Adaptive Impairment Mitigation Techniques for Satellite Communications

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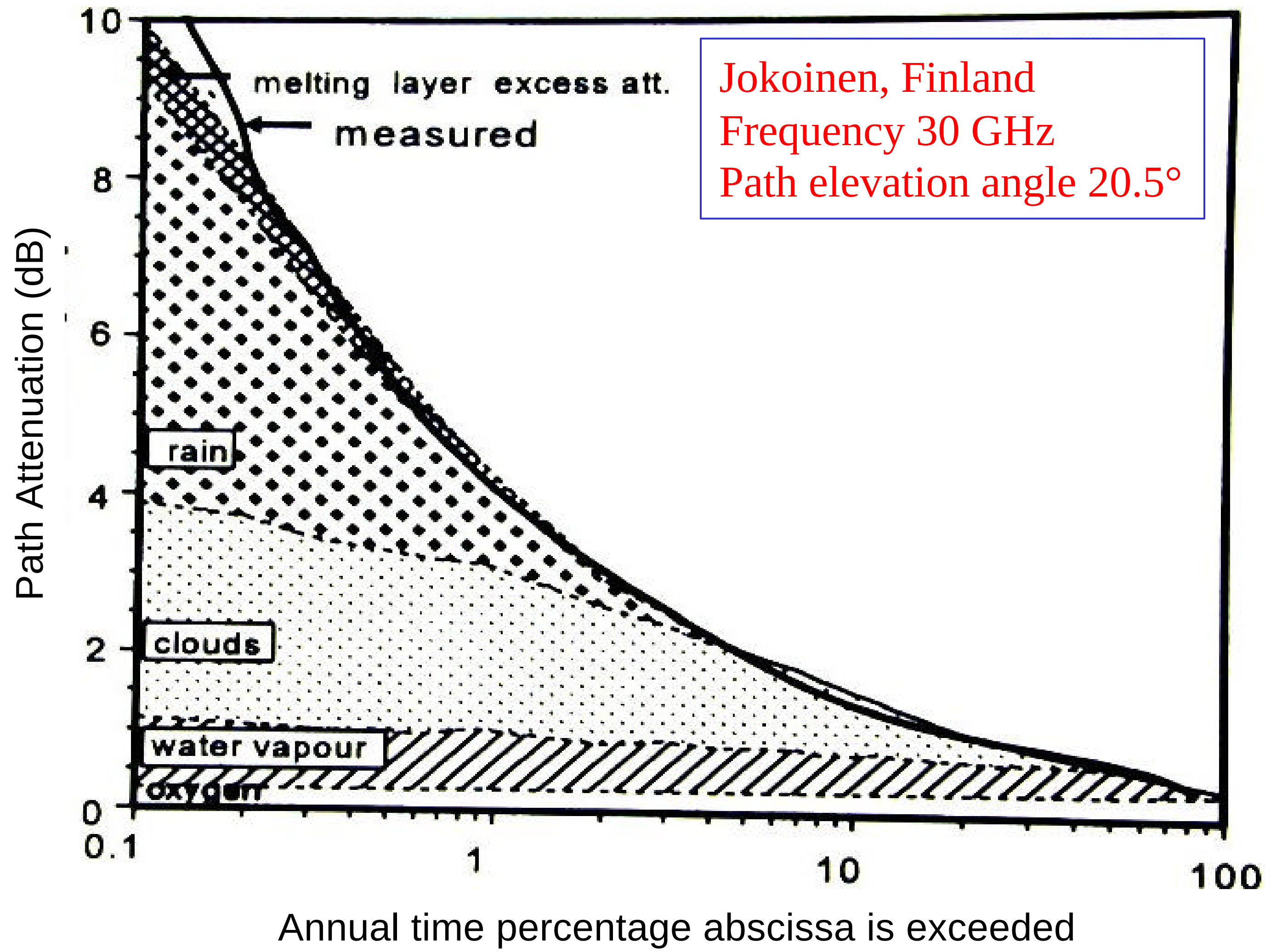
Overview of Presentation

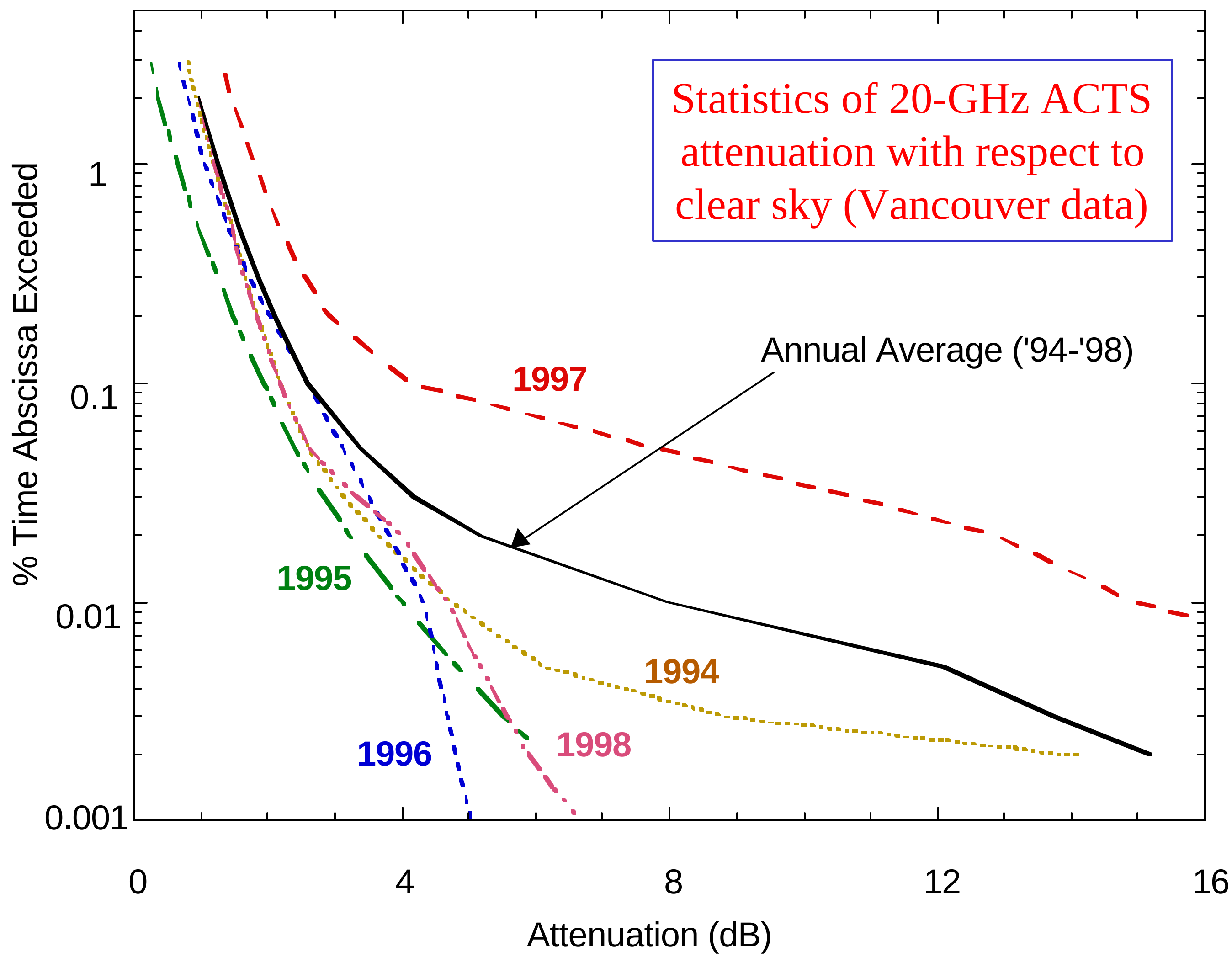
- Summary of Propagation Impairments Affecting Satellite Communication Systems
- Summary of Impairment Mitigation Techniques
- Example Techniques and Propagation Issues
  - Site Diversity
  - Uplink Power Control (ULPC)
  - Adaptive Depolarization Compensation

PROPAGATION IMPAIRMENTS AFFECTING SATELLITE COMMUNICATION SYSTEMS

Impairment	*Physical Cause*	Prime Importance
Signal attenuation, sky noise increase	***Gaseous absorption; scatter/emission from precipitation hydrometers***	**Systems at frequencies above about 10 Ghz**
Signal depolarization	***Differential phase shift and differential attenuation caused by nonspherical scatterers (e.g., raindrops, ice crystals)***	**Frequency-reuse systems (cross-polar interference)**
Signal scintillations (tropospheric and ionospheric)	***Forward scatter from refractive-index variations in atmosphere***	**Small-margin systems; paths at low elevation angles; antenna tracking systems**
Refraction, atmospheric multipath	***Atmospheric density variations; ducts, elevated layers***	**Systems operating at low elevation angles; antenna tracking; antenna isolation**
Reflection multipath, shadowing, blockage	***Interaction with earth's surface, vegetation, objects on earth's surface***	**Mobile-satellite services**
Propagation delays and delay variations	***Free-space propagation time; variation in composition of troposphere and ionosphere***	**TDMA and position-location systems; adaptive control**
Intersystem interference	***Ducting, diffraction, troposcatter, terrain scatter, precipitation scatter***	**Frequency sharing (terminal siting, path planning, etc.)**



Composite sum of propagation contributions to annual cumulative statistics of 30-GHz attenuation, derived from radiosonde data (Salonen et al.)



