Double Channel Bandwidth and Microwave RF Repeaters

Benefits of Wider Bandwidth

Introduction

Microwave radio systems typically follow regulated channel plans managed by national telecommunications administrations. These channel plans are intended to organize the use of the radio spectrum bands, minimize interference, and maximize resource utilization. As needs and equipment capabilities have changed, so have the channel plans.

A change that is growing in value is the availability of wider bandwidth channels. Administrations began allowing adjacent channels to be combined in certain frequency bands and under specific circumstances. For example; ITU-R[i] recommended combining two 28 MHz channels into one 56 MHz channel, and US-FCC[ii] allowed combining two 30 MHz channels into one 60 MHz channel. The intent is to allow for increased radio capacity per channel and reduce equipment cost.

In recent years, microwave radio equipment has become able to better utilize these wider channels. Peninsula Engineering Solutions introduced 60 MHz bandwidth at 6 GHz in 2015 and 80 MHz bandwidth at 11 GHz in 2016.

The demand for greater bandwidth is driven by more Internet traffic, streaming services and video. Rural areas, that have been a sweet spot for Peninsula's RF repeaters, are noticeably growing in traffic demand.

This application note explores the benefits of bandwidth and how Peninsula's microwave RF Repeaters may be best used to take advantage of wider bandwidth channels.

Bandwidth Considerations

Wider channels allow for greater radio capacity but also increase the noise floor. Evaluating the effects of bandwidth require investigation of a number of parameters.

Primary considerations resulting from double bandwidth channels and maintaining the same modulation include:

- Double capacity
- Thermal noise increases 3 dB
- Threshold increases ~3 dB
- Dispersive fade margin decreases
- Transmit power may need to increase
- Radio power consumption may increase
- System gain will likely decrease

System gain considerations:

- System gain increases for same capacity in double channels vs. single channels. Increase is about 15 dB with no change in transmit power.
- Receiver noise figure may improve (decrease) slightly due to less loss in wider bandwidth receive filters. Improvement is about 0.2 ~ 0.5 dB.
- Improved noise figure reduces the threshold dB for dB. Thus the net change in receiver sensitivity is about 2.5 ~ 2.8 dB.
- Branching losses are less for one double bandwidth 1+0 channel vs. two single bandwidth 2+0 channels, link capacity being the same. Difference is about 0.4 ~ 0.6 dB per each receiver and transmitter.

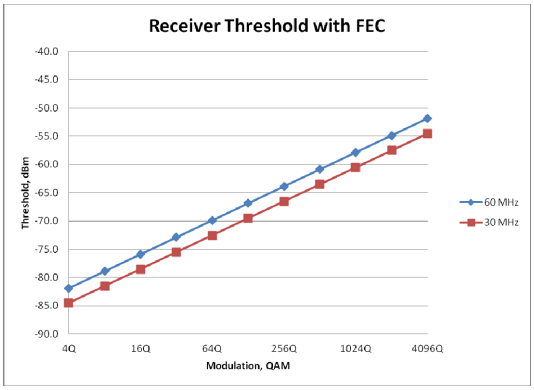

Figure 1, Receiver Thresholds, 30 & 60 MHz

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Table 1, Typical Capacities, Mb/s

	Channel Bandwidth, MHz			
Modulation	*30*	*60*	*40*	*80*
4QAM	50	100	68	136
16QAM	100	200	136	272
32QAM	125	250	170	**340**
64QAM	150	**300**	204	408
128QAM	175	350	238	476
256QAM	200	400	272	544
512QAM	225	450	306	612
1024QAM	250	500	**340**	680
2048QAM	275	550	374	748
4096QAM	**300**	600	408	816

Equal capacities shown in bold above indicate the significant difference in modulation complexity needed with double bandwidth channels. Specific radios will vary.

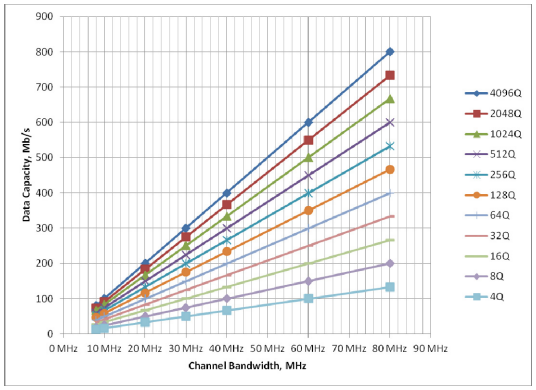

Figure 2, Channel Capacities, 5 to 80 MHz

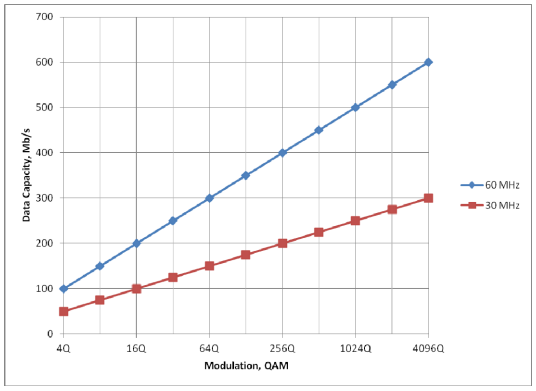

Figure 3, Capacity, 30 & 60 MHz

Strategic use of Bandwidth

Where wider bandwidth channels are available, their use is usually beneficial to system performance and cost. Interference considerations are critical in planning for wider bandwidth channels, this work is normally done during the frequency coordination process.

Microwave RF repeaters strategically benefit from wider bandwidth channels and less complex modulation while meeting a capacity objective.

Microwave RF repeaters are designed to minimize DC power consumption at remote, off-grid, solar powered sites. Power amplifier output is less than most digital radios due to reduced power consumption. On-frequency RF repeaters are gain limited by the practical isolation between receive and transmit antennas at the repeater site. Using less complex modulation allows for greater transmit power level and requires less antenna isolation, both are possible with wider bandwidth channels.

Today's microwave digital radios include adaptive modulation (ACM[iii] or AMR) for packet traffic such as Ethernet. This is a technique where the microwave radio equipment can change its carrier modulation as propagation conditions dictate. For example; when conditions are good, the link can support 400 Mb/s at 256QAM, then, when a fade occurs, the modulation is reduced to 16QAM and supports 200 Mb/s traffic. The reduction in modulation can increase the system gain by 8 ~ 10 dB or more, thus improving reliability at the expense of temporary reduction in throughput and an increase in latency.

ACM enables longer hops or smaller antennas to be used and still meet reliability objectives. When ACM capable radios are combined with RF Repeaters supporting ACM, then highly reliable microwave networks can be built in difficult situations more easily than with TDM and fixed modulation radio equipment.

Peninsula Engineering's microwave RF repeaters support ACM by setting linear output power for the most complex modulation employed on the link. As modulations are reduced, the RF repeater maintains linear operation and gains the benefit of the improved radio receiver threshold and system gain.

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Often radios with ACM also dynamically increase transmitter power during modulation step-downs. Transmitter power can be increased because less complex modulations require less amplifier linearity. When dynamic transmitter power is used with microwave RF repeaters, there are two approaches for best practice:

1. Fix the radio transmitter power to the setting for the most complex modulation used on the link.
2. Allow the radio transmitter power to increase providing the increase does not exceed the RF repeater's upfade reserve.
    a. Peninsula's RF repeaters normally are designed with 5 dB minimum ALC upfade reserve. Since the step-downs are typically brief, this approach is completely acceptable.

As modulation complexity increases, the value of adaptive equalization and forward error correction become much greater. These radio modem capabilities are able to support the two or more hops through microwave RF repeaters thus extending these capabilities to RF repeaters.

