CHAPTER 3

RAIN ATTENUATION MEASUREMENT SYSTEM

3.1 Review of Rain Attenuation Measurement System

The method of rain attenuation measurement along the earth-satellite path can be classified as 3 types: 1) a direct measurement method, 2) a radiometric measurement method, and 3) a radar measurement method. The combination of both the direct and the radiometric methods or all three measurement methods can improve high accuracy and high reliability of measurement system.

In our experiment, the four radiometers were installed in Southeast Asia to collect rain attenuation data and rain intensity data over a three year period from March 1, 1992 to February 28, 1995. After the radiometer measurement systems were terminated, the new beacon measurement system was installed at the CAT's Si-racha earth station, in Chonburi province and at the CAT's submarine cable station, in Songkla province, the southern east-coast of the Thailand Peninsular.

1) The Direct Measurement Method

Beacon receiver is often used in many rain attenuation studies both in the Ku-band and in the Ka-band satellite system. It has advantage on a large measurement range up to 30 dB. A satellite transmits continuous beacon frequencies with high stability, the beacon receiver can pick up those beacon signals in the satellite foot-print. The direct measurement consists of a beacon receiver, a parabolic antenna, and a data acquisition system. The beacon receiver continuously receives the beacon signal at a short sampling time (< 10 seconds). Data can be stored in the hard disk before sending to an analysis process. The received beacon amplitude will be decreased when rainfall appears on the propagation path, and attenuation can be measured. There are some errors at relatively low signal variations (±1 dB) due to the movement of satellite's position, the signal variation due to the receiver's gain variation. One limitation of the beacon measurement method is, the unavailability of the beacon signals to all locations, all frequencies, and all elevation angles.

2) The Radiometric Measurement Method

Radiometer has been widely used for many years due to its advantages over the direct measurement in terms of flexibility and easy to operate, but the range of measurement is limited up to 10 - 12 dB. In this method, attenuation can be calculated from the measured sky-noise temperature along a slant path. When rainfall appears along the slant path, noise signals generated from the rainstorm (T_s) will be received by the radiometer. It will be converted to rain attenuation by a general energy conversion process.

3) The Radar Measurement Method

Radar has been used in the weather observation, but little is used on the propagation studies due to the high implementation cost and more complexity in operation and maintenance. However, the radar measurement is very powerful to study for the rainfall's structure which is essential for developing a powerful rain attenuation prediction model. The radar measurement, not only observes rain extending over large areas, but also monitors the effective rain height. One difficulty in radar method is the accuracy of the conversion of measured radar reflectivity to rain intensity and rain attenuation.

3.2 Theory of the Radiometric Measurement

G. Burssaard [1984] found that measurement of sky noise temperature (Ts) by the radiometer provided significant information for rain attenuation statistics. The radiometric measurement has been investigated and used by many researchers such as: W.J. Vogel, G.W. Torrence, J.E. Allnutt [1990], Kozu t., Fukuchi, H, and Otsu, Y [1986]. Normally, the sky noise temperature is generated by the energy conversion process. When radio waves pass through the absorbing medium (e.g. rain, cloud) which has a certain medium temperature (T_m), rain will absorbs and scatter those radio energy. The absorbed energy causes the signal loss (attenuation), and it energy loss is transferred to heat and increasing the medium temperature of the rain (T_s). This increase of the noise temperature can be detected by receiving the noise coming from the sky and the increasing noise temperature (T_s) is directly related to the signal loss (attenuation) by the following equation.

$$T_S = (1 - \sigma)\, T_m \quad \text{degree Kelvin} \quad \text{------------------(3.1)}$$

or $$T_S = 1\text{- } \exp(-A/4.34) \quad \text{degree Kelvin} \quad \text{------------------(3.2)}$$

or $$T_S = (1 - 10^{-(A/10)}) \quad \text{degree Kelvin} \quad \text{------------------(3.3)}$$

where

σ is the fractional transmissivity of the medium (Rain), $0 \le \sigma \le 1$,

A is the attenuation in decibels,

Ts is the increasing noise temperature in degree kelvin,

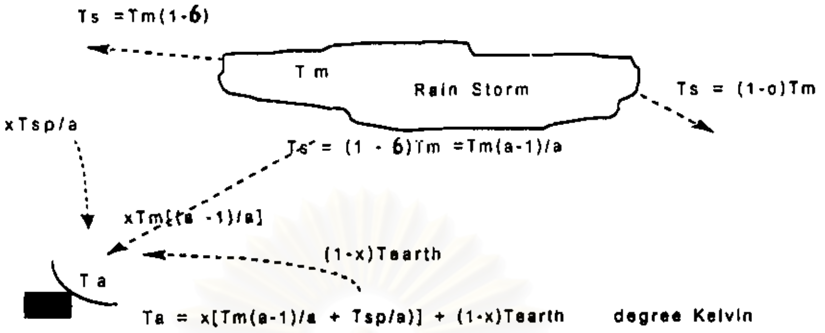
Tm is the effective medium temperature of the absorbing medium (rain)

The attenuation is related to the fractional transmissivity by

$$a = 1/\sigma$$

$$A\ (\text{dB}) = 10\text{Log}(1/\sigma) \qquad \text{-----------------(3.4)}$$

or $$A\ (\text{dB}) = 10\text{Log}(T_m/(T_m-T_s)) \qquad \text{-----------------(3.5)}$$