Interannual (and seasonal) variations in propagation impairments can be large, and average impairment statistics can be strongly influenced by severe years.

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IMPAIRMENT MITIGATION TECHNIQUES

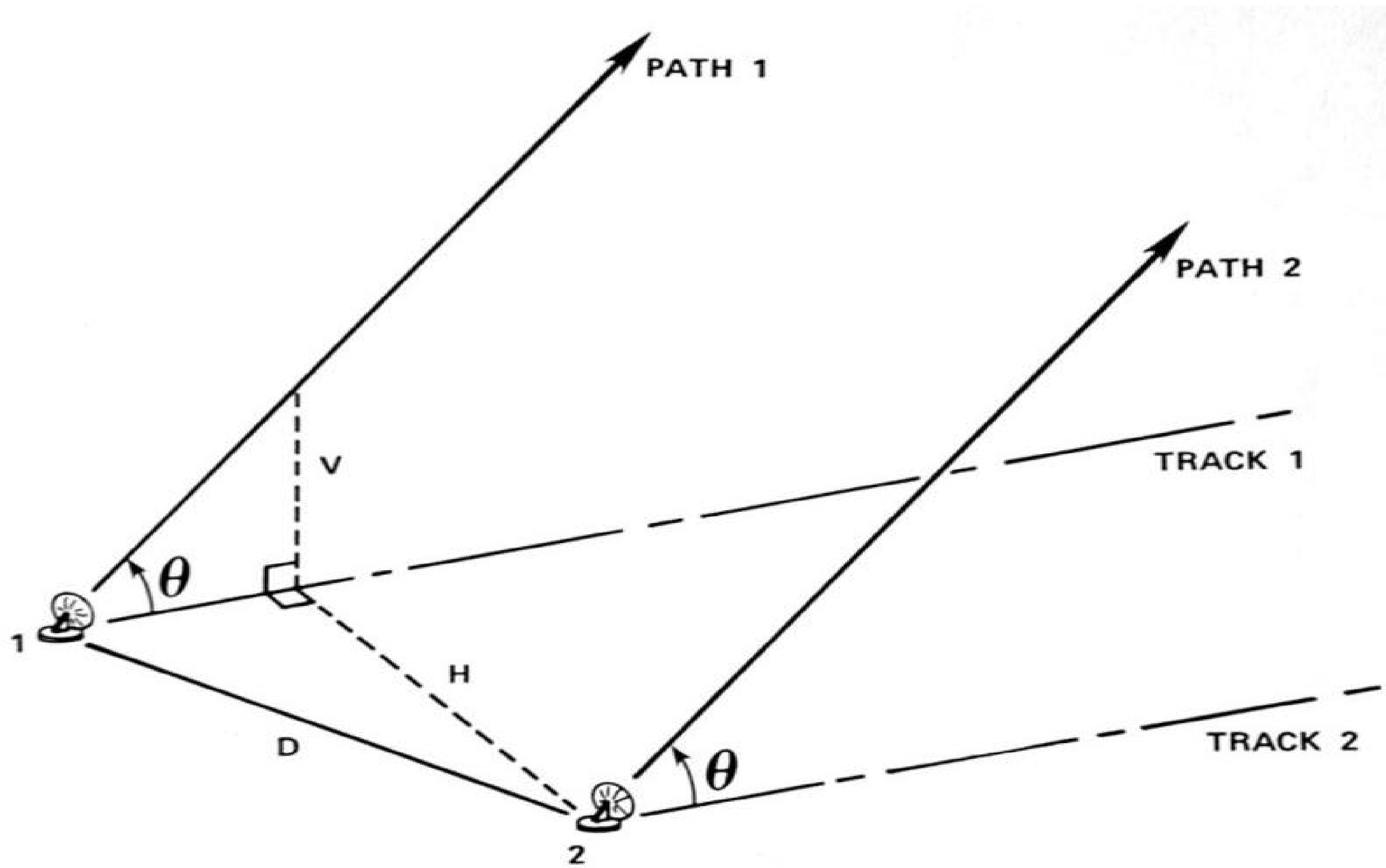
Techniques	*Main Impairment(s)*	Main System Application
Site diversity (multiple earth stations)	***Path attenuation and fading, depolarization***	**FSS earth stations and MSS feeder links for f > 10 GHz; BSS systems delivering time-sensitive information (e.g., TV programming)**
Path/orbital diversity (multiple satellites)	***Path attenuation and fading; shadowing and blockage***	**Standard FSS systems; other satellite systems using nongeostationary constellations**
Transmit power control	***Path attenuation/fading***	**FSS and MSS feeder-link uplinks; CDMA systems**
Depolarization compensation	***Path depolarization (cross-polarization interference)***	**FSS earth stations (C-band or low-path angle systems at Ku-band)**
Frequency diversity	***Any frequency-sensitive impairment***	**[Usually spectrally inefficient; difficult system configuration issues]**
Time diversity	***Any time-varying impairment***	**Transmission of relatively time-insensitive information (e.g., packets)**
Digital methods (variable symbol rate, FEC, etc.)	***Path attenuation and fading***	**Adaptively improve E_b/N_o (requires spare system resources in many cases)**

Service Designations:

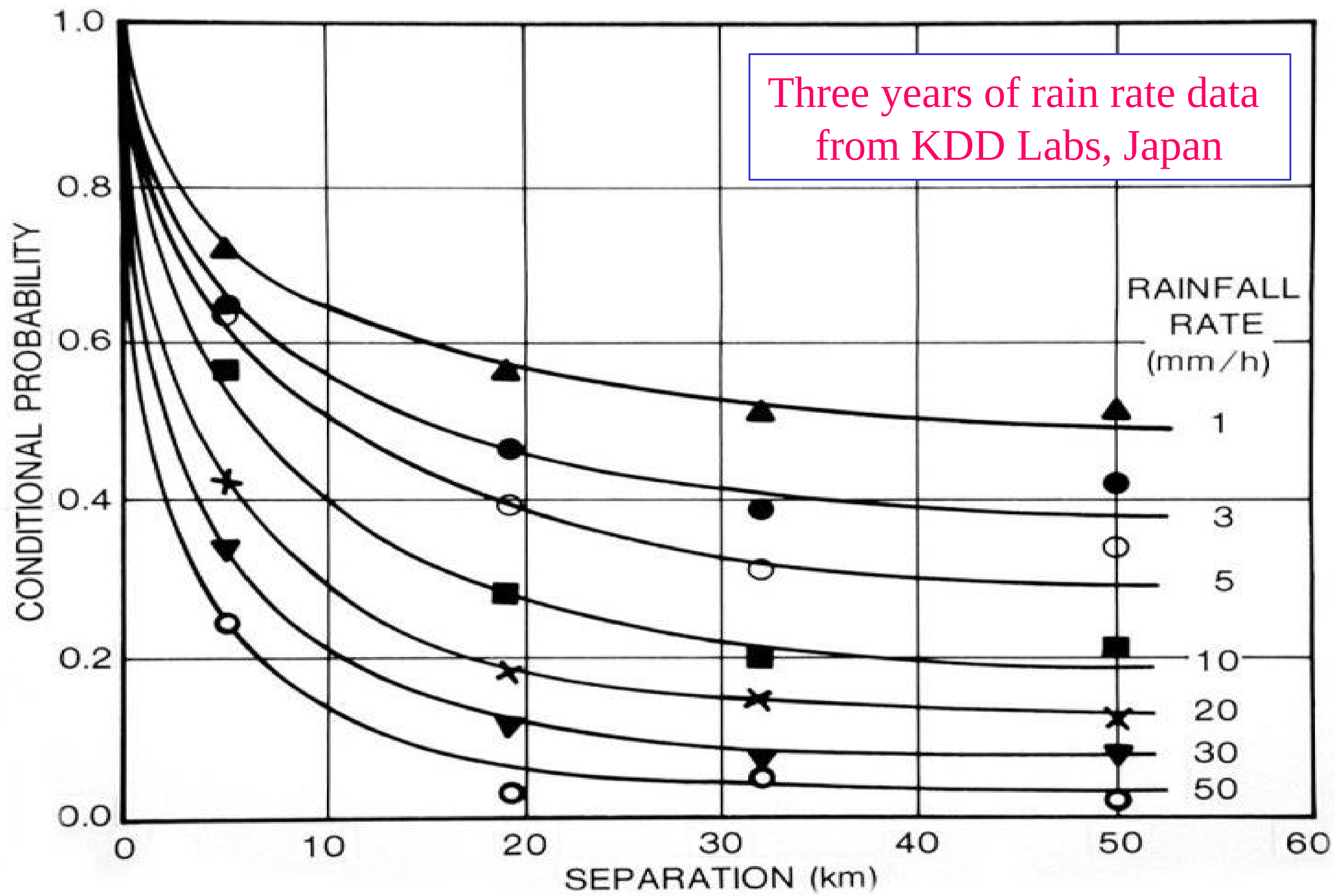
FSS = Fix-Satellite Service; MSS = Mobile-Satellite Service; BSS = Broadcast-Satellite Service

