Radiometer Calibration Procedure
and
Beacon Attenuation Estimation
Reference Level

by

Robert K. Crane
University of Oklahoma
• VSWR through switch is high (~ 2:1)
• Match secondary reference to LNA not the same as match antenna to LNA
• Hot/Cold load measurements not necessary match probably different from other loads
• No absolute calibration possible using loads and secondary reference
RADIOMETER CALIBRATION

PRIMARY:

• Compare Radiometer Attenuation with Beacon Attenuation

• Compare Sky Temperature Estimates with Calculations Using Simultaneous Meteorological Data

SECONDARY:

• Noise Diode and Reference Load Measurements

• Adjust for Outside Temperature and Component Temperature Changes
RADIOMETER CALIBRATION MODEL

\[ Tr = A + BV \]
\[ Ts = CTr + DT_0 + E \]
\[ Ar = -4.343 \ln \left( \frac{(Tm - Ts)}{(Tm - Tb)} \right) \]

A, B from noise diode, reference load measurements
C from beacon attenuation vs radiometer attenuation measurements
D, E from radiometer estimates of sky temperature vs calculated sky temperature
Tm from calculations
Tb from theory
SYSTEM CALIBRATION IS ITERATIVE

• Need beacon attenuation to compare to radiometer
• Need radiometer attenuation to set beacon reference level

Assumptions

• Beacon receiver is linear, need only find reference level to estimate beacon attenuation

• Radiometer receiver temperature is a linear function of radiometer output voltage, need only estimate gain and offset

• Sky temperature is a linear function of radiometer receiver temperature, need only estimate efficiency and background temperature

• Radiometer attenuation may be estimated from sky temperature if the medium temperature is known
Ratio = 0.097±0.002
Time Period April 16 through April 22, 1994

<table>
<thead>
<tr>
<th>April</th>
<th>AB1/AR1</th>
<th>AB2/AR2</th>
<th>AB2/AB1</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.04±0.03</td>
<td>1.07±0.01</td>
<td>1.58±0.05</td>
</tr>
<tr>
<td>11</td>
<td>1.03±0.01</td>
<td>1.02±0.01</td>
<td>1.62±0.02</td>
</tr>
<tr>
<td>22</td>
<td>0.89±0.01</td>
<td>0.88±0.01</td>
<td>1.67±0.04</td>
</tr>
</tbody>
</table>

- **20 GHz Beacon**
- **20 GHz Radiometer**
- **27 GHz Beacon**
- **27 GHz Radiometer**
DATA CENTER STATUS REPORT

BY

WOLFHARD J VOGEL
&
ALI SYED

EERL/UTAU
10100 BURNET RD
AUSTIN, TX 78758-4497
PRESENTED AT APSW-VI
VANCOUVER, BC
JUNE 16, 1994
ACTS DC Services

- Archive Raw and Pre-processed Data from Stations
- Archive Event & Fault Logs from Stations
- Audit Pre-processed Data
- Distribute Monthly Audit Reports to Stations
- Distribute Archived Data to Propagation Community
### Raw Data Status

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>03/31</td>
<td>28</td>
<td>XX</td>
</tr>
<tr>
<td>03/29</td>
<td>18</td>
<td>30</td>
</tr>
<tr>
<td>03/26</td>
<td>XX</td>
<td>XX</td>
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<td>03/25</td>
<td>17</td>
<td>30</td>
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<tr>
<td>03/24</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td>03/23</td>
<td>17</td>
<td>30</td>
</tr>
<tr>
<td>03/22</td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td>03/21</td>
<td>17</td>
<td>30</td>
</tr>
</tbody>
</table>

**Date Format:**
- DD/MM/YYYY
- HH-MM-SS

**Notes:**
- XX indicates missing or unspecified data.
Data Archival Status

FIRST RAW DATA CD-ROM WRITTEN ON 5/27/94

1105 MB IN 838 RAW DATA FILES

COMPRESSION RATIO OF ~2.0

543 MB ON CD-ROM

751 MB IN 570 PP DATA FILES

COMPRESSION RATIO OF ~3.5

213 MB ON HARD DISK
# Audit & Analysis Status

⚠️ INCORRECT DATA STRUCTURE CAUSED ERROR IN AUDIT & ANALYSIS. BUG FIXED.

