Rain Fades and Traffic Outages

RAIN ATTENUATION FADES

Rain attenuation at the higher microwave frequencies (“millimeterwave” bands) has been under intense study and investigation for more than 60 years. Much is known about the qualitative aspects, but the problems faced by the microwave transmission engineer – that make quantitative estimates of the probability distribution of the rainfall attenuation for a given frequency band as a function of path length and geographic area - remains a most interesting challenge, albeit now greatly assisted by computer rain models..

In order to estimate this probability of rain (also wet snow – dry snow and ice crystals do not impede microwave propagation) outage distribution, instantaneous rainfall data is needed. The available rainfall data is usually in the form of a statistical description of the amount of rain that falls at a given measurement point over various time periods

The rain-induced attenuation along a given path at a given instant in time is a function of the integrated effect of the rainfall existing at all points along the path and is affected not only by the total amount of water in the path at that instant but also by its distribution along the path in volume and drop size.

For heavy rain rates the instantaneous distribution of volume and drop size along the path is highly variable, and difficult to predict with any sort of accuracy from the kind of rainfall data generally available.

One of the earliest and most comprehensive attempts at developing a workable prediction method was carried out by Bell Laboratories in the 1950's, and was described in Hathaway and Evans *“Radio Attenuation at 11 GHz and Some Implications Affecting Radio-Relay Systems Engineering”* (1958). In their paper Hathaway and Evans developed a method of predicting annual outages for microwave paths operating in the 11 GHz common carrier band, as a function of path length, fade margin and geographical area within the contiguous United States.

This study has proved to be a worthwhile prediction tool, and when used with recognition of its limitations, is still one of the best references available for microwave engineers working within the United States. Additional studies have been conducted in Europe and Asia. The combined information has been reviewed and published by the ITU-R in several Recommendations, e.g. ITU-R Rec. P.837, P.838, and P.839

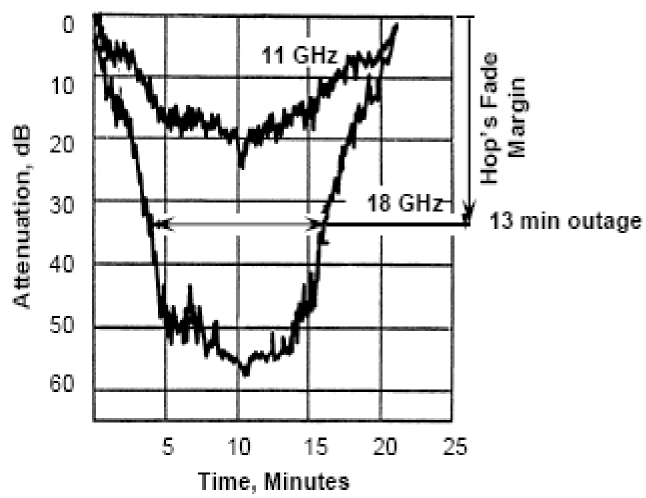
Increasing the fade margins by shortening path lengths or increasing antenna sizes are the most readily available tools for reducing the per hop outage in a given area, although “route” diversity or a lower less vulnerable lower frequency band may have to be considered.

The total annual rainfall in an area has almost no relation to the rain attenuation for the area. Within the U.S., the northwestern states, for example, have the greatest annual rainfall, in excess of 100 inches per year, but very few thunderstorm events, but it is characterized by long periods of steady rain of relatively low intensity at any given time that even provides high availability (low rain outage) in 38 GHz millimeterwave hops. Other areas of the country with much lower annual rates experience types of rainfall such as thunderstorms and frontal squalls which produce short duration rains of extreme intensity, and it is the incidence of rainstorms of this type which determines the rain attenuation characteristics of an area.

Even rain statistics for a day or an hour have little relationship to the excess path attenuation. A day with only a fraction of an inch of total rainfall may have a path outage due to a short period of extremely high localized rain cell intensity, while another day with several inches of total rainfall may experience little or no path attenuation because the rain is spread over a long time period or the high intensity rain cell misses the hop. .

