimental Procedures

- (1) Adjust the frequency of the AT6030D on some point of $f_c=100\text{MHz}-3000\text{MHz}$, SPAN=0MHz, Connect the input and output of the AT6030D Spectrum Analyzer with cable and calibrate it.
- (2) Connect all the lines to form a circuit as show in [Fig.8-5]. (the slider distance of the microstrip line more than 170mm).



[Fig.8-5] Connect 50 Ω load experiment

- (3) Connect the 50 Ω Load to the microstrip line, move the slider module, the VSWR is less than 1.05 displaying on the MMIC Amplifier.
 - (4) Connect Open to the microstrip line, move the slider module, the VSWR is more than 10 displaying on the AT6030D.
 - (5) Connect Short to the output of the microstrip line, then record the peak value and its position measured with slowly moving the probe from the left to the right ends. Here, take care to apply constant force to the probe during moving it. The VSWR is more than 10 displaying on the AT6030D, further more, the maximum position of the slider module just is the minimum position of the slider module in shorting.
- ※ Note: Use an average value because errors can occur during the measurements. Theoretically, VSWR is ∞ , but due to the characteristics of the instrument, it is hard to measure the minimum voltage and the minimum point. Therefore, obtaining a huge standing wave ratio is satisfactory.

V. Review

- (1) Is the measured standing wave ratio large enough as expected when the load is short and open?

Otherwise, what is the reason?

- (2) Calculate the effective dielectric constant ϵ_e of the microstrip line. (Here, the characteristic impedance of the line $Z_0=50$, the relative dielectric constant of the dielectric substance $\epsilon_r = 2.4$, thickness $h=0.063\text{inch}$, and $l=6.69\text{inch}$)
- (3) When finding the maximum/minimum point by moving silder module for the standing wave ratio side to side, what is the reason for a case that the voltage at the measured maximum/minimum point is different as the probe moves to the signal source?
- (4) Calculate inversely the size of Γ from the standing wave ratio obtained. In addition, the load impedance can be obtained from the reflection coefficient Γ . When the characteristic impedance of the line Z_0 is $50\ \Omega$, what is Z_L ?

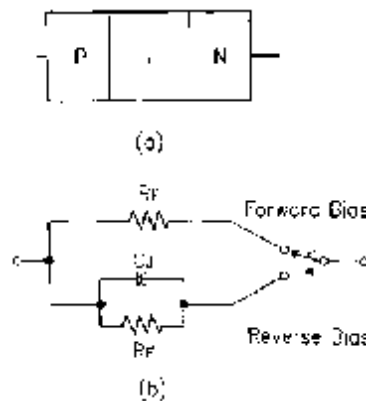
9. Theory and Experiment of PIN Diode Switch

I. Objective

To comprehend the PIN diode switch, which turns on /off the signal or connect the microwave signal from one transmission line to another.

II. Theory

The microwave switch can be divided into the mechanical and the electric switches. The electric switch mainly uses the PIN diode. The PIN diode is commonly used not only for the switch, but also for the variable attenuator, the limiter, and the modulator.



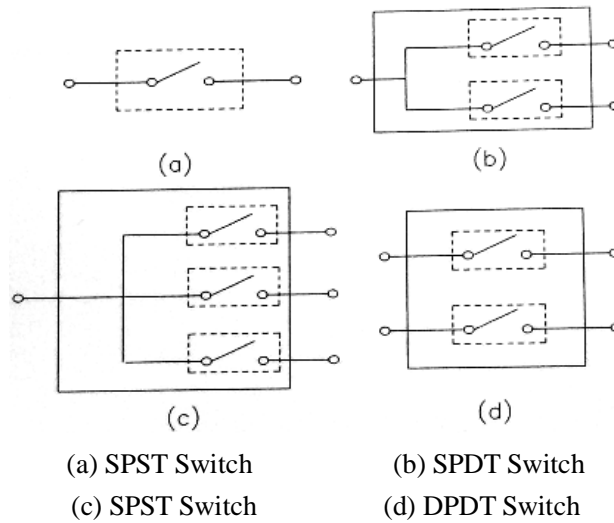
(a) PIN Diode (b) Equivalent Circuit of PIN Diode

[Fig.9-1] Structure of PIN Diode

The PIN diode is formed by a junction of the semiconductor I (Intrinsic) area having high resistance with lightly doped between the PIN junction, as shown in [Fig.9-1] (a).

When the forward current flows through the diode, the electron and the hole are inserted to the I area but they cannot recombine entirely, so that part of them kept as the stored charges. Due to these charges, the resistance of the I area becomes lower. It shows the same rectifying characteristics as the common diode up to 100 MHz, but shows the characteristics of the variable resistor at higher frequency. This is due to time necessary for passing the stored charges and the I area, and it shows the resistance of about 1 at the short state according to the forward DC voltage.

The equivalent circuit of the PIN diode at the forward and reverse bias conditions is shown in figure (b) with excluding the inductance of the lead and the parasitic capacitance of the package. R_F is the equivalent resistor for the forward voltage, has a value of 0~1, and decreases as the forward current increases. R_R is the reverse resistor having a value of about 10~1. C_j is the reverse junction capacitance having a value of 0.1-2 pF, and decreases as the reverse voltage increases.



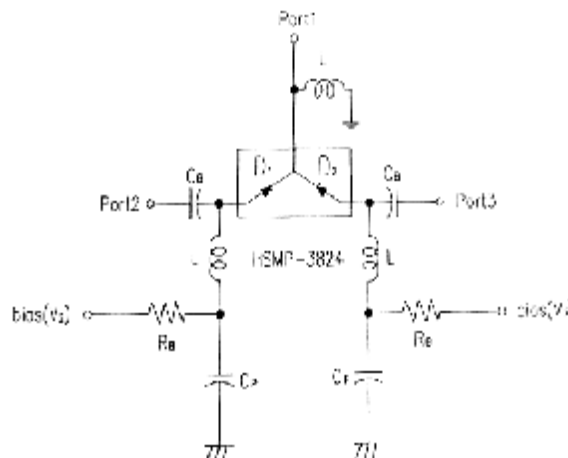
[Fig.9-2] Various Switches

[Fig.9-2] shows various switches using the PIN diode. A portion shown as a dashed line in the figure indicates the PIN diode. Figure (a) is a switch which connects or disconnects one signal to or from another port, and called the SPST (Single Pole Single Through) switch. Figure (b) is the SPDT (Single Pole Double Through) switch, and according to the purpose, various switches such as the SP3T and the DPDT (Double Pole Double Through) switches as shown in figure (c) and (d) can be formed. [Fig. 67] shows the circuit diagram for the SPDT switch using the PIN diode, where the path is selected according to two biased voltages V_2 and V_3 . The element is **HSMP-3824** of Hewlett Packard Ltd., which has a common cathode type of two diodes in one package.

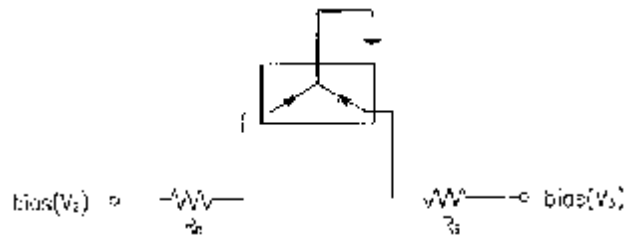
The forward bias is supplied through the resistor R_B for controlling the forward current, so that it prevents the PIN diode from damaging due to the excess current. In such a case, the current flows through $R_B \rightarrow L \rightarrow D1 \rightarrow L$ to the ground, and the blocking capacitor C_B is connected to prevent from flowing to each port. C_P is the bypass capacitor to remove the AC noise. Therefore, if all the capacitors in [Fig.9-3] are opened and the inductor is short, the DC equivalent circuit as shown in [Fig.9-4] (a) can be obtained.

On the contrary, if all the capacitors are short and the inductor is opened, the AC equivalent circuit as shown in figure (b) can be obtained.

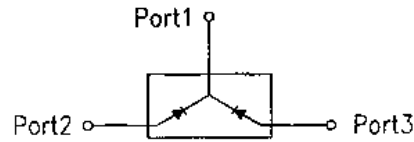
When the forward and the reverse voltages are respectively applied to V_2 and V_3 , D1 turns ON and D1 turns OFF, so that the signal from port 1 to port 2 is transmitted while the signal is not transmitted to port 3. Of course, port 2 and port 3 are isolated. Or, in the opposite way, if the reverse and the forward voltages are respectively applied to V_2 and V_3 , the signal from port 1 to port 3 is transmitted while the signal is not transmitted to port 2.



[Fig.9-3] Circuit Diagram of SPOT Switch

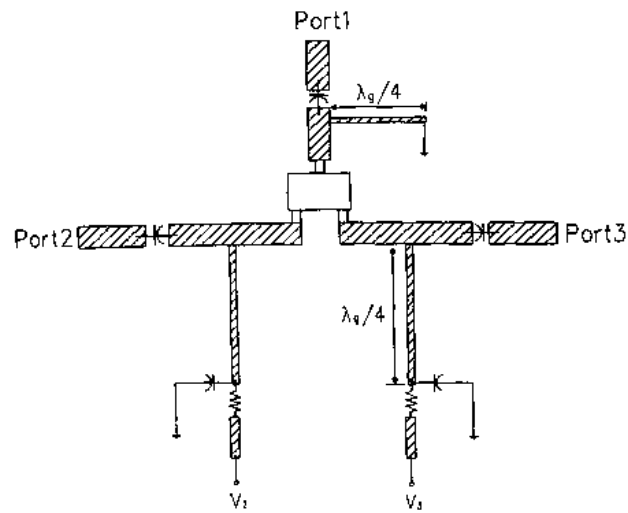


(a) DC Equivalent Circuit



(b) AC Equivalent Circuit

[Fig.9-4] DC and AC Equivalent Circuit of Switch



[Fig.9-5] Switch Using Microstrip Line

The PIN diode SPDT switch shown in [Fig.9-5] is a real circuit formed by inserting the diode in serial to the microstrip line. The DC bias (V_2 and V_3) is supplied to the $\lambda_g/4$ of higher impedance. In the microwave signal point of view, one end of this line has an impedance of 0 (grounded), but an impedance of ∞ at the $\lambda_g/4$ point. Therefore, the DC bias is supplied to the diode without affecting the microwave line. The following figure shows the specifications of the element used in the PIN diode switch module.

Surface Mount PIN Diodes

Technical Data

HSMP-38XX and HSMP-48XX Series

Features

- Diodes Optimized for:
Low Current Switching
Low Distortion Attenuating
Ultra-Low Distortion
Switching
Microwave Frequency
Operation
- Surface Mount SOT-23 and
SOT-143 Packages
Single and Dual Versions
Tape and Reel Options
Available
- Low Failure in Time (FIT)
Rate¹⁾

Note:

1. For more information see the
Surface Mount PIN Reliability Data
Sheet.

Description/Applications

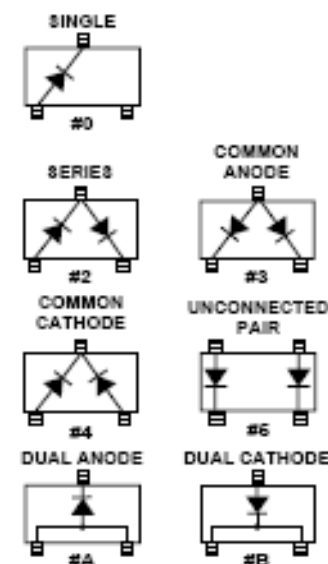
The HSMP-380X and HSMP-381X series are specifically designed for low distortion attenuator applications. The HSMP-382X series is optimized for switching applications where ultra-low resistance is required. The HSMP-3880 switching diode is an ultra low distortion device optimized for higher power applications from 50 MHz to 1.5 GHz. The HSMP-389X series is optimized for switching applications where low resistance at low current and low capacitance are

required. The HSMP-48XX series are special products featuring ultra low parasitic inductance in the SOT-23 package, specifically designed for use at frequencies which are much higher than the upper limit for conventional SOT-23 PIN diodes. The HSMP-4810 diode is a low distortion attenuating PIN designed for operation to 3 GHz. The HSMP-4820 diode is ideal for limiting and low inductance switching applications up to 1.5 GHz. The HSMP-4890 is optimized for low current switching applications up to 3 GHz.

The HSMP-386X series of general purpose PIN diodes are designed for two classes of applications. The first is attenuators where current consumption is the most important design consideration. The second application for this series of diodes is in switches where low cost is the driving issue for the designer.

The HSMP-386X series Total Capacitance (C_T) and Total Resistance (R_T) are typical specifications. For applications that require guaranteed performance, the general purpose HSMP-383X series is recommended. For low distortion

Package Lead Code Identification



attenuators, the HSMP-380X or -381X series are recommended. For high performance switching applications, the HSMP-389X series is recommended.

A SPICE model is not available for PIN diodes as SPICE does not provide for a key PIN diode characteristic, carrier lifetime.

Absolute Maximum Ratings¹⁾ $T_A = 25^\circ\text{C}$

Symbol	Parameter	Units	Absolute Maximum
I_f	Forward Current (1 ms Pulse)	Amp	1
P_t	Total Device Dissipation	mW ²⁾	250
P_{IV}	Peak Inverse Voltage	—	Same as V_{BR}
T_j	Junction Temperature	$^\circ\text{C}$	150
T_{STG}	Storage Temperature	$^\circ\text{C}$	-65 to 150

Notes:

1. Operation in excess of any one of these conditions may result in permanent damage to this device.
2. CW Power Dissipation at $T_{LEAD} = 25^\circ\text{C}$. Derate to zero at maximum rated temperature.

PIN Attenuator Diodes

Electrical Specifications $T_A = 25^\circ\text{C}$ (Each Diode)

Part Number HSMP-	Package Marking Code ^[1]	Lead Code	Configuration	Nearest Equivalent Axial Lead Part No. 5082-	Minimum Breakdown Voltage V_{BR} (V)	Maximum Series Resistance R_S (Ω)	Maximum Total Capacitance C_T (pF)	Minimum High Resistance R_H (Ω)	Maximum Low Resistance R_L (Ω)
3800	D0	0	Single	3080	100	2.0	0.37	1000	8
3802	D2	2	Series						
3804	D4	4	Common Cathode						
3810	E0	0	Single	3081	100	3.0	0.35	1500	10
3812	E2	2	Series						
3813	E3	3	Common Anode						
3814	E4	4	Common Cathode						
Test Conditions					$V_R = V_{BR}$ Measure $I_R \leq 10 \mu\text{A}$	$I_F = 100 \text{ mA}$ $f = 100 \text{ MHz}$	$V_R = 50 \text{ V}$ $f = 1 \text{ MHz}$	$I_F = 0.01 \text{ mA}$ $f = 100 \text{ MHz}$	$I_F = 20 \text{ mA}$ $f = 100 \text{ MHz}$

Typical Applications for Multiple Diode Products

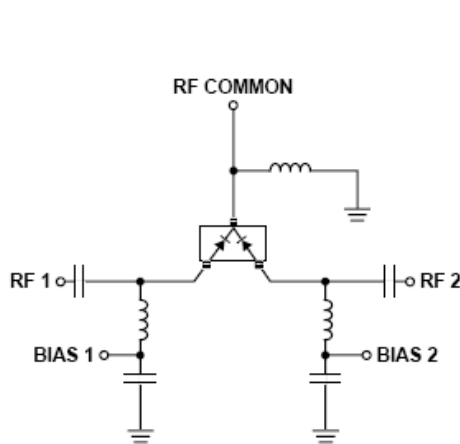


Figure 22. Simple SPDT Switch, Using Only Positive Current.

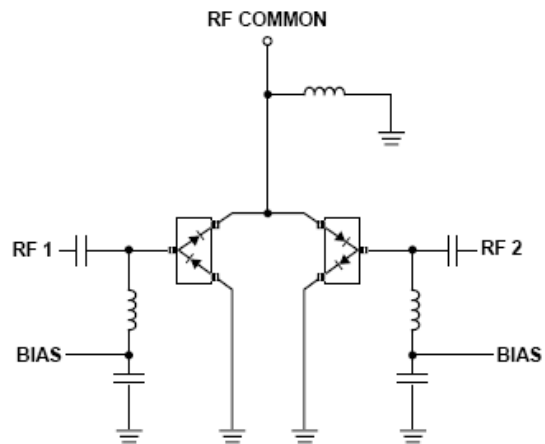


Figure 23. High Isolation SPDT Switch, Dual Bias.

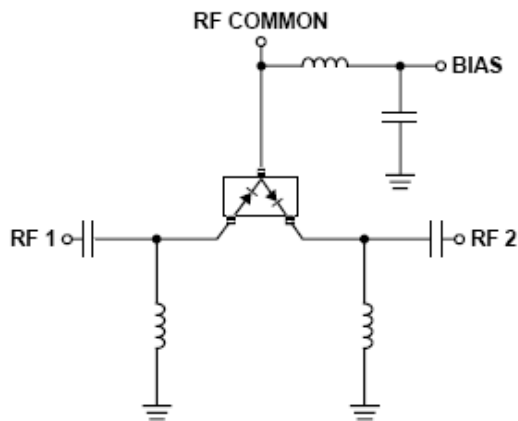


Figure 24. Switch Using Both Positive and Negative Bias Current.