<table>
<thead>
<tr>
<th>Time Stamp</th>
<th>Beacon at 20 GHz</th>
<th>Radiometer at 20 GHz</th>
<th>Beacon at 27 GHz</th>
<th>Radiometer at 27 GHz</th>
<th>Status 1</th>
<th>Status 2</th>
</tr>
</thead>
</table>

✅ Time Stamp | Beacon at 20 GHz | Beacon at 27 GHz | Radiometer at 20 GHz | Radiometer at 27 GHz | Status 1 | Status 2 |

⚠️ INCORRECT SCALING FOR STATUS QUANTITIES CAUSED ERROR IN AUDIT REPORT. BUG FIXED.

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>CORRECT SCALE</th>
<th>RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RainGauge [Volts]</td>
<td>1000</td>
<td>0 to 500 mm/Hr</td>
</tr>
<tr>
<td>AirTemp. [C]</td>
<td>100</td>
<td>-50 to 70 C</td>
</tr>
<tr>
<td>Rel.Humd [%]</td>
<td>100</td>
<td>0 to 100 %</td>
</tr>
</tbody>
</table>
DC System Status

- CD WRITER OK
- 120 MB TAPE DRIVE OK
- HARD DRIVE SCSI CARD FAILURE IN 3/94 RESULTED IN ~2 WEEKS DOWNTIME
- SYSTEM & DATA RESTORED FROM TAPES
- DAILY BACKUP SCHEDULE ADOPTED
Data Tapes Status

44 DATA TAPES RECEIVED FROM STATIONS

DIFFERENT BACKUP PATHS NOT A PROBLEM

COLORADO BACKUP LITE VER 1.20 USED BY DATA CENTER

DATA TAPES WILL BE RECYCLED
CONCLUSION

• DATA COMPRESSION AND ARCHIVAL HAS WORKED WITH REAL DATA
• BUGS FOUND IN AUDIT & ANALYSIS Routines HAVE BEEN-fixed
• WEEKLY DATA RECEIVED STATUS REPORT WILL BE DISTRIBUTED VIA E-MAIL
• MONTHLY AUDIT REPORT FOR STATIONS WILL BE DISTRIBUTED VIA E-MAIL
• SOME FINE TUNING IS EXPECTED IN THE FOLLOWING MONTHS
OUTLINE

I. DATA ANALYSIS PROCEDURE AND RESULTS  
   - JAEGER

II. SYSTEM STATUS AND RESULTS  
    - MAYER

III. FUTURE PLANS  
     - MAYER
I. DATA ANALYSIS PROCEDURE

A. COUNT EVENTS
B. ANALYZE INDIVIDUAL EVENTS
C. ANALYZE CUMULATIVE STATISTICS
D. FORMULATE MODELS OF VARIOUS PARAMETERS

A. COUNT EVENTS

- RAIN EVENTS
- SNOW EVENTS
- SCINTILLATION EVENTS

CATEGORIZE THESE EVENTS IN TERMS OF MAXIMUM FADE, FADE SLOPE, FADE DURATION, ETC.
B. ANALYZE INDIVIDUAL EVENTS

- TIME SERIES ANALYSIS
- POWER SPECTRAL DENSITY ANALYSIS
- SCINTILLATION INTENSITY
- FADE SLOPE

C. ANALYZE CUMULATIVE STATISTICS

- BIN THE VARIABLES
- RUNNING AVERAGE TO REMOVE SCINTILLATIONS
- CUMULATIVE BINS
  - DAY
  - MONTH
  - YEAR
  - EXPERIMENT LENGTH
C. ANALYZE CUMULATIVE STATISTICS

