



Long Reach WiFi Link: A joint EsLaRed-ICTP effort

ICTP-ITU School on
Wireless Networking for Scientific Applications
in Developing Countries
Abdus Salam ICTP, Trieste, February 2007

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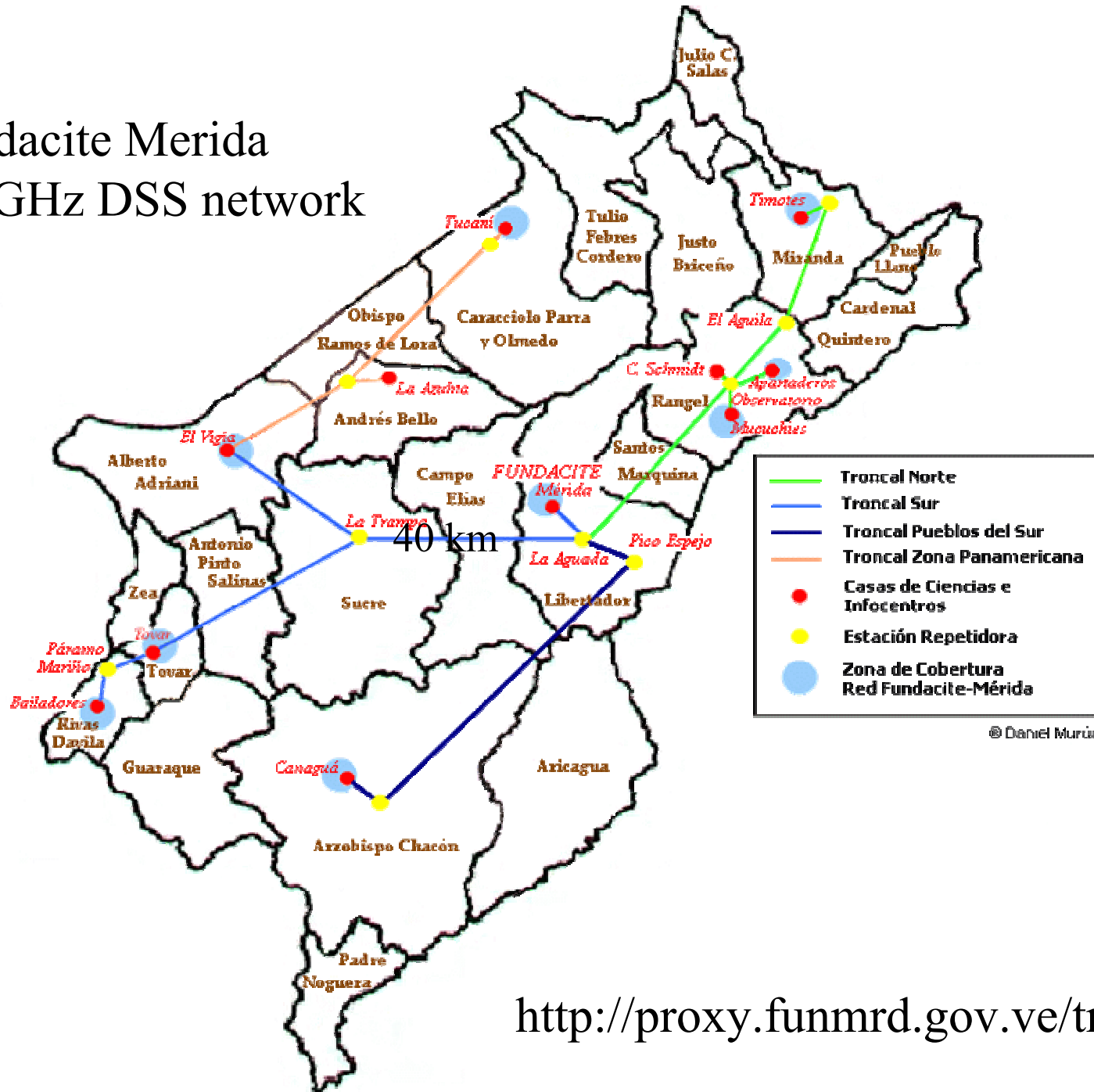
Motivation

- Wireless techniques are the most cost effective to provide communication service in rural areas
- Packet Radio cannot provide the access speed people demands nowadays
- Satellite is still too expensive and dependent on the offers of very large enterprises
- Data over cellular is expensive and current offers are limited in speed

Motivation

- Spread Spectrum technology based networks have been used for the last 15 years as a cost effective way to provide connectivity
- The establishment of the IEEE 802.11 standard in 1999 spurred competition among manufacturers that allowed a substantial price decrease
- The limited telephony infrastructure of Venezuela in the eighties led us to use packet radio for data communications. In our LabCom at Universidad de los Andes we built antennas and used commercially available radios and modems to link several remote sites using Phil Karn's TCP/IP implementation

Fundacite Merida 2.4 GHz DSS network



© Daniel Murcia

<http://proxy.funmrd.gov.ve/trafico>

Why strive for long links?

- Every repeater site increase cost, logistics and frequently significantly reduces throughput
- In rural areas, best repeaters sites often lack power and may present security and accessibility problems

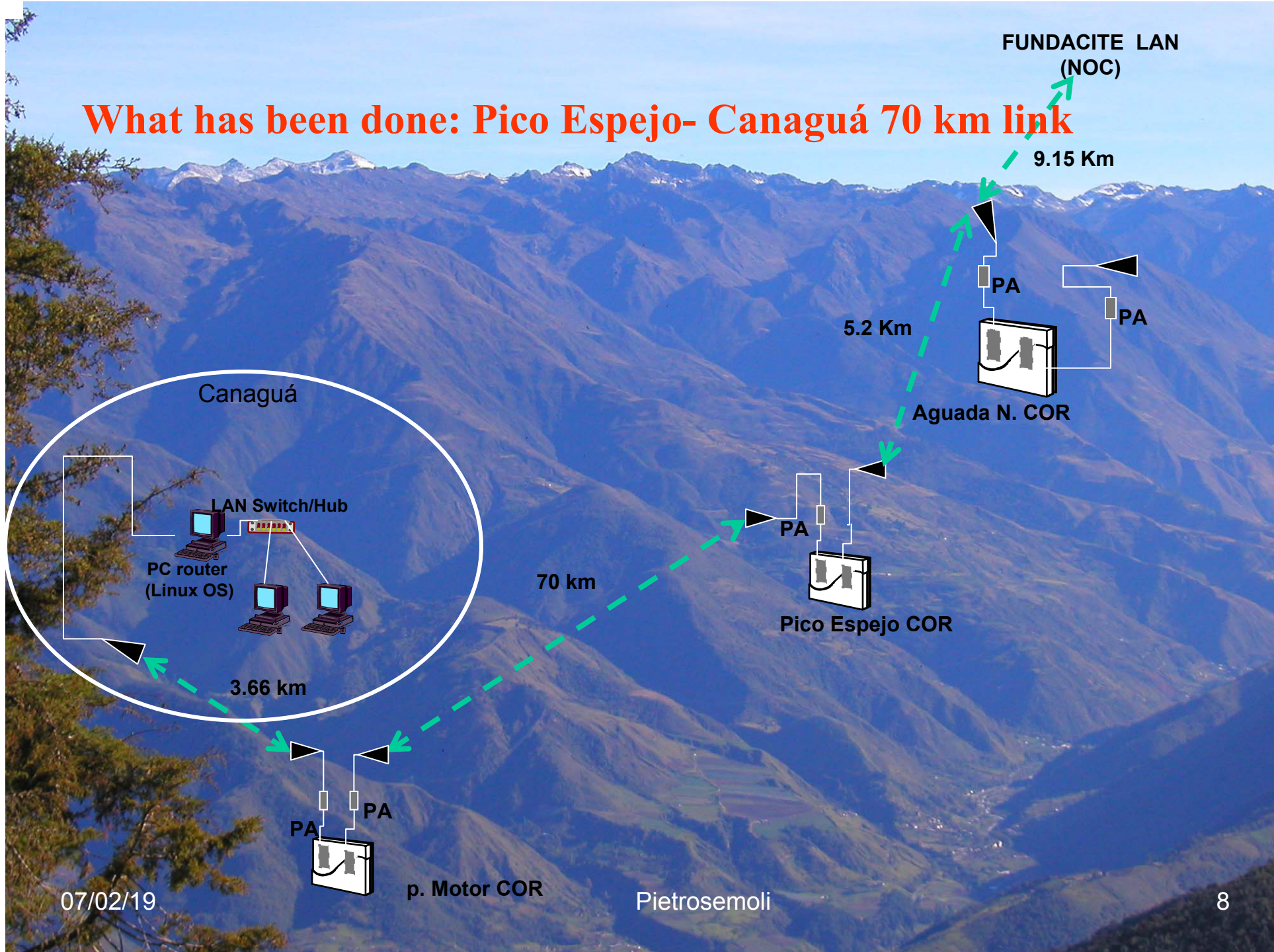
What factors limits the achievable span?