Bandwidth Examples

A series of path calculations were run for the same path with single and double bandwidth channels to see the differences and advantages. The examples use a 39 mile path with a mid-path RF-6000E-041 repeater on a mountain top. Lower 6 GHz, 30 and 60 MHz channels are used.

Table 2, Bandwidth Example Summary

Channel Bandwidth	***30 MHz***	***60 MHz***
Reference Modulation	512QAM	64QAM
Reference Capacity	200 Mb/s	300 Mb/s
Availability	99.9860%	99.9986%
ACM Step	16QAM	16QAM
ACM Capacity	100 Mb/s	200 Mb/s
Availability	99.99950%	99.99967%
ACM Step	4QAM	4QAM
ACM Capacity	50 Mb/s	100 Mb/s
Availability	99.99957%	99.99971%

It can be seen that the 60 MHz channel provides greater capacity at less complex reference modulation and with greater availability.

Gigabit Links

The demand for bandwidth and greater data throughput is evident in requests for traffic of 1 Gb/s or more on a route. At 6, 7, 8, and 11 GHz, this capacity can be achieved using multiple radio carriers. When double bandwidth channels are available, then, 2+0, 3+0, and 4+0 system configurations can be used to provide the required throughput. When Ethernet packet data is used, the individual channels can be combined using link aggregation (LAG) or proprietary radio bit-stream combining.

Peninsula's microwave RF repeaters are available in multi-carrier configurations. Modes supported include ACAP[iv], ACCP[v], and co-channel XPIC[vi]. Repeater Operations Manuals provide more detail on these configurations.

An example of 11 GHz, 2.4 Gigabit link design is included in the appendix.

Conclusion

Peninsula Engineering Solutions' Microwave RF Repeaters benefit from wider bandwidth channels by supporting greater traffic capacity at lesser modulation complexity and still providing their very low power consumption advantages.

Appendix

Path Calculations, Microwave RF Repeaters; Bandwidth and Gigabit Examples:

1. 30 MHz Channel
    a. 512QAM, 200 Mb/s
    b. 16QAM, 100 Mb/s
    c. 4QAM, 50 Mb/s
2. 60 MHz Channel
    a. 64QAM, 300 Mb/s
    b. 16QAM, 200 Mb/s
    c. 4QAM, 100 Mb/s
3. 80 MHz Channels, 4+0 ACAP, 2.4 Gb/s
    a. 512QAM, 600 Mb/s
    b. 32QAM, 300 Mb/s
    c. 4+0 RF Repeater Diagrams

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[i] ITU: Certain national administrations permit 56, 60, and 80 MHz channels in L6, 7, 8 and 11 GHz bands.

[ii] US-FCC CFR 47 Part 101.109, 101.147. 4x 60 MHz pairs in L6 GHz and 6x 80 MHz pairs in 11 GHz bands. Successful frequency coordination is typically found in rural areas with lesser density of occupied channels.

[iii] ACM/AMR: Adaptive Coding and Modulation or Adaptive Modulation Radio; a technique to improve link propagation reliability in packet based networks.

[iv] ACAP: Adjacent Channel on Alternate Polarization. Microwave RF repeaters support on common and separate feeders and antennas.

[v] ACCP: Adjacent Channel on Co-Polarization. Microwave RF repeaters support on separate feeders and antennas.

[vi] XPIC: Cross-Polarization Interference Cancellation. Microwave RF repeaters support on separate feeders and common, dual polarized, antennas.

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Path Data Sheet for RF Repeaters

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Customer	Our Best		Rev 1			Page 1
Terminal	L6 ETH 200Mb/s 30MHz					
Repeater: RF-6000E			Path Length Source		Coordinates	
Units Select	English/Imperial		Coordinates Quadrant		North Lat, West Lon	
Radio Administration Rules	FCC 101		Model Methods		Vigants-Barnett	
Modulation,Terminal	512QAM		Traffic		ETH IP 200 Mb/s	
Configuration	1+0 or 1+1 Hot Stby		Delay Equalization		Unequalized	
Tx Power Level	A <- R		2	2	R -> B	
Site	Terminal A		Repeater			Terminal B
Name	Crescent		Bald Mtn			Silver Lake
Site Coordinates	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
Degrees	43	121	43	121	43	121
Minutes	27	40	16	21	7	2
Seconds	44.74	2.94	28.36	17.21	35.66	46.86
Elevation, AMSL, ft	5205.0		7380.0	7380.0		4352.0
Antenna Center, AGL, ft	25.0		16.0	16.0	Incl'd Ang's	16.0
Antenna Direction, Azimuth	129.36 deg		309.58 deg	123.15 deg	173.57 deg	303.36 deg
Elevation	1.00 deg		-1.30 deg	-1.90 deg	176.80 deg	1.63 deg
Tx Frequency, MHz	6 175.0	V-V			H-H	6 175.0
Path Length, mi		**20.40**	***Coordinates***		**18.63**	
Free Space Loss, dB		138.6			137.8	
Absorption Loss, dB		0.2			0.2	
Obstruction Loss, dB						
Field Margin, dB		1.0			1.0	
Path Loss, dB		139.8			139.0	
Feeder Length, ft	50.0		20.0	20.0		30.0
Loss/100 ft, dB	1.2	EWP52	1.2	1.2		1.2
Feeder Loss, dB	0.6		0.2	0.2		0.4
Connector Loss, dB	0.2		0.2	0.2		0.2
Jumper Loss, dB						
T/R Attenuator Pad, dB						
Component Loss, dB	0.6					0.6
Radome Loss, dB						
Total Fixed Loss, dB	1.4		0.4	0.4		1.2
Total Losses, dB		141.6			140.6	
Antenna Type	UHX8-59		UHX8-59	UHX8-59		UHX8-59
Antenna Size, ft	8.0		8.0	8.0		8.0
Antenna Gain, dBi	41.3		41.3	41.3		41.3
Front/Back, dB			69.0	69.0		
Total Gains, dB		82.5			82.5	
Net Path Loss, dB		59.1			58.0	

Transmit Power, dBm	29.5					28.4
Repeater Input, dBm			-29.6	-29.6		
Input Pad, dB			0.0	0.0		
Repeater Max Gain, dB			58.0	58.0		
Var Gain Reduction, dB		Max -20	0.0	0.0	Max -20	
AGC, dB			14.9	14.9		
Amplifier Power, dBm			16.0	16.0		
Power Reduction, dB			0.0	0.0		
Output Pad, dB			0.0	0.0		
Repeater Output, dBm			13.5	13.5		
Nom RSL(+/-2dB), dBm	-45.6					-44.5
Receiver Threshold, dBm	-61.6					-61.6
Extra C/I Required, dB						
Rec. Noise Figure, dB	6.1		8.6	9.2		6.1
Min Rec. Power, dBm	-61.6		-59.1	-58.5		-61.6
Flat Fade Margin, dB	16.0		29.5	28.8		17.1
Dispersive F.M., dB	52.0					52.0
Composite F.M., dB	16.0		29.5	28.8		17.1
Per Hop Reliability	99.9914%		99.99961%	99.99966%		99.9949%
One Way Path Reliability	99.9910%					99.9945%

Repeater Antenna Coupling

Feed Point Sep., ft	12.0	
Antenna Sep Loss, dB	44.6	
Antenna XPD Loss, dB	6.6	
Receive C/E, Repeater, dB	49.6	49.6

Reliability Data

Terrain Roughness = User Entered, W = 140.0 ft — User Entered — W
Climate Type = Mountainous or very dry — Mountainous or very dry
Mean Temperature = 39.0 degrees F — Fading Season, days : 72.6 — 3.9 C

Climate / Terrain Factor	0.131
Undp (A<- R<- B)	4.52E-04
Undp (A ->R ->B)	2.76E-04

Frequency Spacing Tx A	MHz	Non-Diversity Configuration
Frequency Spacing Tx B	MHz	Non-Diversity Configuration