Ta= Antenna Noise Temperature (K)
Tm = effective medium temperature (K)
a = ratio of attenuation
x =ratio of antena side lobe
Tsp = asmospheric noise(K)
Tearth = ground noise (K)

Figure 3.1 The contribution of antenna noise temperature (T_a)

As shown in Figure 3.1, the antenna noise temperature (T_a) measured by a radiometer consists of contributions of the gaseous components of the atmosphere (T_{sp}), absorption, scattering by hydrometeos or precipitation (T_m), and noise from the ground (T_{earth}). Rain is the main effect to the microwave frequencies above 10 GHz including the Ku-band and Ka-band assigned for satellite communication. Water vapor absorbs the radio frequencies at 22.5 GHz, while the molecular oxygen absorbs the 55-60 GHz frequencies. If rain were purely absorbing medium (100% absorption), the effective medium temperature (T_m) would equal the physical temperature of the rain. At 12 GHz, , the fraction of the incident energy which is scattered by rain is relatively small compared with the absorbing energy (σ) and it increases with rainfall rate. Therefore, the amount of antenna noise temperature received by the radiometer which is used to produce the attenuation has little value lower than the effective medium temperature and the physical temperatures of rain. If rainfall rate is high or large water condensed in the rainstorm , the antenna noise temperature (T_a) could be reached to the maximum level that may be close to the effective medium temperature (T_m).

When the radiometer is looking to the sky, the main lobe of the antenna almost received all sky noise directly coming from the sky. However, the side lobe of the antenna may receive a small portion of the noise from the earth (T_{earth}). Under this condition, the energy received by the radiometer is given by:

$T_a = x[\ T_m(a-1)/a) + T_{sp}/a] + (1- x)T_{earth}$ °K-----------------------------(3.6)

where

x is the fraction of the energy received by the antenna main lobe,

(1-x) is the fraction of the energy received by the antenna side lobe,

a is the attenuation ratio equals to $1/\sigma$ with $1 \leq a \leq \infty$,

T_{sp} is the noise generated from the atmosphere and stars in the absent of rain (°K),

T_{earth} is the noise temperature generated by the earth (°K),

T_m is the effective medium temperature of rain storm (°K).

In the absence of rain, T_m is equal to 0 °K and "a" is equal to 1, therefore the antenna noise temperature (T_a) can be defined as the clear sky temperature (T_{cs}) which can be expressed by:

$T_{cs} = xT_{sp} + (1-x)T_{earth}$ °K ---------------------------------(3.7)

and $T_a = x[T_m(a-1)/a + T_{sp}/a] + T_{cs}$ °K -------------------------(3.8)

Since T_{sp} is relatively small (<10° K) compared with T_m (250 °K - 290 °K), therefore the term T_{sp} may be ignored. Then the antenna noise temperature can be given by

$T_a = xT_m((a-1)/a + T_{cs}$ °K ----------------------------------(3.9)

When "a" increases to ∞, T_a can approach T_m , then we can substitute T_a with T_m, and $a = \infty$, to equation (4.9) and T_m can be given by

$T_m = xT_m + T_{cs}$ °K --(3.10)

By rearranging the expression (3.9),(3.10) the attenuation can be expressed by

$a = (T_m-T_{cs})/(T_m-T_a)$ --(3.11)

or

$A\ (dB) = 10\log[(T_m-T_{cs})/(T_m-T_a)]$ --------------------------------(3.12)

where T_m is the effective medium temperature of rain (°K)

T_a is the measured antenna noise temperature (°K)

T_{cs} is the antenna temperature under a clear sky condition (°K)

To obtain rain attenuation (A) in equation (3.12), T_m and T_{cs} must be specified. The valve of T_{cs} can be obtained by measuring clear sky temperature, but the value of T_m do not have any straightforward solution. T_m is a function of temperature, frequency, polarization and the medium structure of each rain storm. Many scientists have focused on how to choose the appropriate value of T_m. W.J Vogel, G.W. Terrence, and J.E. Allnutt [1990] estimated T_m by comparing the value of attenuation measured by a radiometer and a beacon receiver at Austin Texas over a 2-year period. They found that $T_m = 274^\circ$ K can give acceptable accuracy over 15 dB attenuation for Austin, Texsas. G. Brussaard [1993] compared 3 years measurement of the radiometer with the beacon receiver in Surabaya, Indonesia. He found that when T_m equals 290° K, attenuation measured by the radiometer and the beacon is similar. In our radiometric measurement, the effective medium temperatures in Singapore and Bundung were calibrated at 290° K while the radiometer in Bangkok and Si-racha were calibrated at 280° K.

In our radiometer, the accuracy of the measured attenuation is better than 0.5 dB for attenuation less than or equal 6 dB while attenuation accuracy is +/- 1 dB error for the attenuation of 10 dB. Figure 3.2 illustrates attenuation (dB) versus antenna temperature (T_a) given different values of T_m (270° K, 280° K, 290° K, and 300° K). It is clearly indicated that when T_a less than 200° K, attenuation may vary at +/- 0.2 dB, and when T_a equals 250° K, attenuation may vary at +/- 1.5 dB. Therefore, we decide to analyze rain attenuation not more than 12 dB.