The most common reason for the strong preference for lower frequencies for even short-haul routes is the susceptibility of frequencies above 10 GHz to rainfall attenuation. Although the effect is present to some degree at lower frequencies, it increases rapidly with frequency. For example, as seen below rainfall intensity causing only a few dB of attenuation at lower frequencies could be sufficient to cause a path outage at 18 GHz.

*An increase in fade margin reduces the numbers of rain outage events and their durations only minimally**



**Frequency, Polarization, and Path Length have much greater impact on Rain Outage*

Although fades caused by rainfall are occasionally observed at lower frequencies (10-20 dB fades at 6 GHz have even been recorded in tropical regions), this type of fade generally causes outages only on paths above 10 GHz. The outages are usually caused by blockage of the path by the passage of rain cells (thunderstorms, etc.), averaging 3-5 miles in diameter and 5-15 minutes in duration. As seen in the above fade chart, rain fades exhibits fairly slow, erratic level changes, with rapid path failure as the cell intercepts the path.

The fades are nonselective, i.e. all paths and frequencies in both directions of a hop are affected simultaneously. Vertical polarization is less susceptible to rainfall attenuation than horizontal in all millimeterwave bands. Again, as seen in the above fade chart increased fade margin is of minimal help in rainfall attenuation fading; but margins as high as 45 to 60 dB have been used in some highly vulnerable links for increased hop availability (“uptime”).

The following are a few basic considerations (“lessons learned”) in deploying millimeterwave microwave hops:

- Rain outage doubles in each higher millimeterwave band, e.g. 18 to 23 GHz.
- Rain outage is directly proportional to path length, assuming a constant fade margin.
- Rain outage increases X2 to X3 for H-pol millimeterwave hops as compared to V-pol.
- H-pol hops require ~6 dB more fade margin than V-pol hops for equal rain outage.
- Rain outage in tandemly connected short hops is the same as for a single long hop, assuming that all hops have the same fade margin.
- Rain outage durations are ~5-15min each. A Pathloss, Starlink, etc. path calc that shows small outage, e.g. 1min/year, equates to one 10min outage in 10/1 = 10 years.
- Rain cells typical travel E-W, thus causing fewer but longer duration outages to E-W millimeterwave hops than to N-S hops. The total rain outage to both are the same.
- Traffic is 100% protected from subscriber disconnect caused by a long-term rain outage in a millimeterwave hop with ring ("route diversity") protection
- Two hops out of a repeater site will not both be affected (exhibit simultaneous rain outage) if separated in azimuth by at least 80^0.
- Multipath fading in millimeterwave hops does not occur during periods of heavy rainfall, so the entire path fade margin is available to combat rain attenuation fades.
- Neither space diversity nor in-band frequency diversity provides any improvement against rain attenuation fade outage.

RAIN CELL PASSAGE

Heavy rainfall, usually in cells accompanying thunderstorm activity, has a great impact on path availability above 10 GHz in some areas, but this outage time is always kept separate from the multipath outage time computed above because such long-term outages disconnect traffic so are categorized as "Availability, %, rather than as Performance or Path Reliability, % events that do not disconnect traffic.

These long-term rain outages increase dramatically with frequency, and then with path length. Extended 10-15 minute duration fades to over 50 dB similar to that seen in the above fade chart have been recorded on a 3-mile 18 GHz path in Houston, for example. A similar outage was observed on a 6-mile 11 GHz link in Tampa.

Lesson learned: Do not deploy millimeterwave hops of any length in Tampa, the U.S. "ground zero" for high-intensity rain cell and thunderstorm activity (more than 100 per year).