Site Diversity

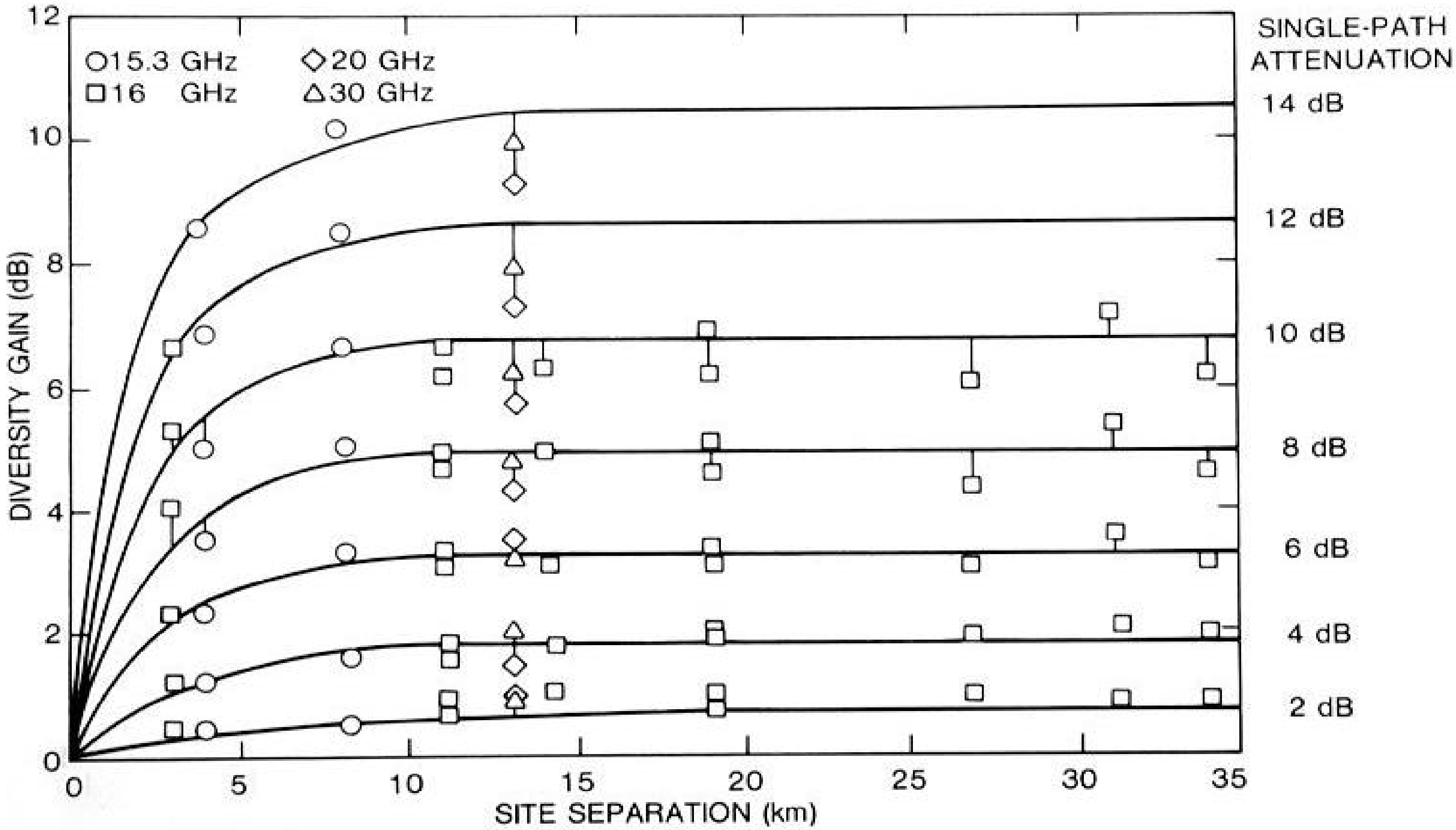
(two or more earth terminals to provide path diversity)



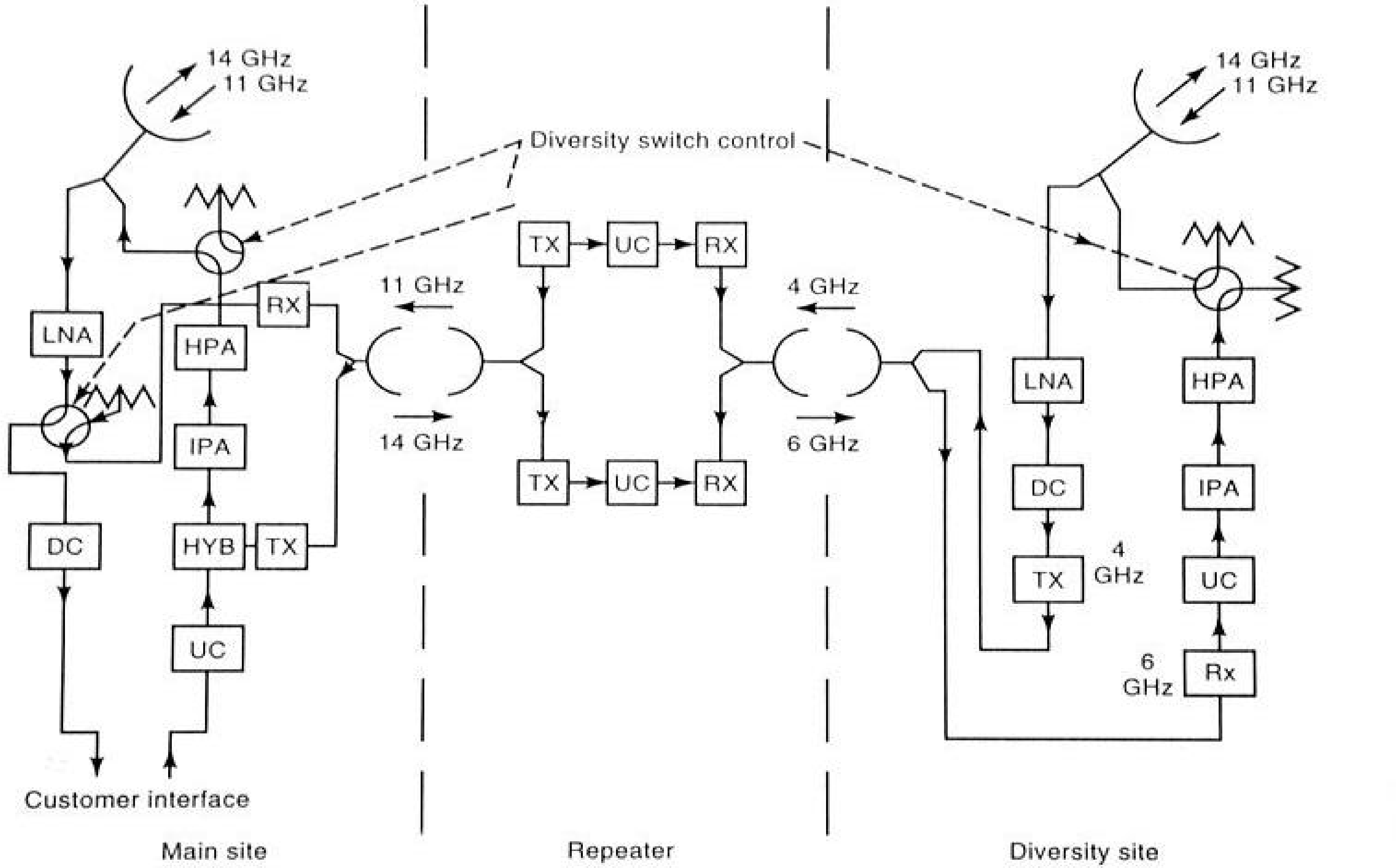
Dual-site diversity configuration. Site separation D and path elevation angle θ.
(H and V are horizontal/vertical path separations; tracks are path projections.)