Undp (A<- R<- B)	4.52E-04
Undp (A ->R ->B)	2.76E-04

Outage/year, A receive	2835.3	Seconds	99.9910%
Outage/year, B receive	1733.0	Seconds	99.9945%
Two Way Outage/year	4568.2	Seconds	99.986%
	76.1	Minutes	
Path Length, End to End	39.0	Miles	

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Customer	Our Best		Rev 1 ACM Step			Page 1
Terminal	L6 ETH 200Mb/s 30MHz		16QAM 100 Mb/s			
Repeater: RF-6000E			Path Length Source		Coordinates	
Units Select	English/Imperial		Coordinates Quadrant		North Lat, West Lon	
Radio Administration Rules	FCC 101		Model Methods		Vigants-Barnett	
Modulation,Terminal	16QAM		Traffic		ETH IP 200 Mb/s	
Configuration	1+0 or 1+1 Hot Stby		Delay Equalization		Unequalized	
Tx Power Level	A <- R		2	2	R -> B	
Site	Terminal A		Repeater			Terminal B
Name	Crescent		Bald Mtn			Silver Lake
Site Coordinates	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
Degrees	43	121	43	121	43	121
Minutes	27	40	16	21	7	2
Seconds	44.74	2.94	28.36	17.21	35.66	46.86
Elevation, AMSL, ft	5205.0		7380.0	7380.0		4352.0
Antenna Center, AGL, ft	25.0		16.0	16.0	Incl'd Ang's	16.0
Antenna Direction, Azimuth	129.36 deg		309.58 deg	123.15 deg	173.57 deg	303.36 deg
Elevation	1.00 deg		-1.30 deg	-1.90 deg	176.80 deg	1.63 deg
Tx Frequency, MHz	6 175.0	V-V			H-H	6 175.0
Path Length, mi		**20.40**	***Coordinates***		**18.63**	
Free Space Loss, dB		138.6			137.8	
Absorption Loss, dB		0.2			0.2	
Obstruction Loss, dB						
Field Margin, dB		1.0			1.0	
Path Loss, dB		139.8			139.0	
Feeder Length, ft	50.0		20.0	20.0		30.0
Loss/100 ft, dB	1.2	EWP52	1.2	1.2		1.2
Feeder Loss, dB	0.6		0.2	0.2		0.4
Connector Loss, dB	0.2		0.2	0.2		0.2
Jumper Loss, dB						
T/R Attenuator Pad, dB						
Component Loss, dB	0.6					0.6
Radome Loss, dB						
Total Fixed Loss, dB	1.4		0.4	0.4		1.2
Total Losses, dB		141.6			140.6	
Antenna Type	UHX8-59		UHX8-59	UHX8-59		UHX8-59
Antenna Size, ft	8.0		8.0	8.0		8.0
Antenna Gain, dBi	41.3		41.3	41.3		41.3
Front/Back, dB			69.0	69.0		
Total Gains, dB		82.5			82.5	
Net Path Loss, dB		59.1			58.0	

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Our Best		RF Repeater Site:	Bald Mtn		Page 2
Transmit Power, dBm	29.5				28.4
Repeater Input, dBm		-29.6	-29.6		
Input Pad, dB		0.0	0.0		
Repeater Max Gain, dB		58.0	58.0		
Var Gain Reduction, dB	Max -20	0.0	0.0	Max -20	
AGC, dB		14.9	14.9		
Amplifier Power, dBm		16.0	16.0		
Power Reduction, dB		-8.0	-8.0		
Output Pad, dB		0.0	0.0		
Repeater Output, dBm		13.5	13.5		
Nom RSL(+/-2dB), dBm	-45.6				-44.5
Receiver Threshold, dBm	-76.2				-76.2
Extra C/I Required, dB					
Rec. Noise Figure, dB	6.1	8.6	9.2		6.1
Min Rec. Power, dBm	-76.2	-73.7	-73.1		-76.2
Flat Fade Margin, dB	30.6	44.1	43.4		31.7
Dispersive F.M., dB	62.0				62.0
Composite F.M., dB	30.6	44.0	43.4		31.7
Per Hop Reliability	99.99970%	99.999986%	99.999988%		99.99982%
One Way Path Reliability	99.99969%				99.99981%

Repeater Antenna Coupling

Feed Point Sep., ft	12.0	
Antenna Sep Loss, dB	44.6	
Antenna XPD Loss, dB	6.6	
Receive C/E, Repeater, dB	49.6	49.6

Reliability Data

Terrain Roughness = User Entered, W = 140.0 ft	User Entered	W		
Climate Type = Mountainous or very dry	Mountainous or very dry			
Mean Temperature = 39.0 degrees F	Fading Season, days :	72.6	3.9 C	

Climate / Terrain Factor	0.131
Undp (A<- R<- B)	1.57E-05
Undp (A ->R ->B)	9.59E-06

Frequency Spacing Tx A		MHz	Non-Diversity Configuration
Frequency Spacing Tx B		MHz	Non-Diversity Configuration

Undp (A<- R<- B)	1.57E-05
Undp (A ->R ->B)	9.59E-06

Outage/year, A receive	98.4	Seconds	99.99969%
Outage/year, B receive	60.2	Seconds	99.99981%
Two Way Outage/year	158.6	Seconds	99.99950%
Path Length, End to End	39.0	Miles	
Two Way Objective, Short Haul	499.6	Seconds	

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Repeater: RF-6000E			Path Length Source		Coordinates	
Units Select	English/Imperial		Coordinates Quadrant		North Lat, West Lon	
Radio Administration Rules	FCC 101		Model Methods		Vigants-Barnett	
Modulation,Terminal	4QAM		Traffic		ETH IP 200 Mb/s	
Configuration	1+0 or 1+1 Hot Stby		Delay Equalization		Unequalized	
Tx Power Level	A <- R		2	2	R -> B	
Site	Terminal A		Repeater			Terminal B
Name	Crescent		Bald Mtn			Silver Lake
Site Coordinates	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
Degrees	43	121	43	121	43	121
Minutes	27	40	16	21	7	2
Seconds	44.74	2.94	28.36	17.21	35.66	46.86
Elevation, AMSL, ft	5205.0		7380.0	7380.0		4352.0
Antenna Center, AGL, ft	25.0		16.0	16.0	Incl'd Ang's	16.0
Antenna Direction, Azimuth	129.36 deg		309.58 deg	123.15 deg	173.57 deg	303.36 deg
Elevation	1.00 deg		-1.30 deg	-1.90 deg	176.80 deg	1.63 deg
Tx Frequency, MHz	6 175.0	V-V			H-H	6 175.0
Path Length, mi		**20.40**	***Coordinates***		**18.63**	
Free Space Loss, dB		138.6			137.8	
Absorption Loss, dB		0.2			0.2	
Obstruction Loss, dB						
Field Margin, dB		1.0			1.0	
Path Loss, dB		139.8			139.0	
Feeder Length, ft	50.0		20.0	20.0		30.0
Loss/100 ft, dB	1.2	EWP52	1.2	1.2		1.2
Feeder Loss, dB	0.6		0.2	0.2		0.4
Connector Loss, dB	0.2		0.2	0.2		0.2
Jumper Loss, dB						
T/R Attenuator Pad, dB						
Component Loss, dB	0.6					0.6
Radome Loss, dB						
Total Fixed Loss, dB	1.4		0.4	0.4		1.2
Total Losses, dB		141.6			140.6	
Antenna Type	UHX8-59		UHX8-59	UHX8-59		UHX8-59
Antenna Size, ft	8.0		8.0	8.0		8.0
Antenna Gain, dBi	41.3		41.3	41.3		41.3
Front/Back, dB			69.0	69.0		
Total Gains, dB		82.5			82.5	
Net Path Loss, dB		59.1			58.0	