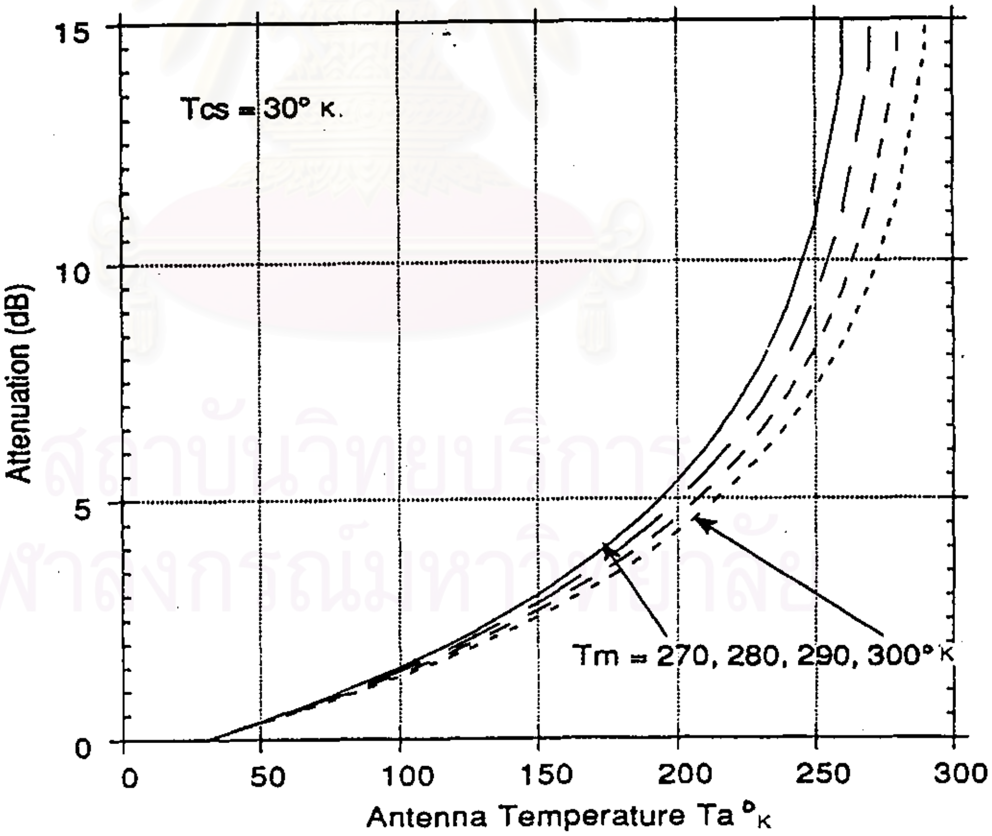


Figure 3.2 Attenuation (dB) versus antenna temperature (T_a) for different T_m (270° K, 280° K, 290° K, and 300° K).

3.3 Radiometric Measurement System

In this research, both radiometers and beacon receivers are used. The radiometer system is designed to measure the antenna temperature continuously every 2 seconds sampling. The system was designed by the Diversital Communications Inc. [1993] of Canada.

The measurement system consists of four major components:

1. A dual-slope radiometer uses to continuously measure the noise power generated by rain storm at frequencies 12 GHz with 200 MHz band. It consists of a 1.2 m parabolic antenna shown in Figure 3.3, an out-door unit, an in-door unit. The antenna noise temperature is converted to the digital form and sent to the indoor unit and stored in a non-volatile static RAM memory at every 2 seconds sample. The calibration process consists of measuring the radiometer response to a relatively cold load (the clear sky) and the hot load (a reference termination). The calibration is performed automatically at every hour. At the beginning of each hour, the mean and variance of the previous hour are calculated. If the calculated variance is less than a specified limit, it is assumed that no rain-attenuation occurred in the previous hour when the calibration is taking place. If the variance exceeds that limit, it is assumed that rain-attenuation is occurring and the calibration remains unchanged.

Figure 3.3 The 1.2 meter parabolic antenna and the outdoor unit located at the focal point.

2. The Data Acquisition System consists of a computer with a color display. The data are saved and displayed the attenuation, and rain intensity as a function of time on the color display and the plotter. Data can be edited and can remove some discrepancy data caused by sun transit or any measurement error.

3. The tipping bucket rain gauge with variable integration time, as shown in Figure 3.4, measures rainfall rate or rain intensity in every rain accumulation of 0.2 mm using the light emitting diode (LED) sensor.