- STATISTICAL ANALYSIS
  - CDFs
  - TIME PERCENTAGES VALUES EXCEEDED
  - WORST MONTH
    - WORST MONTH TO ANNUAL AVERAGE
    - WORST MONTH TO OTHER MONTHS
  - FREQUENCY SCALING
    - ATTENUATION RATIOS
    - SCINTILLATION RATIOS
  - SCINTILLATION DIURNAL AND ANNUAL VARIABILITY PLOTS
  - RAIN RATE ANALYSES
    - DIURNAL VARIABILITY
    - ANNUAL VARIABILITY

D. FORMULATE MODELS OF VARIOUS PARAMETERS

- ATTENUATION RATIO VS. FREQUENCY
- SCINTILLATION RATIO VS. FREQUENCY
- SCINTILLATION INTENSITY VS. ELEVATION ANGLE
- ULTIMATE FADE DEPTH
- FADE DURATION
- TIME BETWEEN FADES
II. SYSTEM STATUS

- APT MODIFICATIONS
  - ANGLED MOUNT POLE
  - RF BOX BRACING
  - SNOW FAN
  - ADDITIONAL INSULATION WITH REFLECTIVE COATING

- PROBLEMS
  - EMI
  - DYNAMIC RANGE LIMITATIONS
  - SATELLITE POINTING VARIATIONS

- OPERATION
  - POWER OUTAGES
27.505 GHz Radiometer CDFs

- Dec-93 to Apr-94
- May-94

Alaska ACTS Propagation
Median values of instantaneous event 20.185 GHz attenuation for each 1 dB increment of event 27.505 GHz attenuation

Spread in instantaneous event 20.185 GHz attenuation

Equiprobable attenuation pairs from May cdfs

Alaska ACTS Propagation
27.505 GHz Scintillation Spectrum
Scintillation Intensity of 0.19 on 5/25/94 07:41:51-07:42:42.2 GMT

Alaska ACTS Propagation
Mean Square Fluctuation of Amplitude (dB^2/Hz)

27.505 GHz Scintillation Spectrum
Scintillation Intensity of 0.50 on 5/25/94
22:57:04-22:57:55.2 GMT
27.505 GHz Scintillation Spectrum
Scintillation Intensity of 0.51 with 3.4 dB AFS on 5/27/94 23:14:42-23:15:33.2 GMT

Alaska ACTS Propagation
SATELLITE TO EARTH GEOMETRY

Fairbanks, Latitude 64.9°N, Longitude 147.8°W

ACTS Geosynchronous Satellite, 100°W

25,000 miles

22,335 miles

4,000 miles

1 Atmospheric Depth

7 Atmospheric Depths

Path to ACTS

Alaska ACTS Propagation

DYNAMIC RANGE OF APT

RF BLOCK 70 MHZ OUT

IF ATTN IF AMP CHAIN

SIGNAL OUT 455 KHZ TO ADC

RECEIVER 1 DB COMPRESSION LEVEL

NOMINAL CLEAR SKY SIGNAL LEVEL

DYNAMIC RANGE

RECEIVER NOISE FLOOR

Alaska ACTS Propagation
Alaska ACTS Propagation

ACTS 20 GHz EIRP Contours
NOTE: DATA FITS SINUSOID WELL, EXCEPT FOR: DIP + HUMP EVERY DAY.
27 GHz Beacon + ARD
0.4 dB/tick mark
2/20-23/94
Site: AK

Alaska ACTS Propagation
Alaska ACES Propagation

AK 6/2/94

Time (GMT)

22:30:00 22:45:00 23:00:00 23:15:00

27 Beacon Status

Lock

Unlock

AK Dynamic Range Limitation
Alaska ATS Propagation

Time (GMT)

00:00:00 02:00:00 04:00:00 06:00:00 08:00:00 10:00:00 12:00:00 14:00:00 16:00:00 18:00:00 20:00:00 22:00:00 24:00:00

00.00
-9.00
-10.00
-11.00
-12.00
-13.00
-14.00
-15.00
-09.75
-12.75
-15.00

20 Beacon (dB)

20.185 GHz Beacon 5/14/94 0-24 H GMT
27.505 GHz Beacon 5/14/94 5-6 H GMT

Alaska ACTS Propagation
Scatter Plot of Scintillation Intensity 5/14/94 5-6 H GMT