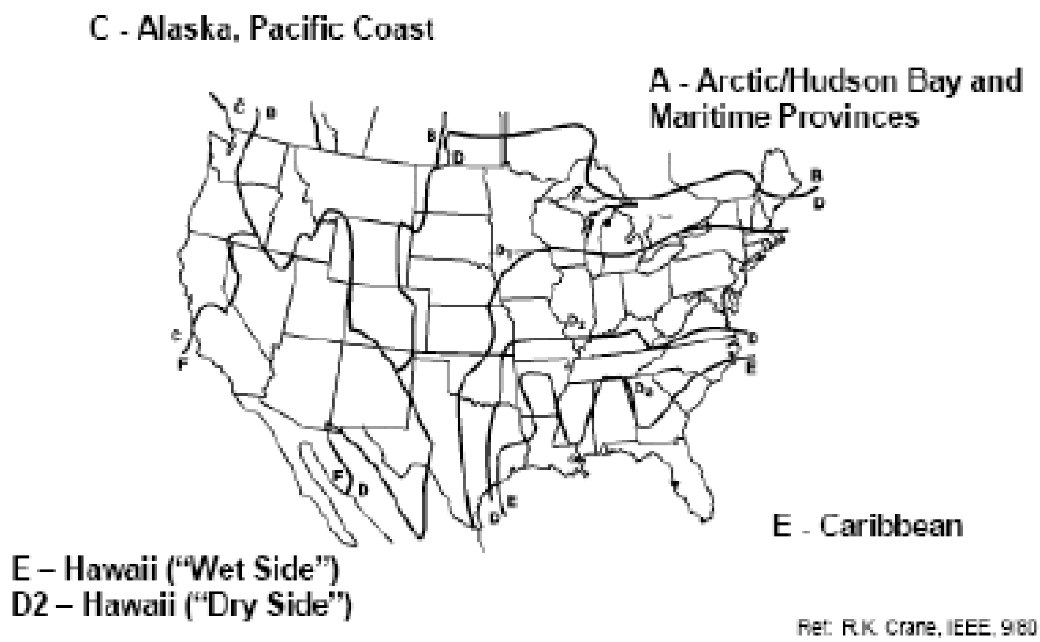
The predicted annual outage may not occur for years, and then accumulate over a single rainy season for a long-term average. Increased outage at 23 GHz can result in a 2-to-1 reduction in path length in the band over 18 GHz for a given availability.

Rain has long been recognized as one of the principal causes of unwanted signal loss in millimeterwave microwave radio paths through the lower atmosphere. Rain is not the only cause. Variations in water vapor along the path or the occurrence of liquid water clouds or fog on the path will cause a fixed loss in path calculations as Atmospheric Absorption Loss. But in millimeterwave bands, rain is very often the sole cause of increased attenuation and fading.

Early studies, both theoretical and experimental, resulted from the recognition of the importance of rain in designing microwave paths with reliabilities in excess of 99%. In recent years the emphasis has been on establishing predictive techniques for the statistical estimation of the attenuation probability distribution for a particular path. Robert F. Crane, in his *"Prediction of Attenuation by Rain"* paper (1980) has developed a model, below, for determining the attenuation due to rain, based on several factors including path length, frequency, polarization, and point rain rates shown in the Canadian/U.S. rain rate tables and rain region map below:

% of Time Rain Rate Exceeded	CRANE NORTH AMERICAN RAIN REGION (1980*)							
	A	B	C	D_1	D_2	D_3	E	F
0.1	6.5	6.8	7.2	11.0	15.0	22.0	35.0	5.5
0.05	8.0	9.5	11.0	16.0	22.0	31.0	52.0	8.0
0.01	**15.0**	**19.0**	**28.0**	**37.0**	**49.0**	**63.0**	**98.0**	**23.0**
0.005	19.0	26.0	41.0	60.0	64.0	81.0	117.0	34.0
0.001	28.0	54.0	80.0	90.0	102.0	127.0	164.0	66.0

These rain rates, in mm/hr exceeded __% of the time, are long-term averages over perhaps a 10 year or longer period. Rain rates (and high-frequency access link outage) are probably greater or smaller over shorter term periods.