Figure 3.4 The 8 inches tipping bucket rain gauge with 0.2 mm per tip

The specification of the radiometric measurement system is described below:

Specifications

Radiometer

Frequency	12.0 GHz
Resolution	0.5K maximum with 5-second integration
Feed	Prime focus
Calibration	Manual and automatic using the clear sky and reference termination as cold and hot loads respectively
Serial Ports	RS-232, 9-pin, for connection to a modem, terminal or computer
Raingauge	Connection for one tipping-bucket raingauge, contact closure, BNC connector
Temperature range	Indoor unit, 0°C to 40°C, non-condensing Outdoor unit, -5°C to 45°C
Data storage	Non-volatile static RAM sufficient to store data acquired over at least 96 hours
Cable	Multi-conductor cable with connectors, 40m length
Power	220/240 V (±10%), 48-66 Hz, 100 VA maximum

Raingauge

Raingauge	Standard tipping bucket with contact closure, normally open
Cable	RG-58 cable with spade lugs and BNC male connector, 40m length

3.4 Beacon Measurement System

The Ku-band measurement system configuration is depicted in Figure 3.5 and the antenna including outdoor equipment, installed in Si-racha, are shown in Figure 3.6. The Ku-band measurement system is a special design, manufactured by the TIW USA, which can measure both attenuation and depolarization. It consists of 2.4 meter antenna with a dual linear-feed, low noise amplifiers, 2-channel beacon receivers as in Figure 3.7, down converters, and a data logging system. The dual-channel beacon receivers have two identical channels (co-pol and x-pol) with a high image rejection signal. Frequency selection is provided by four fixed crystals that can be selected from any beacon frequency of INTELSAT satellite (11.198 - 11.459 GHz). The down converter utilizes a dual-down conversion with a phase-lock agile output to accurately produce a frequency-stable signal with 70 MHz output. The demodulator subsystem uses the well-known TIW coherent monopulse tracking system with very high accuracy of level measurement between -40 to -100 dBm. The phase lock loop has bandwidth = 500Hz with the acquisition range of +/- 150 KHz. The amplitude of the received beacon signal is converted into a digital form with 0.1 dB resolution. The data logger system collects both x-pol and co-pol signals in the digital form and saves into a hard disk. Table 3.1 shows the link budget for the beacon experiment.