20.185 GHz Scintillation Intensity (dB)

27.505 GHz Scintillation Intensity (dB)

y = 1.17x

y = 1.01x + 0.10

Alaska ACTS Propagation
Alaska ACTS Propagation
SCINTILLATION RATIO PREDICTIONS

- FREQUENCY RATIO, 27.5/20.2 GHZ
  - FOR 1.22-M ANTENNA
    » 1.19
- ANTENNA SIZE RATIO, 1.5"/1.22-M
  - FOR 20.2 GHZ FREQUENCY
    » 1.03
- USED CCIR/CRANE MODEL

III. FUTURE PLANS

- INSURE INTEGRITY OF DATA
- RAIN SEASON
- SCINTILLATION SEASON
- CONTINUE ANALYSES
- CLOUD EFFECTS
- DEVELOP MODELS OF PROPAGATION PHENOMENA
U.B.C. ACTS PROPAGATION EXPERIMENT

By:

I. Dommel
R. Hulays
M. Kharadly

Electrical Engineering Department
University of British Columbia

June 16, 1994
OUTLINE

• STATUS

• SOME PROBLEMS

• SOME OBSERVATIONS

• PRESENT AND FUTURE WORK
STATUS

• LATEST DACS SOFTWARE UPDATE INSTALLED ON JUNE 7, 1994

• RAW DATA, PRE-PROCESSED DATA AND EVENT AND FAULT LOGS UP TO, AND INCLUDING APRIL 1994 WERE SENT TO ACTS DATA CENTER. MAY DATA IS NOW COMPLETE

• ELEVATION TILT SCAN

◇ Weather has not been cooperative!

◇ No local sounding stations. The closest stations are:
* Quillayute (Olympic peninsula): 220 km, S.W.

* Port Hardy (Northern Vancouver island): 360 km, N.W.

* Vernon (Okanagan): 300 km, E.

◊ Possibility of interpolating between the three sounding sites

◊ Results thus obtained may not be valid at our site up to a height of 2 km.

◊ Attempting to arrange for a sounding on Campus
• HYDROPHOBIC PAINT TEST

◊ This has been tested, loss is hardly measurable, less than 0.1 dB signal loss at 29.6 GHz

◊ Has not yet been applied to antenna

• SURVEILLANCE CAMERA AND TIME-LAPSE RECORDER

◊ Installed to keep track of antenna surface conditions (e.g., Icing) and weather conditions (e.g., Rain, Snow)

◊ Records are obtained every 8 seconds with tape lasting 40 days
ADDITIONAL RESOURCE

• AIRPORT WEATHER STATION

♦ Approx. 8 km from APT site

♦ Close to propagation path

♦ Will use their monthly statistics to compare to ours
SOME PROBLEMS

- 27 GHz RADIOMETER STEPS CAUSING RADIOMETER RESTARTS, Fig. 1

- RADIOMETERS VOLTAGE DRIFT, Fig. 2
  - A manual reboot, at times, corrects the problem

- ACTSEDIT PROBLEMS
  - Inability of software to remove certain spikes (e.g. Fig. 3)
This causes error in the attenuation cumulative distribution function plots (Fig. 4)

• DR. CRANE'S EDITING PROGRAM
  
  We have not yet been able to make it work
SOME OBSERVATIONS
• TYPICAL FADES AT VANCOUVER, Figs. 5 and 6

◊ Long duration

◊ Low fade

◊ Radiometer-derived attenuation generally agrees with Beacon-derived attenuation
• ATYPICAL FADES AT VANCOUVER, Figs. 7 and 8

◊ Strong fade - System lost lock

◊ Radiometer-derived attenuation does not agree with Beacon-derived attenuation (Radiometer saturates at 10 dB?)