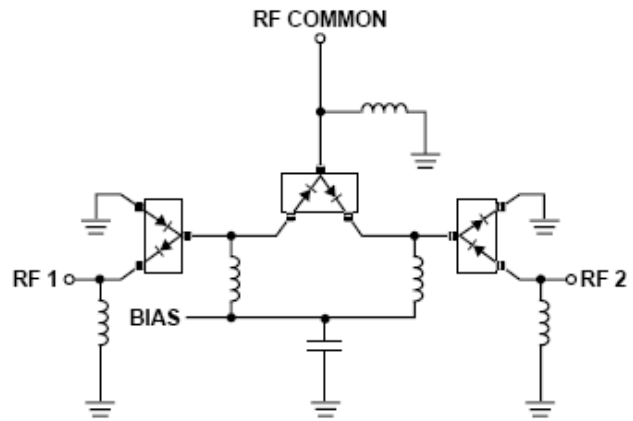


Figure 25. Very High Isolation SPDT Switch, Dual Bias.

Typical Applications for Multiple Diode Products

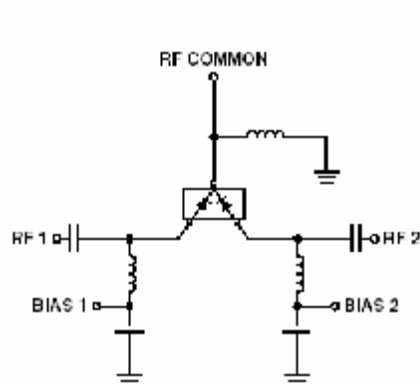


Figure 7. Simple SPDT Switch, Using Only Positive Current.

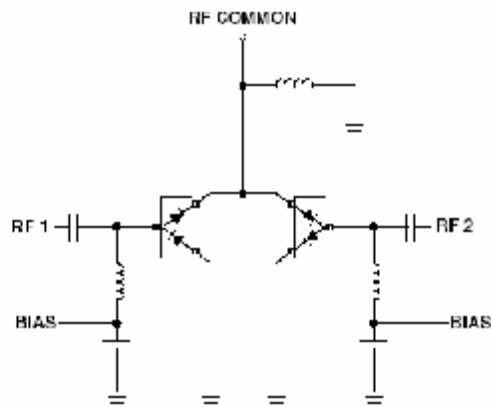


Figure 8. High Isolation SPDT Switch, Dual Bias.

III. Measuring Instruments

Item	Module Name	Quantity
AT6030D	Spectrum Analyzer(tracking generator)	1
TPR3002-3C	DC Power	1
AT-RF3030-10	PIN Diode Switch	1
Accessory	SMA 50 Ω Load	1
Accessory	SMA-SMA	2
Accessory	Banana- SMB	1

IV. Experimental Procedures

- (1) Adjust the frequency of the AT6030D on some point of $f_c=100\text{MHz}-3000\text{MHz}$, SPAN=0MHz, Connect the input and output of the AT6030D Spectrum Analyzer with cable and calibrate it.
- (2) Open the TPR3002-3C (DC Power) and adjust the output to zero.
- (3) Connect all the lines to form a circuit as show in [Fig.9-6]. Connect the output of the AT6030D to the port 1 of the AT-RF3030-10(PIN Diode Switch) module, connect the port 2 of the AT-RF3030-10(PIN Diode Switch) module to the output of the AT6030D, connect the 50 Ω Load to the port 3 of the AT-RF3030-10(PIN Diode Switch) module.



[Fig.9-6] Measuring Characteristic of PIN Diode Switch

- (4) Open the controlling voltage of the port 4 $V_c=5\text{V}$, that is, $V_5=5\text{V}$, input from port 2.
- ※Note: The voltage can't over 5V, it will damage the AT-RF3030-10(PIN Diode Switch).
- (5) Connect the input of the AT6030D to the port 3 of the AT-RF3030-10(PIN Diode Switch) module,

connect the $50\ \Omega$ Load to the port 2 of the AT-RF3030-10(PIN Diode Switch) module. Open the controlling voltage of the port 5 of the AT-RF3030-10(PIN Diode Switch) module madding $V_c=5V$, input from port 3. When the voltage of the port 5 is invariability, connect the input of the AT6030D to the port 2 of the AT-RF3030-10(PIN Diode Switch) module, connect the $50\ \Omega$ Load to the port 3 of the AT-RF3030-10(PIN Diode Switch) module, and then, measure the isolation coefficient.

V. Review

- (1) What is the reason for increasing (narrowing the bandwidth) the impedance of the $\lambda/4$ line for the DC bias in AT-RF3030-10(PIN Diode Switch) ?
- (2) Referring to the experimental results about the transmission and the isolation of the switch reasonable?
- (3) Explain the principle of the switch composed of the microstrip line.

10. Theory and Experiment of Wilkinson Power Divider

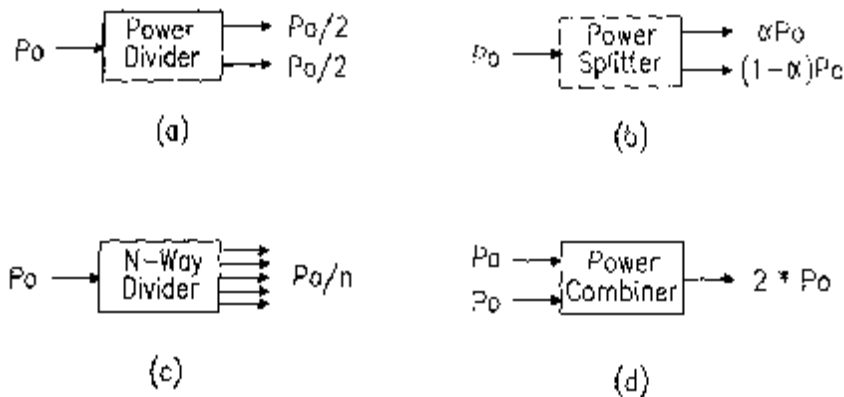
I. Objective

To comprehend the operational principle of the Wilkinson power divider and the difference between the coupler and the divider through the power division of the Wilkinson power divider.

II. Theory

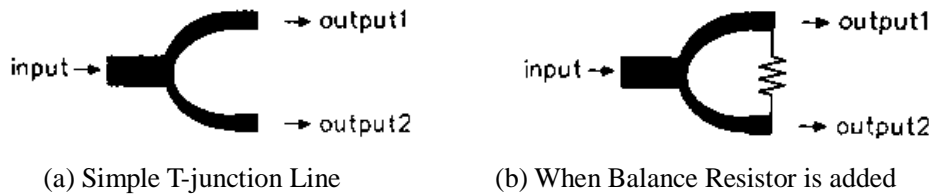
1. Power Divider

The coupler refers to the passive element which makes coupling part of signals in the RF signal path, while the power divider means the passive element for dividing power. That is, the divider is a common name of the element used for dividing large amount of power, and the coupler is more general name which includes not only the coupler's concept and the dividing power but also a concept of detecting power. Among the coupler, one that makes coupling large amount of power and divides the power can be called the power divider, and the divider may be thought as one of the application concepts of the coupler. The power divider divides power to equally 1:2 or 1:N, or can divide power unequally. The power divider can be easily formed by changing the input and output. [Fig.10-1] shows some examples of the coupler according to their functions.



[Fig.10-1] Functional Classification of Coupler

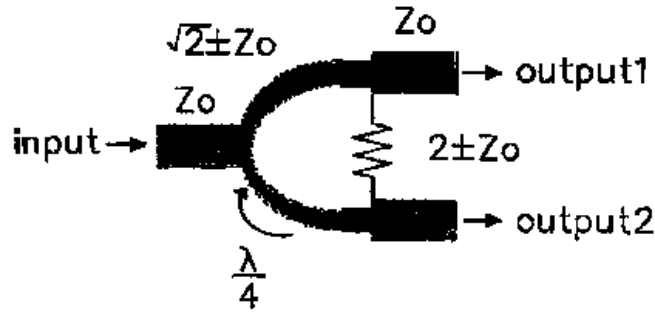
When the power is required to be divided equally into two paths in the transmission line, the power can be divided equally using the transmission line of the T-junction structure as shown in [Fig.10-2] (a). However, because the T-junction line has no loss and it cannot be calibrated or converted when there exists an impedance difference between ports, three ports in the T-junction line cannot be matched perfectly. To solve this problem of the T-junction, a resistor is used for inserting between two paths as shown in [Fig.10-2] (b).



[Fig.10-2] T-junction structure

For dividing power with perfectly matched state in the radio frequency (RF) region, the impedance converting and balance between ports are required. The Wilkinson power divider is made with considering various characteristics of the radio frequency (RF).

[Fig.10-3] shows the structure and impedance relationship of the Wilkinson power divider.

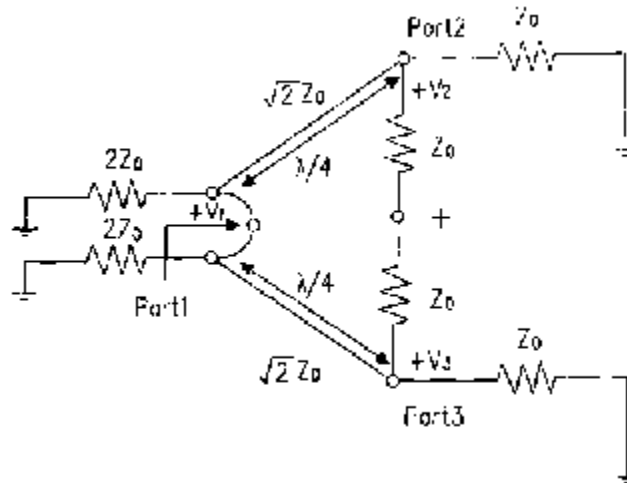


[Fig.10-3] Structure and Impedance Relationship of Wilkinson Power Divider

2. Wilkinson Power Divider

The Wilkinson power divider is a three-port divider having loss made in such a manner that the output ports are isolated and all the ports are matched. This divider has no loss when the output port is matched but only loss of the reflected power. The Wilkinson power divider can be fabricated to divide power arbitrarily and can be manufactured in the microstrip or stripline type. Here an equal division (3 dB) is targeted, and the Even-odd mode analyzing method is used as an analyzing method, which analyzes by making two simple circuits with the application of the symmetric and unsymmetric signals to the output port.

As shown in [Fig.10-4], in order to analyze the divider with the principle of superposition by the even mode and the odd mode, if the 2 V power having the internal impedance Z_0 is applied to port 2 and only Z_0 is terminated for port 1 and 2, it can be considered as a superposition of the even and odd modes as shown in [Fig.10-5] (a) and (b). Such an Even-Odd mode analyzing method is also used for analyzing the directional coupler, the branch line coupler and the hybrid ring coupler, and also applied to the analysis of the differential amplifier which is commonly used for the input terminal of the operational amplifier in an electric circuit.



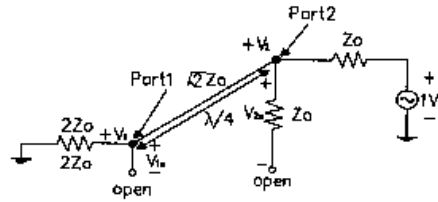
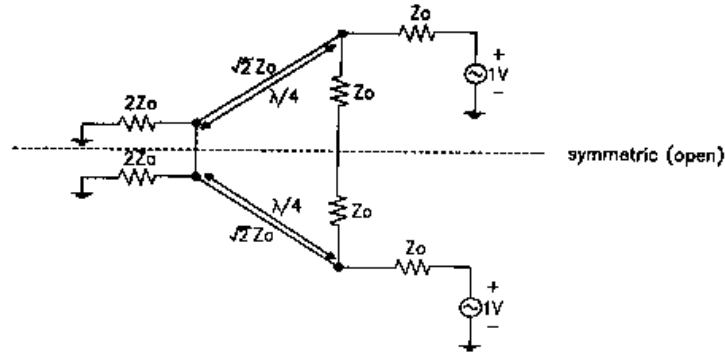
[Fig.10-4] Wilkinson Power Divider Having Symmetry

In [Fig.10-5], resulting equation for each terminal by the superposition of two modes from the applied input to port 2 is as follows.

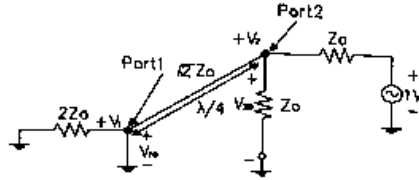
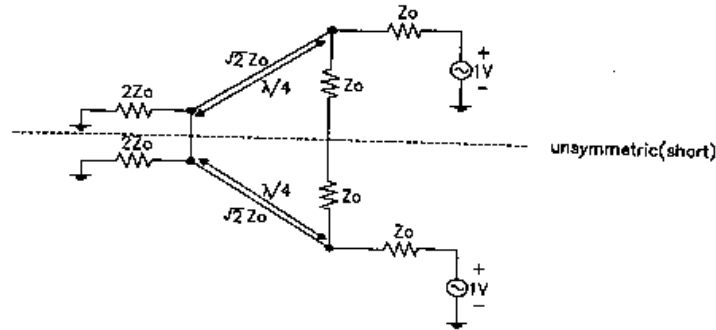
$$V_2 = V_{2e} + V_{2o} = 1$$

$$V_1 = V_{1e} + V_{1o} = -j0.707$$

$$V_3 = V_{3e} - V_{3o} = 0$$



(a)



(b)

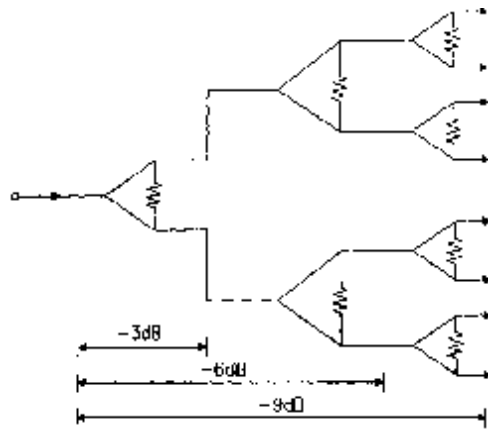
(a) Even-Mode Excitation

(b) Odd-Mode Excitation

[Fig.10-5] Even and Odd Mode Analysis of Wilkinson Power Divider

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} = \begin{bmatrix} 0 & -j0.707 & -j0.707 \\ -j0.707 & 0 & 0 \\ -j0.707 & 0 & 0 \end{bmatrix}$$

When a signal is applied to port 2, it becomes 0.707 or $(\frac{1}{\sqrt{2}})$ times (or half of the power) at port 1, and the others $S_{12}=S_{13}=S_{21}=S_{31}= -j0.707$ become 0.707 times in the same way and their phases are delayed by 90° . Since each port is matched $S_{11}=S_{22}=S_{33}=0$, while since port 2 and port 3 are isolated $S_{23}=S_{32}=0$. If the input is applied to port 1 and the output port is matched, power is not consumed at the resistor. Therefore, when the outputs are matched, the divider has no loss. While when port 2 and port 3 are mismatched, only the reflection power is consumed at the resistor.



[Fig.10-6] 1 X 8 Divider

The Wilkinson power divider, as described above, is a 2-way divider. By utilizing this, 4-way or 8-way... divider can be made. Like the 8-way divider shown in [Fig.10-6], the input signal is attenuated by 3 dB when it passes through one step. For example, if a 7 dBm signal is applied to the input, eight -2 dBm signals can be obtained eventually.

III. Measuring Instruments

Item	Module Name	Quantity
AT6030D	Spectrum Analyzer(tracking generator)	1
AT-RF3030-8	Power Divider	1
Accessory	50 Ω Load	2
Accessory	SMA-SMA	1

IV. Experimental Procedures

- (1) Connect the input and output of the AT6030D Spectrum Analyzer with cable and calibrate it, obtain the referring voltage P_1 .
- (2) Connect all the lines to form a circuit as show in [Fig.10-7]. Connect the output of the AT6030D to the port 1 of the AT-RF3030-8(Power Divider) module, connect the input of the AT6030D to the port 2 of the AT-RF3030-8(Power Divider)module, connect 50 Ω load to the port 3 of the AT-RF3030-8(Power Divider) module, obtain the inserted voltage P_2 . Because this is two sub-power splitter, the ideal value of the distribution loss is 3dB, so the inserted loss $L=P_2-3$.



[Fig.10-7] Power Divider experiment

- (3) Connect exchanging the port 2 and the port 3 of the AT-RF3030-8(Power Divider) module, measure

the inserted voltage P_3 , inserted loss $L=P_3-3$.

- (4) Connect the output of the AT6030D to the port 2 of the AT-RF3030-8(Power Divider) module, connect the input of the AT6030D to the port 3 of the AT-RF3030-8(Power Divider)module, connect $50\ \Omega$ load to the port 1 of the AT-RF3030-8(Power Divider) module, obtain the inserted voltage P_4 , isolation coefficient $I=P_1-P_4$.
- (5) Connect the output of the AT6030D to the port 3 of the AT-RF3030-8(Power Divider) module, connect the input of the AT6030D to the port 2 of the AT-RF3030-8(Power Divider)module, connect $50\ \Omega$ load to the port 1 of the AT-RF3030-8(Power Divider) module, obtain the inserted voltage P_5 , isolation coefficient $I=P_1-P_5$, the effective bandwidth ∇F is the work bandwidth of the power divider when the isolation $I \geq 8\text{dB}$ of the power splitter.