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Our Best RF Repeater Site: Bald Mtn

Transmit Power, dBm	29.5					28.4
Repeater Input, dBm			-29.6	-29.6		
Input Pad, dB			0.0	0.0		
Repeater Max Gain, dB			58.0	58.0		
Var Gain Reduction, dB		Max -20	0.0	0.0	Max -20	
AGC, dB			14.9	14.9		
Amplifier Power, dBm			16.0	16.0		
Power Reduction, dB			-12.0	-12.0		
Output Pad, dB			0.0	0.0		
Repeater Output, dBm			13.5	13.5		
Nom RSL(+/-2dB), dBm	-45.6					-44.5
Receiver Threshold, dBm	-86.9					-86.9
Extra C/I Required, dB						
Rec. Noise Figure, dB	6.1		8.6	9.2		6.1
Min Rec. Power, dBm	-86.9		-84.4	-83.8		-86.9
Flat Fade Margin, dB	41.3		54.8	54.1		42.4
Dispersive F.M., dB	64.0					64.0
Composite F.M., dB	41.2		54.3	53.7		42.3
Per Hop Reliability	99.999974%		99.999999%	99.999999%		99.999985%
One Way Path Reliability	99.999973%					99.999984%

Repeater Antenna Coupling

Feed Point Sep., ft	12.0	
Antenna Sep Loss, dB	44.6	
Antenna XPD Loss, dB	6.6	
Receive C/E, Repeater, dB	49.6	49.6

Reliability Data

Terrain Roughness = User Entered, W = 140.0 ft — User Entered — W

Climate Type = Mountainous or very dry — Mountainous or very dry

Mean Temperature = 39.0 degrees F → Fading Season, days : 72.6 3.9 C

Climate / Terrain Factor	0.131
Undp (A<- R<- B)	1.35E-06
Undp (A ->R ->B)	8.27E-07

Frequency Spacing Tx A		MHz	Non-Diversity Configuration
Frequency Spacing Tx B		MHz	Non-Diversity Configuration

Undp (A<- R<- B)	1.35E-06
Undp (A ->R ->B)	8.27E-07

Outage/year, A receive	8.4	Seconds	99.999973%
Outage/year, B receive	5.2	Seconds	99.999984%
Two Way Outage/year	13.6	Seconds	99.999957%
Path Length, End to End	39.0	Miles	
Two Way Objective, Short Haul	499.6	Seconds	

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PENINSULA ENGINEERING SOLUTIONS	Date: 02 Mar 2018
	Calc. by: Ed Johnson
Danville, CA 94526, USA	Tel: +1 925-837-2243
	Fax: +1 925 837-2298
www.peninsulaengineering.com	
Path Data Sheet for RF Repeaters	*Copyright Oct 2016*

Customer	Our Best		Rev 1			Page 1
Terminal	L6 ETH 300Mb/s 60MHz					
Repeater: RF-6000E			Path Length Source		Coordinates	
Units Select	English/Imperial		Coordinates Quadrant		North Lat, West Lon	
Radio Administration Rules	FCC 101		Model Methods		Vigants-Barnett	
Modulation,Terminal	64QAM		Traffic		ETH IP 300 Mb/s	
Configuration	1+0 or 1+1 Hot Stby		Delay Equalization		Unequalized	
Tx Power Level	A <- R		2	2	R -> B	
Site	Terminal A		Repeater			Terminal B
Name	Crescent		Bald Mtn			Silver Lake
Site Coordinates	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
Degrees	43	121	43	121	43	121
Minutes	27	40	16	21	7	2
Seconds	44.74	2.94	28.36	17.21	35.66	46.86
Elevation, AMSL, ft	5205.0		7380.0	7380.0		4352.0
Antenna Center, AGL, ft	25.0		16.0	16.0	Incl'd Ang's	16.0
Antenna Direction, Azimuth	129.36 deg		309.58 deg	123.15 deg	173.57 deg	303.36 deg
Elevation	1.00 deg		-1.30 deg	-1.90 deg	176.80 deg	1.63 deg
Tx Frequency, MHz	6 175.0	V-V			H-H	6 175.0
Path Length, mi		**20.40**	***Coordinates***		**18.63**	
Free Space Loss, dB		138.6			137.8	
Absorption Loss, dB		0.2			0.2	
Obstruction Loss, dB						
Field Margin, dB		1.0			1.0	
Path Loss, dB		139.8			139.0	
Feeder Length, ft	50.0		20.0	20.0		30.0
Loss/100 ft, dB	1.2	EWP52	1.2	1.2		1.2
Feeder Loss, dB	0.6		0.2	0.2		0.4
Connector Loss, dB	0.2		0.2	0.2		0.2
Jumper Loss, dB						
T/R Attenuator Pad, dB						
Component Loss, dB	0.6					0.6
Radome Loss, dB						
Total Fixed Loss, dB	1.4		0.4	0.4		1.2
Total Losses, dB		141.6			140.6	
Antenna Type	UHX8-59		UHX8-59	UHX8-59		UHX8-59
Antenna Size, ft	8.0		8.0	8.0		8.0
Antenna Gain, dBi	41.3		41.3	41.3		41.3
Front/Back, dB			69.0	69.0		
Total Gains, dB		82.5			82.5	
Net Path Loss, dB		59.1			58.0	

PENINSULA ENGINEERING SOLUTIONS Date: 02 Mar 2018 By: Ed Johnson

Our Best RF Repeater Site: Bald Mtn

Transmit Power, dBm	30.7					30.7
Repeater Input, dBm			-28.4	-27.3		
Input Pad, dB			0.0	0.0		
Repeater Max Gain, dB			58.0	58.0		
Var Gain Reduction, dB		Max -20	0.0	0.0	Max -20	
AGC, dB			12.1	13.2		
Amplifier Power, dBm			20.0	20.0		
Power Reduction, dB			0.0	0.0		
Output Pad, dB			0.0	0.0		
Repeater Output, dBm			17.5	17.5		
Nom RSL(+/-2dB), dBm	-41.6					-40.5
Receiver Threshold, dBm	-67.9					-67.9
Extra C/I Required, dB						
Rec. Noise Figure, dB	6.1		8.6	9.2		6.1
Min Rec. Power, dBm	-67.9		-65.4	-64.8		-67.9
Flat Fade Margin, dB	26.3		37.0	37.4		27.4
Dispersive F.M., dB	50.0					50.0
Composite F.M., dB	26.3		36.8	37.2		27.3
Per Hop Reliability	99.99919%		99.999928%	99.999950%		99.99952%
One Way Path Reliability	99.99914%					99.99945%

Repeater Antenna Coupling

Feed Point Sep., ft	12.0	
Antenna Sep Loss, dB	44.6	
Antenna XPD Loss, dB		
Receive C/E, Repeater, dB	43.0	43.0

Reliability Data

Terrain Roughness = User Entered, W = 140.0 ft — User Entered — W

Climate Type = Mountainous or very dry — Mountainous or very dry

Mean Temperature = 39.0 degrees F → Fading Season, days : 72.6 3.9 C

Climate / Terrain Factor	0.131
Undp (A<- R<- B)	4.32E-05
Undp (A ->R ->B)	2.77E-05

Frequency Spacing Tx A	MHz	Non-Diversity Configuration
Frequency Spacing Tx B	MHz	Non-Diversity Configuration

Undp (A<- R<- B)	4.32E-05
Undp (A ->R ->B)	2.77E-05

Outage/year, A receive	271.2	Seconds	99.99914%
Outage/year, B receive	173.8	Seconds	99.99945%
Two Way Outage/year	445.0	Seconds	99.9986%
Path Length, End to End	39.0	Miles	
Two Way Objective, Short Haul	499.6	Seconds	