◊ 20 GHz attenuation > 27 GHz attenuation, Fig. 9

* Some snow-fall was recorded

* Possible cause (defocusing due to snow layer on antenna surface?)
• MONTHLY ATTENUATION STATISTICS

◊ For the Month of January, Figs. 10 and 11

◊ For the Month of March, Figs. 12 and 13

⇒ 20 GHz attenuation reaches higher values than 27 GHz attenuation!

• SCINTILLATIONS

◊ Clear weather, Fig. 14

◊ Rain, Fig. 15
PRESENT AND FUTURE WORK

• ANALYSIS PACKAGE

◊ Exceedance statistics

◊ 27 GHz attenuation vs 20 GHz attenuation

◊ Fade-duration statistics

◊ Fill in missing data
• MELTING LAYER

◊ Estimation of the excess attenuation caused by the presence of the melting layer

• SCINTILLATIONS
Fig. 1: Typical 27 GHz radiometer steps causing automatic restart.
Fig. 2: Radiometer voltage drift
Fig. 3: Pre-processing software was unable to remove spike in 27 GHz radiometer-derived attenuation
Fig. 4: Effect of the spike in Fig. 3 on the Cumulative Distribution Function of the 27 GHz radiometer-derived attenuation
Fig. 5: 20 GHz attenuation for March 1, 1994
Fig. 6: 27 GHz attenuation for March 1, 1994.
Fig. 7: 20 GHz attenuation for March 22, 1994
Fig. 8: 27 GHz attenuation for March 22, 1994

Fig. 11: Cumulative distribution functions of the 20 and 27 GHz bandwidths, showing the percentage of time each bandwidth is attenuated by less than a certain level.

JAN 1994 - 20 GHz AND 27 GHz RADIODOMETER - BC
Fig. 12: Cumulative distribution functions of the 20 and 27 GHz beacon-derived attenuation for the month of March, 1994

Fig. 13: Cumulative distribution functions of the 20 and 27 GHz.

MAR 1994 - 20 GHz AND 27 GHz RADIOMETER - BC
Fig. 14: Clear air scintillation on May 11, 1994
Fig. 15: Rainy weather scintillation on February 17, 1994
Ka-band Propagation Measurements
Using the ACTS Propagation Terminal
and the CSU-CHILL Multiparameter Radar

Experimenters
Colorado State University
Department of Electrical Engineering
Ft. Collins, CO 80523

Investigators
V.N. Bringi, Professor
John Beaver, Ph.D. Candidate
Joseph Turk, Research Associate

ACTS Propagation Studies Mini-Workshop
June 16, 1994
Outline

- CSU – ACTS Propagation Terminal Status
  - Hardware Problems and Solutions
  - Software Discussion

- ACTS Propagation Measurements
  - ACTS and CSU – CHILL measurements

- Modelling Efforts
Hardware Problems and Solutions

• Snow accumulation on the antenna surface
  – Installed a heating unit on the back surface of antenna

• Frequent system crashes and reboots
  – Reduced the receiver enclosure temperature to 40°Celsius

• Loss of 27GHz beacon signal
  – Lost lock on February 28, 1994.
  – After retuning the Master Oscillator, reacquired signal on March 4.
Source: 940424C0.RVO

System Status - XXXXXX
RH: XXX %  CRG: XXXXX mm/hr
BP: XXXX mb   ORG: XXXXX mm/hr
WS: XXXX m/s  TRG: XXXXX mm/hr
WD: XXX °    OT: XXXXX °C
Time: 00:25:29 Date: 06/15/94

Ready for Spectrum
Source: 940227co.RVD

System Status - XXXXXX

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>RH</td>
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<tr>
<td>CRG</td>
<td>XXXXX mm/hr</td>
</tr>
<tr>
<td>BP</td>
<td>XXXX mb</td>
</tr>
<tr>
<td>ORG</td>
<td>XXXXX mm/hr</td>
</tr>
<tr>
<td>WS</td>
<td>XXXX m/s</td>
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<td>XXXXX mm/hr</td>
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<tr>
<td>WD</td>
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<tr>
<td>DT</td>
<td>XXXXX °C</td>
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<tr>
<td>Time</td>
<td>10:05:50</td>
</tr>
<tr>
<td>Date</td>
<td>06/14/94</td>
</tr>
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</table>