Normalized conditional probability to exceed rain rate R jointly at two points decreases with increasing separation between those points, and is the prime technical basis for earth-terminal site diversity



Dual-site diversity gain vs. site separation, parameterized in terms of single-path attenuation, compared to measurements (Hodge)



Ku-band site diversity configuration and interconnect link designed by COMSAT. Mainly for downlink protection; uplink switch is installed for redundancy.

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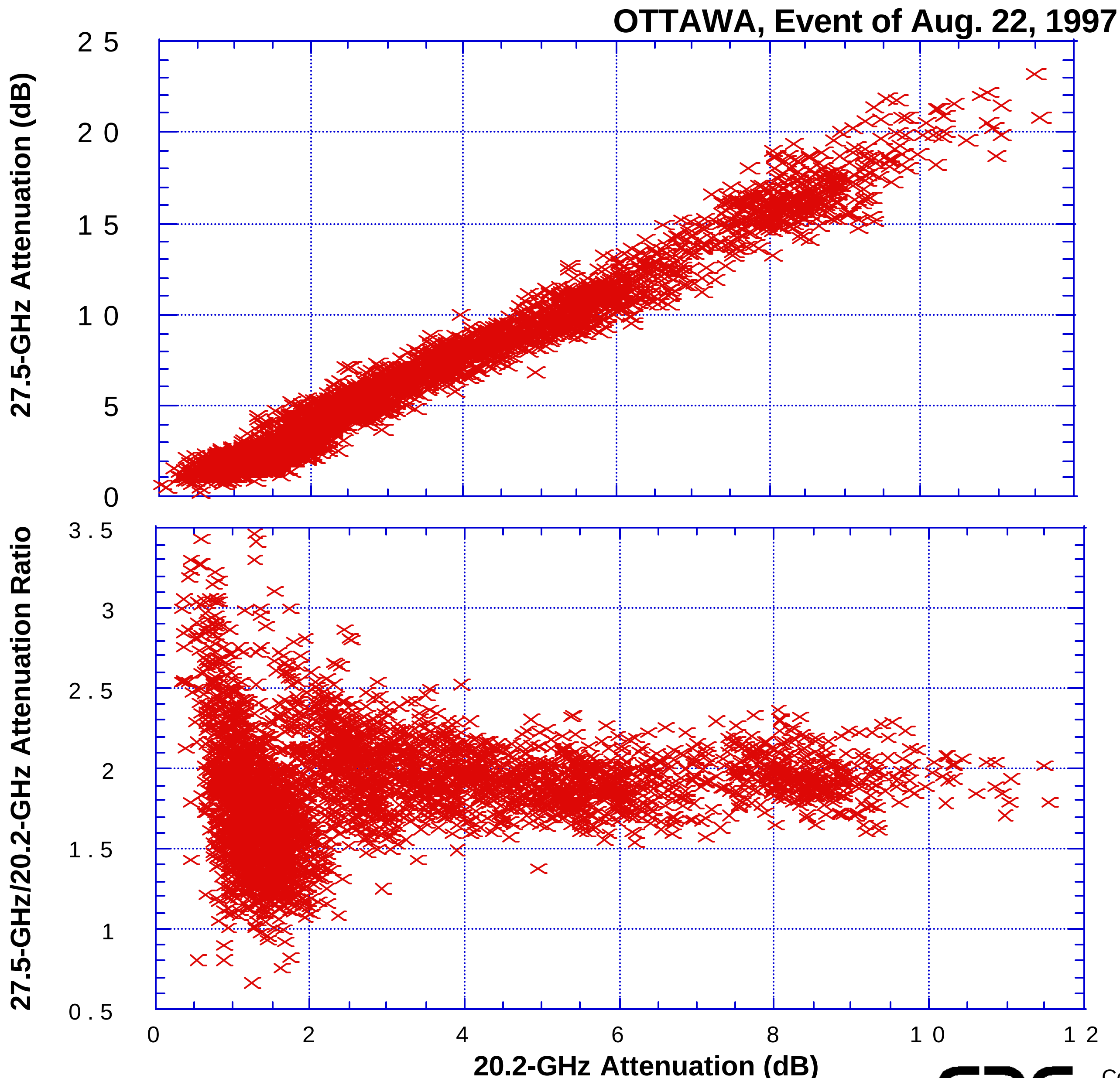
Transmit Power Control

(transmitter power adjusted in response to variations in path fading; more common for uplink applications)

Instantaneous fade ratio for beacon time series showing scatter in ratio



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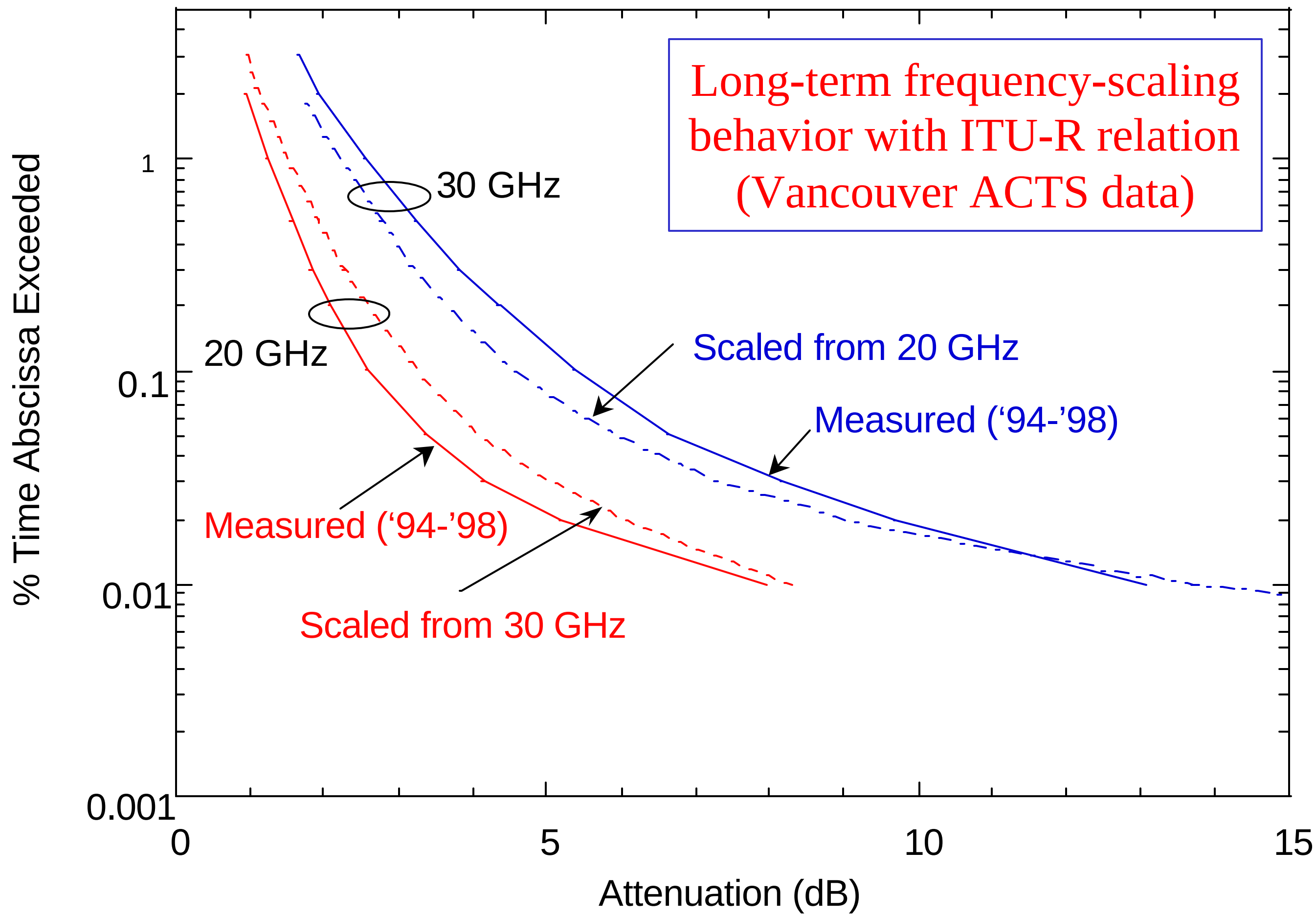
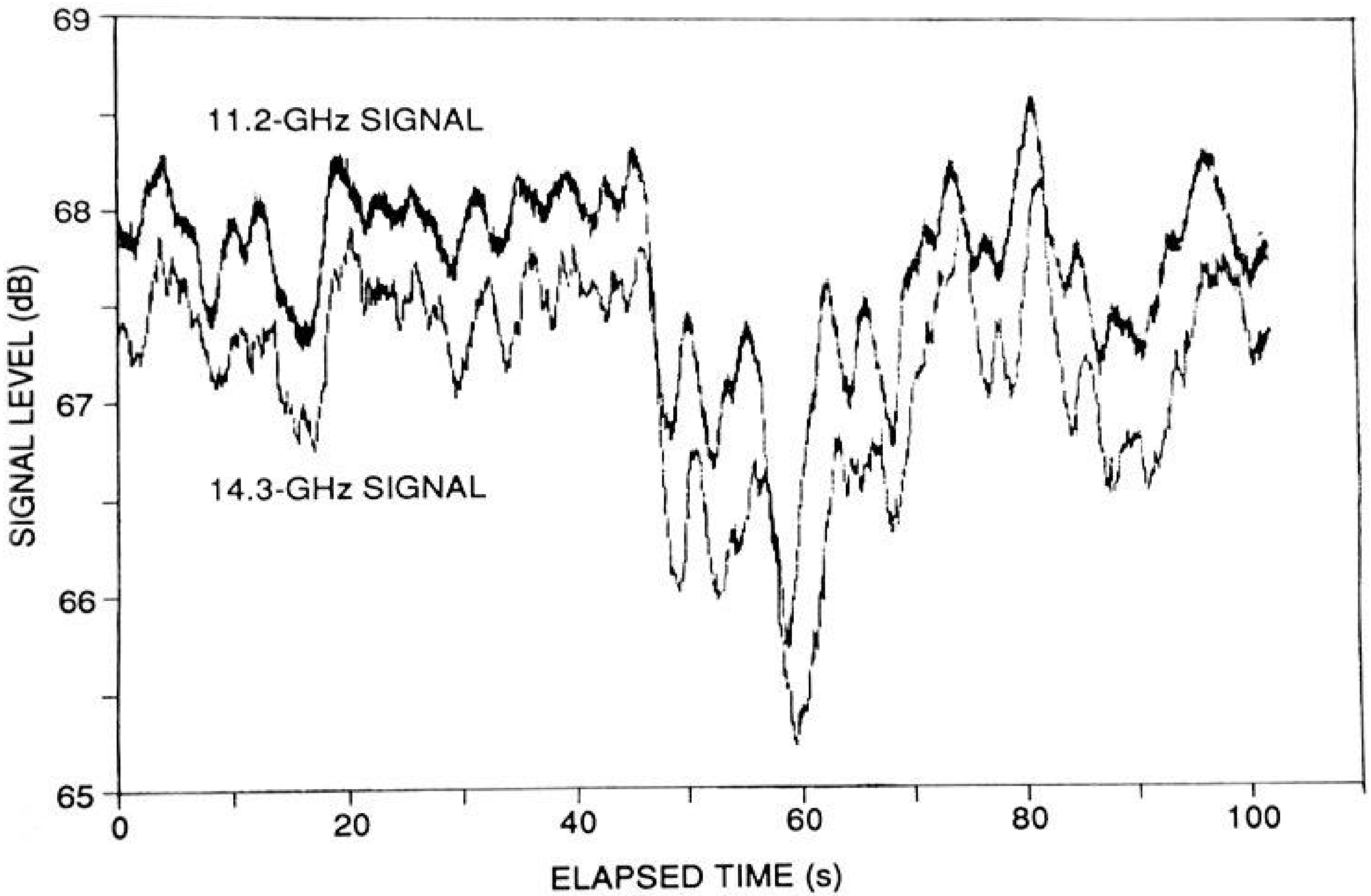