- **Power budget**
 - ◆ Legal regulations on maximum EIRP
 - ◆ Increased cost of high power devices
- **Fresnel zone clearance**
 - ◆ 60 % of first zone for a reliable link
- **ACK timeout**
 - ◆ IEEE 802.11 MAC requires that the sending station receives an ACK for every frame sent. For WLANs the propagation time is negligible, but at 300 km it reaches 1 ms
- **These factors are being addressed by WiMAX but at a considerably higher cost for terminal equipment**

What can be done?

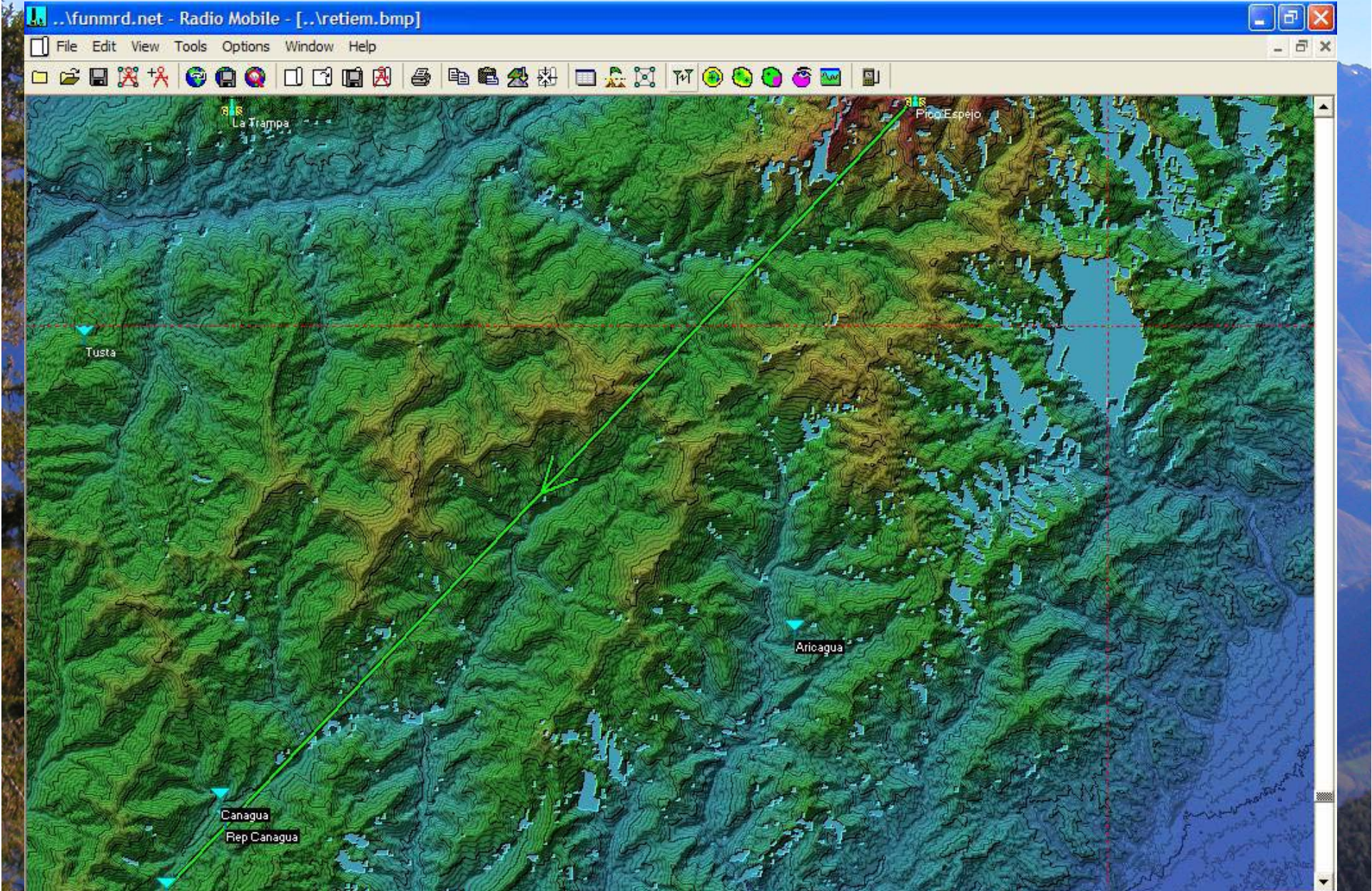
- **Power budget**
 - ◆ Use high gain antennas (cheaper if recycled)
 - ◆ Use more sensitive radios
 - ◆ Minimize RF cable length
- **Fresnel zone clearance**
 - ◆ Choose endpoints carefully using coverage prediction software like “radio mobile”
- **ACK timeout**
 - ◆ Third party firmware allows changing of this parameter
- **MAC modifications to customize for longer distances**

What has been done: Pico Espejo- Canaguá 70 km link

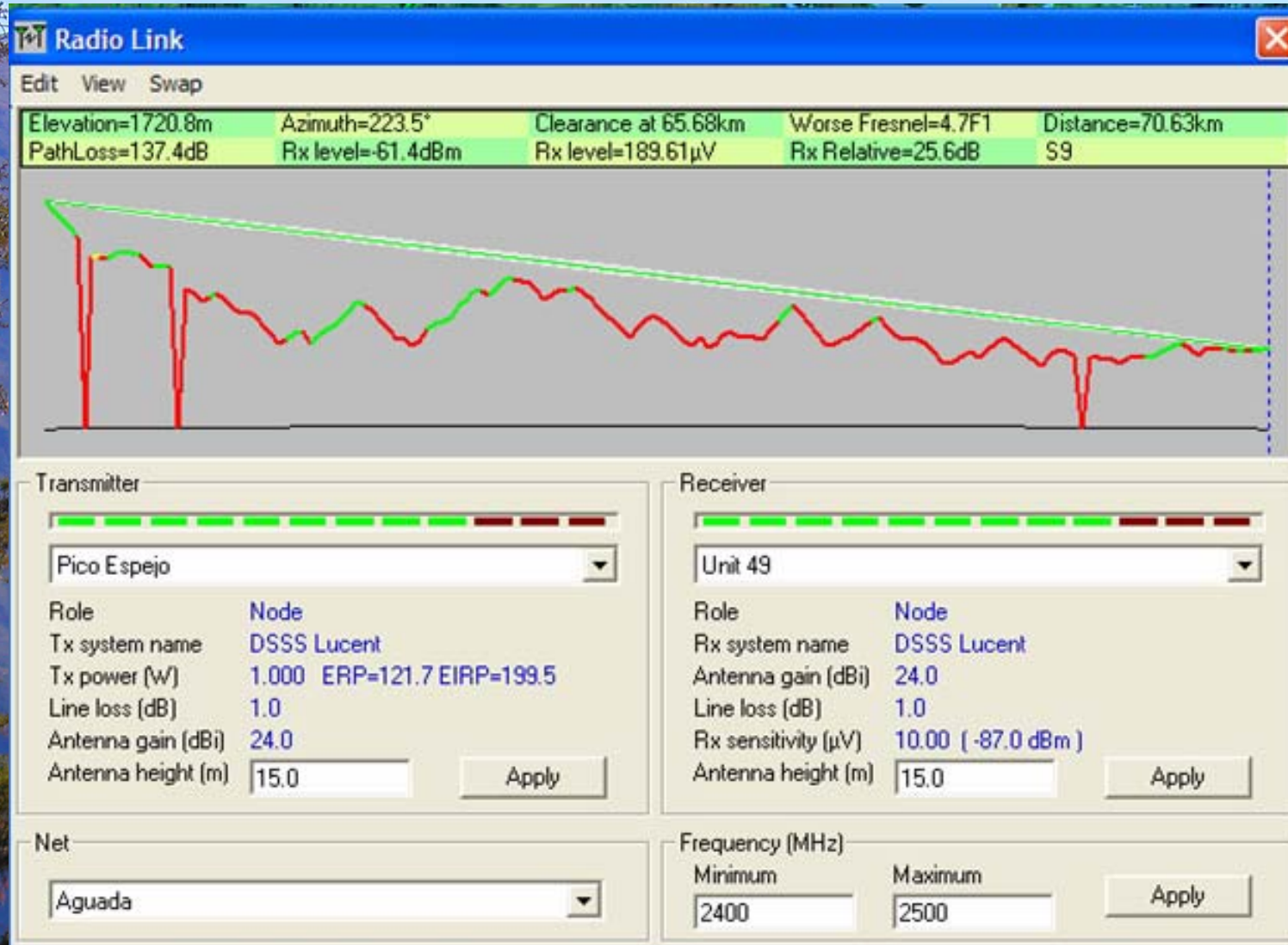


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Pico Espejo- Canaguá 70 km link