Ready for Spectrum
Snow Accumulation on Antenna Surface

ACTS Propagation Data (CO)

20 GHz Data
- Beacon
- Rad

27 GHz Data
- Beacon
- Rad

Hour (UTC)
The SoftHeat Radiant Anti-Icing System family comprises models for the Prodelin 1.2m, 1.8m, and 2.4m reflectors. Field installation is simple, making them ideal for either initial installation or subsequent retrofit applications. Through the use of self-regulating heating elements, sufficient thermal power is delivered to the front surface of the antenna for effective anti-icing, while the uniform radiant heat minimizes reflector distortion.

Self-Regulating Performance

The polymer heater element used in SoftHeat Radiant Anti-Icing Systems is self regulating, allowing the thermal power delivered to the antenna to vary depending on the environmental conditions the antenna experiences: as ambient temperature decreases, heat output increases.

Radiant Heating Simplicity

Radiant heat transfer, as applied to antenna anti-icing, provides special benefits due to its inherent uniformity. Furthermore, SoftHeat Radiant systems respond differently to varying heat transfer conditions across the reflector surface, so that no mechanical means are required for even heat distribution. Thus the system has no moving parts other than controller contacts.

Ease of Installation

The SoftHeat Radiant Anti-Icing System is designed for quick and simple installation. It is complete and ready for installation as shipped, requiring no special structural adaptations or additional framing.

High Thermal Flux

SoftHeat Radiant Anti-Icing Systems provide a high thermal flux, strongly biased forward, where snow and ice accumulation can cause severe signal attenuation. SoftHeat/Prodelin systems have demonstrated greater than 85% thermal efficiency toward the front of the antenna.

Features

SoftHeat Radiant Anti-Icing Systems are designed specifically for Prodelin 1.2m, 1.8m, or 2.4m reflectors. All systems operate on 120 volt A.C.; power connection for 1.2m and 1.8m systems uses a simple plug and cord. A feedhorn heating system reduces outages from ice and snow accumulation in the critical feedhorn window. An advanced solid state moisture/temperature sensor reduces energy consumption on 1.8m and 2.4m systems.
Measured Snow Event after De-Icing Unit was Installed

ACTS Propagation Data (CO)

20 GHz Data

- Beacon
- Rad

27 GHz Data

- Beacon
- Rad

AFS (dB)

AR (dB)

Hour (UTC)
Software Discussion

- Shorter set up times
- Level shifts in data after set ups
- Time axis in bias removal
Rain / Wet Snow Event

4/9/94 ACTS Propagation Data (CO)

20 GHz Data
- Beacon
- Rad

27 GHz Data
- Beacon
- Rad

AFS (dB)

Hour (UTC)
Date: 5/1394
Start RAY#: 484, total: 225 rays
from 4. to 4. km
Azim: 173.69
CSU-CHILL

Height (km)

Phdp.T = 3. deg
Dfr.T = 0. dB
Ldr.T = 0. dB
Ro.T = 0.80
Zh.T = 40. dB
Radit = 2
Zslope = 40. dB
RCcf = 0.00 dB
may1394v117

370
Date: 51394
Time: 155518
AZ: 171.97 to 171.97
EL: 43.50 to 43.50

ZH (IIR5)

Zdr (IIR5)

CSU-CHILL Range (km)

RAY NO.: 548

Rhv (IIR5)

Delta

Phidp.T = 3.0 deg
Ro.T = 0.80
Zh.T = 40 dB
Madflit = 2

Dfr.T = 0.0 dB
Zslope = 40 dB
RCCf = 0.00 dB
DfrC = 0.00 dB

may1394v117

371
ACTS/CSU CHILL Data (Convective Case)

6/3/94 ACTS Propagation Data (CO)

20 GHz Data
- Beacon
- Rad

27 GHz Data
- Beacon
- Rad

AFS (dB)

Hour (UTC)