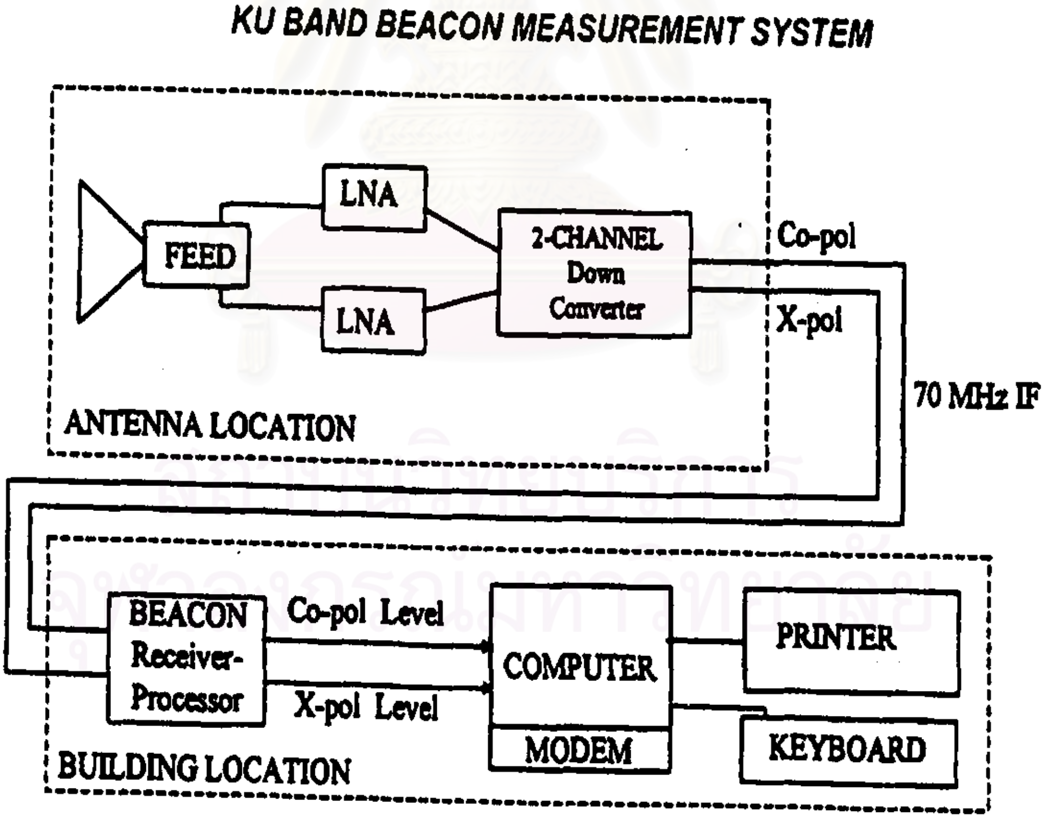


Figure 3.5 Block diagram of Ku-band beacon measurement system

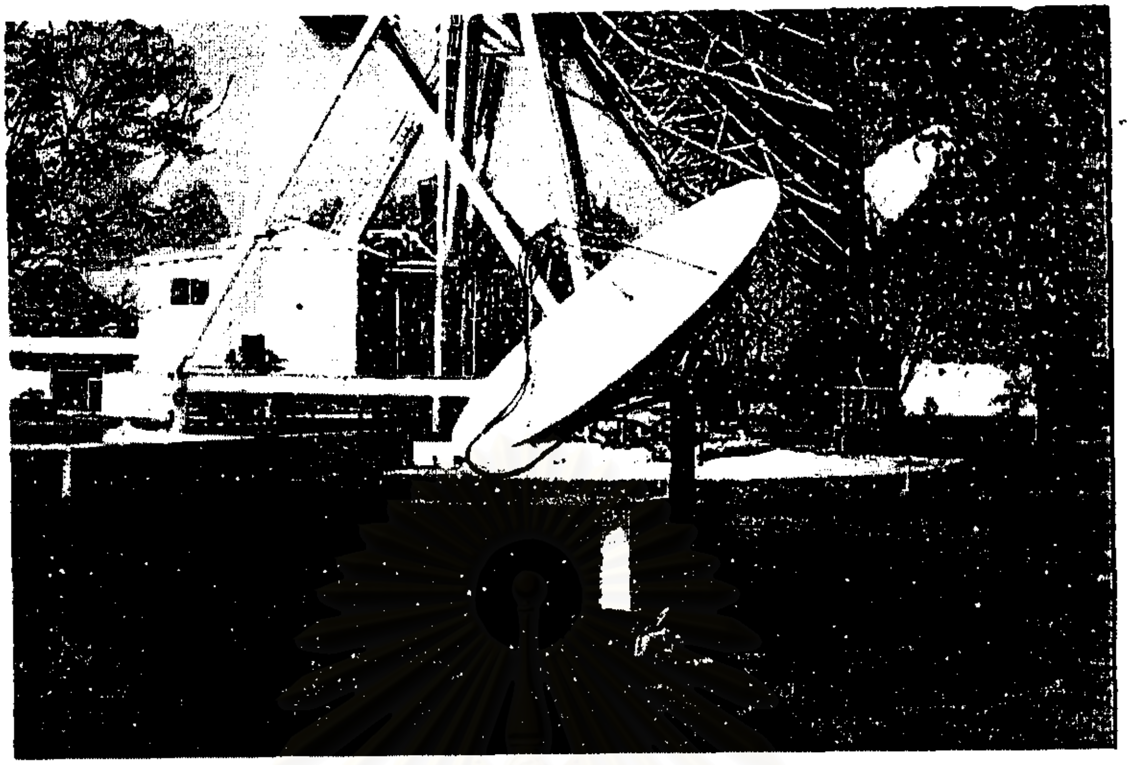


Figure 3.6 The 2.4 meter parabolic antenna and the outdoor unit at Si-racha earth station looking at the INTELSAT VII satellite at elevation angle 42 degree.

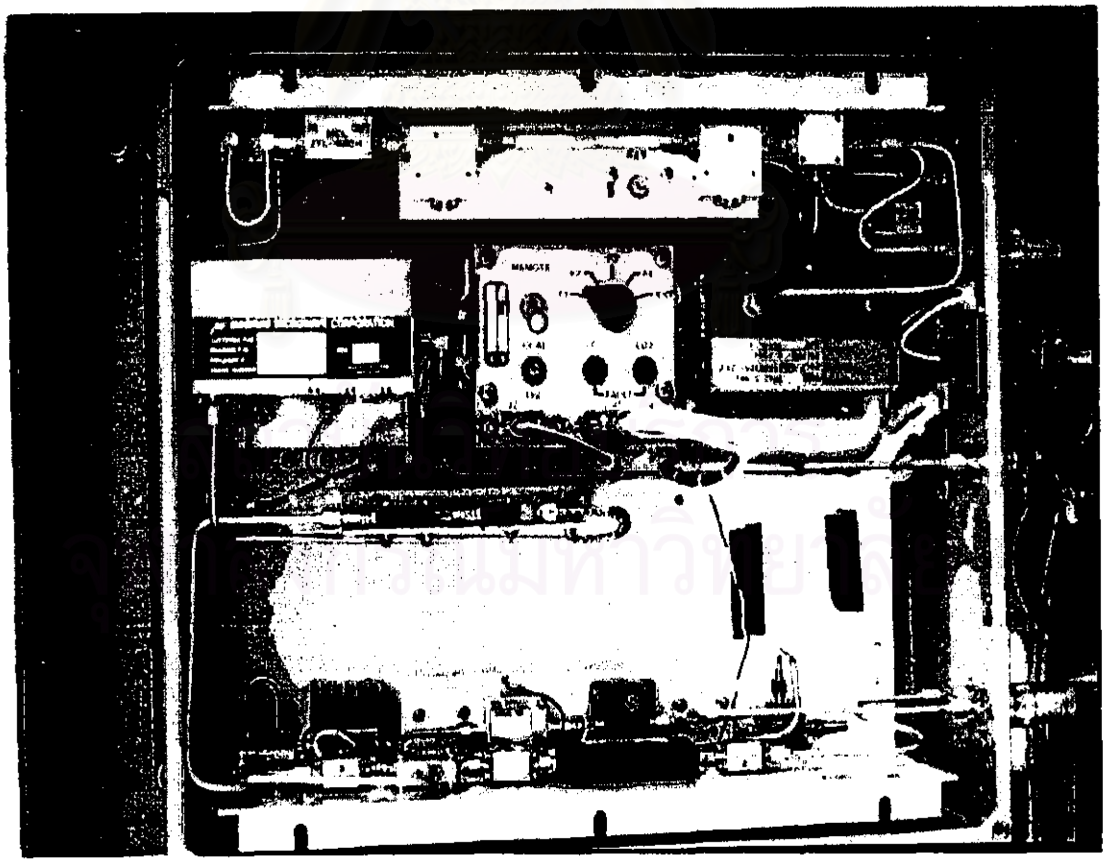


Figure 3.7 Dual-channel beacon receivers and down converters.