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Path Data Sheet for RF Repeaters	*Copyright Oct 2016*

Customer	Our Best			Rev 1 ACM Step		Page 1
Terminal	L6 ETH 300Mb/s 60MHz			16QAM 200 Mb/s		
Repeater: RF-6000E			Path Length Source	Coordinates		
Units Select	English/Imperial		Coordinates Quadrant	North Lat, West Lon		
Radio Administration Rules	FCC 101		Model Methods	Vigants-Barnett		
Modulation,Terminal	16QAM		Traffic	ETH IP 300 Mb/s		
Configuration	1+0 or 1+1 Hot Stby		Delay Equalization	Unequalized		
Tx Power Level	A <- R		2	2	R -> B	
Site	Terminal A		Repeater		Terminal B	
Name	Crescent		Bald Mtn		Silver Lake	
Site Coordinates	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
Degrees	43	121	43	121	43	121
Minutes	27	40	16	21	7	2
Seconds	44.74	2.94	28.36	17.21	35.66	46.86
Elevation, AMSL, ft	5205.0		7380.0	7380.0		4352.0
Antenna Center, AGL, ft	25.0		16.0	16.0	Incl'd Ang's	16.0
Antenna Direction, Azimuth	129.36 deg		309.58 deg	123.15 deg	173.57 deg	303.36 deg
Elevation	1.00 deg		-1.30 deg	-1.90 deg	176.80 deg	1.63 deg
Tx Frequency, MHz	6 175.0	V-V			H-H	6 175.0
Path Length, mi		**20.40**	***Coordinates***		**18.63**	
Free Space Loss, dB		138.6			137.8	
Absorption Loss, dB		0.2			0.2	
Obstruction Loss, dB						
Field Margin, dB		1.0			1.0	
Path Loss, dB		139.8			139.0	
Feeder Length, ft	50.0		20.0	20.0		30.0
Loss/100 ft, dB	1.2	EWP52	1.2	1.2		1.2
Feeder Loss, dB	0.6		0.2	0.2		0.4
Connector Loss, dB	0.2		0.2	0.2		0.2
Jumper Loss, dB						
T/R Attenuator Pad, dB						
Component Loss, dB	0.6					0.6
Radome Loss, dB						
Total Fixed Loss, dB	1.4		0.4	0.4		1.2
Total Losses, dB		141.6			140.6	
Antenna Type	UHX8-59		UHX8-59	UHX8-59		UHX8-59
Antenna Size, ft	8.0		8.0	8.0		8.0
Antenna Gain, dBi	41.3		41.3	41.3		41.3
Front/Back, dB			69.0	69.0		
Total Gains, dB		82.5			82.5	
Net Path Loss, dB		59.1			58.0	

PENINSULA ENGINEERING SOLUTIONS Date: 02 Mar 2018 By: Ed Johnson

Our Best RF Repeater Site: Bald Mtn

Transmit Power, dBm	30.7					30.7
Repeater Input, dBm			-28.4	-27.3		
Input Pad, dB			0.0	0.0		
Repeater Max Gain, dB			58.0	58.0		
Var Gain Reduction, dB		Max -20	0.0	0.0	Max -20	
AGC, dB			12.1	13.2		
Amplifier Power, dBm			20.0	20.0		
Power Reduction, dB			-4.0	-4.0		
Output Pad, dB			0.0	0.0		
Repeater Output, dBm			17.5	17.5		
Nom RSL(+/-2dB), dBm	-41.6					-40.5
Receiver Threshold, dBm	-74.2					-74.2
Extra C/I Required, dB						
Rec. Noise Figure, dB	6.1		8.6	9.2		6.1
Min Rec. Power, dBm	-74.2		-71.7	-71.1		-74.2
Flat Fade Margin, dB	32.6		43.3	43.7		33.7
Dispersive F.M., dB	58.0					58.0
Composite F.M., dB	32.6		43.1	43.6		33.7
Per Hop Reliability	99.99981%		99.999983%	99.999989%		99.99989%
One Way Path Reliability	99.99980%					99.99987%

Repeater Antenna Coupling

Feed Point Sep., ft	12.0	
Antenna Sep Loss, dB	44.6	
Antenna XPD Loss, dB		
Receive C/E, Repeater, dB	43.0	43.0

Reliability Data

Terrain Roughness = User Entered, W = 140.0 ft — User Entered — W

Climate Type = Mountainous or very dry — Mountainous or very dry

Mean Temperature = 39.0 degrees F — Fading Season, days : 72.6 — 3.9 C

Climate / Terrain Factor	0.131
Undp (A<- R<- B)	1.01E-05
Undp (A ->R ->B)	6.47E-06

Frequency Spacing Tx A	MHz	Non-Diversity Configuration
Frequency Spacing Tx B	MHz	Non-Diversity Configuration

Undp (A<- R<- B)	1.01E-05
Undp (A ->R ->B)	6.47E-06

Outage/year, A receive	63.4	Seconds	99.99980%
Outage/year, B receive	40.6	Seconds	99.99987%
Two Way Outage/year	104.0	Seconds	99.99967%
Path Length, End to End	39.0	Miles	
Two Way Objective, Short Haul	499.6	Seconds	

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Path Data Sheet for RF Repeaters	*Copyright Oct 2016*

Customer	Our Best		Rev 1 ACM Step			Page 1
Terminal	L6 ETH 300Mb/s 60MHz		4QAM 100 Mb/s			
Repeater: RF-6000E			Path Length Source		Coordinates	
Units Select	English/Imperial		Coordinates Quadrant		North Lat, West Lon	
Radio Administration Rules	FCC 101		Model Methods		Vigants-Barnett	
Modulation,Terminal	4QAM		Traffic		ETH IP 300 Mb/s	
Configuration	1+0 or 1+1 Hot Stby		Delay Equalization		Unequalized	
Tx Power Level	A <- R		2	2	R -> B	
Site	Terminal A		Repeater			Terminal B
Name	Crescent		Bald Mtn			Silver Lake
Site Coordinates	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
Degrees	43	121	43	121	43	121
Minutes	27	40	16	21	7	2
Seconds	44.74	2.94	28.36	17.21	35.66	46.86
Elevation, AMSL, ft	5205.0		7380.0	7380.0		4352.0
Antenna Center, AGL, ft	25.0		16.0	16.0	Incl'd Ang's	16.0
Antenna Direction, Azimuth	129.36 deg		309.58 deg	123.15 deg	173.57 deg	303.36 deg
Elevation	1.00 deg		-1.30 deg	-1.90 deg	176.80 deg	1.63 deg
Tx Frequency, MHz	6 175.0	V-V			H-H	6 175.0
Path Length, mi		**20.40**	***Coordinates***		**18.63**	
Free Space Loss, dB		138.6			137.8	
Absorption Loss, dB		0.2			0.2	
Obstruction Loss, dB						
Field Margin, dB		1.0			1.0	
Path Loss, dB		139.8			139.0	
Feeder Length, ft	50.0		20.0	20.0		30.0
Loss/100 ft, dB	1.2	EWP52	1.2	1.2		1.2
Feeder Loss, dB	0.6		0.2	0.2		0.4
Connector Loss, dB	0.2		0.2	0.2		0.2
Jumper Loss, dB						
T/R Attenuator Pad, dB						
Component Loss, dB	0.6					0.6
Radome Loss, dB						
Total Fixed Loss, dB	1.4		0.4	0.4		1.2
Total Losses, dB		141.6			140.6	
Antenna Type	UHX8-59		UHX8-59	UHX8-59		UHX8-59
Antenna Size, ft	8.0		8.0	8.0		8.0
Antenna Gain, dBi	41.3		41.3	41.3		41.3
Front/Back, dB			69.0	69.0		
Total Gains, dB		82.5			82.5	
Net Path Loss, dB		59.1			58.0	