In addition to short-term fluctuations in scaling ratio between uplink and downlink attenuation (previous figure), there is also uncertainty in the long-term frequency-scaling relation required for uplink power control



High correlation of signal scintillations for a common transmit/receive aperture indicates frequency-scaling power control method can also work for this effect
(Relative power levels on plot are arbitrary and intentionally offset for illustration)

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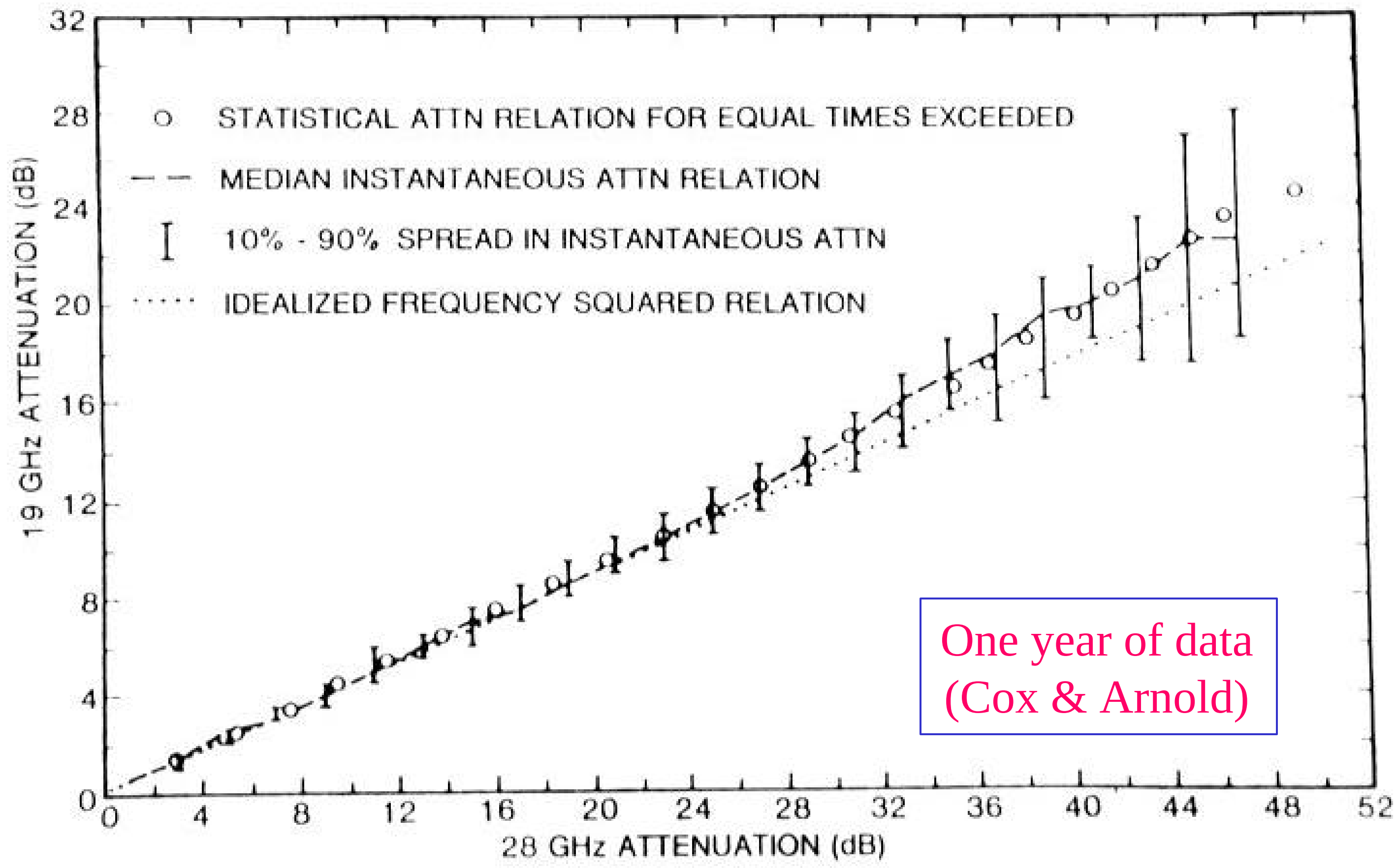
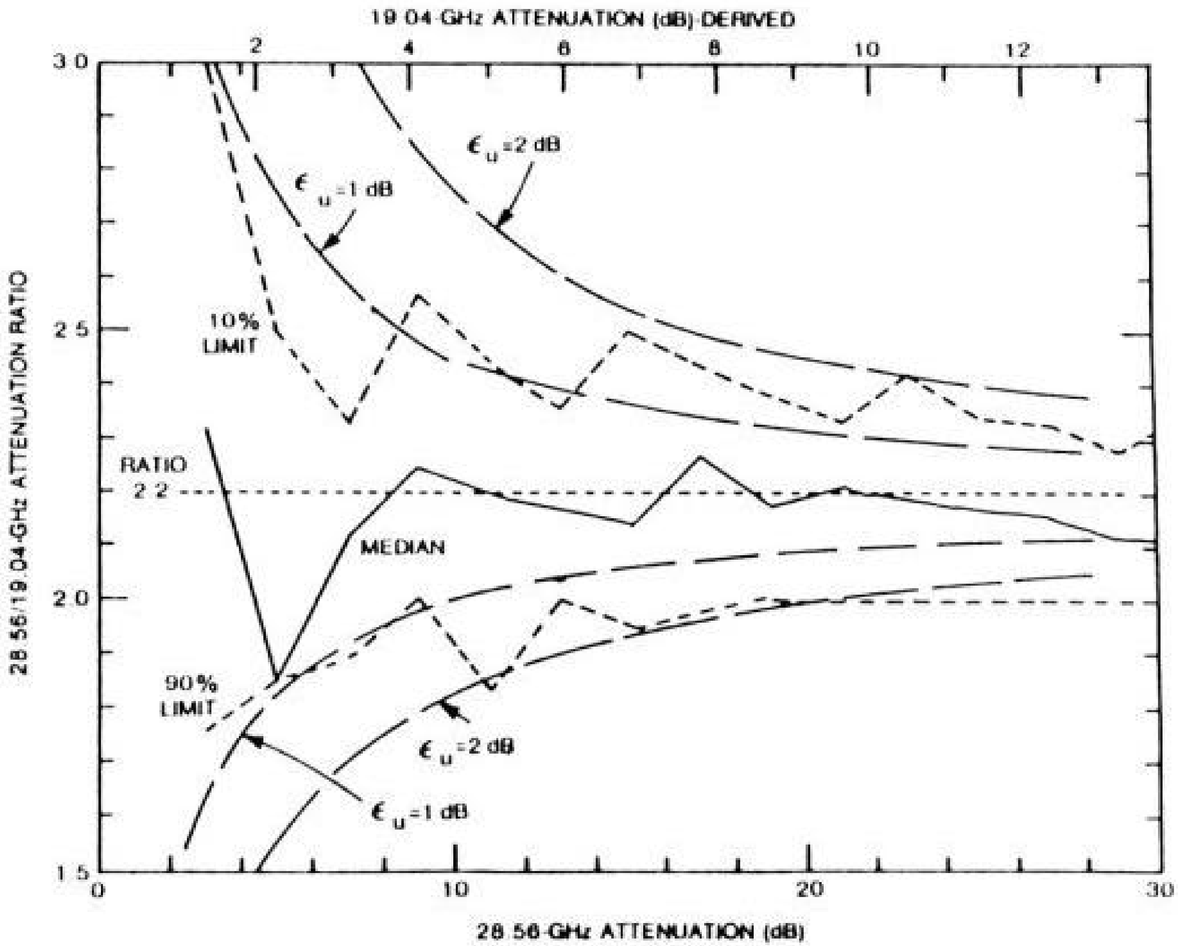
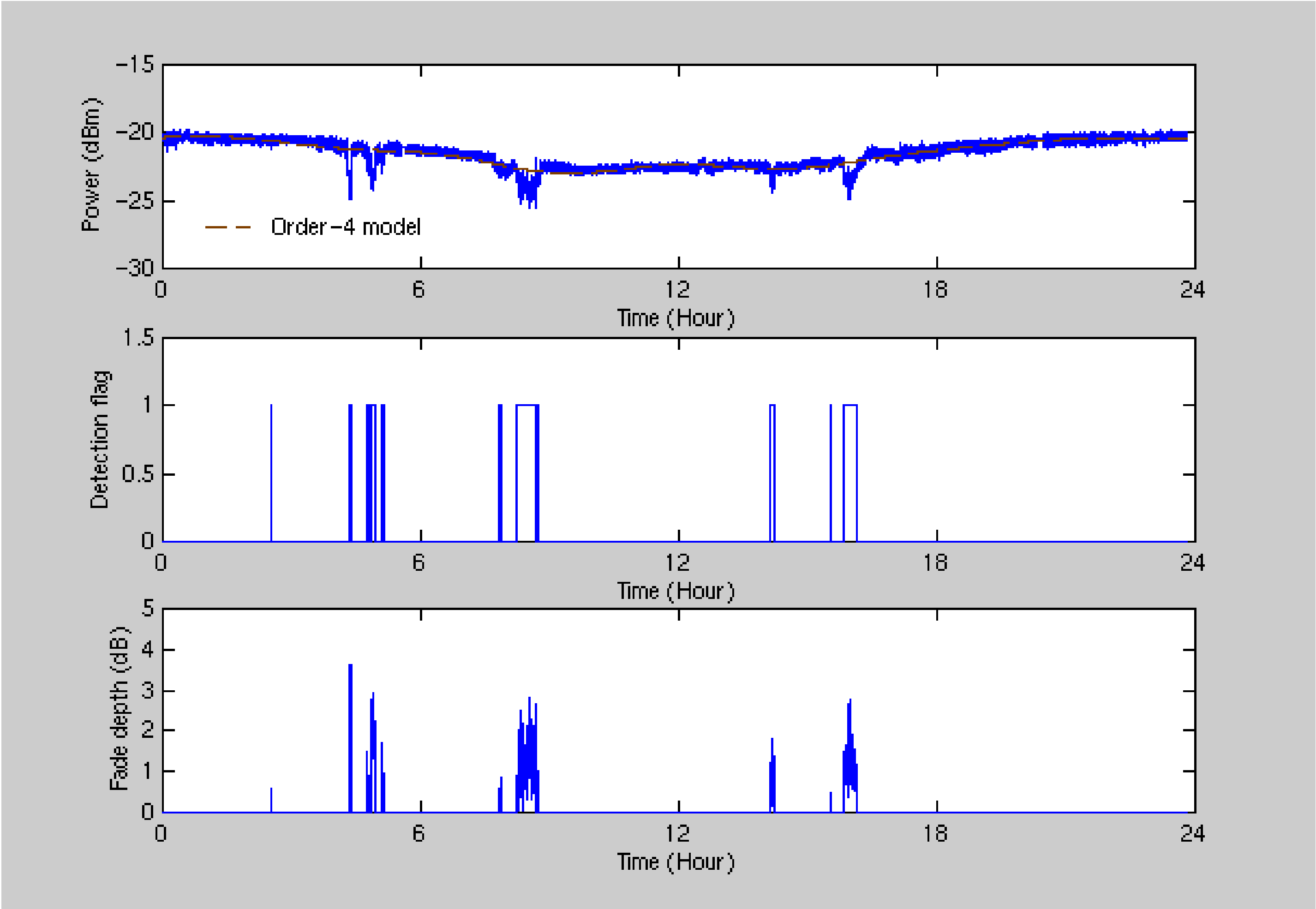


Concurrently-measured 28/19-GHz attenuation showing equiprobable and median instantaneous attenuation ratios, and 10% and 90% spread in attenuation ratio, indicating variability in frequency-scaling ratio



Data of previous figure plotted as attenuation ratio, with uplink power control errors ε_u of ±1 and ±2 dB derived by assuming average fade ratio of 2.2, indicating difficulty in maintaining ±2 dB control errors at Ka-band

– ACTS measurement, Aug.10, 1998



ACTS 20-GHz beacon data. Baseline modeled and deleted by 4th-order sinsusoid. Detection flag shows when fade detected; derived fade depth shown at bottom.