V. Results

<Table 10-1> Division by Wilkinson Powe Divider

Frequency [GHz]	Input Power P_1		Output Power P_2		Output Power P_3		Output Power P_3'		Transmission Loss[dB] $P_1[\text{dBm}]-P_2[\text{dBm}]$
	[V]	[dBm]	[V]	[dBm]	[V]	[dBm]	[V]	[dBm]	
1.5									
1.6									Transmission Loss[dB] $P_1[\text{dBm}]-P_3[\text{dBm}]$
1.7									
1.8									Isolation Loss[dB] $P_1[\text{dBm}]-P_3[\text{dBm}]$
1.9									

VI. Review

- (1) What is the average power divided by the Wilkinson power divider in the rage of 1.7GHz-1.9GHz?
In other words, which decibel (dB) divider is it?
- (2) What kind of problems are caused when the unused port for the measurement is not matched?
- (3) How much signals are expected to be detected from port 1 and 3 when the signal having a frequency of 1.8 GHz and a power of 10 dBm is input to port 2 referring to the results?
- (4) Calculate $P_1 \rightarrow P_2$, $P_1 \rightarrow P_3$, $P_2 \rightarrow P_3$ and P_2 values from the results in <Table 10-1>.
- (5) Find other type elements which combine or divides power, or make coupling part of the power.
- (6) Build an experimental set using modules of the experimental instruments in order to obtain S_{11} or the return loss for port 1 of the Wilkinson power divider.

11. Theory and Experiment of Ring Resonator

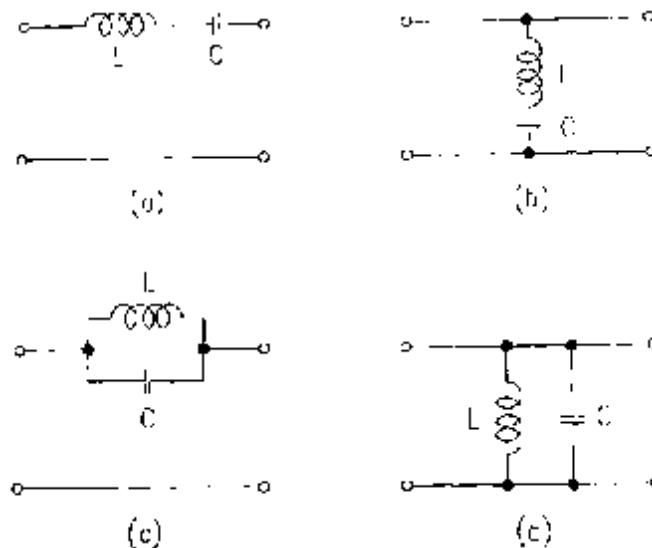
I. Objective

To comprehend the characteristics and principle of the resonance using the AT-RF3030-16(Ring Resonator) module and obtain the resonance frequency.

II. Theory

The resonance refers to concentration of energy to a certain frequency. The resonance can be divided into the electric and the structural resonances. The electric resonance is formed from energy exchange of the opposite imaginary of L and C, while the structural resonance occurs when the wavelength becomes a multiplied number of half wavelength or 1/4 wavelength proportional to the wavelength of the corresponding frequency. One of devices using principle of the resonance is the filter. In general meaning, the resonance can be defined as a phenomenon having selective characteristics for the frequency. All the RF systems have individual frequency bands, so the signal should be processed to select the corresponding components. To all cases selecting the frequency, the concept of resonance can be applied. As such, the resonance is a basic concept which is used in various RF circuit elements such as the filter, the oscillator, the frequency counter and the antenna.

Then, the electric resonance commonly used in the electric circuit will be described in details. The electric resonance means the so-called LC resonance. The inductor and the capacitor have characteristics of accumulating and discharging the electromagnetic energy, and shows the opposite frequency characteristics. The inductor has smaller impedance as the frequency lowered, while the capacitor has smaller impedance as the frequency increases. Connecting two elements of these characteristics causes the resonance at a certain frequency. The resonance circuits which can be formed by 4 combinations of L and C are shown in [Fig.11-1].



[Fig.11-2] Four Basic Resonance Circuits and Their Transmission Characteristics

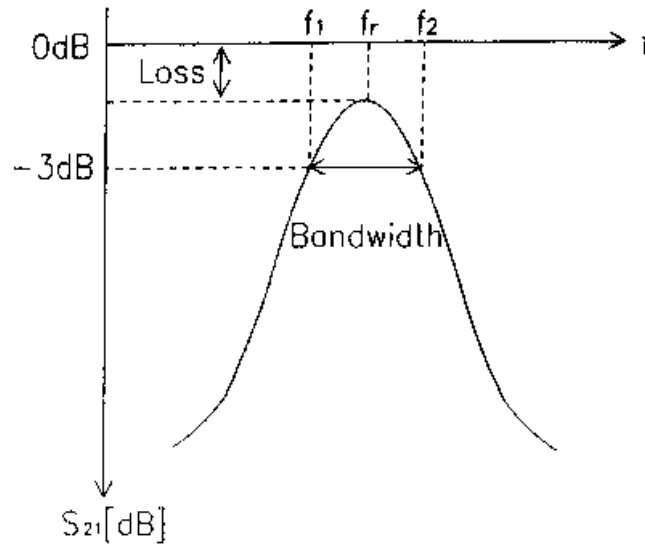
The resonance frequencies for the four circuits are

$$\omega^2 = \frac{1}{LC}$$

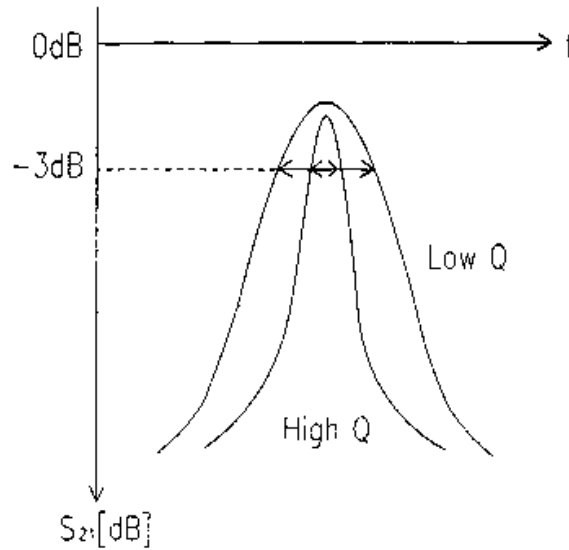
$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Because the LC serial impedance is '0' at the resonance frequency f, and the LC parallel impedance is '∞'

the signal is transmitted without loss for (a) and (b) of [Fig.11-1]. While the signal is perfectly reflected for (b) and (c). Assuming $f_r=1.5$ GHz, S-parameters according to the frequency can be expressed as [Fig.11-2].



[Fig.11-2] Frequency Characteristics of Resonator Having Loss



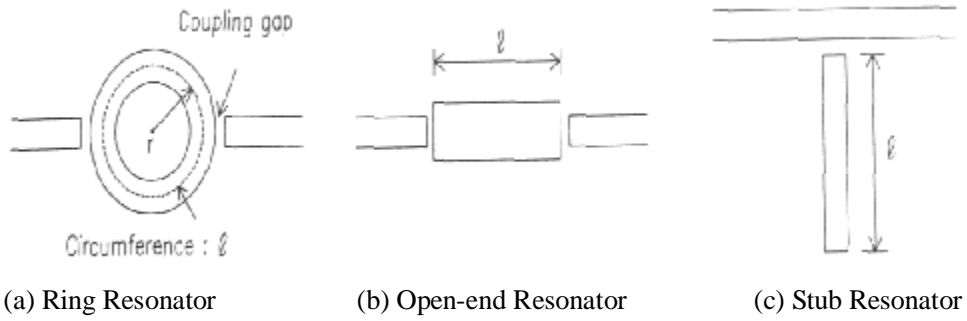
[Fig.11-3] Bandwidth of Resonator according to Q Values

A little loss (R) exists in an actual resonator, where A (Quality) factor is an important factor in determining the energy loss and the frequency selecting characteristics.

The Q factor can be defined as follows.

$$Q = \frac{f_r}{f_1 - f_2} = \frac{\text{Resonance Frequency}}{\text{3dB Bandwidth}}$$

[Fig.11-3] shows the change of the frequency bandwidth according to Q values. Smaller Q values mean the broad band, while larger Q values mean the narrow band. Similar to the LC resonance, the resonance can occur in the microstrip line and the waveguide and some examples are illustrated in [Fig.11-4].



[Fig.11-4] Various Microstrip Resonators

The resonance occurs in the following conditions.

For the ring resonator,

$$\ell = 2\pi r = n\lambda_g \quad n=1,2,3,\dots$$

For the open-end,

$$\ell = \frac{n\lambda_g}{2} \quad n=1,2,3,\dots$$

For the open stub,

$$\ell = \frac{n\lambda_g}{4} \quad n=1,2,3,\dots$$

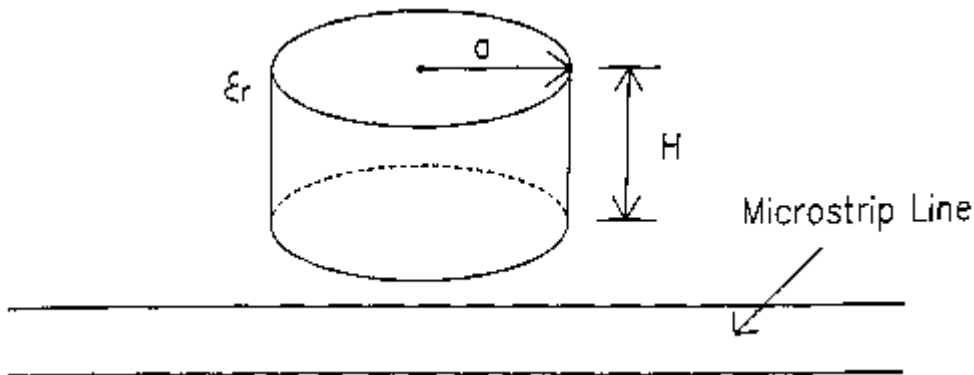
Here, the wavelength is

$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_{eff}}} = \frac{3 \times 10^{10}}{\sqrt{\epsilon_{eff}}} [cm]$$

Because the ring resonator has no open-end and almost no radiation loss, it has an advantage of being able to measure more accurately than the open-end or open stub resonator. Because the dielectric resonator, shown in [Fig.11-5], is used with the microstrip line and manufactured to have quite a large relative dielectric constant ϵ_r of 30~50, it can be made smaller than the microstrip resonator in [Fig.11-4].

The resonance frequency of the dielectric resonator is

$$\lambda_g = \frac{34}{a\sqrt{\epsilon_r}} \left(\frac{a}{H} + 3.45 \right) GHz$$



[Fig.11-5] Dielectric Resonator

For the reference, Q value of the microstrip resonator is less than 200, that of the dielectric resonator is about 1000, and that of the waveguide resonator is a few thousands.

III. Measuring Instruments

Item	Module Name	Quantity
AT6030D	Spectrum Analyzer(tracking generator)	1
AT-RF3030-16	Ring Resonator	1
Accessory	SMA—SMA	2

IV. Experimental Procedures

- (1)First, adjust the frequency of the AT6030D in $f_c=1500\text{MHz}$, SPAN=3000MHz. Connect the input and output of the AT6030D Spectrum Analyzer with cable and calibrate it. Then, measure the refer voltage P_1 .
- (2)Connect all the lines to form a circuit as show in [Fig.11-6]. Connect the output of the AT6030D to one port of the AT-RF3030-16(Ring Resonator) module, connect the output of the AT6030D to the other port of the AT-RF3030-16(Ring Resonator) module, then, measure the relation curve between the output voltage of the AT-RF3030-16(Ring Resonator) module and frequency.



[Fig.11-6] Ring Resonator experiment

- (3) Measure the resonator frequency, inserted loss L , bandwidth and so on .

V. Review

- (1) Plot the frequency characteristics of the ring resonator with using the measured values.
- (2) Find the resonance frequency f_r and Q value of the ring resonator with using the measured values.
- (3) Does the circumference of the actual AT-RF3030-16 module agree with ℓ value of the ring resonator calculated from the measured resonance frequency f ,? Here. $E_c=2.4$.
- (4) Examine the waveguide resonator.

12. Theory and Experiment of Low Pass and Band Pass Filter

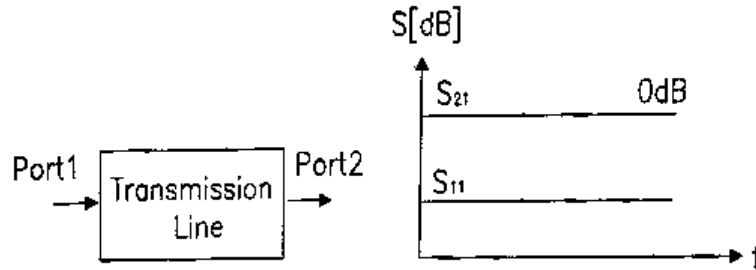
I. Objective

To comprehend the principle of the filter with the low pass filter and the band pass filter using the microstrip transmission lines.

II. Theory

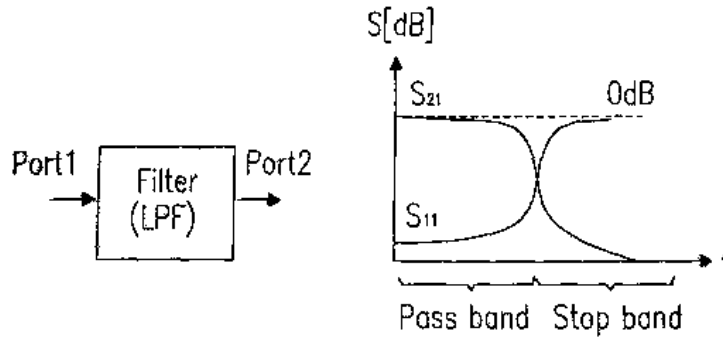
The filter allows for passing a certain frequency and attenuates the others out of various frequency components. It is one of the most frequently used circuit in the entire RF systems, and can be formed in a variety of types and shapes.

Before understanding the filter in various points of view, first take a look at the filter by using a representative RF characteristic graph, S parameter.



[Fig.12-1] Transmission Characteristics of S Parameter

When the RF signal is applied to a common line, all the RF signals are obtained as the output except for a little transmission line loss as shown in [Fig.12-1]. S_{21} of 0dB in the S parameter means that the ratio of the output to the input is unity. That is, since $10 \cdot \log 1 = 0$, the input power is transmitted to the output without loss. S_{11} locating lower than S_{21} indicates that the reflected amount is very small.



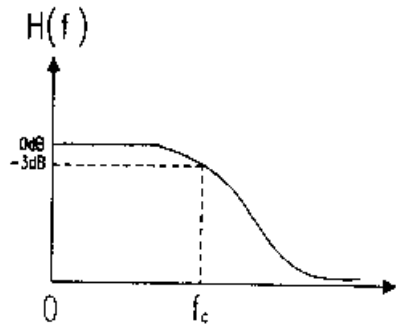
[Fig.12-2] S Parameter Transmission Characteristics of Low Pass Filter

Such a case that S_{21} is maintained as about 0 dB and S_{11} has a small value in [Fig.12-2] means that the input signal of the corresponding frequency is transmitted to the output at its maximum and the reflection occurs at its minimum. That is, it corresponds to the frequency pass band. Contrarily, when S_{21} is small and S_{11} is about 0 dB, it means the input signal of the corresponding frequency is mostly reflected and not transmitted, which becomes the frequency stop band. Passing a specific frequency to the output at its maximum without loss and reflecting the other frequencies are main roles of the filter.

Generally, the filter can be divided into five types according to the frequency pass band.

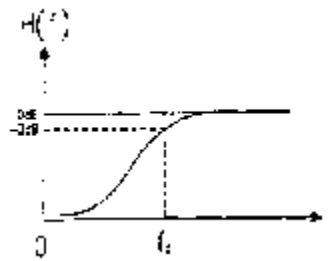
- ① Low Pass Filter

This filter is a basic type of all the filters, The LPF (Low Pass Filter) blocks the radio frequency signals and transmits only the necessary low frequency signal (within the block frequency). It is formed as the simplest form, and other types of filters can be made by converting this basic form in variety. This type of filter is fairly used in the various areas such as removing the low frequency ripple, removing the radio frequency spurious, suppressing the harmonic, and various detections.

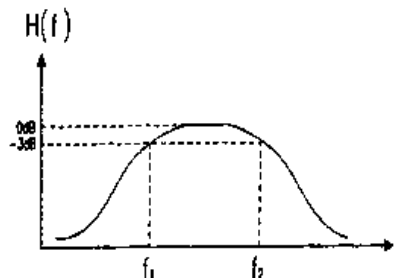


② High Pass Filter

The HPF (High Pass Filter) has a characteristic that blocks the low frequency signals and transmits only the radio frequency signals higher than the necessary bandwidth (higher than the block frequency). The biggest problem of the HPF is that it cannot be formed using the distributed element.

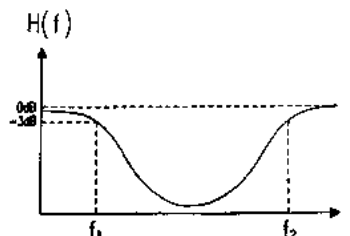


③ Band Pass Filter.