Table 3.1 Details of Link calculation for the Ku-band measurement system

Items	Si-racha	Songkla
Beacon EIRP @ INTELSAT 66E (dBW)	10	10
Free - space Loss @ 12 GHz (dB)	-205.2	-205.2
Clear -sky Loss (dB)	-0.3	-0.3
E/S Pointing Loss (dB)	-0.7	-0.7
E/S Antenna Gain (dB)	47.2	47.2
E/S G/T(dB/K)	26	26
Receive IF Input of Beacon (dBm)	-60	-50
C/No (dB-Hz)	57.4	57.4
C/N at 500Hz Bandwidth (dB-Hz)	31.5	31.5
Attenuation Range (dB)	0 - 30	0 - 30

The beacon signal amplitudes are sampled every 5 seconds. The data are stored in the computer hard disk. In order to ignore some discrepancies of data at low attenuation and save a hard-disk memory, attenuation less than 3 dB will not be recorded. During the measurement period, if attenuation is higher than 3 dB, the attenuation value and sampling time every 5 seconds will be recorded. Every end of the day, the daily files including each attenuation value and time are recorded.

3.5 Rainfall Measurement

Rainfall measurement have been extensively recorded for over 100 years by the Meteorological Department. This long term rainfall data are more reliability for the prediction of rainfall. Since to attenuation mainly relies on the fluctuation of rainfall (rain intensity) which can be measured by a short integration time rain gauge (< 1 minute), many researchers attempt to use the rainfall data to be the fundamental tools to predict the attenuation distribution. Unfortunately, the rainfall accumulation data with longer integration time more than 1 hour which is stored in the meteorological data bank are not sufficient to be used for the attenuation prediction. Only the fast response rain gauge with the short integration time and a tipping bucket rain gauge with variable integration time are widely used in today's radio propagation studies.

The tipping bucket rain gauges were mounted near each radiometer. Each rain-gauge tip provides rainfall amount of 0.2 mm. The time of each tip is stored in the memory and the instantaneous rain intensity can be calculated by measuring the time difference between each tip using the following equation.

$$R\ (\mathrm{mm/h}) = 72000/\Delta T \qquad \text{---------------}(3.13)$$

where

R is an instantaneous rain intensity in mm/h

ΔT is the difference between each rain gauge tip in hundreds of seconds.

There are some errors in the measurement of rainfall rate using the conventional tipping bucket rain gauge and the error can affect the attenuation prediction. Allnutt [1989] classified three errors of raingauge measurement as the spatial error, the integration error, and the inherent error.

1) The spatial error occurs when rain falls along some distances on the slant path but not fall in the rain gauge.

2) The integration error occurs when the integration time of the raingauge is too slow, and the high rainfall rate can not be detected. For example, at 0.01% of the time that rainfall rate exceeds the threshold, the 12 minute integration time provides larger error than the short integration time (<1 minutes). ITU-R recommended the integration time less than or equal one minute which shall be appropriate for the measurement accuracy.

3) The inherent error is due to the mechanical error in the design of the equipment. The tipping-bucket raingauge is the most common raingauge. It has some mechanical error due to the insufficient tip for a small rainfall rate (< 5 mm/h) and the tip cannot follow the very high rainfall rate due to the inertia of the tipping bucket. However, this type of raingauge is acceptable in accuracy between 5 - 150 mm/h.