CRANE'S RAINFALL OUTAGE MODEL (in all Path Engineering Calculation Programs)

$A = \alpha R_P^{\beta} [F(R_P, D)]$ (dB/km)

$A = \alpha R_P^{\beta} [(\{e^{\lambda\beta d}-1\}/\lambda \beta)-(\{b^{\beta}e^{c\beta d}\}/c\ \beta)+(\{b^{\beta}e^{c\beta D}\}/c\ \beta)]$; For d<D<Do

$A = \alpha R_P^{\beta} [\{e^{\lambda\beta d}-1\}/\lambda\ \beta]$; For D<d

Where R_P = Rain Rate exceeded p% of the time, mm/hr
D = path length in kilometers,
λ = $[\{\ln(be^{cd})\}/d]$,
b = $2.3\ R_P^{-0.17}$,
c = $0.026-0.03\ \ln(R_P)$,
d = $3.8-0.6\ \ln(R_P)$.
α = multiplier coefficient, a function of frequency and polarization (table below)
β = exponent coefficient, a function of frequency and polarization (table below)

$P'=P[D_o/D]$, where D_o =22.5 km. For D>22.5 km

The regression coefficients, multiplier α and exponent β in both the Crane model above, as well as in the competing ITU-R P.530-7 rain model sometimes used internationally, are from the following ITU-R Rec. P.838 table:

Frequency, GHz	Vertical Pol α_V	Vertical Pol β_V	Horizontal Pol α_H	Horizontal Pol β_H
7.0	0.0027	1.312	0.0030	1.332
7.5	0.0033	1.311	0.0037	1.329
8.0	0.0040	1.310	0.0045	1.327
10.8	0.0109	1.243	0.0122	1.258
11.2	0.0132	1.224	0.0145	1.242
13.0	0.024	1.182	0.026	1.203
15.0	0.034	1.128	0.037	1.154
18.7	0.058	1.080	0.064	1.112
22.4	0.089	1.047	0.097	1.080
30.0	0.167	1.000	0.187	1.021
38.0	0.278	0.942	0.314	0.954
60.0	0.642	0.824	0.707	0.826

A much simplified P.530-7 rain outage model easily programmable in scientific calculators and computers that uses only the 0.01% rain rates and frequency/polarization coefficients in the above two tables, is now often used in place of the above Crane algorithm.

RAIN AVAILABILITY OBJECTIVES
Unlike short-term multipath fading discussed later, rain fades always cause long-term (defined as a >10 CSES/event) traffic outages 3-20min durations that disconnect subscribers if not ring-protected.

A typical per-hop rain outage objective in a millimeterwave Access link is around 26min/year (99.995% availability or "uptime") which equates to 2-3 rain outage events per year.

If this if unacceptable, it may be necessary assign V-polarization, increase fade margin (for a minimal improvement), or migrate the hop to a lower frequency band.

RELIABILITY OBJECTIVES

Rain outage is always causes long-term, and thus is not included in path reliability calculations that consider only short-term (<10 CSES/event) multipath outages.

In considering how to establish realistic outage or reliability objectives, several things need to be kept in mind. A single overall design objective for not more than X hours, minutes, or seconds outage over some period such as a year is an over-simplification. The character of the particular kind of outage and its effect on the system should be taken into account and perhaps there should even be different objectives for different types of outage.

For example, propagation outages due to multipath fading are usually short. Annual outage of 30min/yr due to multipath fading might represent 1,000 or more individual SES (severely errored second) outages most averaging less than 1 second in duration each in properly configured hops.