The BPF (Band Pass Filter) transmits signals in the desirable bandwidth while it blocks signals in the undesirable bandwidth. When the transmission terminal receives or transmits the exactly necessary frequency out of many frequencies, the BPF is used.

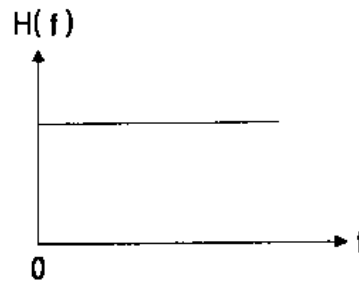
④ Band-Stop Filter or Band-Reject Filter



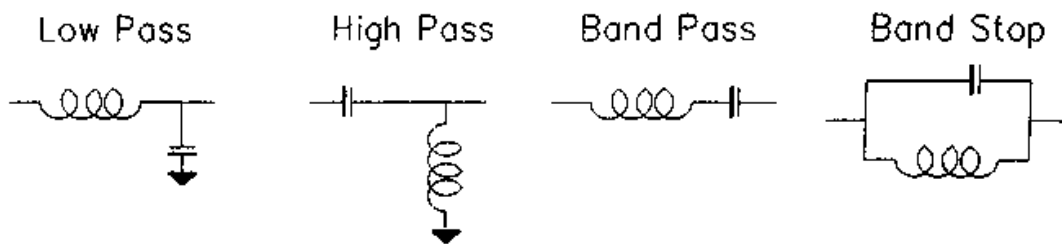
In contrast to the BPF, the BSF blocks signals in the desirable bandwidth, while it passes signals in the other bandwidth. This filter is mainly used for blocking inflow of the specific frequency, and is formed by arranging and combining the serial and parallel resonances.

⑤ All Pass Filter

The APF passes signals of all the frequency components and only delays their phases. This filter is commonly used for the phase delay circuit.

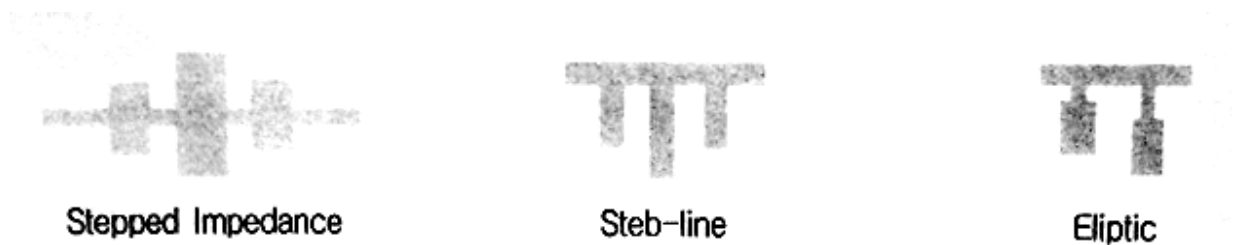


[Fig.12-3] shows a basic filter circuit using LC.

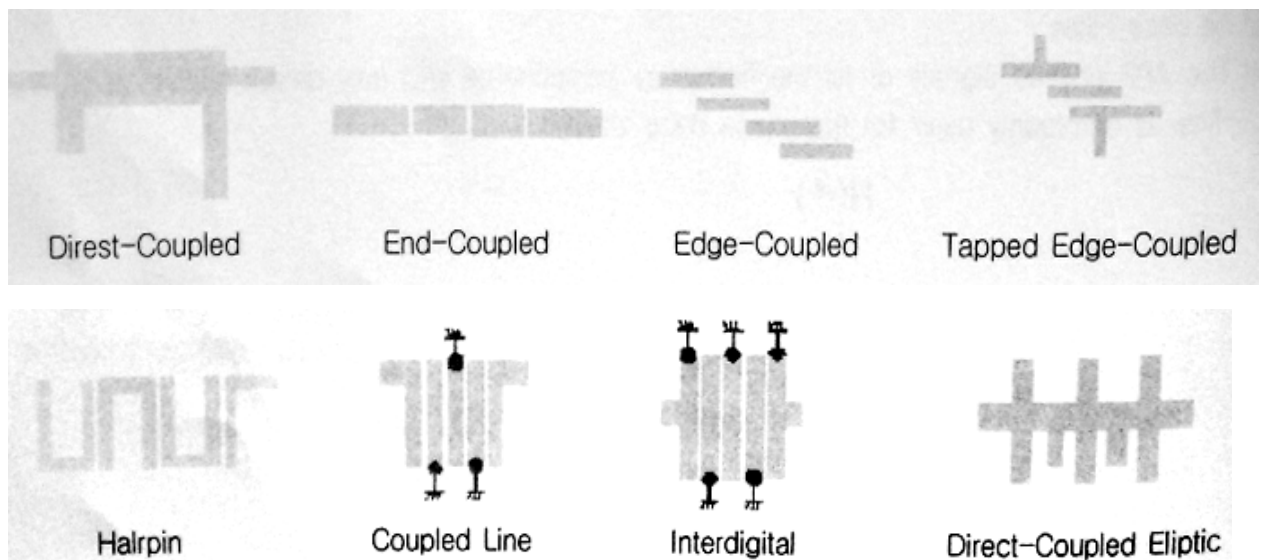


[Fig.12-4] Basic Filter Circuit Using LC

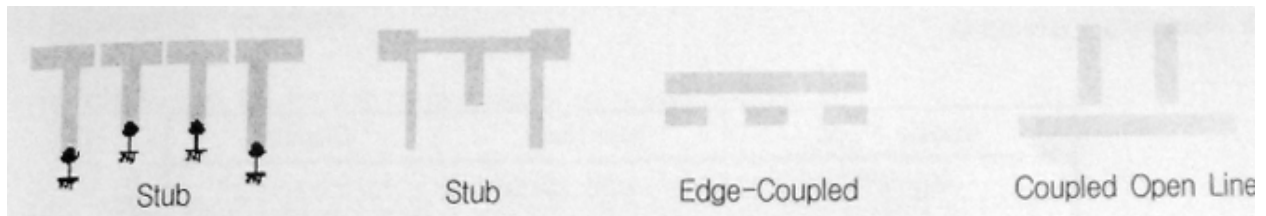
[Figs.12-2~4] show filter circuits using the microstrip transmission lines.



[Fig.12-5] Low Pass Filter Using Microstrip Transmission Line



[Fig.12-6] Band Pass Filter Using Microstrip Transmission Line



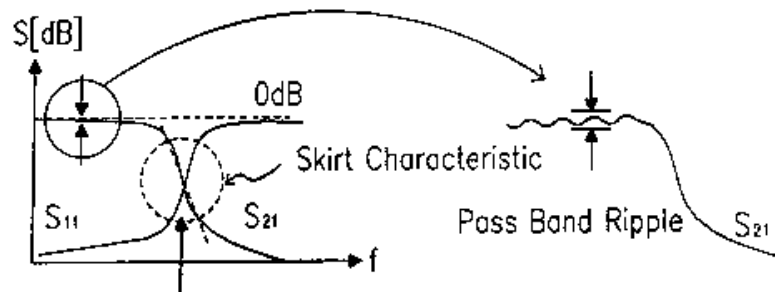
[Fig.12-7] Band Pass/Stop Filter Using Microstrip Transmission Line

⑥ Measuring Insertion Loss and Skirt

The most important characteristics of the filter are the insertion loss and the skirt. The insertion loss means the power loss occurring during passing of the signal through the filter, and in the pass band S_{21} is less than 0 dB and has a value of near 0 dB. The skirt characteristic having a skirt-shape of women indicates how clear it is to separate the pass band and the stop band.

The insertion loss is better as it is smaller, while the skirt curve has a better characteristic when the slope of skirt curve is steeper.

[Fig.12-8] is the frequency characteristic of the low pass filter for representing the insertion loss and the skirt characteristic.



[Fig.12-8] Frequency Characteristic of LPF

III. Measuring instruments

Item Name	Module Name	Quantity
AT6030D	Spectrum Analyzer(tracking generator)	1
AT-RF3030-12	Loss Pass Filter	1
AT-RF3030-13	Band Pass Filter	1
AT-RF3030-14	Band Stop Filter	1
AT-RF3030-15	Band high Filter	1
10dB Att	10dB attenuator	1
Accessory	SMA—SMA	2

IV. Experimental Procedures

- (1)First, adjust the frequency of the AT6030D in $f_c=1500\text{MHz}$, $\text{SPAN}=3000\text{MHz}$. Connect the input and output of the AT6030D Spectrum Analyzer with cable and calibrate it. Then, measure the reference voltage P_1 .
- (2)Connect all the lines to form a circuit as show in [Fig.12-9]. Connect the output of the AT6030D to one port of the AT-RF3030-12(Loss Pass Filter) module, connect the output of the AT6030D to the other port of the AT-RF3030-12(Loss Pass Filter) module, then, measure the relation curve between the output voltage and frequency, so that, obtain the inserted loss L , frequency response, bandwidth and so on .



[Fig.12-9] Loss Pass Filter experiment

- (3) Repeat step (1) and (2), measure the parameters of the AT-RF3030-13 (Band Pass Filter), or other filter as AT-RF3030-14 (Band stop Filter) and AT-RF3030-15 (High Pass Filter).

V. Results

<Table 12-1> Measuring Loss Pass Filter

Frequency [GHz]	Loss Pass Filter						
	Input Voltage [V]	Input Power [mW]	[dBm]	Output Voltage [V]	Output Power [mW]	[dBm]	Insertion Loss [dB]
1.50							
1.55							
1.60							
1.65							
1.70							
1.75							
1.80							
1.85							
1.90							
1.95							
2.00							

VI. Review

- (1) Plot the insertion loss-frequency characteristic as a graph from the measured values of two filters.
- (2) Find the stop frequency of the filter from the measured values of two filters.
- (3) Explain about the waveguide filter.
- (4) Design the band pass filter using L and C.

Ripple = 0.5dB, Center Frequency = 1GHz

Band Width = 10%, N = 3, Impedance: 50 Ω

13. Theory and Experiment of MMIC Amplifier

I. Objective

To comprehend the principle of the MMIC amplifier using the AT-RF3030-21(MMIC Amplifier) module, the amplification gain and the characteristic of P₁dB.

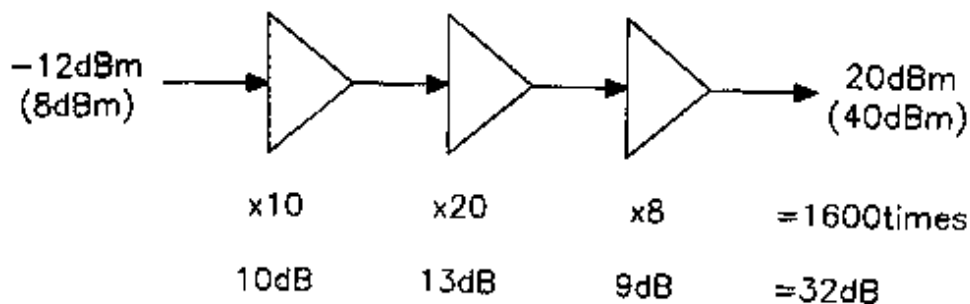
II. Theory

The amplification means increasing the amplitude of a signal while keeping the signal itself. The characteristics of the amplifier in the transmitter/receiver vary according to its purpose of the use.

Because the transmitter has to radiate the signal from its antenna at the maximum power so that the electromagnetic wave can reach the target, it needs to be amplified to higher power as much as it can, while because the receiver has the received signal of very small size and noise in addition to the original signal, it needs to be amplified with minimizing the noise. The power amplifier is mainly used for the transmitter, while the low noise amplifier is used for the receiver. Details on the amplifier will be described hereafter.

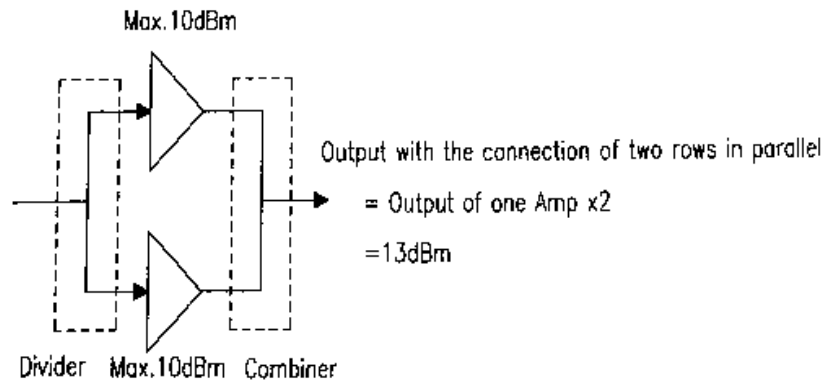
1. Gain and Maximum Output Power

The gain and the maximum output power are often thought as equal concepts, but the gain represents the size of output signal relative to the input signal. That is, if the size of output signal becomes ten times larger than the input signal, the gain of this amplifier will be 10 dB. Contrarily, the maximum output power represents how much power can be operated at the output terminal of the amplifier, and it means the maximum power (W, dBm) to be output. Therefore, sizes of the maximum output power and the gain should be regarded as different concepts. The following illustrates how to increase the gain by the dependent connection. When the gain cannot be obtained with one amplifier, many amplifiers are connected for obtaining the gain.



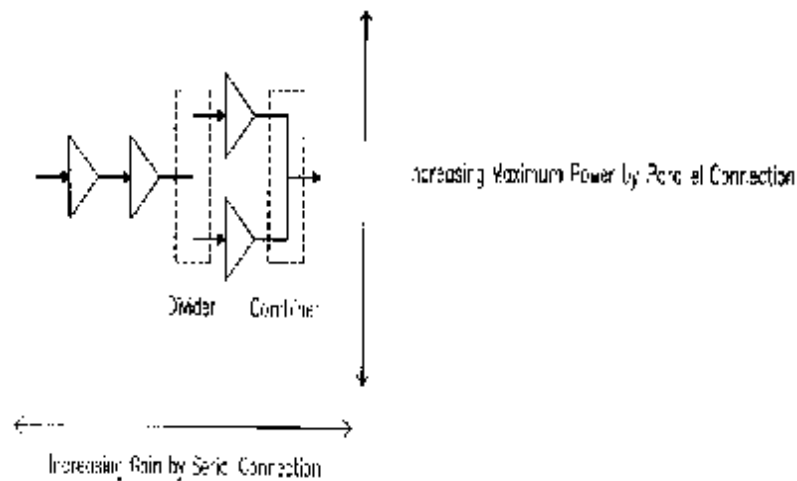
As the gain of the amplifier increases, the output also increases. When -12 dBm is applied to the input of the amplifier having total gain of 32 dB , the output becomes to 40 dBm (10 W), so that it is beyond the acceptance of the normal amplifier. Therefore, the maximum available power of the terminal amplifier should be increased to more than 40 dBm in order to obtain the desirable output and gain.

In order to increase the maximum output power, two amplifiers are connected in parallel at the terminal as shown in [Fig.13-1], so that the desirable output can be obtained while keeping the gain constant. If necessary, more amplifiers can be additionally connected in parallel.



[Fig.13-1] Amplifying Output Power

As such, to increase the gain and the power simultaneously, the amplifier should be connected in a structure as shown in [Fig.13-2].



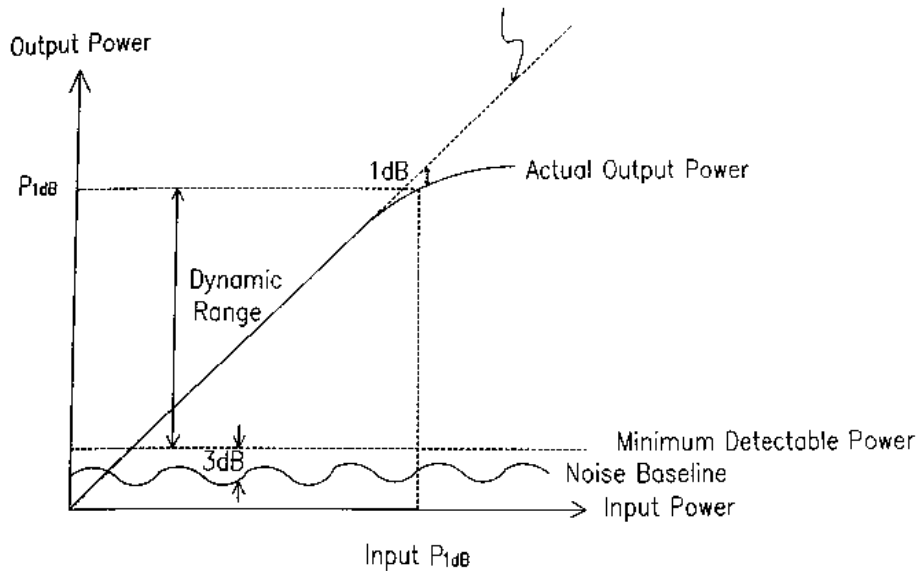
[Fig.13-2] Multiple Power Amplifier Increasing Gain and Maximum Output Power

2. P_{1dB} (1 dB Gain Compression Point)

All the amplifiers cannot radiate infinite power, but has a certain limiting point. An index to indicate this limiting point that is the maximum power point is P_{1dB} . Assuming the output power of the amplifier is not saturated, the output power where the difference between the unsaturated power and the actually saturated curve becomes 1 dB is P_{1dB} . In addition, the gain in this case is called G_{1dB} . For example, if 0dBm is input to an Amp having the gain of 20 dB, the output is 20dBm, but it does not guarantee the output of 30dBm when 10dBm is input. The gain slowly decreases as the input power increases, so that the saturation state, where the output power is not increased any more when an input power above the certain level is used. That is, 1 dB gain compression point is used for indicating the maximum power point available before reaching the saturated power. Eventually, P_{1dB} means the power at a point where the gain is decreased by 1Db. P_{1dB} has various meanings depending whether the actual amplifier is used for the linearity purpose or not, but basically, it can be regarded as the maximum linear input/output power stably available for that amplifier. When using the amplifier in normal condition, use it up to the range a few dB lower than the P_{1dB} point in order to have the table characteristic.