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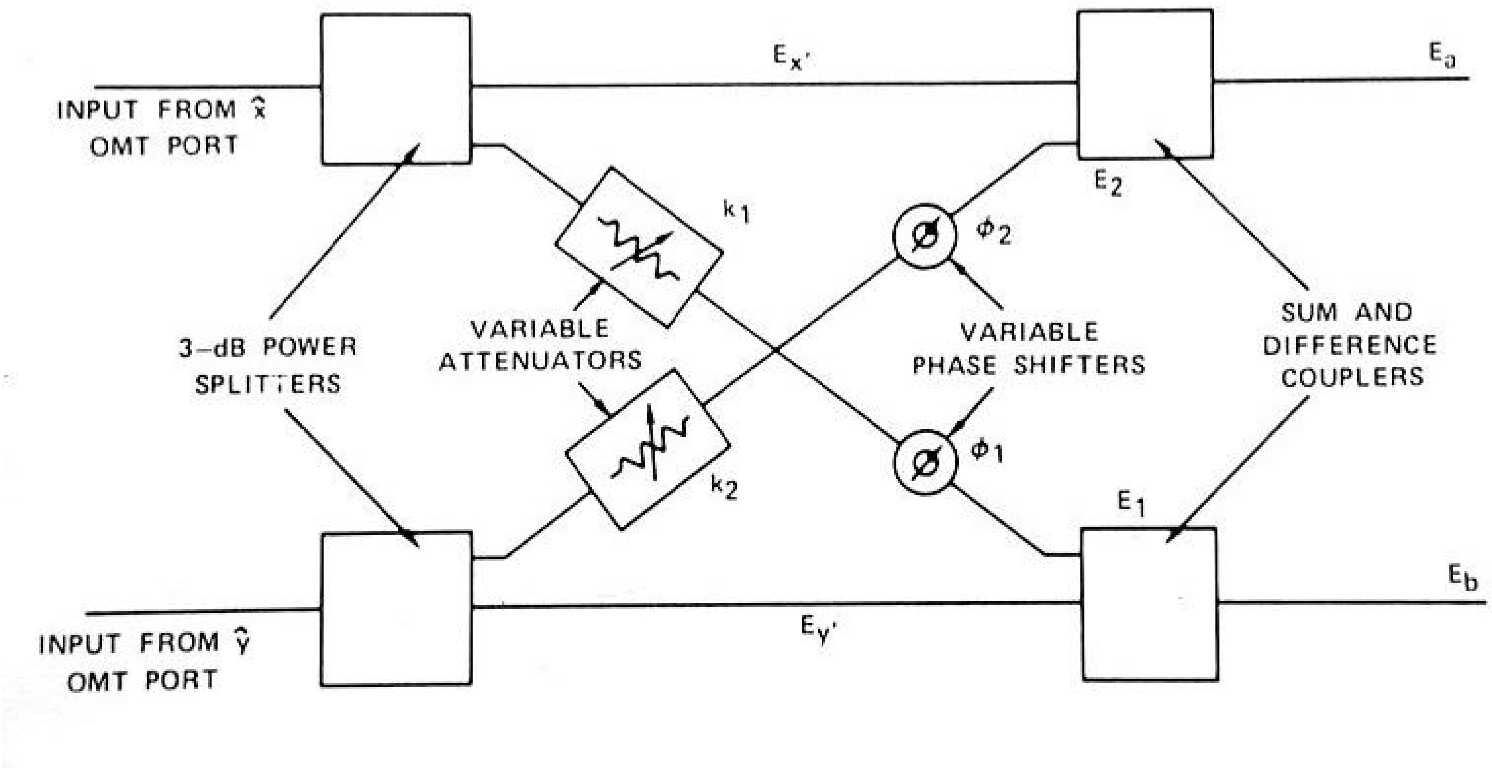
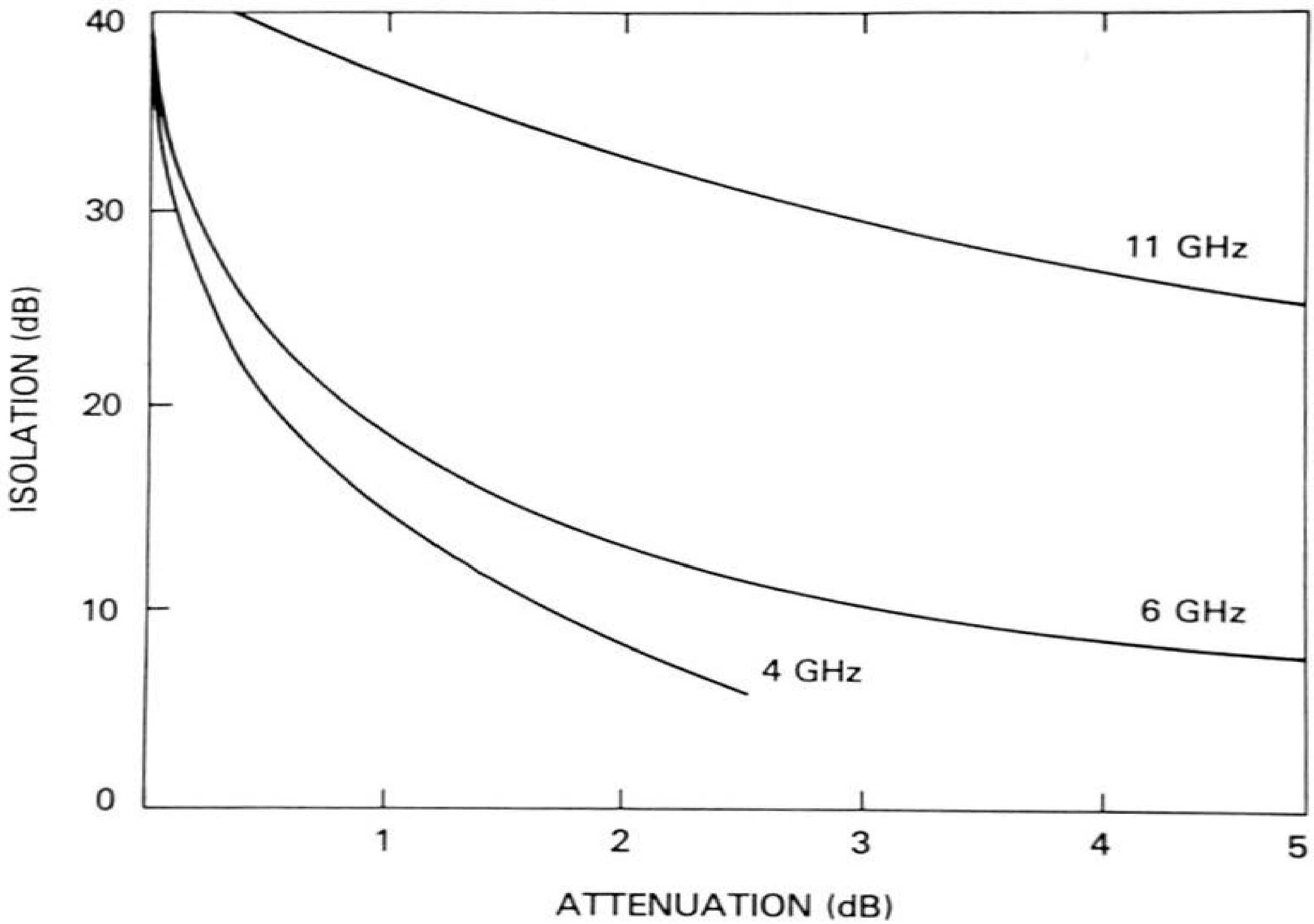
Adaptive Polarization Compensation

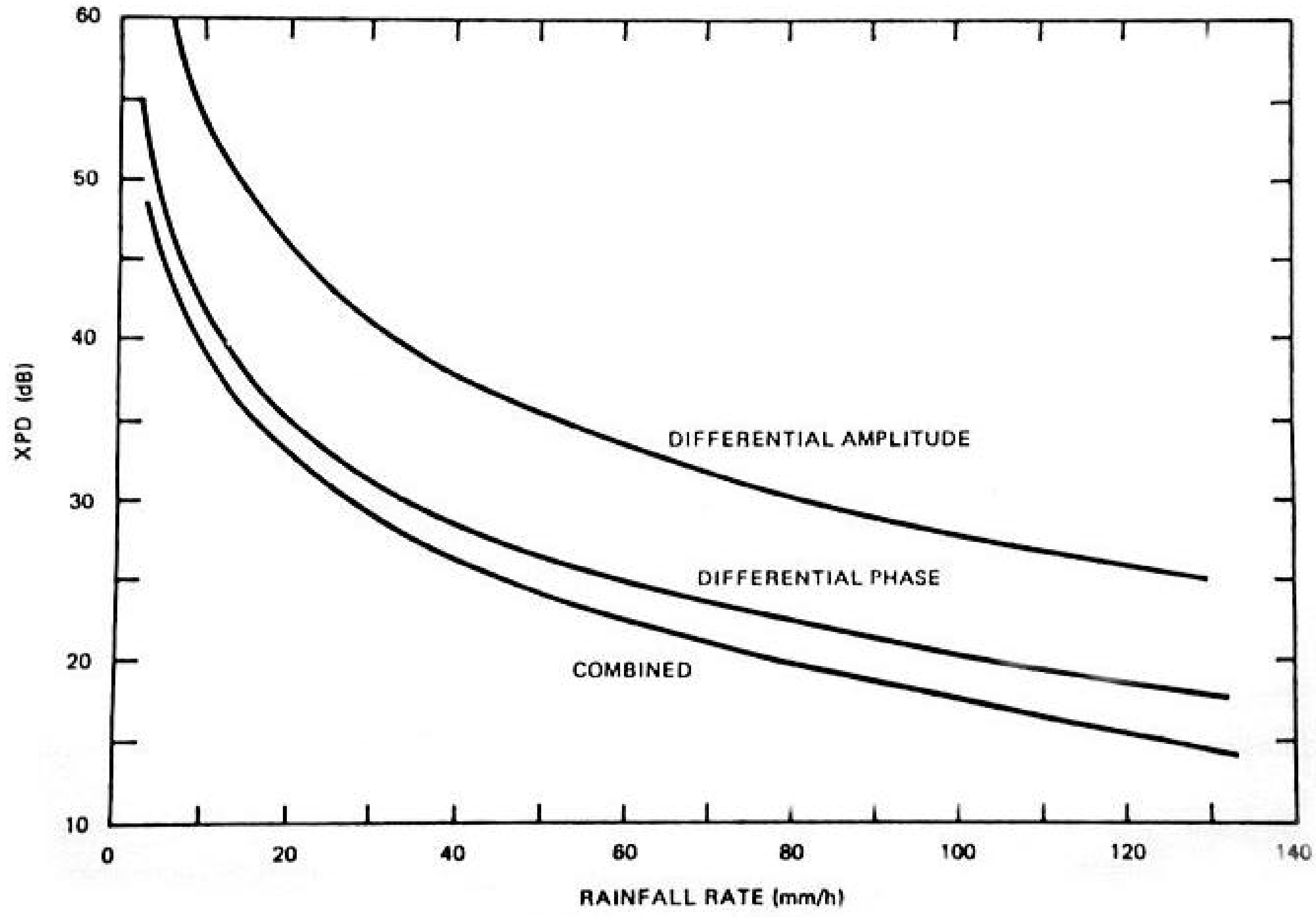
(introduce differential phase and/or attenuation to counteract propagation-path contributions that cause crosspolarization; of interest for dual-polarization frequency-reuse systems)