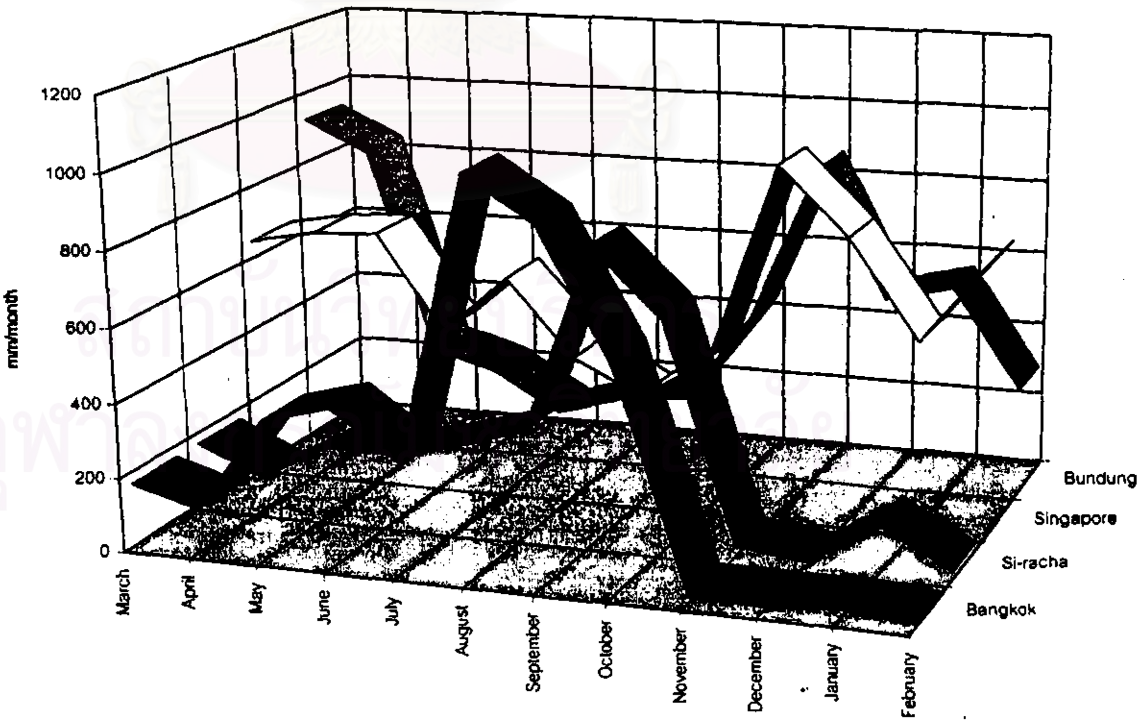
In our experiment, we use the variable integration time tipping-bucket rain gauge which has more sufficient accuracy for the rainfall rate in Southeast Asia. The measurement of this rain gauge is between 0 - 300 mm/h. It must be noted that at relatively high rain intensity (> 200 mm/h) or very small integration times, loss of accuracy may be introduced due to the above errors. M.S Assis found that the measured values of this type of rain gauge underestimated the actual rain intensity at very high values. ITU-R 836 [1986] recommended the used of one minute integration time for measuring rain intensity distribution. However, J. Goldhirsh [1992] used the same type of this rain gauge and he found that the cumulative distribution of rain intensity gave only slightly lower value than those measured by the variation time rain gauge. In our analysis, we decide not to apply any correction factor to the measured intensity.

3.6 Characteristics of Experimental Sites

In 1992, 12 GHz radiometers and tipping bucket rain gauges were installed to obtain long-term attenuation and rainfall statistics in Bundung (200 Km from Jakarta to the West), Indonesia, Singapore, Bangkok and Si-racha (80 Km from Bangkok to the East), Thailand. The location of four experimental sites in Southeast Asia is shown in Chapter 2, Figure 2.1.

The weather and climate in Southeast Asia are affected by a large extent of the monsoon which is the natural phenomenon of weather circulation. In addition the Intertropical Convergence Zone (ITCZ) and some tropical storms produce heavy rainfall in this region. ITU-R [1990] divided rain climate zone of Southeast Asia in an ITU-R Zone-N and an ITU-R Zone-P. The ITU-R Zone-N (topical moderate climate) provides average annual rainfall accumulation of 1000 - 2000 mm/yr, while the ITU-R Zone-P (tropical wet climate) has annual rainfall accumulation of about 2000 - 5000 mm/yr. From June to October, the southwest monsoon, the ITCZ, and some tropical storms are established over the northern part of Southeast Asia (Thailand, Laos, Vietnam, the Philippines) causing heavy rainfall. From November to April, the northeast monsoon, the ITCZ move down to the South causing heavy rainfall in the Indonesia, Malaysia, Singapore, and the peninsular of Thailand but the northern path is relatively dry.

Figure 3.8 shows a 3-year average monthly rainfall accumulation at four locations. It indicates that heavy rainfall in Bangkok and Si-racha usually occur when the southwest monsoon and the ITCZ move over the country (June-October) but rainfall in Singapore and Bundung are decreased. When the northeast monsoon and the ITCZ move to the South (November - April) the change of wind direction causes relatively cold and dry weather in Bangkok and Si-racha, meanwhile heavy rainfall occurs in Singapore and Bundung.



Monthly Rainfall Accumulation in Southeast Asia over 3 years

Figure 3.8 Average annual rainfall accumulation in Southeast Asia.

Site characteristics are illustrated in Table 3.2 including: the longitude, the latitude, the altitude above sea level, the elevation angle, the azimuth angle. Bangkok and Si-racha are situated on the fore front of the Gulf of Thailand above the equator while Singapore and Bundung are situated near and below the equator. Bundung is situated in the mountain-valley at 870 m height, while Bangkok, Si-racha and Singapore are in the coastal area. The radiometers in Bangkok, Si-racha, and Bundung were pointed to the East at low elevation angle of 7.9°, 8°, and 15° respectively, while the radiometer of Singapore was pointed to Southwest at elevation angle of 39.4°. Figure 3.9 Shows the radiometer and the rain gauge at Si-racha looking at the east direction with low elevation angle (8 degree) to the INTELSAT satellite in the Pacific Ocean Region (POR).

Table 3.2 Characteristics of experimental sites

Site name	Station longitude (deg.)	Station latitude (deg.)	Attitude above sea level (meter)	EL angle (deg.)	AZ angle (deg)
Bangkok	100.5° E	13.7° N	30	7.4	94
Si-racha	100.9° E	13.1° N	54	7.9	93.9
Singapore	103.9° E	1.3° N	20	39.4	268.3
Bundung	107.6° E	6.9° S	870	15	87

Figure 3.9. The Radiometer and the rain gauge at Si-racha earth station Chonburi, Thailand.