[Fig.13-3] shows the input-output at the point where the gain is decreased by 1 dB than the maximum power point of the amplifier.

For Unsaturated and Ideal Linear Amp



[Fig.13-3] Power Characteristic Curve of Amplifier

3. IMD (Intermodulation Distortion)

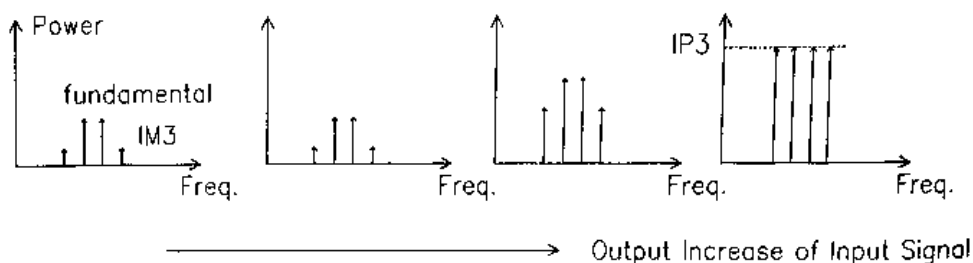
When a frequency f_1 is applied to the non-linear amplifier, harmonics such as $2f_1$, $3f_1$, $4f_1$ and so on occur at the output. Similarly, if many signals are simultaneously applied to the amplifier, the intermodulation distortion among these signals are caused, which is called the IDM (Intermodulation Distortion). The IMD partly occurs in the passive element having very high output, and mainly occurs in the active element, especially the amplifier. The power amplifier having drastically decreased distortion is called the LPA (Linear Power Amplifier).

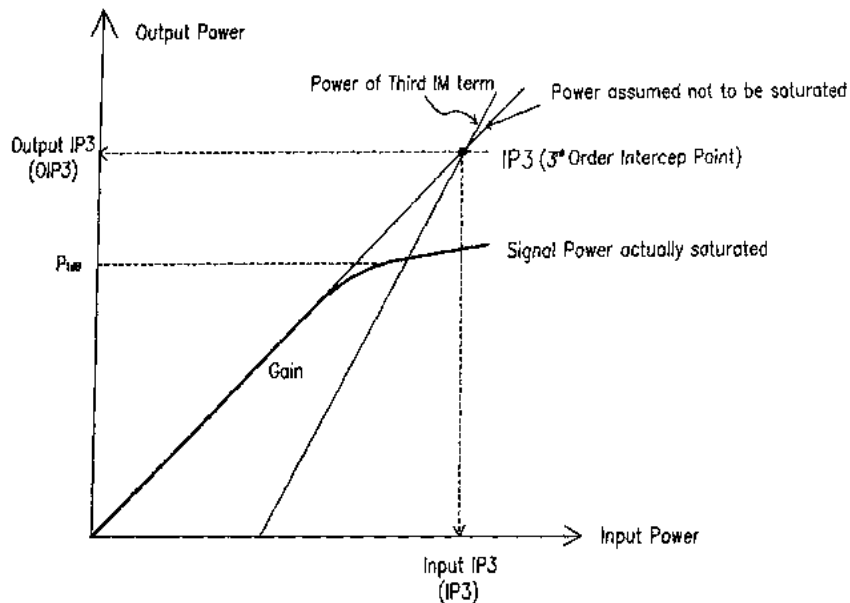
4. IP3 (Third Order Intercept Point)

IP3 refers to a point where the fundamental output power and the IM3 component increase without saturation so that two power points become equal. This point is used as an index for evaluating the linearity. As shown in [Fig.13-4], if the output power increases, IM3 also increases. Because increasing rate of the IM3 component is faster than that of the fundamental signal, the increasing leads to the equal point of the fundamental and the IM3 components, which is called IP3. IM3 increases faster than the fundamental signal.

When the input signal of $x = a_1 \cos \omega_0 t + a_2 \cos \omega_2 t$ is used in the non-linear system, the output y has an infinite geometrical series equation of $y = a + bx + cx^2 + dx^3 + \dots$. Here, the first order term bx is the putout of the fundamental frequency signal. Because IM3 is the signal coming from the third order term, it increases with a slope of the size of the input signal to the third. After all, on the dB scale, IM3 increases with a slope three times larger than that of the fundamental signal.

The above figure shows the increase of the output power and IM3 on the dB scale according to the increase of the input Power.

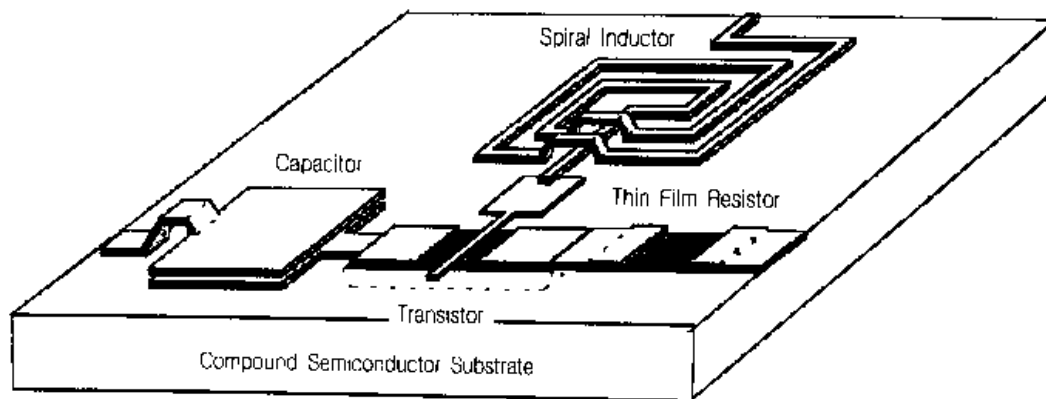




[Fig.13-4] IP3 Characteristic Curve

5. MMIC(Monolithic Microwave Integrated Circuit)

HBT (Heterostructure Bipolar Transistor) or MESFET (Metal Semiconductor Field Effect Transistor) is mainly used as an active element in the microwave amplifier. This is used for forming the matched circuit at the input/output terminal, and the capacitor and the inductor are used for forming the MIC (Microwave Integrated Circuit) type in the microstrip line. Recently, it has developed to the MMIC (Monolithic Microwave integrated Circuit) where the active and passive elements are manufactured on a semiconductor die as a batch process. MMIC is a key technology which can not only achieve minimization and light weight of the RF system, but also increase the production yield by significantly decreasing used parts. As shown in [Fig.13-5], MMIC is simultaneously manufactured using the connection of unit element in addition to the passive and active elements on a semiconductor substrate as a batch process. Therefore, it has smaller size than the existing RF circuit substrate, high reliability, and uniform characteristics, while it has disadvantages of difficult design, almost impossible tuning, and very long manufacturing time.



[Fig.13-5] Schematic Diagram of Inside MMIC

The following data sheet shows the specifications of the MMIC amplifier used in the AT-RF3030-21 module.

MONOLITHIC AMPLIFIERS

50Ω

BROADBAND DC to 8 GHz



low power, up to +13.5 dBm output

all specifications at 25°C

MODEL# NO.	FREQ. GHz	GAIN, dB Typical								MAXIMUM POWER (dBm) at 2 GHz ^a	DYNAMIC RANGE at 2 GHz ^b	VSWR (1) Typ.		ABSOL- UTE MAX. RATING ^c	DC OPERATING POWER ^d at Pin 3		THERMAL RESIS- TANCE °C/W	CASE STYLE	E S S E N T I A L P R I O R I T Y	P R I C E \$ (10)	
		over frequency, GHz										In	Out		Current mA	Power Watt					
		0.1	1	2	3	4	6	8	Max. 2 GHz												DC-3 GHz
ERA-1	DC-4	12.3	12.1	11.6	10.9	9.7	7.8	6.2	9	12.0	10.0	1.6	1.6	15	300	40	3.4	3.0	4.1	VV100	1.37
ERA-2	DC-4	16.2	16.0	15.2	14.4	13.1	11.2	—	13	13.0	11.0	1.3	1.4	15	300	40	3.4	3.0	4.1	VV100	1.62
ERA-3	DC-3	12.1	21.0	16.7	16.6	—	—	—	16	12.5	9.0	1.6	—	15	300	30	3.2	3.0	4.1	VV100	1.67
ERA-15M	DC-4	12.3	12.1	11.6	10.9	9.7	7.8	6.2	9	12.0	10.0	1.6	1.6	15	300	40	3.4	3.0	4.1	—	1.62
ERA-215M	DC-4	14.2	13.9	13.2	12.2	10.9	9.7	8.9	11.2	12.6	10.6	1.3	1.4	15	300	40	3.6	3.0	4.1	—	1.67
ERA-25M	DC-4	16.2	16.0	15.2	14.4	13.1	11.2	—	13	13.0	11.0	1.3	1.4	15	300	40	3.4	3.0	4.1	—	1.67
ERA-335M	DC-3	19.3	19.7	17.4	16.9	—	—	—	16	13.6	11.6	1.6	—	15	300	40	4.3	3.6	4.9	—	1.72
ERA-35M	DC-3	12.1	21.0	16.7	16.6	—	—	—	16	12.5	9.0	1.6	—	15	300	30	3.2	3.0	4.1	—	1.72
ERA-45M	DC-3	10.5	26.0	19.0	18.0	12.0	—	—	17	12.5	—	1.6	—	66	260	36	3.7	3.2	4.2	—	1.72

see suggested PCB layout PL-075 for ERA models

features

- low thermal resistance
- miniature microwave amplifier
- frequency range, DC to 8 GHz, usable to 10 GHz
- up to 18.4 dBm typ. (16.5 dBm min.) output power

absolute maximum ratings

operating temperature: -45°C to 85°C
storage temperature: -65°C to 150°C

model identification

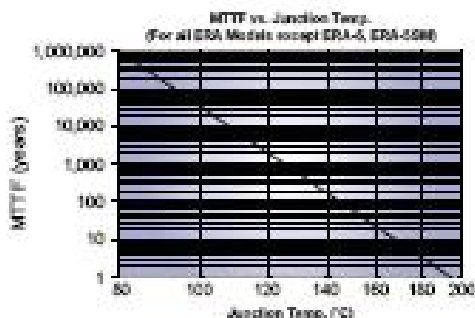
Model	marking
ERA-1, ERA-15M	1
ERA-2, ERA-25M	2
ERA-3	3
ERA-4, ERA-45M	4
ERA-15M	15
ERA-215M	21
ERA-25M	25
ERA-335M	33
ERA-35M	35
ERA-45M	45
ERA-1, ERA-15M	15
ERA-215M	21
ERA-25M	25
ERA-335M	33
ERA-35M	35
ERA-45M	45

Note: First letter (optional) designates assembly location. Suffix letter (optional) line for marker identification.

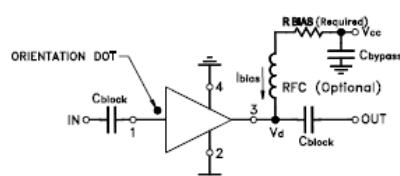
first letter
number
suffix letter

NOTES:

- Aqueous washable.
- at 1 GHz for ERA-4, 5, 6, 45M, 405M, 55M, 505M, 515M, 65M, 65M.
- f₁ is the upper frequency limit for each model as shown in the table for ERA-45M VSWR (In & Out) is specified at DC-1 GHz & 1-4 GHz.
- Gain and VSWR are specified at 1.5 GHz.
- Low frequency cutoff determined by external coupling capacitors.
- Environmental specifications and reflow soldering information available in General Information Section.
- Units are non-hexadecimal unless otherwise noted. For details on case dimensions & finishes see "Case Styles & Outline Drawings".
- Prices and Specifications subject to change without notice.
- For Quality Control Procedures see Table of Contents, Section 3, "Mini-Circuits Guarantees Quality" article. For Environmental Specifications see Amplifier Selection Guide.
- Model number designated by alphanumeric code marking.
- ERA-5M models available on tape and reel.
- Permanent damage may occur if any of these limits are exceeded. These ratings are not intended for continuous normal operation.
- Supply voltage must be connected to pin 1 through a bias resistor in order to prevent damage. See "Biasing MMIC Amplifiers" in minicircuits.com/application/html/ReliabilityPredictions are applicable at specified current & normal operating conditions.



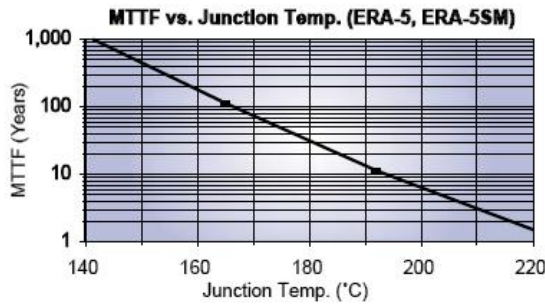
typical biasing configuration



RBIAS

"1%" Resistor Values (ohms) for Optimum Biasing of ERA Models

Vcc	ERA-1 ERA-15M	ERA-2 ERA-25M	ERA-215M	ERA-3 ERA-35M	ERA-335M	ERA-4 45M, 4X5M	ERA-5 55M	ERA-905M -515M, 5X5M	ERA-6 ERA-65M	ERA-85M
7	90.9	88.7	88.7	107	69.8	38.3	33.2	40.2	30.1	88.7
8	113	113	113	133	93.1	52.3	48.7	53.6	43.2	118
9	137	137	137	162	115	66.5	63.4	68.1	56.2	143
10	162	162	162	191	140	80.6	78.7	82.5	69.8	174
11	187	187	187	221	165	95.3	95.3	97.6	84.5	200
12	215	215	215	249	191	110	110	113	97.6	226
13	237	237	237	280	215	127	124	127	113	255
14	261	261	261	309	243	143	140	143	127	280
15	287	287	287	340	267	158	158	158	140	309
16	309	309	316	365	287	174	174	174	154	340
17	332	332	340	392	316	187	187	191	169	365
18	357	365	365	422	340	205	205	205	182	392
19	383	392	392	453	365	221	221	221	198	422
20	412	412	412	475	392	237	232	237	210	453



NSN GUIDE	
MCL NO.	NSN
ERA-1SM	5962-01-459-9075
ERA-3SM	5996-01-516-5438
ERA-4SM	5962-01-459-7410
ERA-5SM	5962-01-459-9314

pin connections	
PORT	cb
RF IN	1
RF OUT	3
DC	3
CASE GND	2,4
NOT USED	—
DEMO BOARD	ERA-TB

designers kits available

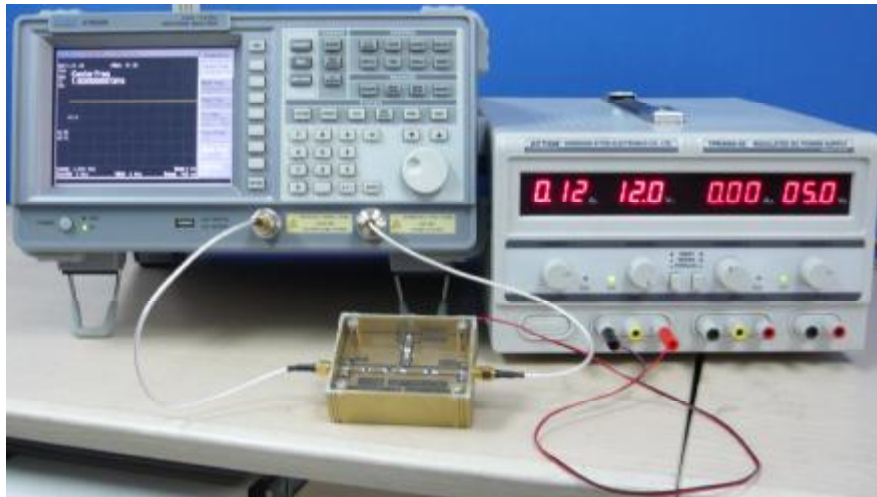
KIT NO.	Model Type	No. of Units in Kit	Description	Price \$ per kit
K1-ERA	ERA	30	10 of each 1,2,3	49.95
K2-ERA	ERA	20	10 of each 4,5	69.95
K1-ERASM	ERA-SM	30	10 of each 1SM, 2SM,3SM	49.95
K2-ERASM	ERA-SM	20	10 of each 4SM, 5SM	69.95
K3-ERASM	ERA-SM	30	10 of each 4SM, 5SM, 6SM	99.95

III. Measuring Instruments

Item	Module Name	Quantity
AT6030D	Spectrum Analyzer(tracking generator)	1
TPR3003-3C	DC Power	1
AT-RF3030-21	MMIC Amplifier	1
10dB Attenuator	10dB	1
20dB Attenuator	20dB	1
Accessory	SMA — SMA	1
Accessory	Banana- SMB	2

V. Experimental Procedures

※Caution : Higher voltage than rated voltage can damage the circuit. Take care not to apply high voltage than rated voltage to the AT-RF3030-21(MMIC Amplifier) modules.