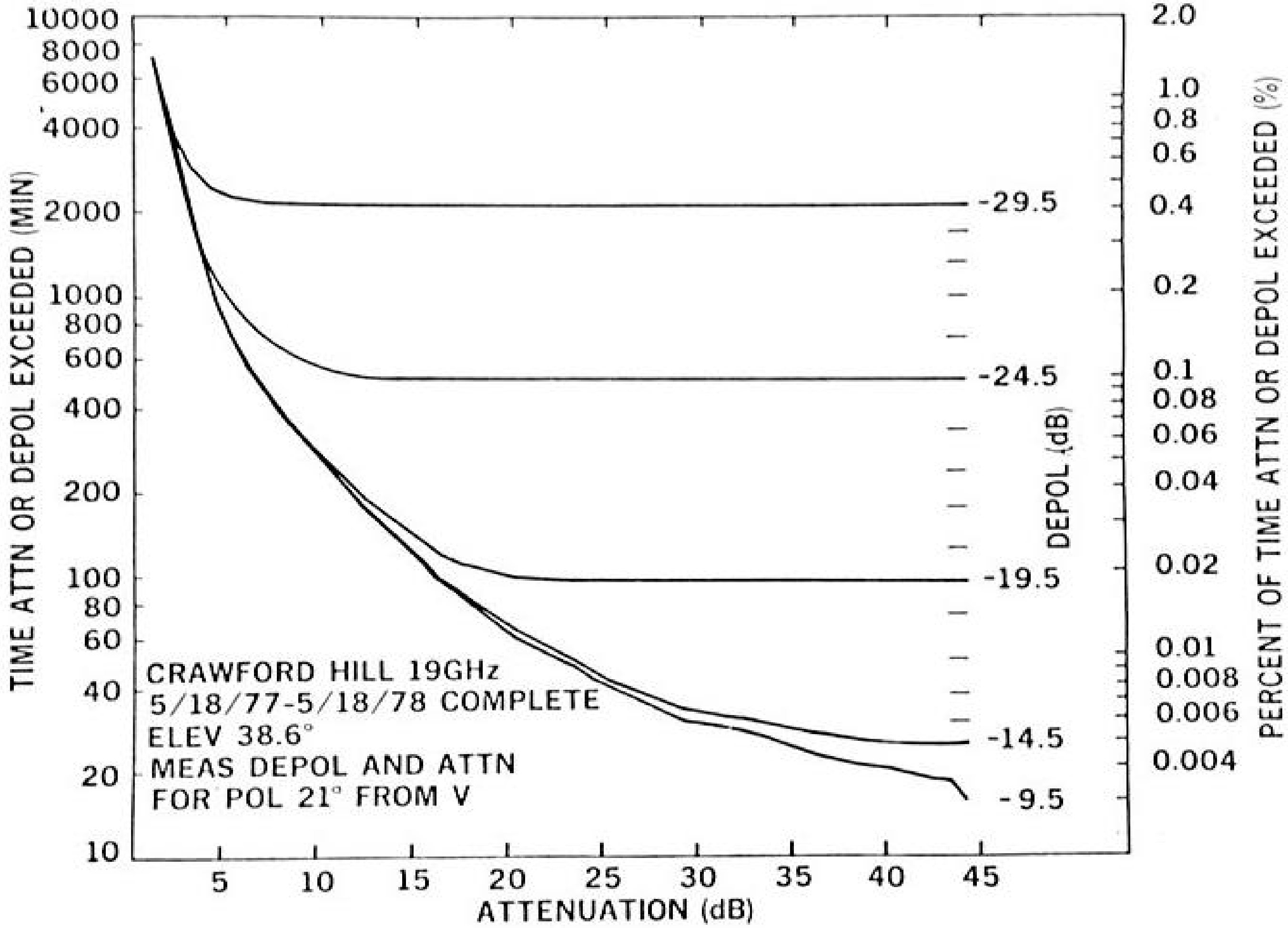
General four-port representation of adaptive depolarization compensation network. Cross-coupling arms allow insertion of differential phase and attenuation to counteract the differential phase and attenuation induced by asymmetrical raindrops and ice crystals on the propagation path.



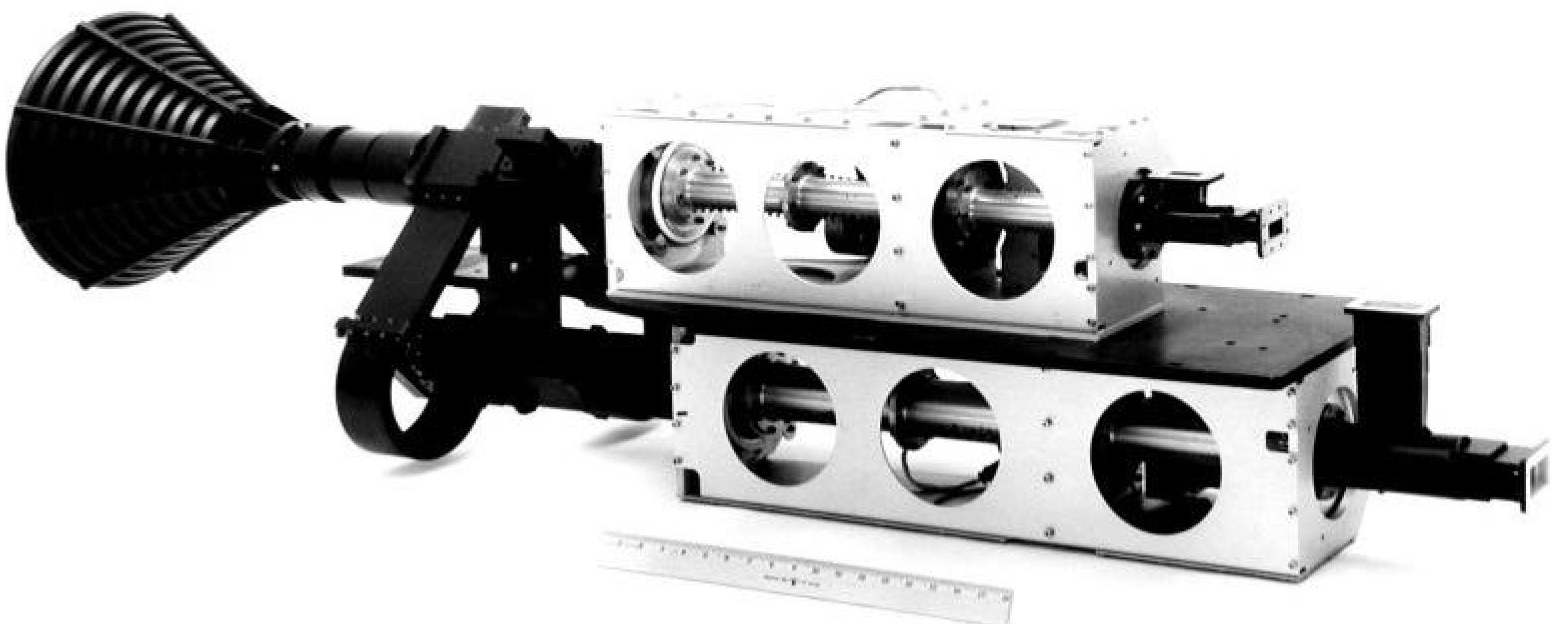
Path depolarization is more severe for a given path attenuation at lower frequencies. Depolarization generally most important at C-band.



Differential attenuation and phase contributions to path cross-polarization discrimination (XPD) at 11-GHz path and path 30° elevation angle, and combined effect. Differential phase generally more important to XPD.



Joint 19-GHz attenuation/depolarization statistics, illustrating relative system importance of attenuation vs. depolarization at Ka band (Cox & Arnold).



Wideband 4/6-GHz phase-only depolarization compensator using cascaded, individually-driven 180° and 90° polarizers, developed for INTELSAT
(low-loss system can be placed between antenna and LNA/HPA assembly)