RELIABILITY AND OUTAGE TIME					
Reliability %	Outage Time %	Outage Time per			
		Year	3 Month Fade Period	Month (Avg)	Day (Avg)
0.0	100.0	8760.0 hrs	2233.3 hrs	720.0 hrs	24.0 hrs
50.0	50.0	4380.0 hrs	1116.7 hrs	360.0 hrs	12.0 hrs
80.0	20.0	1752.0 hrs	446.7 hrs	144.0 hrs	4.8 hrs
90.0	10.0	876.0 hrs	223.3 hrs	72.0 hrs	2.4 hrs
95.0	5.0	438.0 hrs	111.7 hrs	36.0 hrs	1.2 hrs
98.0	2.0	175.2 hrs	44.7 hrs	14.4 hrs	28.8 min
99.0	1.0	87.6 hrs	22.3 hrs	7.2 hrs	14.4 min
99.9	0.1	8.8 hrs	2.2 hrs	43.2 min	1.44 min
99.99	0.01	52.6 min	13.4 min	4.3 min	8.6 sec
99.999	0.001	5.3 min	1.3 min	25.9 sec	0.86 sec
99.9999	0.0001	31.5 sec	8.0 sec	2.6 sec	0.086 sec

On the other hand, propagation outages totaling an hour per hop due to rain attenuation, on a path with a large fade margin, might consist of four or five individual outages averaging ten to fifteen minutes each.

The effects of these two types of system outage would be quite different in nature, long-term rain outage being an “availability” or “uptime” (disconnects traffic) parameter, and short-term multipath fade outage a “error performance” or path “reliability” parameter that does not disconnect traffic.

A distinction should be made between communication circuits for which an outage of a few seconds or a few minutes is just a nuisance or an inconvenience, and circuits for which such an outage might result in danger to life, great economic loss, or other catastrophic consequences. The suitability or unsuitability of a rain-affected band such as 23 GHz as well as protection schemes to mitigate outage could differ widely for these two situations.

Even if the maximum possible reliability objectives are established and a path or a system is engineered to the full limit of the state of the art, the possibility of an outage can never be eliminated but can only be reduced to a very low probability.

Thus it is imperative to make any ultra-important services as fail-safe as possible against a loss of the communications channel. Therefore, regardless of the degree of reliability, a system should be engineered so that if an outage does occur it can be tolerated or its effects at least kept within reasonable bounds.

It seems that in some cases, perhaps many cases, a somewhat more relaxed attitude might be taken toward rain-induced outages than toward multipath outages or even equipment outages. In several respects such rain outages seem to be somewhat benign in nature. If the fade margins are kept high and the paths are not stretched out too much, even in the less advantageous areas of the country, the number of outages per year should not be very large, and the length of individual outages on a hop should only rarely exceed some two to perhaps twenty minutes.

Short (less than 2-second) microwave outages, common on a typical longer non-diversity digital microwave link with high fade margin will not drop any telephone or data lines. Such outages quickly clear with all circuits remaining connected with little note taken of these transient events (except for critical real-time, non repeatable control or data blocks).

Longer outages associated with low fade margins, rain, etc. disconnect all subscribers and block access to the digital link for at least 10 seconds per event. Such events are unacceptable to most users. These vulnerable links clearly require diversity protection.

For high reliability systems, usually involving long-haul systems with a great many hops in tandem, the per-hop objective in long-haul microwave systems may be as stringent as 99.9999% per hop (AT&T's one-way objective for 25mi hop in a long-haul route), allowing only about 30 seconds of short-term multipath fade outage per year.

Short haul systems, up to say ten hops, may be assigned a per-hop design objective of about 99.9995% for about 160 sec/yr of one-way multipath fade outage per year. Spur legs or single hop systems may be designed for something on the order of 99.999% or about 5 minutes of short-term outage per year.

Objectives of these kinds are typical of those used in the telephone industry, for public service networks. Public safety, homeland security, and electrical utilities may demand better performance, while for others even 99.9% or about 9hr/yr outage may be acceptable.

It is important to note that graphs, formulas and computer methods for calculating short-term multipath outages are all for one-way outage as they are selective in frequency, i.e. do not occur at the same time in the two directions of a hop. To derive two-way multipath fade outage (not ever recommended since all ITU and North American performance objectives are only-way only), they would have to be doubled.

Long-term outages due to rain or other non-selective power fades do not have to be doubled since they occur simultaneously in both directions of transmission.