[Fig.13-6] MMIC Amplifier Gain Experiment

- (1) Connect the input and output of the AT6030D Spectrum Analyzer with cable and calibrate it. Then, display the relation curve of $P_1 \sim f$ on the AT6030D.
- (2) Adjust the the frequency of the AT6030D to $f_c = 1500\text{MHz}$, SPAN=3000MHz. In order to ensure amplifier in the signal amplification, connect the 20dB Attenuator to the output of the AT6030D, connect as following figure, and then use cable to connect the input of the AT-RF3030-21(MMIC Amplifier), connect the output of the AT-RF3030-21(MMIC Amplifier) to the input of the AT6030D.
- (3) Access the MMIC Amplifier, adjust the DC Power to less than 15V (Note: higher voltage than rated

voltage can damage the circuit), then, display the relation curve of $P_2 \sim f$ on the AT6030D, so the gain of the MMIC Amplifier $G = P_2 - P_1$.

V. Results

<Table 13-1> Measuring Gain of Each Port

Frequency [GHz]	Input [dBm]	Gain Measuring 1 (10dB Att)			Gain Measuring 2 (20dB Att)		
		Output Voltage [V]	Output [dBm]	Gain[dB]	Output Voltage[V]	Output [dBm]	Gain[dB]
1.5							
1.6							
1.7							
1.8							
1.9							

※Note : Considering the maximum measurement range of the detector, the attenuator is connected to the input terminal of the amplifier.

VI. Review

- (1) Find gain of the MMIC amplifier from the measured results.
- (2) Does the gain change when the attenuator is changed from 20 dB to 10 dB in the above procedures?
If so, what is the reason?
- (3) Explain why the attenuator is used in the above P_1 dB measuring experiment.
- (4) Explain about P_1 Db and IP3 of the amplifier.
- (5) Find return loss, gain and P_1 dB for 2.5 GHz from the data sheet of MMIC used in the AT-RF3030-21 module.
- (6) Find out various active elements used in the amplifier.

14. Theory and Experiment of Patch Antenna

I. Objective

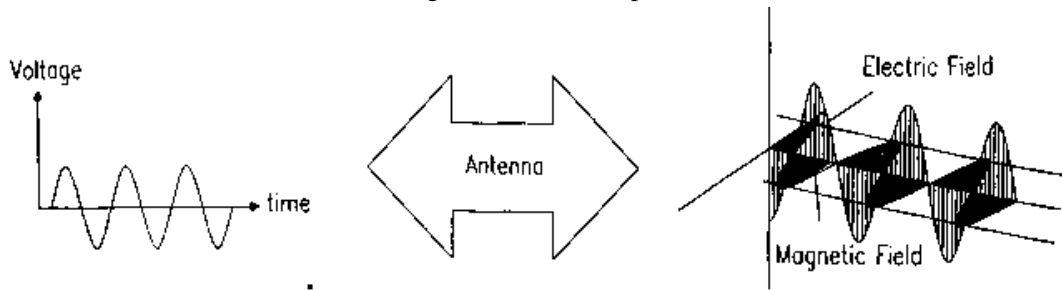
To comprehend the principle and characteristics of the antenna using the AT-RF3030-22 (Patch Antenna) module.

II. Theory

1. Antenna

The antenna is a device built in the air for effectively radiating electric wave for the purpose of wireless communication, or effectively maintaining the electromotive force by the electric wave. That is, the antenna is a device for sending or receiving the electric wave for the communication, and usually called the aerial in Britain. The antenna means a feeler of the insect, and it originates from its role to capture the electric wave. The aerial means 'in the air,' and the antenna is called the aerial due to this reason.

The transmission path in the wireless communication is not a wiring transmission line, but free space. It is the antenna that transmits and receives the signal in such free space as the terminal.



[Fig.14-1] Function of Antenna

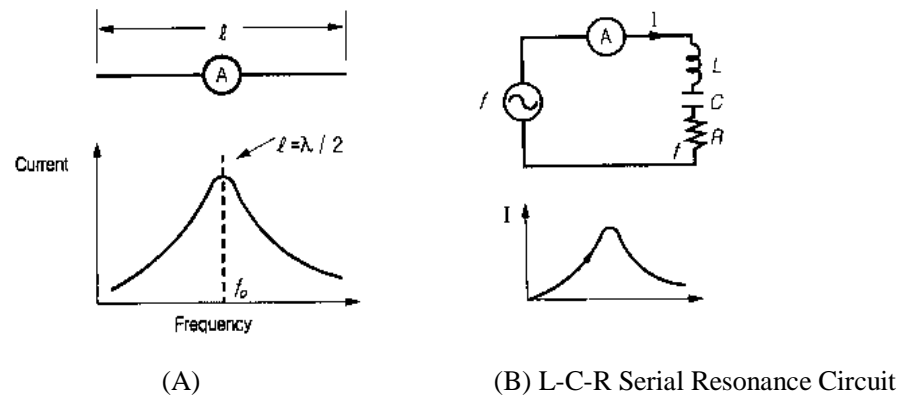
Because the electric signal is transmitted as the flow of charges through a conductor, charges cannot flow through a nonconductor such as free space. However, the electromagnetic wave cannot pass through a conductor and proceeds by forming the electric and magnetic fields on a nonconductor.

The antenna plays a role in inter-converting the electric signal, expressed as voltage and current, and the electromagnetic wave, expressed as the electric and magnetic fields, as shown in [Fig.14-1]. By interconnecting the electric signal on a conducting line of the antenna and the electromagnetic field change outside of the antenna, the electric/electronic device can detect the electromagnetic signal in the air and vice versa.

2. Resonance of Wire

Even the shortest wire can radiate the electric wave proportional to the current intensity when the RF current flows, although the radiation efficiency varies. The problem is thinking about "how to make the optimum current flow through the wire".

When the current flow through the wire having open terminals for RF, the resonance similar to the LCR serial circuit in (B) occurs at a certain frequency f_0 .



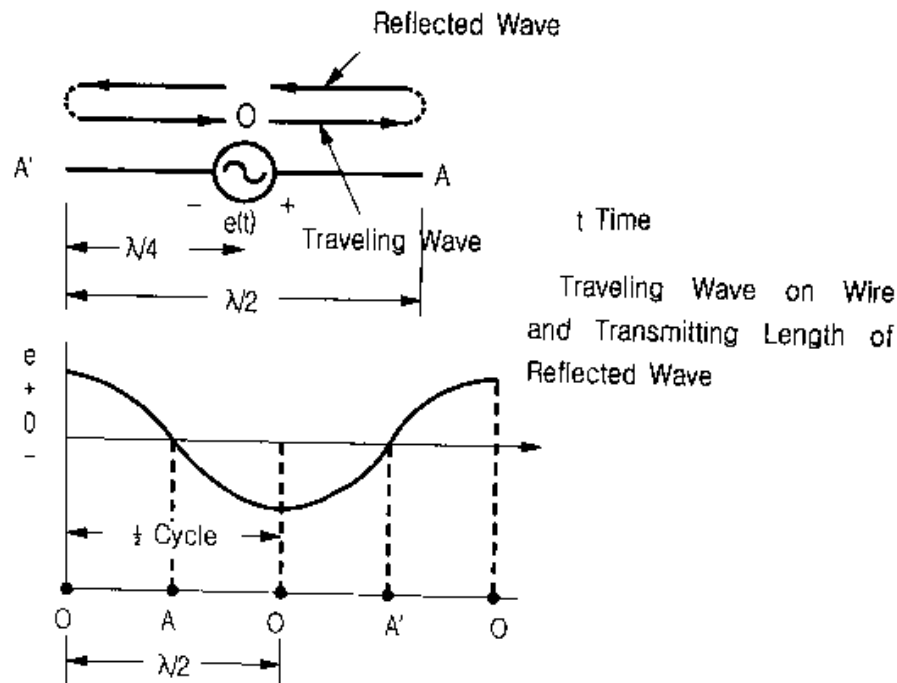
[Fig.14-2] Antenna and Resonance Circuit

As shown in [Fig.14-2] (A), connect the RF ammeter to the middle of a straight wire having a length of l , then connect the RF signal generator.

As the frequency increases gradually from the low frequency, the current starts to flow through the antenna. As it keeps increasing, the current also keeps increasing so that it will have the maximum at a specific frequency f_0 . When the frequency increases over that value, the current now decreases.

The relation between the frequency and the antenna current is very similar to the LCR serial resonance characteristics shown in figure (B). Therefore, a center-fed wire having open terminals is resonant at the frequency f_0 . In such a case, the wire length is almost $1/2$ of the f_0 wavelength.

Why the wire of the length l is resonant at RF having the wavelength twice longer? That can be explained as follows.



[Fig.14-3] Reason Why Electric Wave of Wavelength λ is resonant at Wire of $\lambda / 2$

In [Fig.14-3], the RF current travels along the vertical A direction of the wire by the RF voltage $e(t)$ which is fed to the O point of the wire. This is called the traveling wave, and its traveling speed is same as that of the electric wave radiating in space. After reaching the vertical point A of the wire, the current is perfectly reflected by ∞ impedance so that it returns to the power source. This is called the reflected wave.

Therefore, the traveling and reflected waves continuously sent from the power source exist on the wire. If the frequency of the power source is set to the resonance frequency, the traveling and reflected waves

make a round trip on a wire between $O \leftrightarrow A$ (or $O \leftrightarrow A'$) as shown in the figure. When the polarity of the power source changes at the moment the reflected wave is returning to the power source, the traveling and reflected waves on the wire becomes stronger.

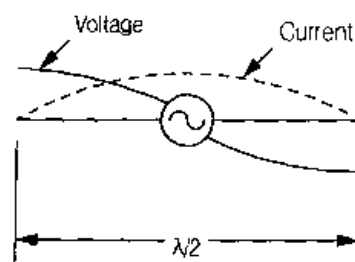
In this case, the relationship between the wire length! And the resonance frequency f_0 is as follows.

$$l = \frac{150}{f_0(\text{MHz})} [m]$$

3. Excitation of Antenna

When the wire is resonant, the traveling and reflected waves of same size occur on the wire. These waves interfere each other so that the voltage and the current on the wire will be as shown in [Fig.14-4].

The figure shows sizes of the voltage and the current at each part on the wire. The current is maximum in the middle, while minimum at both terminals. In addition, the voltage is opposite to the current, so it has the maximum at both terminals and the minimum in the middle.



The standing wave on the sine wave is caused.

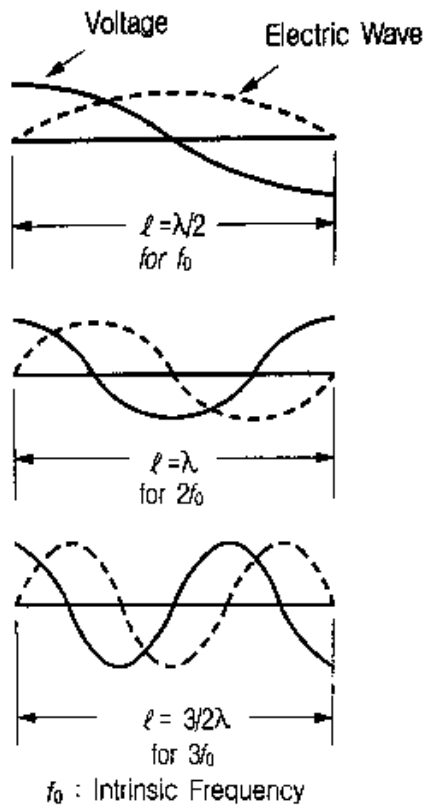
[Fig.14-4] Voltage and Current Distribution on $\lambda/2$ Wire Having Open Terminals

Because the standing wave occurs on the wire, sizes of the voltage and current on the wire are determined by its positions. The on-board antenna is a method for flowing the RF current on the wire, and it causes the standing wave on the wire. [Fig.14-4] illustrates a case that one standing wave occurs when the wire length is $\lambda/2$.

What happens when the frequency of the power source in [Fig.14-2] is changed to value twice, three times of the resonance frequency f_0 ?

The $\lambda/2$ wire for f_0 becomes λ for $2f_0$ while it becomes $3\lambda/2$ for $3f_0$. Therefore, in any case, it becomes an integer multiple of $\lambda/2$ and a plurality of standing waves occur on the wire so that the wire is resonant. In such a case, the voltage and current distribution on the wire will be as shown in [Fig.14-5].

The resonance frequency for the LCR serial circuit is only one (It is not only one actually when performing an experiment. The resonance can occur at a certain multiple frequency.), but the resonance occurs at several frequencies which are integer multiples of the lowest resonance frequency f_0 for the wire. Here, f_0 is called the basic frequency or intrinsic frequency of the wire, and $2f_0$, $3f_0$, and so on are called the harmonics resonance frequencies. When the wire of the antenna is used by the resonance with RF, it is called the RF excitation.

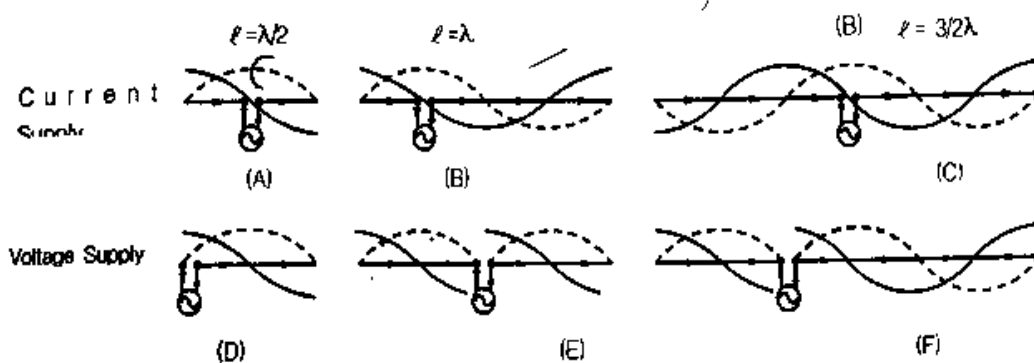


The wire of a constant length is also resonant for the radio frequency having integer multiples of the intrinsic frequency f_0 .

[Fig.14-5] RF Excitation of Wire

The voltage and current distribution on the wire has the minimum current and the maximum voltage at both ends, the maximum current and the minimum voltage at the $\lambda/4$ distant, and this is reversed at every $\lambda/4$ period. A point having the maximum voltage (or current) is called the anti-node, and a point having the minimum is called the node.

When the antenna wire is excited with the standing wave, the power source may be connected to the current anti-node or the voltage anti-node as shown in [Fig.14-6]. The former is called the current supply, while the latter is called the voltage supply.



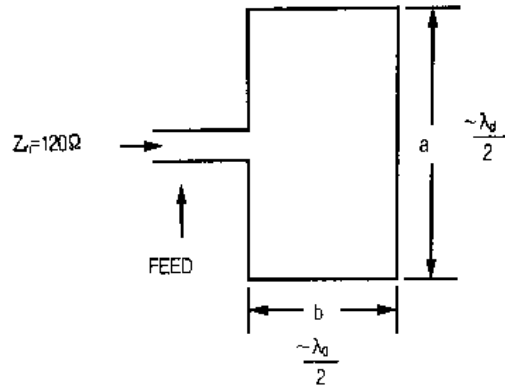
[Fig.14-6] Current and Voltage Supplies and Their Voltage and Current Distribution for Open Straight Antenna Having Length of $\lambda/2, \lambda$, or $3\lambda/2$

In [Fig.14-6], which indicates the direction of current at a certain moment as an arrow, it should be noted that the current direction of two neighboring standing waves becomes opposite (180°) and the voltage and current distribution can change according to the supplying point.

For example, both figures (B) and (E) show the RF antenna having length λ , but the current direction

and voltage polarity change because the supplying points are different. Also, the radiation characteristics, especially the directionality becomes completely different.

4. Characteristics of Rectangular Patch Antenna



[Fig.14-7] Basic Rectangular Microstrip Antenna

[Fig.14-7] shows size of the basic rectangular microstrip patch antenna. The conductance of the antenna is a function of the width a , and the resonance frequency is a function of the length b .

$$b \approx 0.49 \lambda_d = 0.49 \frac{\lambda_0}{\sqrt{\epsilon_r}}$$

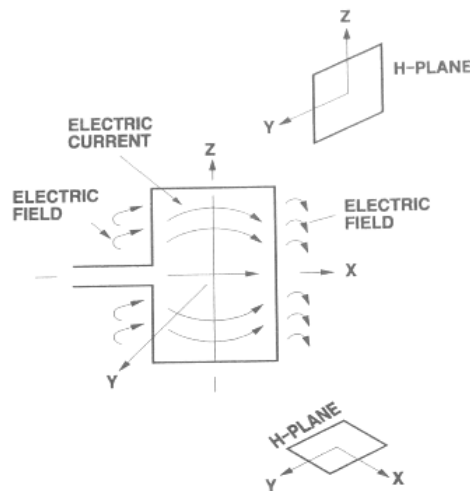
where, λ_d is the wavelength in the dielectric substance,

λ_0 is the wavelength in free space,

ϵ_r is the relative dielectric constant of the substrate.