Pico Espejo- Canaguá 70 km link



Pico Espejo- Canaguá 70 km link

Radio Link

Edit View Swap

Distance between Pico Espejo and Unit 49 is 70.6 km (43.9 miles), Azimuth 223.5°, Elevation -2.9106°
Terrain elevation variation is 4722.2 m
Propagation mode is line-of-sight, minimum clearance 4.7F1 at 65.7km
Average frequency is 2450.000 MHz
Free Space = 137.2 dB, Obstruction = 0.1 dB, Urban = 0.0 dB, Forest = 0.0 dB, Statistics = 0.2 dB
Total propagation loss is 137.4 dB
System gain from Pico Espejo to Unit 49 is 163.0 dB
System gain from Unit 49 to Pico Espejo is 163.0 dB
Worst reception is 25.6 dB over the required signal to meet
50.0% of time, 50.0% of locations, and 50.0% of situations
(The worst S-meter reading is S 9)

Transmitter

Pico Espejo

Role	Node
Tx system name	DSSS Lucent
Tx power (W)	1.000 ERP=121.7 EIRP=199.5
Line loss (dB)	1.0
Antenna gain (dBi)	24.0
Antenna height (m)	15.0

Apply

Receiver

Unit 49

Role	Node
Rx system name	DSSS Lucent
Antenna gain (dBi)	24.0
Line loss (dB)	1.0
Rx sensitivity (µV)	10.00 (-87.0 dBm)
Antenna height (m)	15.0

Apply

Net

Aguada

Frequency (MHz)

Minimum	Maximum
2400	2500

Apply

What has been done: Swedish Space Agency 310 km link

- **Guinness World Records Recognizes World's Longest Wi-Fi Connection**

- **Alvarion and Swedish Space Corporation Achieve Wireless Broadband Connectivity Over 310km**

The link was made in the end of 2002 between a stratospheric balloon that was launched from Esrange near the town of Kiruna in northern Sweden and a base station located near Esrange.

- <http://www.alvarion.com/presscenter/pressreleases/3263/>

What has been done: New world record for unamplified wireless networking!!

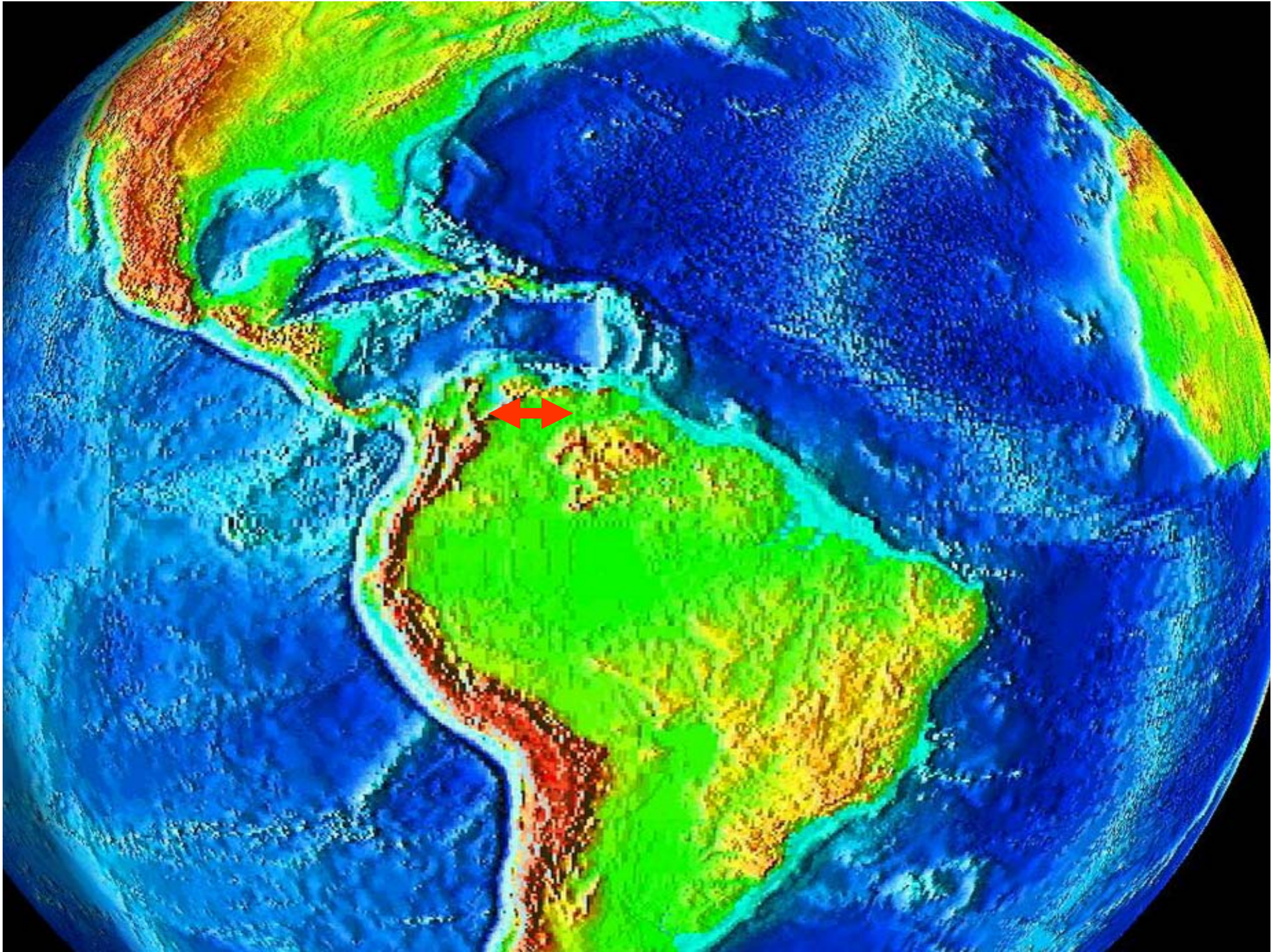
- **125 miles! (201 km)**

<http://www.wifi-shootout.com/>



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Bird's eye view of the path



la 207

El Baul

Image © 2005 MDA EarthSat

© 2005 Google

Pointer 8°55'45.88" N 69°31'16.22" W elev 112 m

Streaming 100%

Eye alt 156.05 km

An aerial photograph of a rugged, brownish mountain range. The terrain is characterized by deep, winding gullies and ridges. In the center of the image, there is a small cluster of buildings, including a prominent structure with a green and white striped roof. Several dirt roads or paths are visible, crisscrossing the landscape. The overall scene is arid and mountainous.

Aerial view of site 1 Pico del Aguila

Telecom Towers

Bronco

A landscape view showing a range of blue mountains under a clear sky. The foreground includes some green foliage and a tree branch on the left side.

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Station Layout: same for both ends



One Station configured as AP, the other as client

..inet1.net - Radio Mobile - [..Picture3.bmp]

File Edit View Tools Options Window Help

Radio Link

Edit View Swap

Azimuth=87,1°	Elev. angle=-2,062°	Clearance at 246,41km	Worst Fresnel=1,8F1	Distance=280,33km
PathLoss=157,4dB	E field=37,0dBμV/m	Rx level=-78,4dBm	Rx level=26,82μV	Rx Relative=11,6dB

08°49'56"N 070°49'44" Transmitter Receiver

start ..inet1.net - Radio M... El Aguila - Microsoft ... 2 Firefox 97% 12:09 p.m.