ARD (dB)
Loss of Both Signals due to Rain Event

6/1/94 ACTS Propagation Data (CO)

20 GHz Data
- Beacon
- --- Rad

27 GHz Data
- Beacon
- --- Rad

AFS (dB)

ARD (dB)

Hour (UTC)
Loss of both signals due to rain event

6/1/94 ACIS Propagation Data (CO)
Propagation Models

- Mueller Propagation Model (Wayne Adams, NCAR)

  - The variation of the electric field along the propagation path is given by

\[
\frac{dE_v}{ds} = (ik + M_{vv})E_v + M_{vh}E_h \\
\frac{dE_h}{ds} = M_{hv}E_v + (ik + M_{hh})E_h
\]

where

\[
M_{ij} = \sum_p n_p \frac{2\pi i}{k} f_{ij}(\hat{k})
\]

→ \( f_{ij} \) are the forward scattering amplitudes
→ \( n_p \) is the number concentration
Propagation Models

- The equations for the variation of the electric field along the propagation path can be used to obtain differential equations in terms of the modified Stokes parameters

\[
\frac{dI_v}{ds} = 2\Re(M_{vv})I_v + \Re(M_{vh})U + \Im(M_{vh})V \\
\frac{dI_h}{ds} = 2\Re(M_{hh})I_h + \Re(M_{hv})U - \Im(M_{hv})V \\
\frac{dU}{ds} = 2\Re(M_{hv})I_v + 2\Re(M_{vh})I_h + [\Re(M_{vv}) + \Re(M_{hh})]U - [\Im(M_{vv}) - \Im(M_{hh})]V \\
\frac{dV}{ds} = -2\Im(M_{hv})I_v + 2\Im(M_{vh})I_h + [\Im(M_{vv}) - \Im(M_{hh})]U + [\Re(M_{vv}) + \Re(M_{hh})]V
\]

where

\[
I_v = \frac{|E_v|^2}{\eta} \\
I_h = \frac{|E_h|^2}{\eta} \\
U = \frac{2\Re(E_vE_h^*)}{\eta} \\
V = \frac{2\Im(E_vE_h^*)}{\eta}
\]
Propagation Models

- Solutions of the four differential equations yield four eigenvalues and eigenvectors

$$\beta(\hat{s}) = \begin{bmatrix} \beta_1(\theta, \phi) \\ \beta_2(\theta, \phi) \\ \beta_3(\theta, \phi) \\ \beta_4(\theta, \phi) \end{bmatrix} = \begin{bmatrix} 2\text{Im}K_1 \\ iK_2^* - iK_1 \\ iK_1^* - iK_2 \\ 2\text{Im}K_2 \end{bmatrix}$$

where

$$K_1 = k - \frac{i}{2} [M_{vv} + M_{hh} + r]$$

$$K_2 = k - \frac{i}{2} [M_{vv} + M_{hh} - r]$$

and

$$r = [(M_{vv} - M_{hh})^2 + 4M_{hv}M_{vh}]^{\frac{1}{2}}$$
The eigenmatrix is given by

\[
\mathbf{H} = \begin{bmatrix}
1 & |b_2|^2 & b_2 & b_2^* \\
|b_1|^2 & 1 & b_1^* & b_1 \\
2\text{Re}(b_1) & 2\text{Re}(b_2) & 1 + b_1^*b_2 & 1 + b_1b_2^* \\
-2\text{Im}(b_1) & 2\text{Im}(b_2) & i(1 - b_1^*b_2) & -i(1 - b_1b_2^*)
\end{bmatrix}
\]

where

\[
b_1 = \frac{2M_{hv}}{M_{vv} - M_{hh} + r}
\]

\[
b_2 = \frac{2M_{vh}}{-M_{vv} + M_{hh} + r}
\]