Because of the dielectric constant and the change of the supplying inductance, it needs to define the accurate length of the patch for the measurement. [Fig.14-8] shows the current flowing inside of the patch and the electric field around it. The electric field mainly exists around the patch connected by the supplying lines and the opposite edges. The electric field is caused by the radiation characteristics of the antenna. A wave radiated from the antenna shown in [Fig.14-8] has the horizontal polarization characteristics. That is, the horizontal direction means E-plane (x-y plane), while the vertical direction means H-plane (y-z plane).

The interval b between two edges of the patch antenna is almost the half-wave length in the dielectric substance ($0.49 \lambda_d$). That is why the opposite slots become the antenna excited to the opposite phases. However, the electric field radiating to two parallel slots becomes the same phase and is added in the normal direction of the antenna element (broadside, that is, y direction).



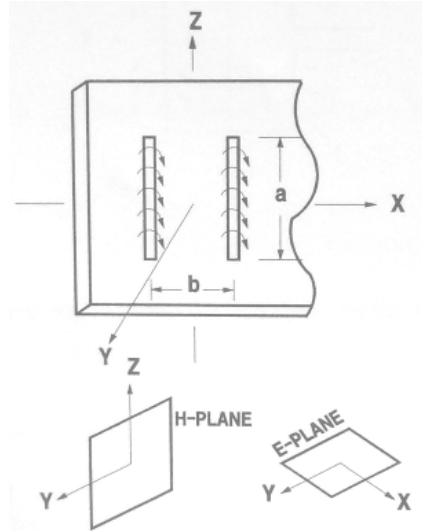
[Fig.14-8] Current Distribution and Common Type of Electric Field

5. Radiation Pattern When Two Waveguide Slots Are Arranged

One simple method to calculate the characteristics of the rectangular patch antenna is comparing the patch antenna in [Fig.14-7] with the waveguide slot antenna having 2-slots in [Fig.14-9].

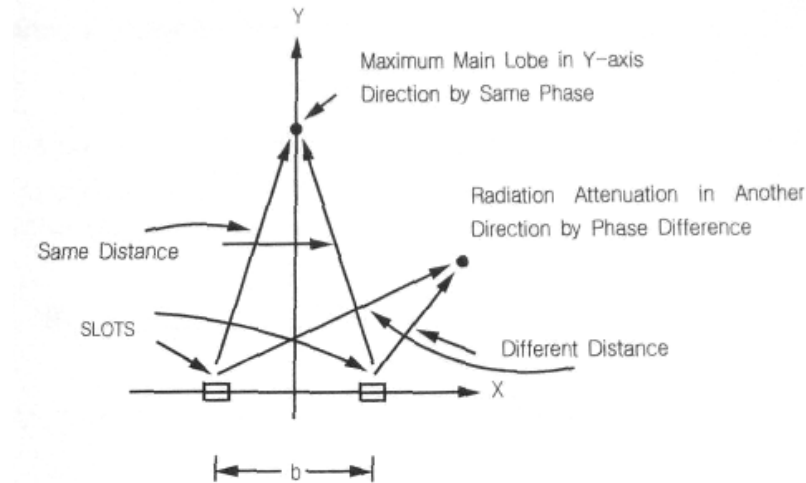
The 2-slots waveguide antenna in [Fig.14-9] is basically equivalent to the patch antenna in [Fig.14-2], so the radiation patterns of these antennas will be identically shown.

To comprehend the radiation pattern of the 2-slots waveguide antenna, it should be noted that the distance b is selected in such a way that the electric fields radiated from two slots can have same phases. At any point in the y axis, the distance between two slots will be same.



[Fig.14-9] Two Parallel Slots in Waveguide

Therefore, the electric fields by two slots become the same phase and are added to each other in the far field region, so that it can be radiated at the maximum. In another direction, the distance between two slots are different, so they cannot be added with the same phase. Accordingly, the radiation pattern will have the main lobe of the maximum size in the y -axis direction.



[Fig.14-10] Analysis of Radiation Pattern in E-plane

Far Field Region for Rectangular Patch

[Fig.14-10] illustrates one slot in a three-dimensional way. In this figure, each axis, ϕ and θ are used as variables for the basic equation, a and b in the following equations, $F_{patch}(\phi)$ and $F_{patch}(\theta)$ are related values with the width a and the length b of the patch shown in [Fig.14-10].

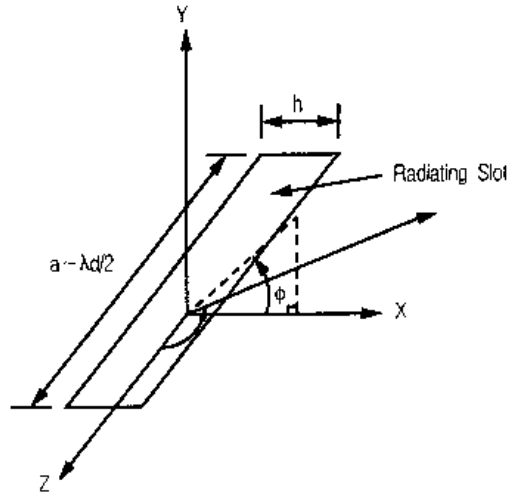
The height h of [Fig.14-10] is related with the thickness of the dielectric substrate in [Fig.14-7] and [Fig.14-8].

The radiation pattern on the E plane for two slots excited to equal amplitude and same phase can be

expressed as the following equation.

$$F_{\text{patch}}(\phi) = \frac{\sin\left(\frac{\beta h}{2} \cos \phi\right)}{\frac{\beta h}{2} \cos \phi} \cos\left(\frac{\beta h}{2} \cos \phi\right)$$

where h is the height of the slot (same as the thickness of the patch antenna substrate), b is the distance between two slots (same as the length of the patch antenna), and $\beta = 2\pi/\lambda$.



[Fig.14-11] Shape for Calculating Radiation Pattern on E- and H-plane for Radiation Slot
H-plane pattern can be expressed as follows.

$$F_{\text{patch}}(\Theta) = \frac{\sin\left(\frac{\beta a}{2} \cos \phi\right)}{\frac{\beta a}{2} \cos \phi} \sin \Theta$$

where, a is the length of the slot.

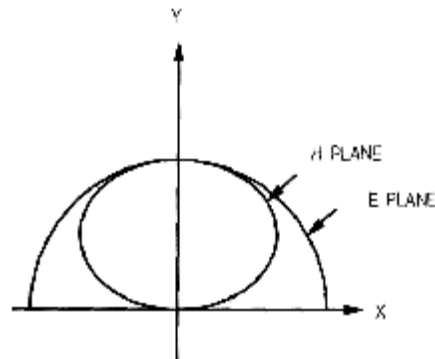
Theoretically, E-plane and H-plane patterns should be shown as [Fig.112].

6. Input Impedance of Microstrip Antenna

Because the input impedances of the 2-slot array antenna and the $\lambda/2$ rectangular patch antenna is resistance components (reactance component "0"), they have good radiation characteristics. The approximate for the input resistance is as follows.

$$R_{\text{in}} \approx \frac{60/\lambda_0}{a} = \frac{60/\lambda_0}{\lambda_0/2} = 120 \Omega$$

Where a is the length of the slot, and λ_0 is the wavelength in free space.



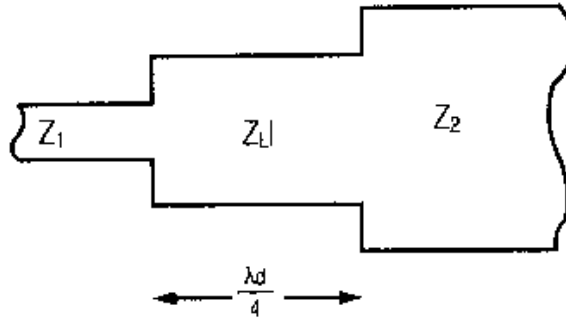
[Fig.14-12] Theoretical E- and H-plane Radiation Patterns for Two Slots Excited

with Same Amplitude and Phase ($b = \lambda_d / 2$, where $\lambda_d < \lambda$)

Ideally, because the input impedance of the patch is about 120Ω , the impedances of the microstrip line and the input terminal of the coaxial cable should be 120Ω . However, in order to connect with the 50Ω coaxial cable used in the antenna experimental set, the 50Ω microstrip line is used.

To match the impedance between the 50Ω microstrip line and the 120Ω patch, the $\lambda/4$ impedance converter as shown in [Fig.14-13] is used. The $\lambda/4$ impedance converter is useful for impedance matching at the narrow band, The characteristic impedance Z_L of the $\lambda/4$ impedance converter for matching the impedances Z_1 and Z_2 is as follows.

$$Z_L = \sqrt{Z_1 Z_2}$$

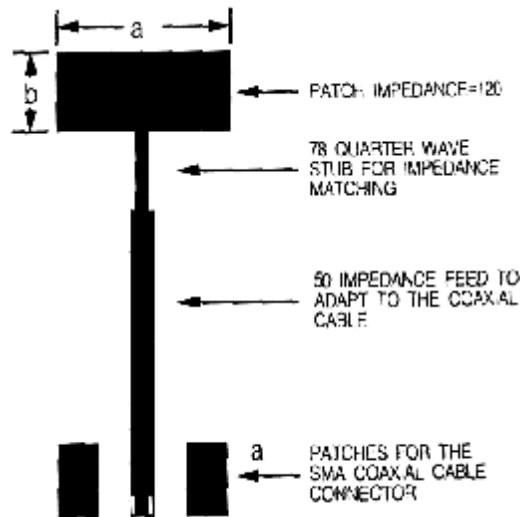


[Fig.14-13] $\lambda/4$ Stub of Impedance Z_L for Matching Impedance Z_1, Z_2

If Z_1 is the impedance of the microstrip line or the 50Ω coaxial cable, and Z_2 is the impedance of the patch antenna, the characteristic impedance of the $\lambda/4$ impedance converter connected to the patch and the microstrip line can be expressed as the following equation.

$$Z_L = \sqrt{Z_1 Z_2} = \sqrt{(50)(120)} = 78 \Omega$$

[Fig.14-14] shows the 78Ω $\lambda/4$ impedance converter and the single patch antenna included in the antenna set.



[Fig.14-14] Single Patch Antenna (Unit: mm)

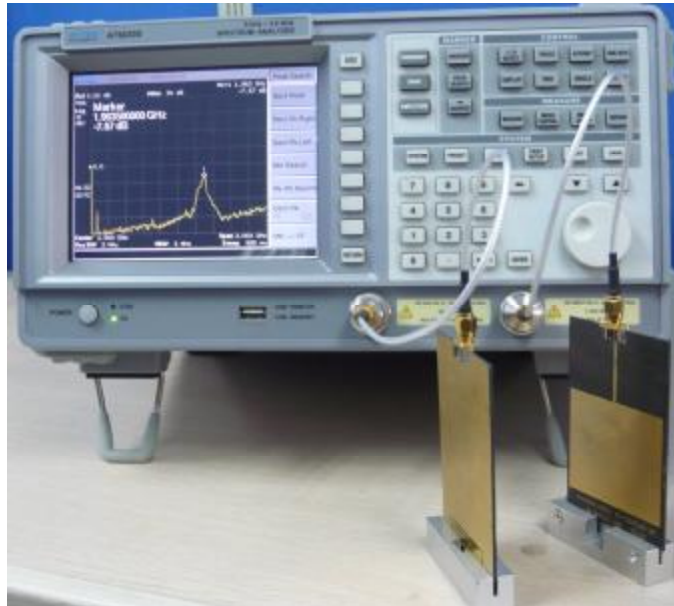
III. Measuring Instruments

Item	Module Name	Quantity
AT6030D	Spectrum Analyzer(tracking generator)	1
AT-RF3030-22	Patch Antenna	2

Accessory	SMA-SMA	2
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IV. Experimental Procedures

- (1) First, adjust the center frequency of the AT6030D to $f_c=1500\text{MHz}$, SPAN=3000MHz. Connect the input and output of the AT6030D Spectrum Analyzer with cable, calibrate, and record the display data on the AT6030D, this data is the transmitting power of the antenna L_r .
- (2) Connect all the lines to form a circuit as show in [Fig.14-15]: Connect the output of the AT6030D to one of the antenna 1, connect the input of the AT6030D to antenna 2. The distance between the two antennas $L \geq 5\text{cm}$, observing the receiving signal spectrum from antenna 2 on the AT6030D, and then press the "MARKER" and "PEAKSEARCH" to obtain the frequency、power on the maximum point, this data is the receiving power from antenna L_r , The difference between the two data is the frequency response characteristics of the antenna.



[Fig.14-15] Antenna Transmission/Reception experiment

- (3) According to radar formula:

$$L_r = L_t + G_t + G_r - N$$

Which, L_r =receiving power level (dBm)

L_t =transmitting power level (dBm)

G_t =the power of the transmitting antenna

G_r =the power of the receiving antenna

$$N = 20 \log (4 \pi R / \lambda)$$

R =the distance between the transmitting antenna and the receiving antenna

λ =wavelength

Then, calculate the G_t 、 G_r , for the two antennas are the same, $G_t = G_r$.

- (4) To the direction angle, need access two same antennas at input and output port. One antenna is static and other antenna around moving so that the angle between the two antennas is changed. Due to Radiation of the antenna is different in different directions, the gain are also different under the changes in the relative angle between each position.

V. Results

<Table 14-1> Measuring Antenna Received Voltage

Antenna Distance[m]	0.5	0.6	0.7	0.8	0.9	1	1.1
Reception Detected Voltage[V]							

VI. Review

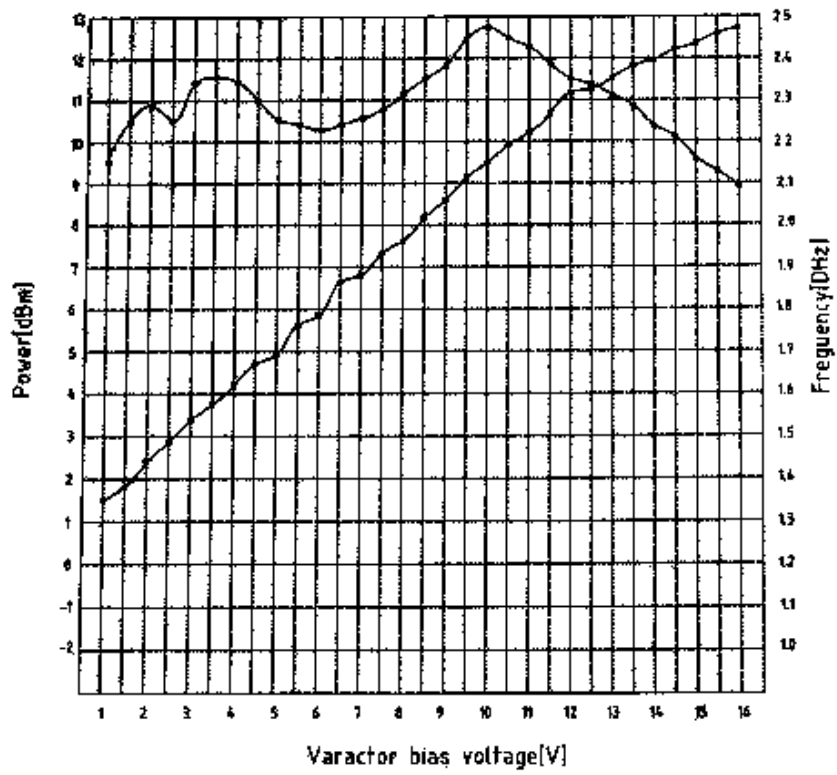
- (1) Explain how the detected voltage changes according to change of the modulator frequency (when the square wave of the function generator is L_0 region).
- (2) Explain the difference between gains of the antenna and the active element.
- (3) Explain characteristics and types of the microwave antenna.
- (4) Convert the detected voltage in <Table14-1>, then calculate the actually received signal with considering gain of the reception amplifier.
- (5) Explain the principle of the PIN modulator.