Links details

Radio Link

Edit View Swap

Distance between Bronco and Morrocoy is 280,3 km (174,2 miles)
True North Azimuth = 87,1°, Magnetic North Azimuth = 95,6°, Elevation angle = -2,0625°
Terrain elevation variation is 4054,8 m
Propagation mode is line-of-sight, minimum clearance 1,8F1 at 246,4km
Average frequency is 2425,000 MHz
Free Space = 149,0 dB, Obstruction = 2,8 dB, Urban = 0,0 dB, Forest = 0,0 dB, Statistics = 5,6 dB
Total propagation loss is 157,4 dB
System gain from Bronco to Morrocoy is 169,0 dB
System gain from Morrocoy to Bronco is 169,0 dB
Worst reception is 11,6 dB over the required signal to meet
50,000% of time, 50,000% of locations, and 70,000% of situations

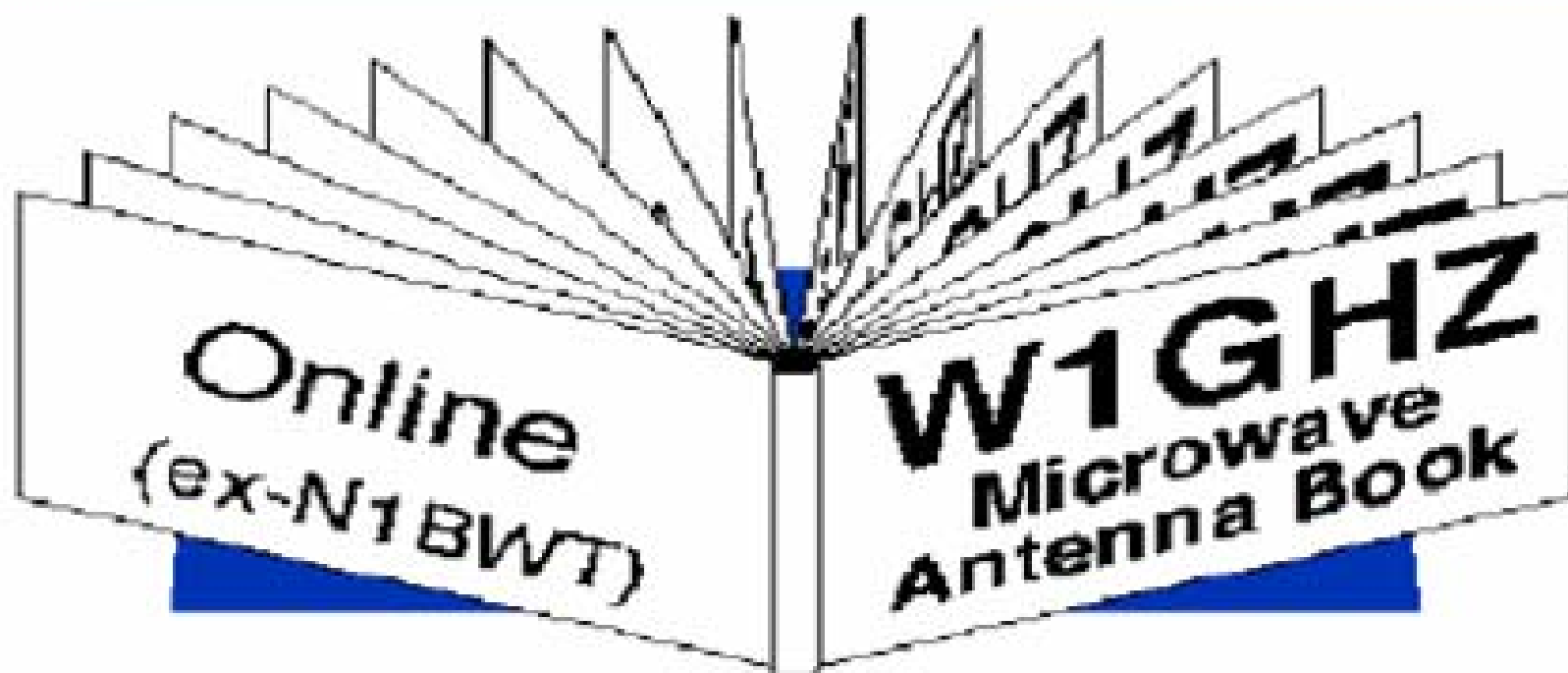
Transmitter		Receiver			
Bronco		Morrocoy			
Role	Node	Role	Node		
Tx system name	Aguila	Rx system name	Aguila		
Tx power	0,1 W	20 dBm	Required E Field	25,4 dB μ V/m	
Line loss	0,5 dB		Antenna gain	30 dBi	27,85 dBd
Antenna gain	30 dBi	27,85 dBd	Line loss	0,5 dB	
Radiated power	EIRP=89,13 W	ERP=54,34 W	Rx sensitivity	7,08 μ V	-90 dBm
Antenna height (m)	2	Apply	Antenna height (m)	2	Apply

Net		Frequency (MHz)		
Aguila		Minimum	Maximum	Apply
		2400	2450	

Higher gain antennas

- The parabolic antenna is by far the one that can provide the most gain in the WiFi band
- Plenty of reflector antennas have been built in many places of the world for satellite reception
- Often this antennas can be acquired at low cost

Very good source for antenna
information: www.w1GHZ.org

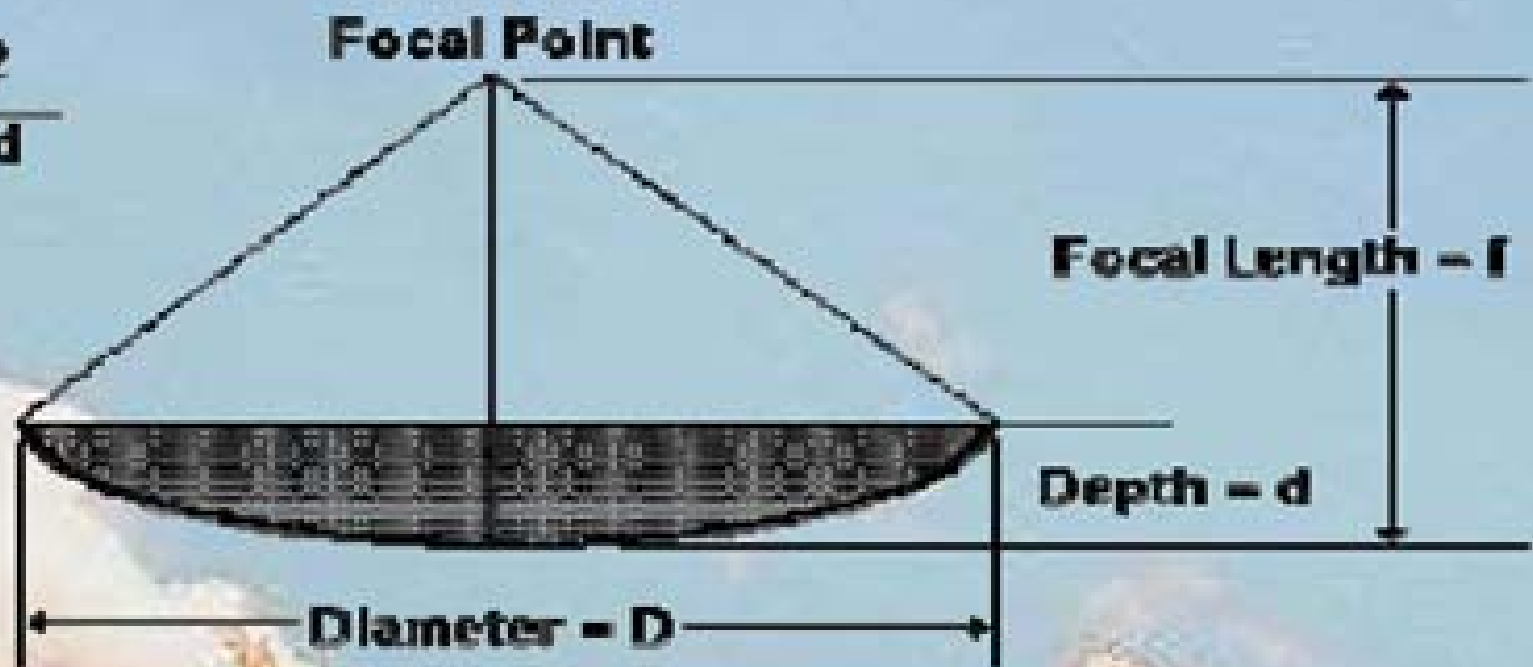


Chapter 5
Offset-fed Parabolic Dishes
Paul Wade W1GHZ ©1998,1999

Geometry of parabolic reflectors

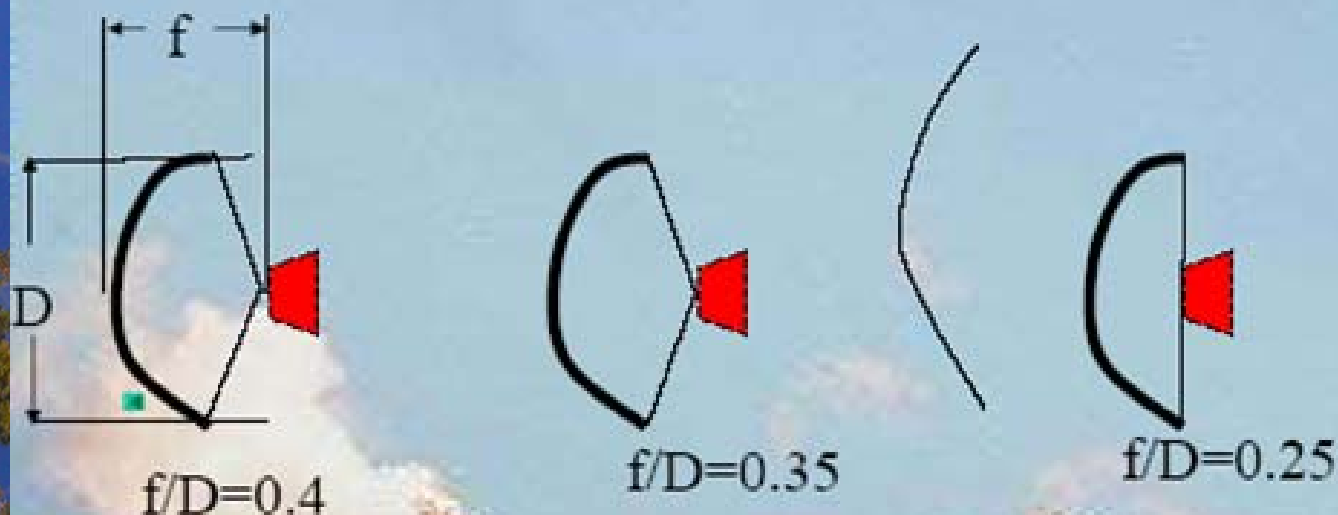
The basic property of a perfect parabolic reflector is that it converts a spherical wave irradiating from a point source placed at the focus into a plane wave. Conversely, all the energy received by the dish from a distant source is reflected to a single point at the focus of the dish. The position of the focus, or focal length, is given by:

$$f = \frac{D^2}{16d}$$



The ratio f/D (focal length/diameter of the dish) is the fundamental factor governing the design of the feed for a dish. The ratio is directly related to the beamwidth of the feed necessary to illuminate the dish effectively. Two dishes of the same diameter but different focal lengths require different design of feed if both are to be illuminated efficiently. The value of 0.25 corresponds to the common focal-plane dish in which the focus is in the same plane as the rim of the dish.

The lower the f/D ratio, the lower the sidelobes, because the feed is more protected from stray rays. Sidelobes can also be reduced by means of additional shielding on the rim of the parabolic reflector (skirt).



Dish Illumination

- The illumination of the dish
- is crucial to the performance
- We should illuminate as much
- as the reflecting surface as
- possible as well as avoiding spillover
- The best results are obtained with a tapered illuminator that will progressively diminish the illumination of the edges thus reducing sidelobes and spillover
- Another critical parameter is the position of the feed with respect to the reflector



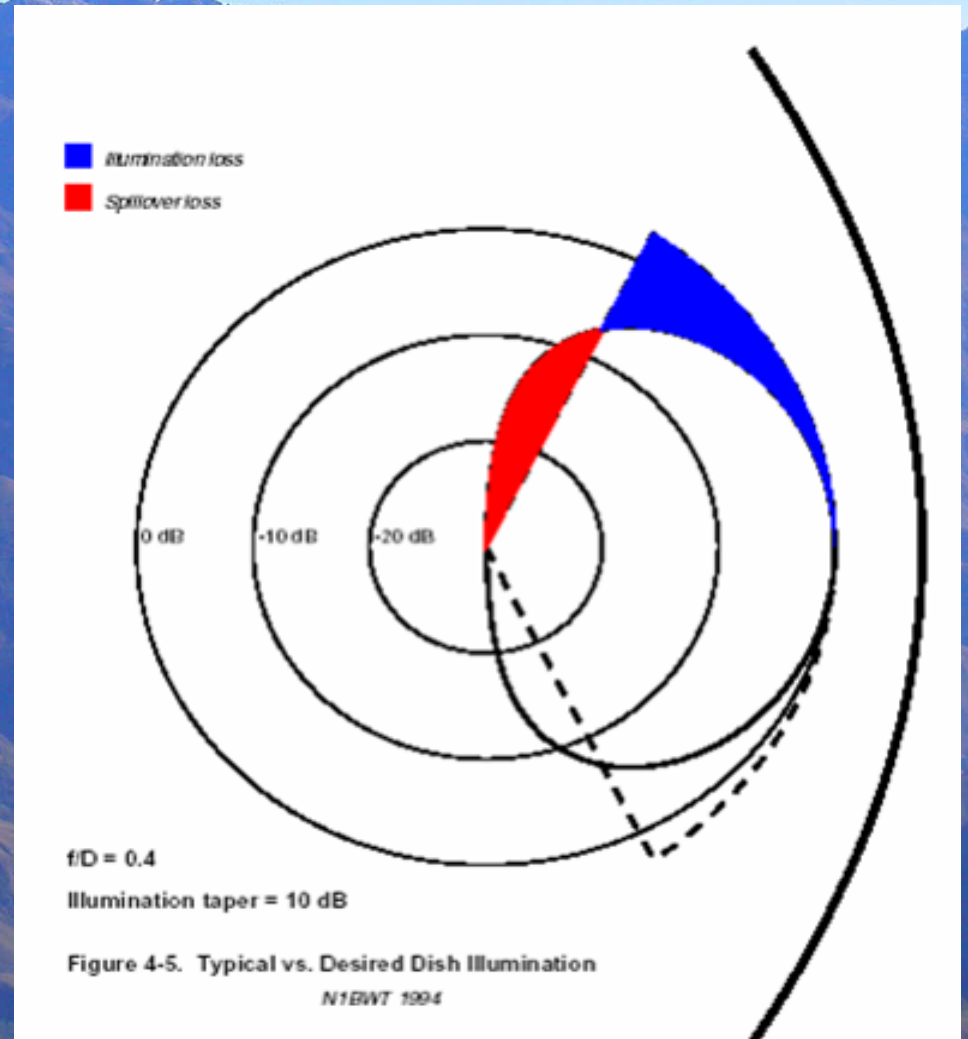
Feeding the parabolic Reflector

Illumination Efficiency:

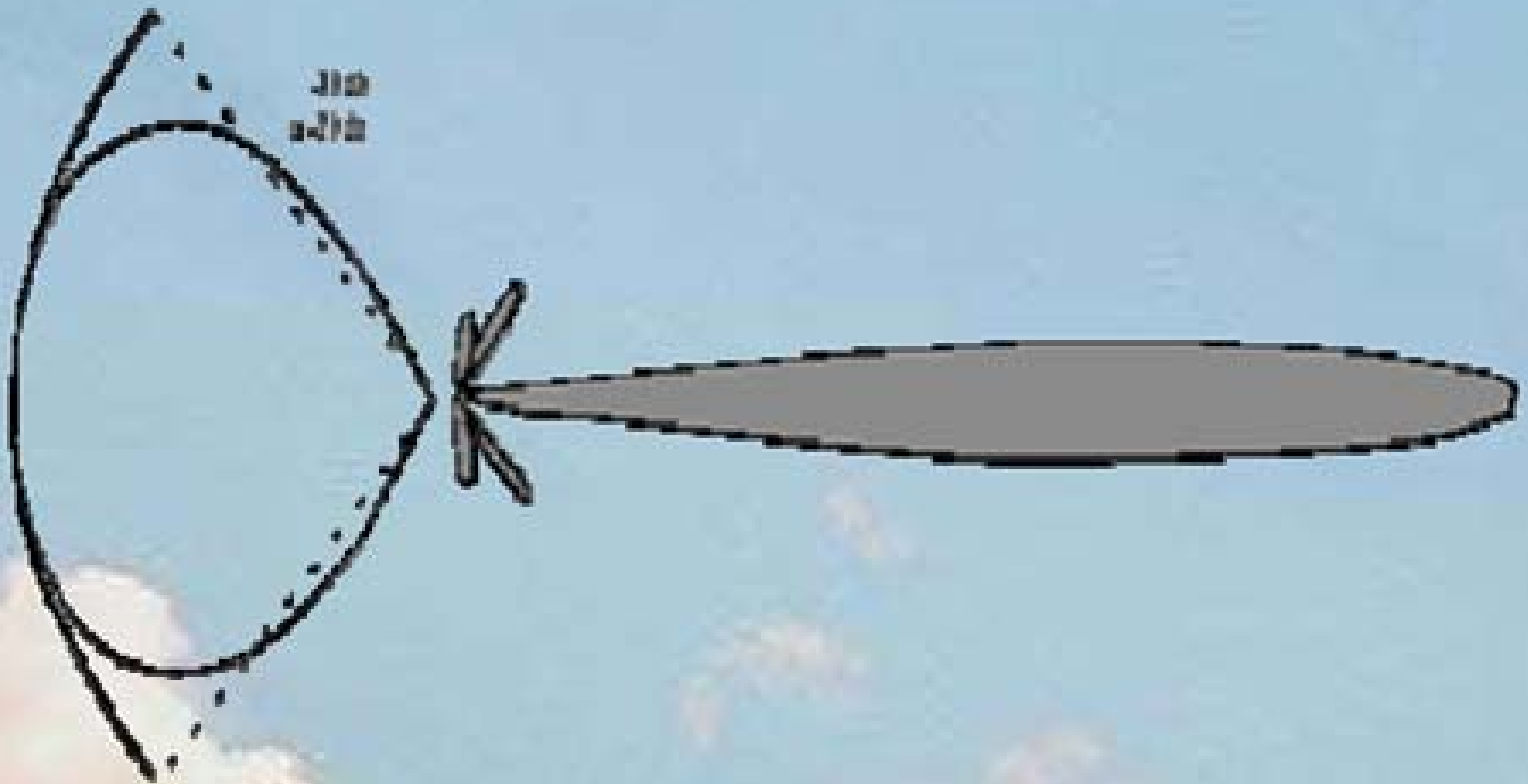
Spillover loss

Sidelobes

Noise absorption



Radiation pattern with sidelobes



Feeding the parabolic Reflector: Some examples

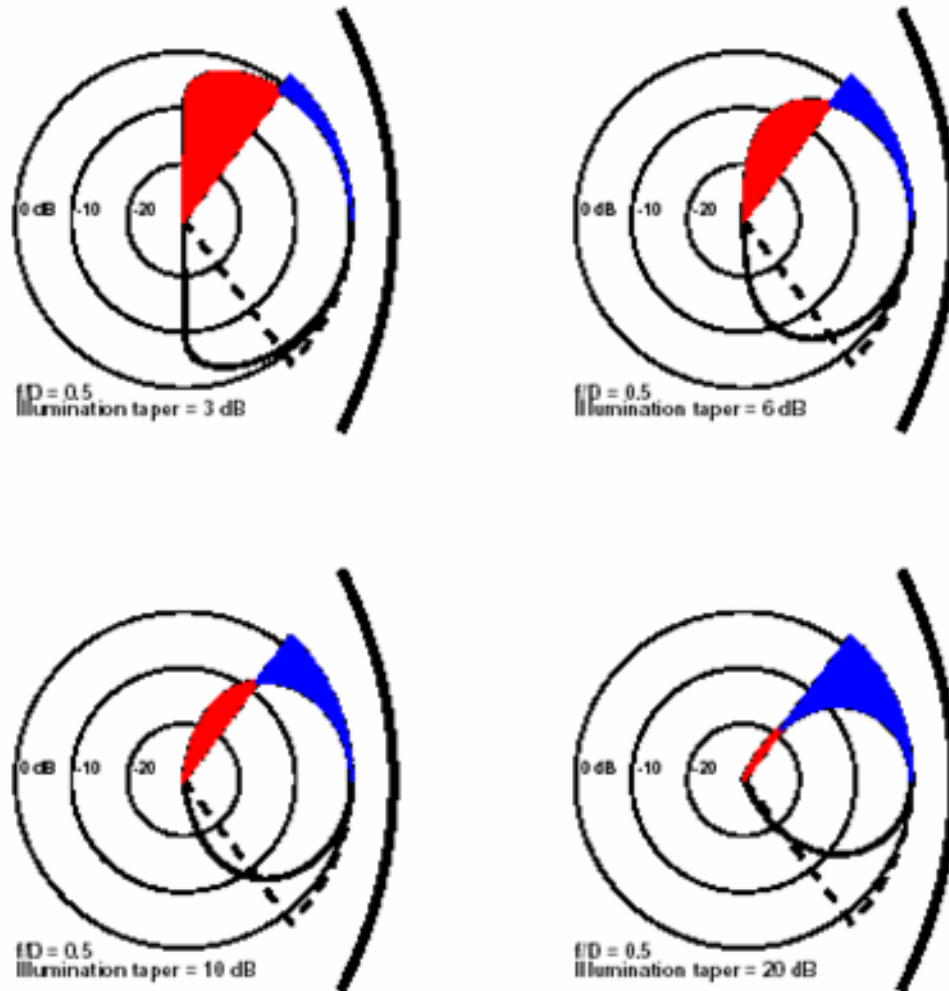


Figure 4-6. Dish Illumination with Various Illumination Tapers
N1BWT 1994

Feeding the parabolic Reflector

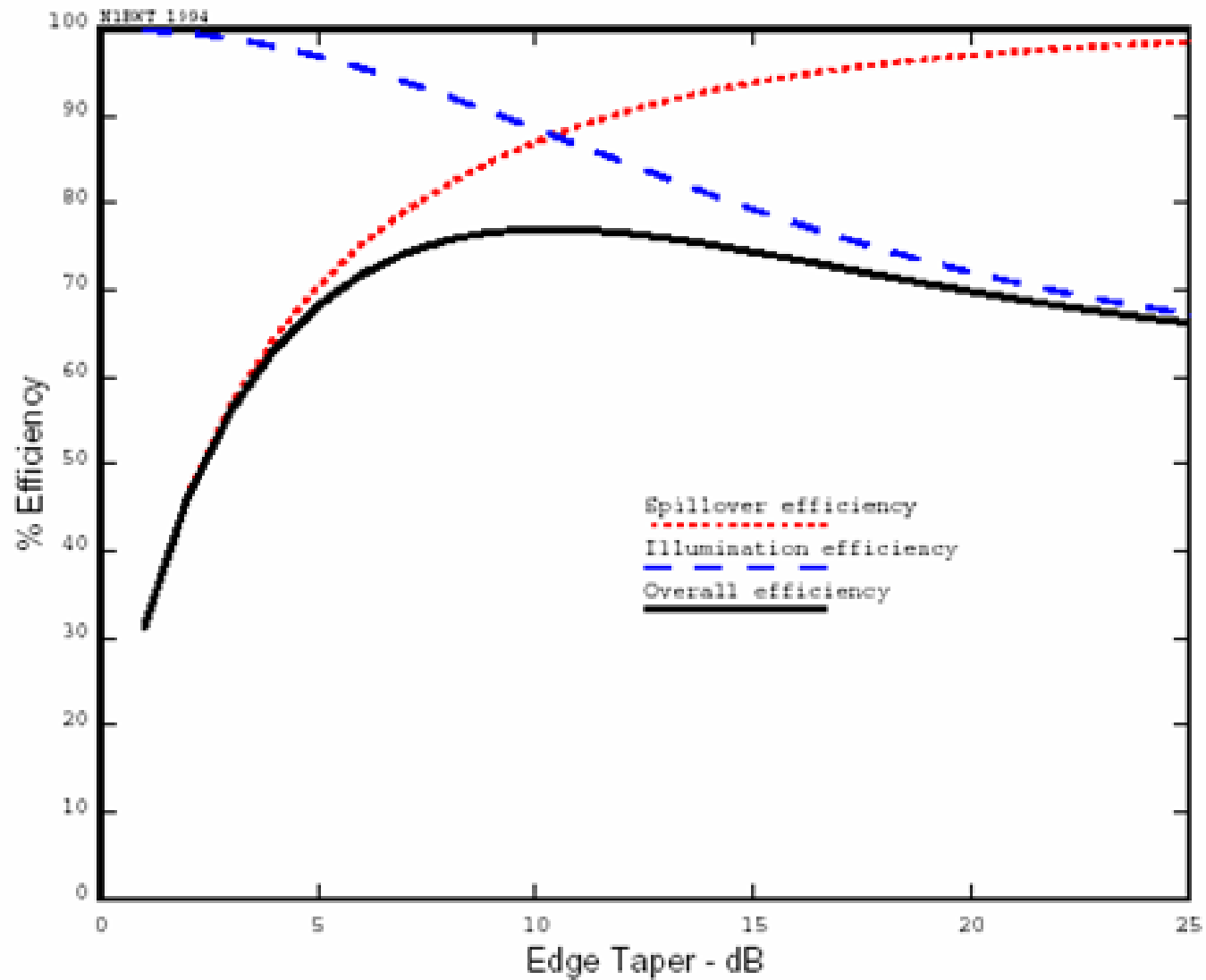
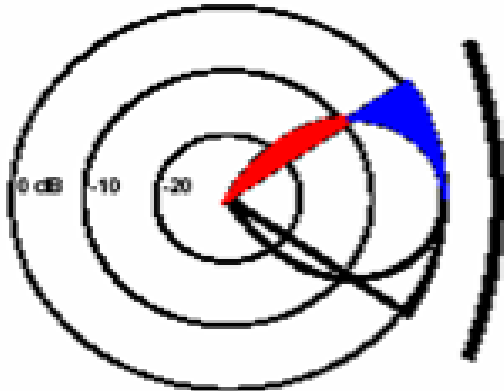


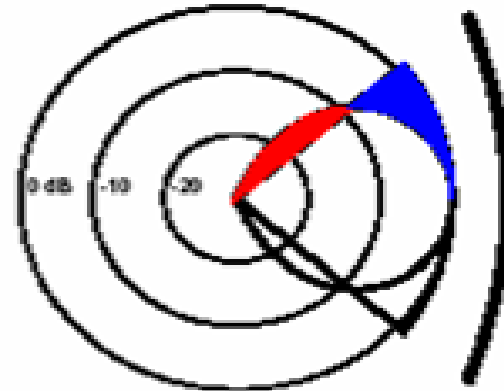
Figure 4-7. Efficiency vs. Edge Taper for a Dish