PENINSULA ENGINEERING SOLUTIONS Date: 02 Mar 2018 By: Ed Johnson

Our Best RF Repeater Site: Bald Mtn

Transmit Power, dBm	30.7					30.7
Repeater Input, dBm			-28.4	-27.3		
Input Pad, dB			0.0	0.0		
Repeater Max Gain, dB			58.0	58.0		
Var Gain Reduction, dB		Max -20	0.0	0.0	Max -20	
AGC, dB			12.1	13.2		
Amplifier Power, dBm			20.0	20.0		
Power Reduction, dB			-8.0	-8.0		
Output Pad, dB			0.0	0.0		
Repeater Output, dBm			17.5	17.5		
Nom RSL(+/-2dB), dBm	-41.6					-40.5
Receiver Threshold, dBm	-84.9					-84.9
Extra C/I Required, dB						
Rec. Noise Figure, dB	6.1		8.6	9.2		6.1
Min Rec. Power, dBm	-84.9		-82.4	-81.8		-84.9
Flat Fade Margin, dB	43.3		54.0	54.4		44.4
Dispersive F.M., dB	60.0					60.0
Composite F.M., dB	43.2		53.0	53.4		44.3
Per Hop Reliability	99.999984%		99.999998%	99.999999%		99.999990%
One Way Path Reliability	99.999982%					99.999989%

Repeater Antenna Coupling

Feed Point Sep., ft	12.0	
Antenna Sep Loss, dB	44.6	
Antenna XPD Loss, dB		
Receive C/E, Repeater, dB	43.0	43.0

Reliability Data

Terrain Roughness = User Entered, W = 140.0 ft — User Entered — W

Climate Type = Mountainous or very dry — Mountainous or very dry

Mean Temperature = 39.0 degrees F → Fading Season, days : 72.6 3.9 C

Climate / Terrain Factor	0.131
Undp (A<- R<- B)	8.87E-07
Undp (A ->R ->B)	5.77E-07

Frequency Spacing Tx A		MHz	Non-Diversity Configuration
Frequency Spacing Tx B		MHz	Non-Diversity Configuration

Undp (A<- R<- B)	8.87E-07
Undp (A ->R ->B)	5.77E-07

Outage/year, A receive	5.6	Seconds	99.999982%
Outage/year, B receive	3.6	Seconds	99.999989%
Two Way Outage/year	9.2	Seconds	99.999971%
Path Length, End to End	39.0	Miles	
Two Way Objective, Short Haul	499.6	Seconds	

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Path Data Sheet for RF Repeaters	*Copyright Oct 2016*

Customer	Our Best		Rev 1			Page 1
Terminal	11G ETH 600Mb/s 80MHz					
Repeater: RF-11000E			Path Length Source		Coordinates	
Units Select	English/Imperial		Coordinates Quadrant		North Lat, West Lon	
Radio Administration Rules	FCC 101		Model Methods		Vigants-Barnett	
Modulation,Terminal	512QAM		Traffic		ETH IP 600 Mb/s	
Configuration	2+0, 1+1 FD		Delay Equalization		Unequalized	
Tx Power Level	A <- R		2	2	R -> B	

Site	Terminal A		Repeater		Terminal B	
Name	Crescent		Bald Mtn		Silver Lake	
Site Coordinates	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
Degrees	43	121	43	121	43	121
Minutes	27	40	16	21	7	2
Seconds	44.74	2.94	28.36	17.21	35.66	46.86
Elevation, AMSL, ft	5205.0		7380.0	7380.0		4352.0
Antenna Center, AGL, ft	25.0		16.0	16.0	Incl'd Ang's	16.0
Antenna Direction, Azimuth	129.36 deg		309.58 deg	123.15 deg	173.57 deg	303.36 deg
Elevation	1.00 deg		-1.30 deg	-1.90 deg	176.80 deg	1.63 deg
Tx Frequency, MHz	11 200.0	V-V			H-H	11 200.0
Path Length, mi		**20.40**	***Coordinates***		**18.63**	
Free Space Loss, dB		143.8			143.0	
Absorption Loss, dB		0.3			0.3	
Obstruction Loss, dB						
Field Margin, dB		1.0			1.0	
Path Loss, dB		145.1			144.3	
Feeder Length, ft	50.0		20.0	20.0		30.0
Loss/100 ft, dB	3.1	EWP90	3.1	3.1		3.1
Feeder Loss, dB	1.5		0.6	0.6		0.9
Connector Loss, dB	0.2		0.2	0.2		0.2
Jumper Loss, dB						
T/R Attenuator Pad, dB						
Component Loss, dB	0.3					0.3
Radome Loss, dB						
Total Fixed Loss, dB	2.0		0.8	0.8		1.4
Total Losses, dB		147.9			146.5	
Antenna Type	UHX8-107		UHX8-107	UHX8-107		UHX8-107
Antenna Size, ft	8.0		8.0	8.0		8.0
Antenna Gain, dBi	46.5		46.5	46.5		46.5
Front/Back, dB			80.0	80.0		
Total Gains, dB		93.1			93.1	
Net Path Loss, dB		54.9			53.4	

PENINSULA ENGINEERING SOLUTIONS Date: 02 Mar 2018 By: Ed Johnson

Our Best RF Repeater Site: Bald Mtn

Transmit Power, dBm	24.0					24.0
Repeater Input, dBm			-30.9	-29.4		
Input Pad, dB			0.0	0.0		
Repeater Max Gain, dB			60.0	60.0		
Var Gain Reduction, dB		Max -20	0.0	0.0	Max -20	
AGC, dB			14.1	15.6		
Amplifier Power, dBm			18.0	18.0		
Power Reduction, dB			0.0	0.0		
Output Pad, dB			0.0	0.0		
Repeater Output, dBm			15.0	15.0		
Nom RSL(+/-2dB), dBm	-39.9					-38.4
Receiver Threshold, dBm	-62.3					-62.3
Extra C/I Required, dB						
Rec. Noise Figure, dB	5.5		6.8	7.0		5.5
Min Rec. Power, dBm	-62.3		-61.0	-60.7		-62.3
Flat Fade Margin, dB	22.4		30.1	31.3		23.9
Dispersive F.M., dB	42.0					42.0
Composite F.M., dB	22.3		29.8	30.9		23.8
Per Hop Reliability	99.9964%		99.99936%	99.99962%		99.9980%
One Way Path Reliability	99.9960%					99.9974%

Repeater Antenna Coupling

Feed Point Sep., ft	12.0	
Antenna Sep Loss, dB	48.5	
Antenna XPD Loss, dB		
Receive C/E, Repeater, dB	57.1	57.1

Reliability Data

Terrain Roughness = User Entered, W = 140.0 ft — User Entered — W

Climate Type = Mountainous or very dry — Mountainous or very dry

Mean Temperature = 39.0 degrees F → Fading Season, days : 72.6 3.9 C

Climate / Terrain Factor	0.131
Undp (A<- R<- B)	2.02E-04
Undp (A ->R ->B)	1.31E-04

Frequency Spacing Tx A	MHz	Non-Diversity Configuration
Frequency Spacing Tx B	MHz	Non-Diversity Configuration

Undp (A<- R<- B)	2.02E-04
Undp (A ->R ->B)	1.31E-04

Outage/year, A receive	1264.5	Seconds	99.9960%
Outage/year, B receive	821.9	Seconds	99.9974%
Two Way Outage/year	2086.4	Seconds	99.9934%
	34.8	Minutes	
Path Length, End to End	39.0	Miles	

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Path Data Sheet for RF Repeaters	*Copyright Oct 2016*

