Rain Fade Compensation Alternatives for Ka Band Communication Satellites

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MOTIVATION OF WORK

• Evaluate system and rain fade characteristics and their impact on future system design of Ka-band communication satellite systems.

• Evaluate alternative rain fade measurement and compensation techniques

• Design and develop technology verification experiments for validating techniques and approaches.
FADE CHARACTERISTICS

Rain Induced (random)

- Rain fade depth
  - Fade rate
  - Fade duration
  - Inter-fade interval
  - Frequency scaling
  - Correlation of fade within 1 GHz band
  - Correlation of rain events over extended areas
- Antenna wetting
- Depolarization
  - Rain
  - Ice

System Induced

- Ground Station
  - Pointing error in rain
  - Snow accumulation
  - LNA stability
  - De-Icers
- Spacecraft
  - Antenna Pointing Thermal
  - Attitude Control
Ground Station System Degradation Effects

- Antenna wetting
- Snow accumulation
- Antenna pointing errors - during rain
- De-Icers thermal effect
- Ground station thermal stability - LNA, LO, etc.
- Measurement error
WET ANTENNA STUDIES

Fade Depth

Red : Dry Antenna
Blue : Wet Antenna
Dry Antenna Fade Rate

Wet Antenna Fade Rate

Fade Rate _ Rain Event June 18

Time (Hrs)

Fade Rate (dB/Sec)

- 0.05 0 0.05

4 12 20

Dry Antenna Fade Rate

Wet Antenna Fade Rate
THEORY VS. EXPERIMENT

FADE AVAILABILITY FOR CLEVELAND - 1996

GROUND STATION AND SPACECRAFT DEGRADATION EFFECTS

- Multibeam antenna pointing errors
- Attitude control errors
- Measurement errors

![Graph showing fade availability for Cleveland 1996 with multibeam antenna pointing errors, attitude control errors, and measurement errors.](image)
KEY SYSTEM MARGIN CONSIDERATIONS

- **Clear Sky margin (fixed)**
  - Clear sky attenuation (gaseous absorption) < 1 dB
  - Measurement errors < 1 dB
  - Frequency scaling error < 1 dB
  - Time delay in applying compensation < 1 dB
    ~ Clear Sky Margin = 4 dB

- **Margin available through dynamic fade compensation**
  - Avoid enabling compensation too frequently by applying wait time
  - Dynamically allocate margin on the basis of rain and other propagation impairments
RAIN FADE COMPENSATION ALGORITHM

FADE DEPTH

FADE DEPTH

TIME

Threshold

TIME

FADE SENSING ALGORITHM

• Fade Depth
• Fade Rate
• Threshold Values
• Decision

COMPENSATION ALGORITHM

• Enable FEC
• Enable Burst Reduction
• Increase RF Power
• Enable Diversity Station

BER UNCOMPENSATED

BER COMPENSATED

TIME

T1

T2

TIME
Rain Fade Sensing Techniques

- **Satellite beacon**
  - in-band or out-band

- **Channel BER monitoring by a known data pattern**
  - e.g., framing bits, unique words, etc.

- **BER monitoring for channel coded data**
  - comparing re-encoded bits

- **Pseudo BER**
  - count number of symbols within an interval

- **Measuring signal-to-noise**
  - estimation from mean and variance

- **Fade estimate from receive AGC level**
Rain Fade Compensation Techniques

- **Increase power**
  - Uplink power in dynamically adjusted
  - Open-loop, closed-loop and feedback-loop

- **Information rate and FEC code rate changes**
  - FDMA, CDMA and TDMA

- **Combination of above**

- **Diversity stations**
ACTS Rain Fade Compensation

UNCODED SIGNALS

FORWARD ERROR CORRECTION (FEC) CODING & BURST RATE REDUCTION

IMPACT ON SYSTEM
Adds 10 dB of Fade Margin

Station #1
LOST MESSAGE

Station #2
MESSAGE IS RECOVERED
SUMMARY

• ACTS has successfully demonstrated at least two different rain fade compensation techniques.
  – VSAT dynamic rain fade compensation
  – Uplink power control

• ACTS has successfully modeled rain fade characteristics.
  – Dr. Manning’s model seems to underestimate fade availability

• ACTS has experimentally characterized system and propagation effects affecting fade availability.
  – Antenna wetting
  – Narrow beam technology
  – Attitude and ground station effects