■ Illumination loss

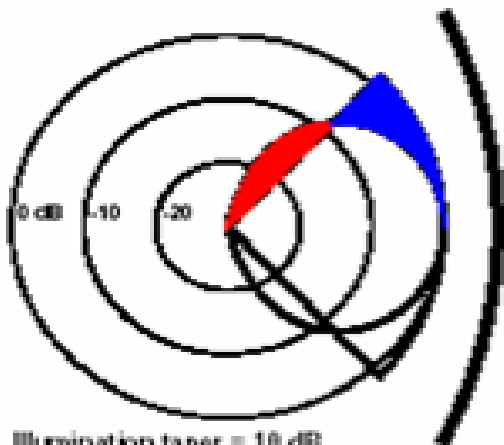
■ Spillover loss



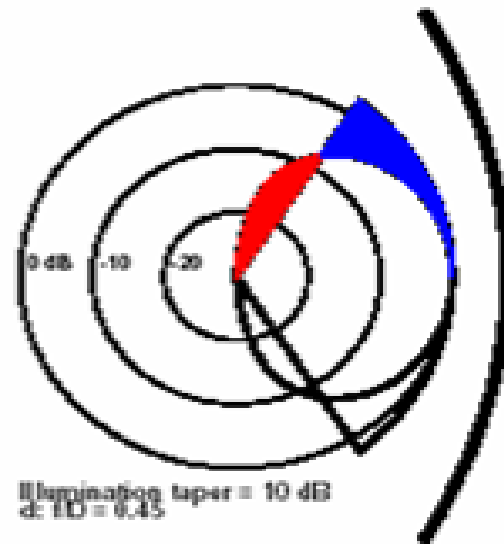
Illumination taper = 10 dB
a: $f/D = 0.75$



Illumination taper = 10 dB
b: $f/D = 0.65$



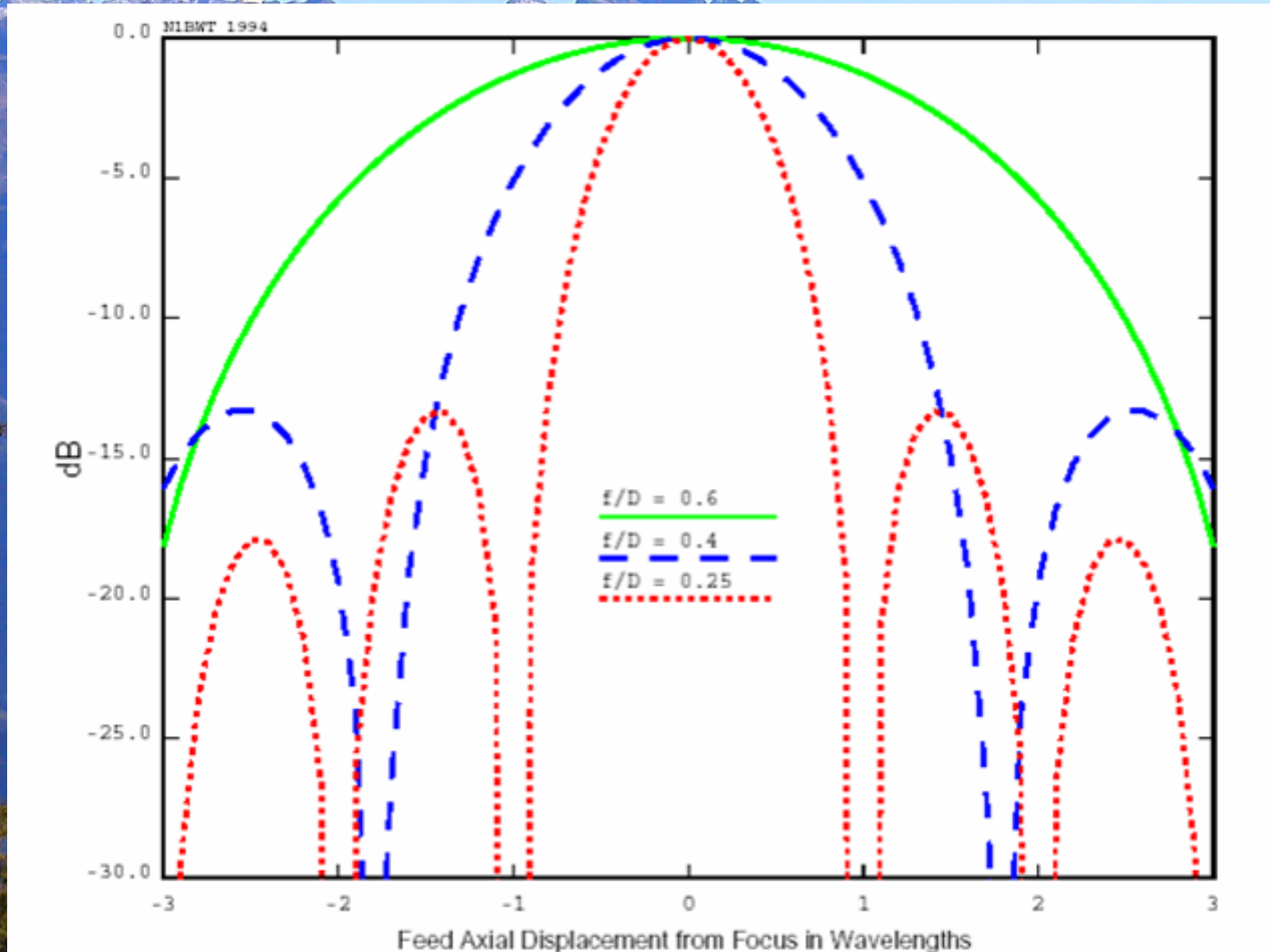
Illumination taper = 10 dB
c: $f/D = 0.55$



Illumination taper = 10 dB
d: $f/D = 0.45$

Figure 4-8. Dish Illumination for Various f/D Ratios
N1BWT 1994

Error in wavelength loss from focus displacement



Disassembling one antenna



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The two antennas



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Elevation Angle



Clinometer

Antenna alignment



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El Baúl site



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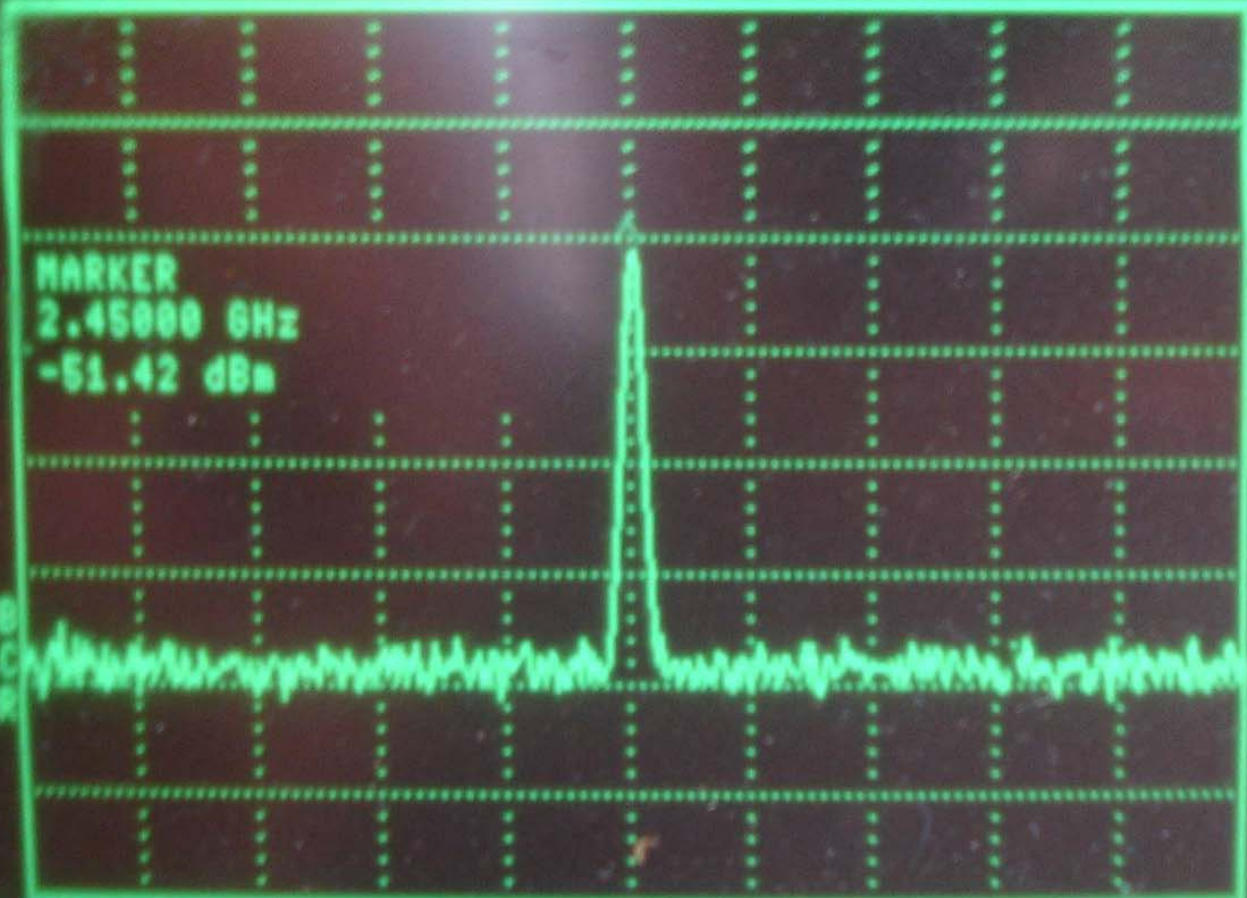
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10116158 APR 13, 2006