Customer	Our Best			Rev 1 ACM Step		Page 1
Terminal	11G ETH 600Mb/s 80MHz			32QAM 300 Mb/s		
Repeater: RF-11000E			Path Length Source		Coordinates	
Units Select	English/Imperial		Coordinates Quadrant		North Lat, West Lon	
Radio Administration Rules	FCC 101		Model Methods		Vigants-Barnett	
Modulation,Terminal	32QAM		Traffic		ETH IP 600 Mb/s	
Configuration	2+0, 1+1 FD		Delay Equalization		Unequalized	
Tx Power Level	A <- R		2	2	R -> B	
Site	Terminal A		Repeater			Terminal B
Name	Crescent		Bald Mtn			Silver Lake
Site Coordinates	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
Degrees	43	121	43	121	43	121
Minutes	27	40	16	21	7	2
Seconds	44.74	2.94	28.36	17.21	35.66	46.86
Elevation, AMSL, ft	5205.0		7380.0	7380.0		4352.0
Antenna Center, AGL, ft	25.0		16.0	16.0	Incl'd Ang's	16.0
Antenna Direction, Azimuth	129.36 deg		309.58 deg	123.15 deg	173.57 deg	303.36 deg
Elevation	1.00 deg		-1.30 deg	-1.90 deg	176.80 deg	1.63 deg
Tx Frequency, MHz	11 200.0	V-V			H-H	11 200.0
Path Length, mi		**20.40**	***Coordinates***		**18.63**	
Free Space Loss, dB		143.8			143.0	
Absorption Loss, dB		0.3			0.3	
Obstruction Loss, dB						
Field Margin, dB		1.0			1.0	
Path Loss, dB		145.1			144.3	
Feeder Length, ft	50.0		20.0	20.0		30.0
Loss/100 ft, dB	3.1	EWP90	3.1	3.1		3.1
Feeder Loss, dB	1.5		0.6	0.6		0.9
Connector Loss, dB	0.2		0.2	0.2		0.2
Jumper Loss, dB						
T/R Attenuator Pad, dB						
Component Loss, dB	0.3					0.3
Radome Loss, dB						
Total Fixed Loss, dB	2.0		0.8	0.8		1.4
Total Losses, dB		147.9			146.5	
Antenna Type	UHX8-107		UHX8-107	UHX8-107		UHX8-107
Antenna Size, ft	8.0		8.0	8.0		8.0
Antenna Gain, dBi	46.5		46.5	46.5		46.5
Front/Back, dB			80.0	80.0		
Total Gains, dB		93.1			93.1	
Net Path Loss, dB		54.9			53.4	

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Our Best RF Repeater Site: Bald Mtn

Transmit Power, dBm	25.0					25.0
Repeater Input, dBm			-29.9	-28.4		
Input Pad, dB			0.0	0.0		
Repeater Max Gain, dB			60.0	60.0		
Var Gain Reduction, dB		Max -20	0.0	0.0	Max -20	
AGC, dB			15.1	16.6		
Amplifier Power, dBm			18.0	18.0		
Power Reduction, dB			-6.0	-6.0		
Output Pad, dB			0.0	0.0		
Repeater Output, dBm			15.0	15.0		
Nom RSL(+/-2dB), dBm	-39.9					-38.4
Receiver Threshold, dBm	-74.0					-74.0
Extra C/I Required, dB						
Rec. Noise Figure, dB	5.5		6.8	7.0		5.5
Min Rec. Power, dBm	-74.0		-72.7	-72.5		-74.0
Flat Fade Margin, dB	34.1		42.9	44.0		35.6
Dispersive F.M., dB	50.0					50.0
Composite F.M., dB	34.0		42.1	43.1		35.5
Per Hop Reliability	99.99975%		99.999962%	99.999977%		99.99987%
One Way Path Reliability	99.99973%					99.99983%

Repeater Antenna Coupling

Feed Point Sep., ft	12.0	
Antenna Sep Loss, dB	48.5	
Antenna XPD Loss, dB		
Receive C/E, Repeater, dB	57.1	57.1

Reliability Data

Terrain Roughness = User Entered, W = 140.0 ft — User Entered — W

Climate Type = Mountainous or very dry — Mountainous or very dry

Mean Temperature = 39.0 degrees F → Fading Season, days : 72.6 3.9 C

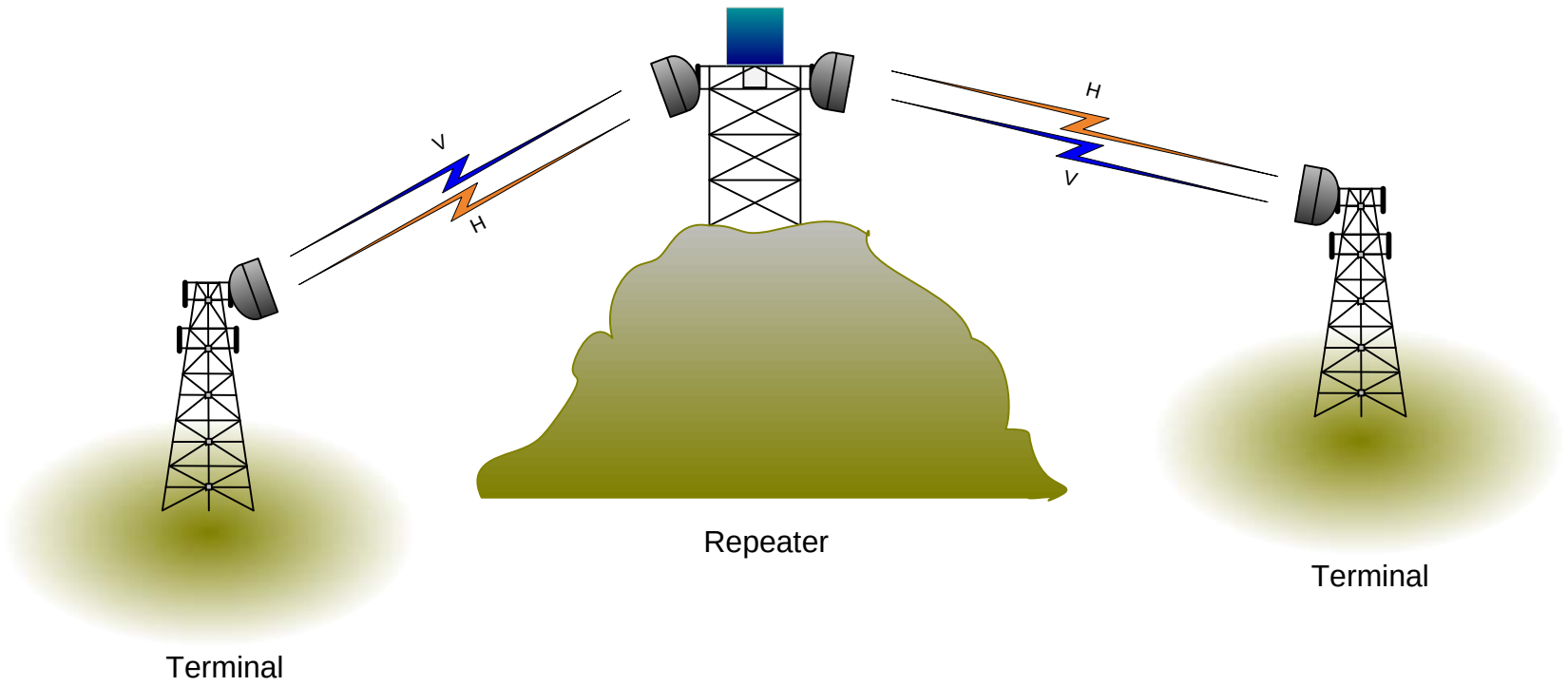
Climate / Terrain Factor	0.131
Undp (A<- R<- B)	1.36E-05
Undp (A ->R ->B)	8.66E-06

Frequency Spacing Tx A		MHz	Non-Diversity Configuration
Frequency Spacing Tx B		MHz	Non-Diversity Configuration

Undp (A<- R<- B)	1.36E-05
Undp (A ->R ->B)	8.66E-06

Outage/year, A receive	85.0	Seconds	99.99973%
Outage/year, B receive	54.3	Seconds	99.99983%
Two Way Outage/year	139.3	Seconds	99.99956%
Path Length, End to End	39.0	Miles	
Two Way Objective, Short Haul	499.6	Seconds	

This path data sheet is for preliminary information purposes only. It does not constitute a full path survey, and no guarantee of path performance, express or implied, is made.