APPENDIX

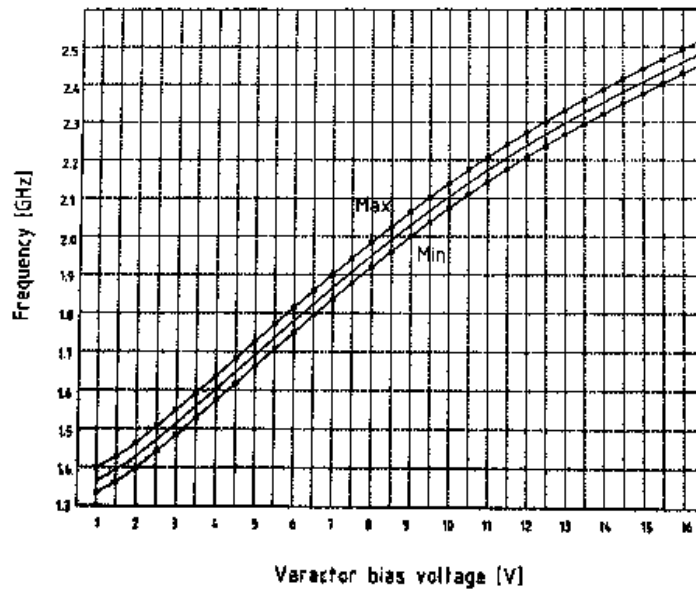
1. VCO [UMS-2400-A16] Output Electric Power

<Table 1> Output Frequency and Output Electric Power of VCO

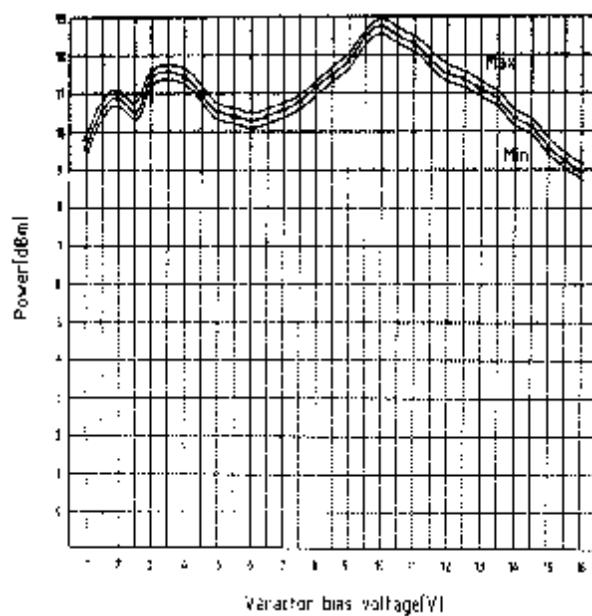
Tuning Voltage (V_{tune})	Power (dBm)	Frequency (GHz)
	24°C when	24°C when
1.0	9.66	1.367
1.5	10.40	1.378
2.0	10.86	1.449
2.5	10.38	1.466
3.0	11.49	1.534
3.5	11.63	1.571
4.0	11.33	1.623
4.5	10.89	1.664
5.0	10.50	1.677
5.5	10.28	1.750
6.0	10.21	1.765
6.5	10.30	1.837
7.0	10.52	1.866
7.5	10.73	1.931
8.0	11.10	1.954
8.5	11.58	2.024
9.0	11.99	2.043
9.5	12.41	2.113
10.0	12.63	2.134
10.5	12.64	2.199
11.0	12.43	2.222
11.5	12.12	2.237
12.0	11.74	2.302
12.5	11.37	2.316
13.0	11.08	2.328
13.5	10.80	2.384
14.0	10.48	2.397
14.5	10.07	2.410
15.0	9.65	2.441
15.5	9.27	2.458
16.0	8.85	2.468



[Fig.1] Tuning Voltage (V_{tune}) versus Output Electric Power and output Frequency graph of VCO



[Fig. 2] Tuning Voltage (V_{tune}) Versus Output Frequency error of VCO

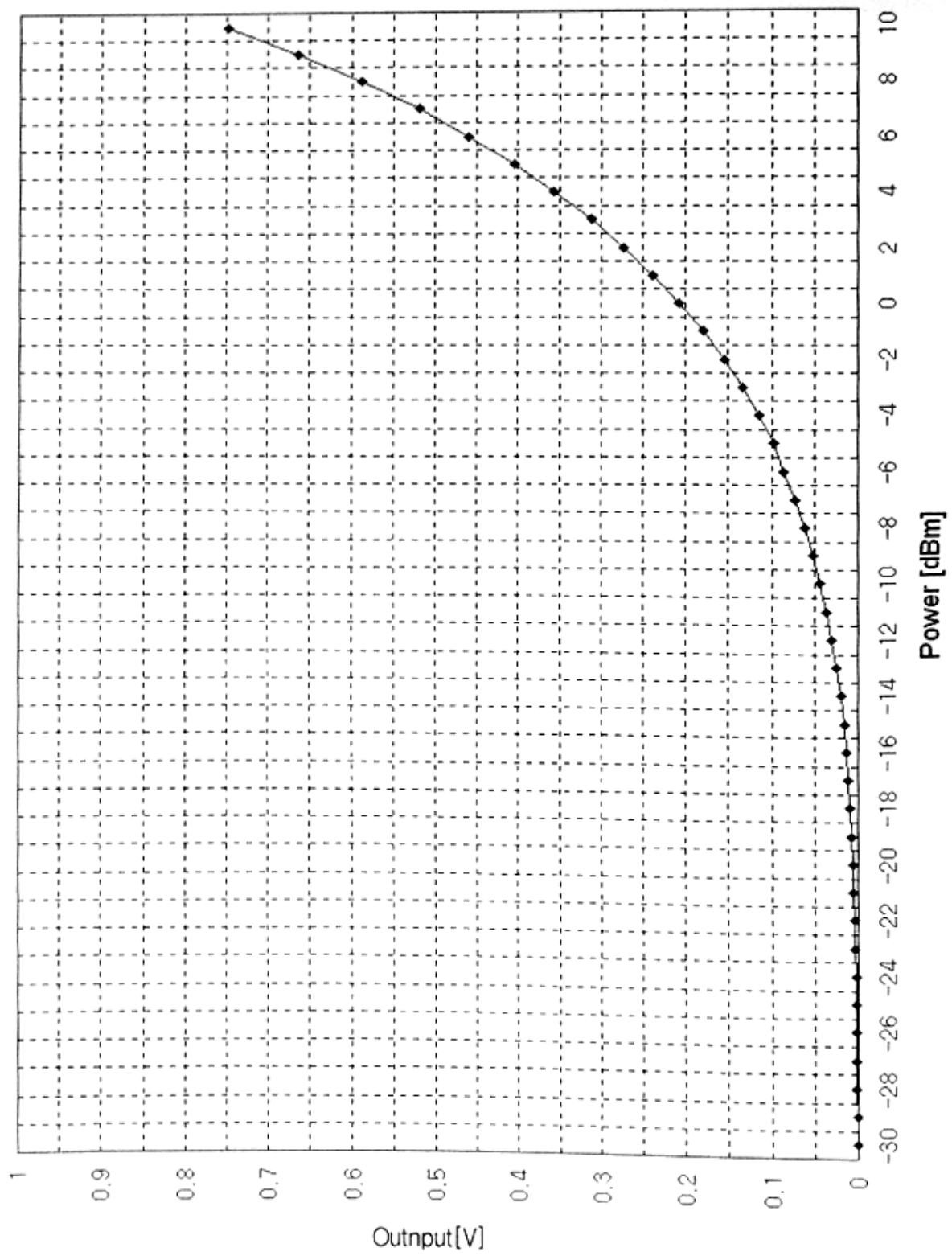


[Fig. 3] Tuning Voltage (V_{tune}) Versus Output Electric Power Error of VCO

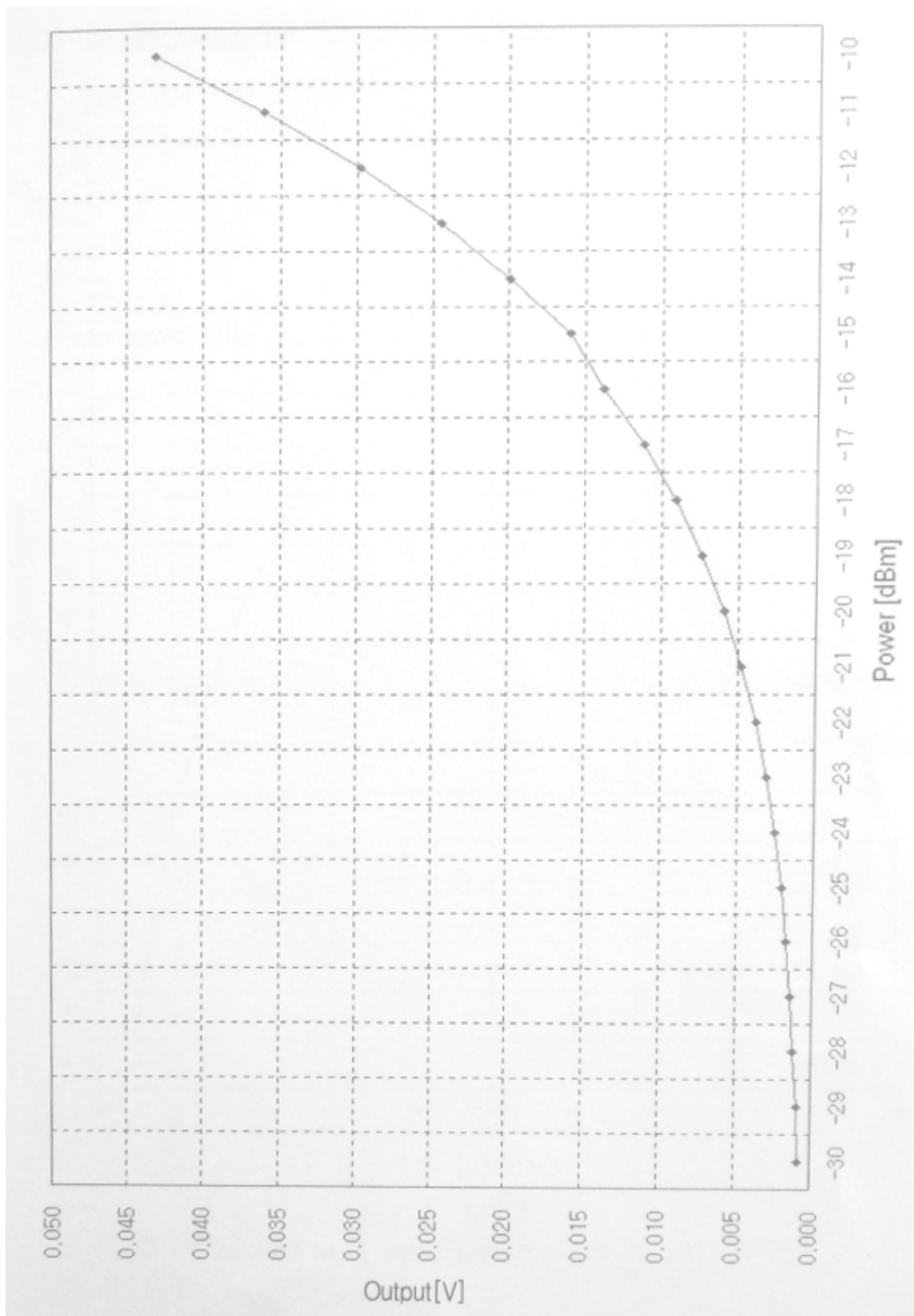
2. Characteristic of Detector

<Table 2> Detector Detected Voltage on the Electric Power

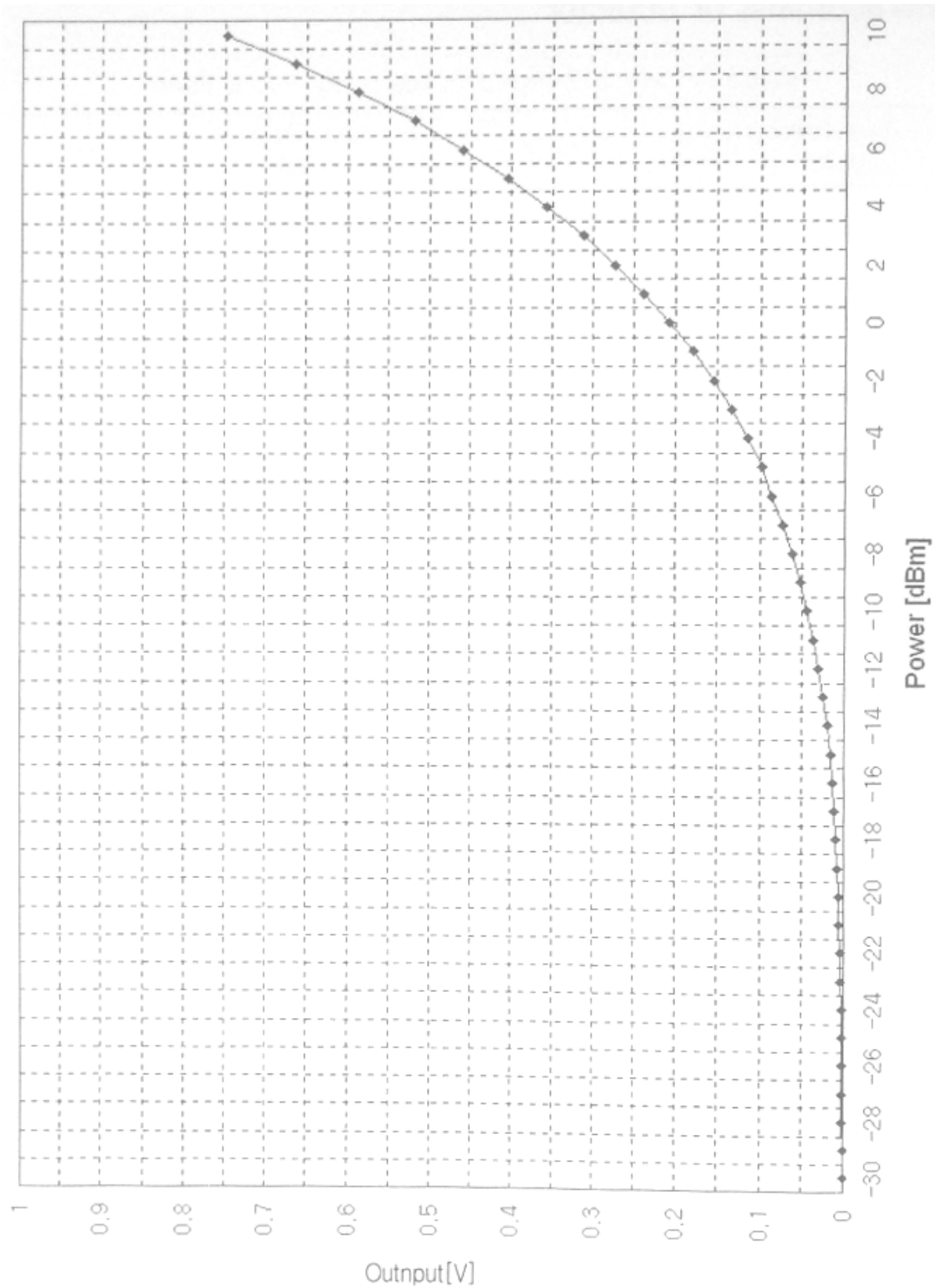
Power [dBm] $\pm 0.3\text{dB}$	Voltage [V]	Power [dBm] $\pm 0.3\text{dB}$	Voltage [V]
-30	0.00031	-7	0.0726
-29	0.00039	-6	0.0872
-28	0.0048	-5	0.1
-27	0.00059	-4	0.125
-26	0.00074	-3	0.149
-25	0.00121	-2	0.176
-24	0.00152	-1	0.205
-23	0.00180	0	0.239
-22	0.00238	1	0.276
-21	0.00297	2	0.303
-20	0.00372	3	0.35
-19	0.0051	4	0.40
-18	0.00640	5	0.48
-17	0.00801	6	0.525
-16	0.01	7	0.599
-15	0.0125	8	0.684
-14	0.0155	9	0.781
-13	0.0184	10	0.89
-12	0.0223	11	0.99
-11	0.0283	12	1.091
-10	0.0339	13	1.202
-9	0.0378	14	1.297
-8	0.0459	15	1.401



[Fig. 4] Characteristic Graph 1 of Detector

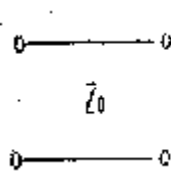


[Fig. 5] Characteristic Graph II of Detector

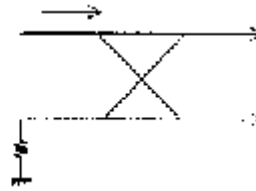


[Fig. 6] Characteristic Graph III of Detector

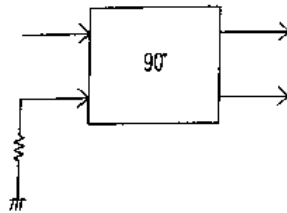
3. Symbol of Microstrip



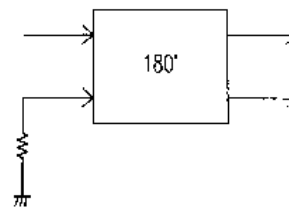
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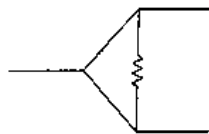
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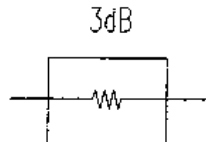
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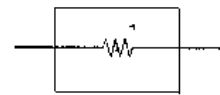
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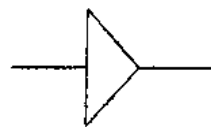
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<Attenuator>



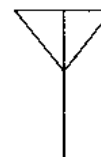
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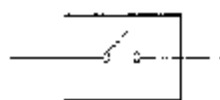
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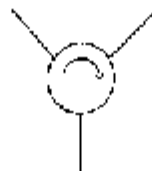
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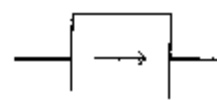
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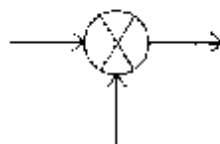
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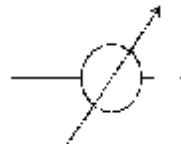
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<Phase Shifter>



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<Band Pass Filter>