REF -30.0 dBm 0AT 0 dB

MKR 2.45000 GHz
-51.42 dBm

PEAK
LOG
10
dB/



MARKER
A

MARKER
A

MARKER
AMPTD

SELECT
1 2 3 4

MARKER 1
ON OFF

More
1 of 2

MA SB
SC FC
CORR

CENTER 2.45000 GHz
RES BW 300 kHz

VBW 100 kHz

SPAN 50.00 MHz
SMP 20.0 usec



El Baúl site



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View from El Baúl towards El Águila



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Javier Triviño and Ermanno Pietrosevoli in front of the 2,4 m dish



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Pietrosevoli

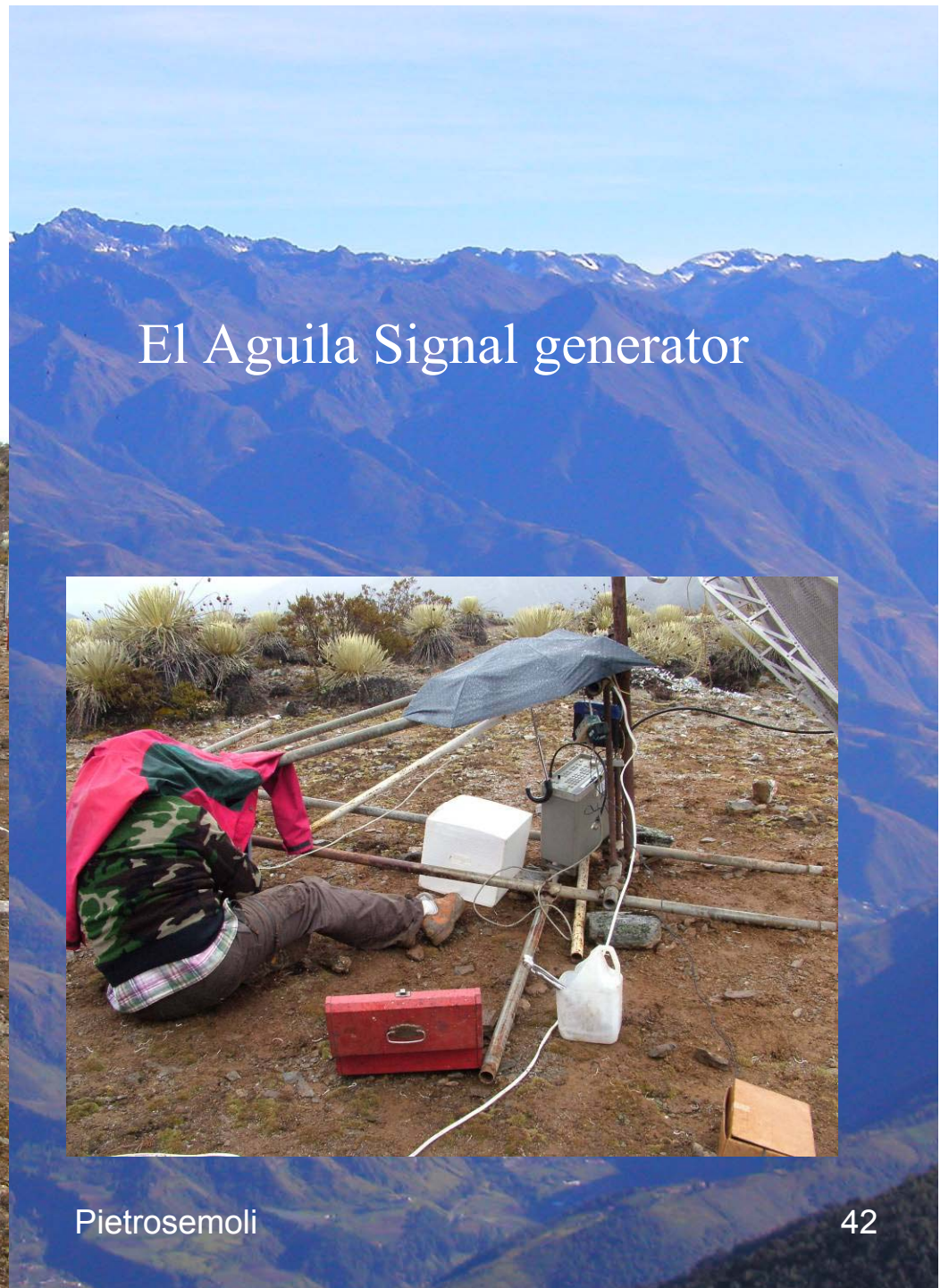
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Carlo Fonda at El Aguila with the meshed dish



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El Aguila Signal generator



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Coordinates

- Site 1: $8^{\circ} 49' 57,0''$ N, $70^{\circ} 49' 49,7''$ W, $h=4090$ m.
- Site 2: $8^{\circ} 57' 27,6''$ N, $68^{\circ} 17' 51,1''$ W,
- $h= 125$ m
- Distance : 279 km

Screenshots from April 13, 2006

The screenshot displays a Windows XP desktop with several open applications. The background is a scenic mountain landscape. The taskbar at the bottom shows the Start button, a network connection icon, and several open windows: Windows Explorer, Firefox, SSH Secure File Transfer, and NetPerSec.

NetPerSec Window: This window shows network performance statistics. It has tabs for Graph, Options, Display, and About. The 'Received' section shows 26.4 Mbits total, with a current rate of 1.2 kbits/s, an average of 2.8 kbits/s, and a maximum of 243.4 kbits/s. The 'Sent' section shows 48.6 Mbits total, with a current rate of 1.2 kbits/s, an average of 32.4 kbits/s, and a maximum of 211.4 kbits/s. There are two line graphs showing data over time. The 'Display' section has checkboxes for 'Current', 'Average', 'bits per second (bps)', and 'Bytes per second (Bps)'. A 'Reset data' button is also present.

SSH Secure File Transfer Window: This window shows a file transfer in progress. The 'Transfer' tab is active, displaying a table of files being transferred:

Source File	Source Directory	Destination Direct...	Size	Status	Speed	Time
wcdma tuto...	C:\Documents an...	/Users/javier	891,055	Complete	7.8 kB/s	00:0...
Tranzeo.pdf	C:\Documents an...	/Users/javier	232,986	Complete	7.6 kB/s	00:0...
Tranzeo.pdf	C:\Documents an...	/Users/javier	232,986	Complete	4.4 kB/s	00:0...
WIMAXNLO...	C:\Documents an...	/Users/javier	653,697	Complete	7.5 kB/s	00:0...
WIMAXNLO...	C:\Documents an...	/Users/javier	653,697	Complete	7.5 kB/s	00:0...
wcdma tuto...	C:\Documents an...	/Users/javier	891,055	Complete	5.9 kB/s	00:0...
WIMAXNLO...	C:\Documents an...	/Users/javier	653,697	15%	5.9 kB/s	00:0...

The status bar at the bottom of the window indicates: 'Transferring file WIMAXNLOgeneral-ver SSH2 - aes128-cbc - hmac-md5 - none 9 items (891.1 KB)'. The 'Queue' tab is also visible but empty.

Terminal Window: A terminal window shows a series of 'Reply from 192.168.1.1: bytes=32 time=5ms TTL=...' messages, indicating network connectivity tests.

Synopsis

Pico del Águila- El Baúl link

Frequency: 2412 MHz : channel 1

Terminal Equipment: Linksys WRT54G, flashed with Open WRT firmware

Length: 279 km

Parabolic antennas were used at both ends, recycled from satellite service: One meshed aluminum reflector central fed, 2,74 m diameter and a fiber glass offset fed reflector 2,4 x 2,74 m

Both reflectors were fed by 12 dBi Yagis.

Further work

- Repeat the experiment tweaking parameters to optimize throughput
- Use the 2P MAC to optimize throughput
- Repeat the experiment at 5,8 GHz
- Use another end point to increase the span