The extinction matrix is defined as

\[
\kappa_e = \begin{bmatrix}
-2\text{Re}(M_{vv}) & 0 \\
0 & -2\text{Re}(M_{hh}) \\
-2\text{Re}(M_{hv}) & -2\text{Re}(M_{vh}) \\
2\text{Im}(M_{hv}) & -2\text{Im}(M_{vh}) \\
-\text{Re}(M_{vh}) & -\text{Im}(M_{vh}) \\
-\text{Re}(M_{hv}) & \text{Im}(M_{hv}) \\
-(\text{Re}M_{vv} + \text{Re}M_{hh}) & (\text{Im}M_{vv} - \text{Im}M_{hh}) \\
-(\text{Im}M_{vv} - \text{Im}M_{hh}) & -(\text{Re}M_{vv} + \text{Re}M_{hh})
\end{bmatrix}
\]
The transmission matrix $T_1$ is given by

$$T_1 = HPH^{-1}$$

where

$$P = \begin{bmatrix}
    e^{-\beta_1 s} & 0 & 0 & 0 \\
    0 & e^{-\beta_2 s} & 0 & 0 \\
    0 & 0 & e^{-\beta_3 s} & 0 \\
    0 & 0 & 0 & e^{-\beta_4 s}
\end{bmatrix}$$
Propagation Models

- The Mueller matrix in resolution volume 2 is then modified to take into account the propagation effects of resolution volume 1.

\[ M'_2 = T_1^t M_2 T_1 \]

- Radar parameters that are normally computed using the Mueller matrix, can now be computed with the new Mueller matrix \( (M'_2) \).
ACTS Up-link Power Control Experiment

A. Dissanayake

June 16, 1994
Ka-band Up-link Power Control

* Power control carried out using a 27 GHz pilot carrier transmitted from the LET at Lewis Center in Cleveland; transponded carrier received at Clarksburg.
* Power control based on down-link attenuation measurements at 20 GHz
* Beacon reception and pilot transmission are done on separate antennas; antenna separation ~ 15 ft.
* Control applied at IF; power control resolution: 0.2 dB; update rate 5 Hz
* Maximum power control range: 25 dB; however, investigation will be limited to a control range of 15 dB.
* Several safety features incorporated into the power controller design to protect space segment

June 16, 1994
Receive Site, Clarksburg, MD

Transmit Site, Cleveland, OH

ACTS Up-link Power Control Experiment Configuration
Measurement Configuration

Transponder/LET linearity test; attenuator setting vs. signal strength received at Clarksburg

x - nominal operating point
Power Control System

* Power control applied via a linearized PIN attenuator

* A default path without power control available in case of a system failure; this path is also activated under exceptional conditions (beacon failure, beacon level jump or unacceptable drift)

* Intel 386 based PC used as the system controller; system controller and control circuitry housed in a standard rack unit.

* Controller parameters programmed through a front panel keypad and display.
Functional Block Diagram of the Up-link Power Controller
Power Control Algorithm

* Detect down-link fade after establishing the reference level; reference level based on long-term observations using an adaptive filter with a time constant of the order of 1 hour.

* Down-link fade separated into rain fade and scintillation components; n averaging time of 20 sec. used in estimating the rain fade.

* Current level of rain fade predicted using an adaptive filter.

* Frequency scaling of rain and scintillation fades to 27 GHz.

June 16, 1994
Initial Results

* Separate transmit and receive antennas do not allow meaningful investigation of scintillation compensation.

* Approximately 24 hours of pilot transmissions completed; three severe rainstorms encountered during this period.

* Algorithm appears to underestimate the up-link fade.

* When restricted to a power control range of 15 dB, the control accuracy can be maintained within ±3 dB.

June 16, 1994
ACTS up-link power control experiment

Rain event 1 on 31 May, 1994; 1: 20GHz, 2: 30GHz, 3: control error
Power control range: 15 dB

ACTS up-link power control experiment
Rain event 1 on 31 May, Pilot level at Clarksburg
Power control range: 15 dB

ACTS up-link power control experiment
Rain event 2 on 31 May, 1994; 1: 20GHz, 2: 30GHz, 3: control error
Rain event 2 on 31 May Pilot level at Clarkson

ACIS up-link power control experiment

Time (min):

Signal strength (dB):

Power control range: 15 dB