PENINSULA·ENGINEERING SOLUTIONS inc

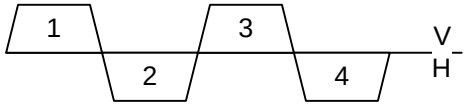
TITLE

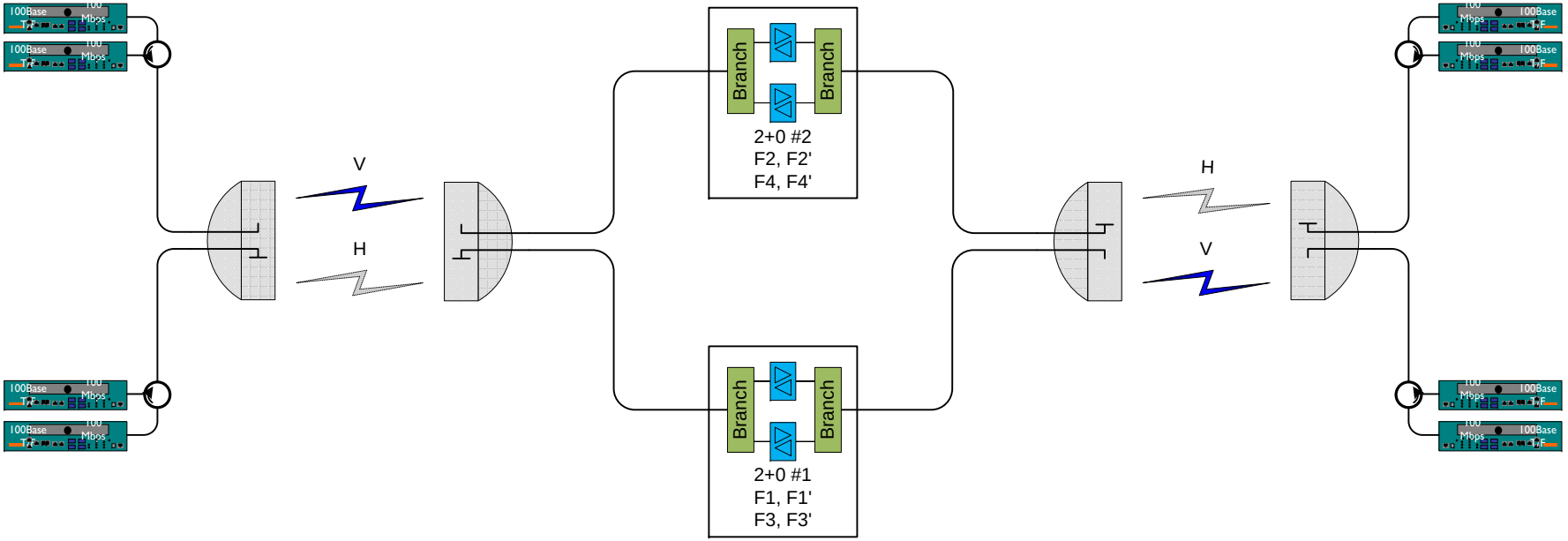
MW RF REPEATER SYSTEM

DRAWN BY

ED JOHNSON

FREQUENCY PLAN ACAP
80 MHz CHANNELS





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TITLE

4+0 ACAP 2.4 Gb/s SYSTEM

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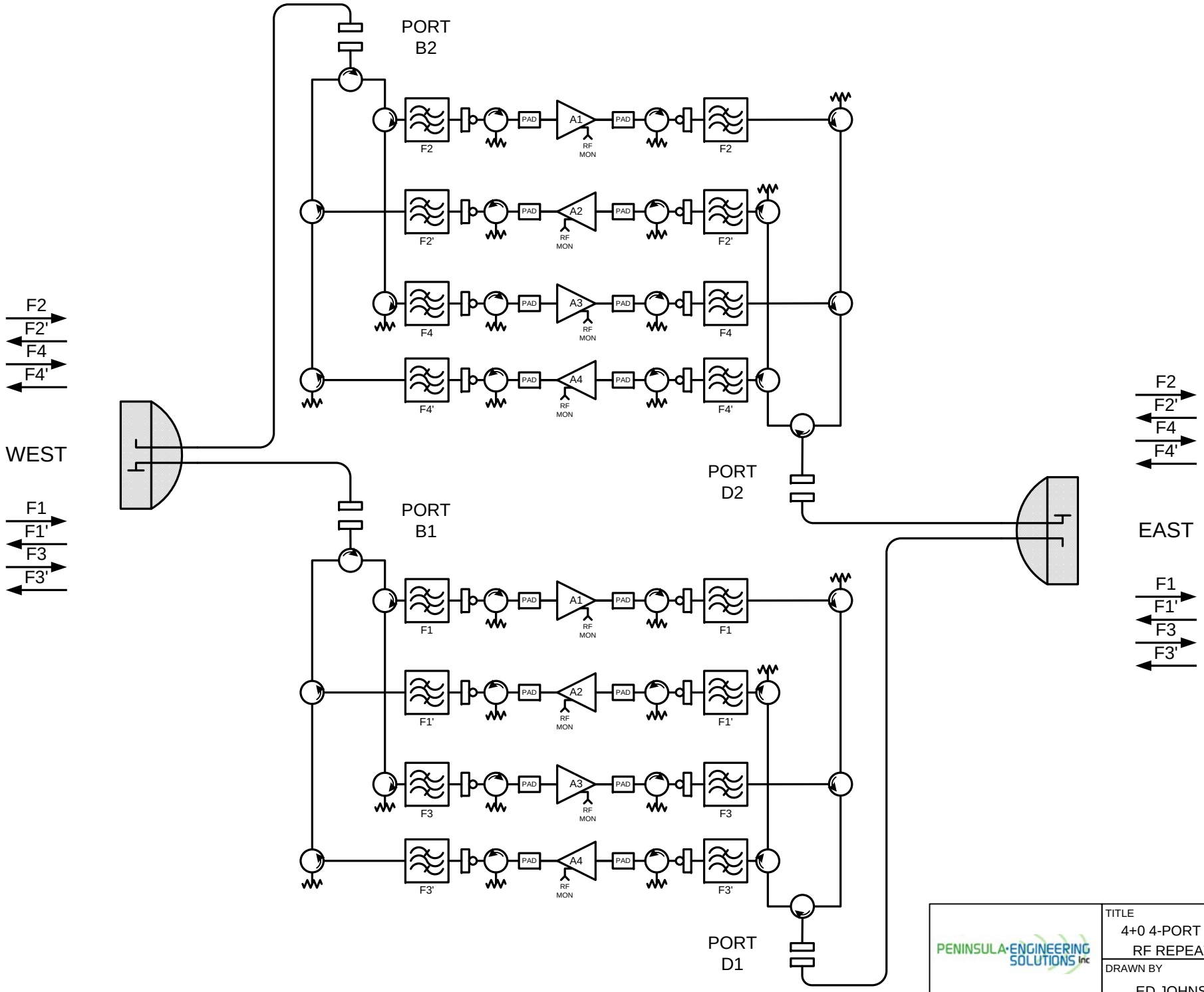

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TITLE
4+0 4-PORT ACAP
RF REPEATER

DRAWN BY
ED JOHNSON