3.7 Measurement Durations and Daily Data

During a measurement period, there were some occasionally losses of data caused by lighting strikes, computers and other equipment failures. Figure 3.10 shows the percentage of time that valid data were obtained for each of the sites. For the three year period, the data availability from the experiment are 84% for Bangkok, 83% for Si-racha, 93% for Singapore and 92% for Bundung. Figures 3.11 - 3.12 show a daily data measured by the radiometer and the beacon receiver in Si-racha Thailand.

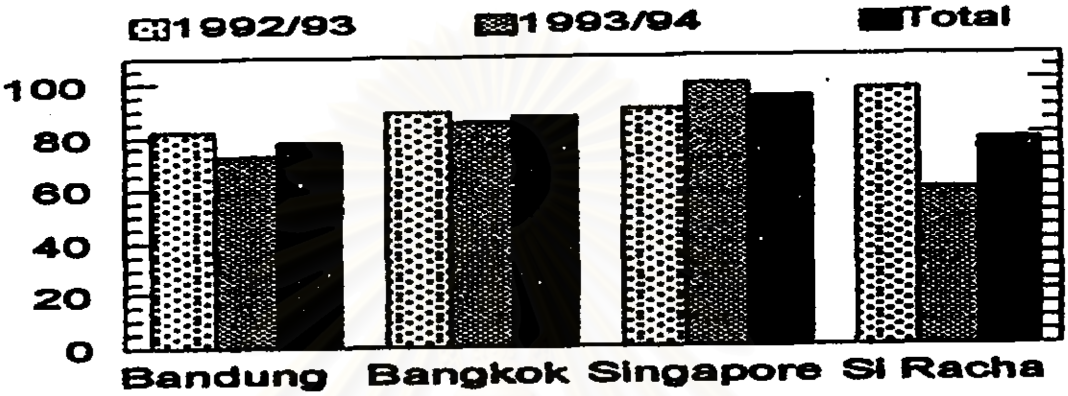


Figure 3.10 Percentage of time that valid data were obtained for each of the experimental sites in Southeast Asia.

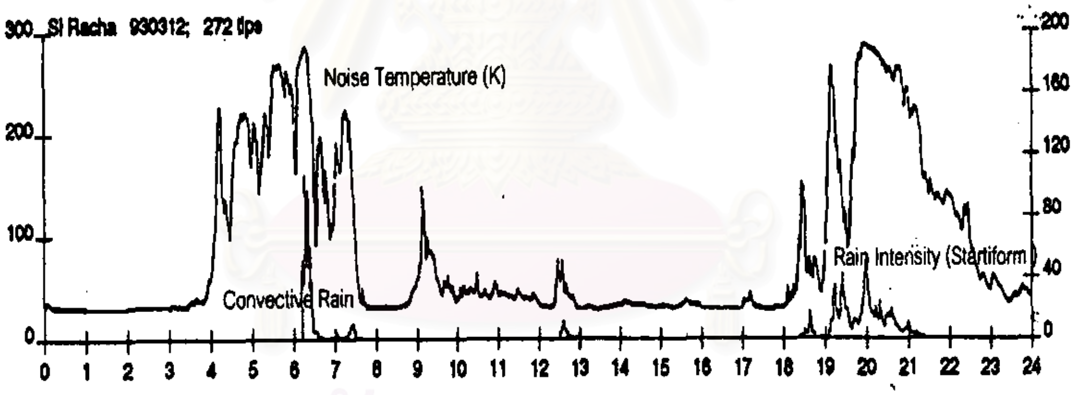


Figure 3.11 Daily measured data from the radiometer in Si-racha on March 12, 1993. Two events of rainfall (a convective rain, a Startiform rain). At low elevation measurement, noise temperatures have more longer duration than rainfall duration.

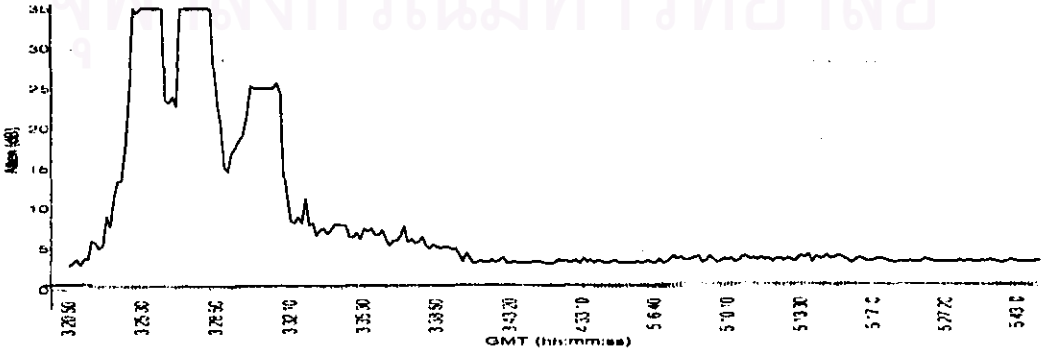


Figure 3.12 Measured rain attenuation using the beacon receiver in Si-racha On June 26, 1997.