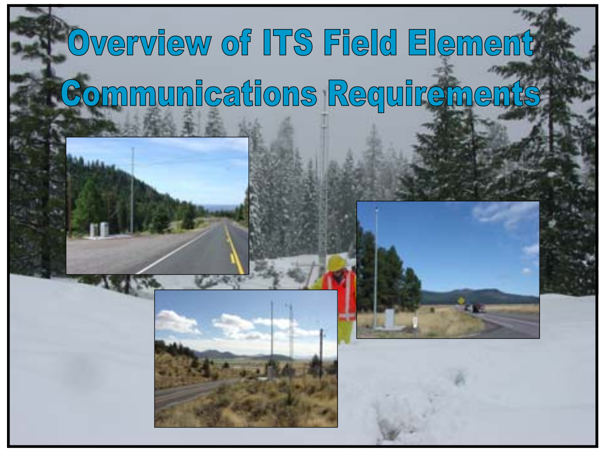


Overview of ITS Field Element Communications Requirements

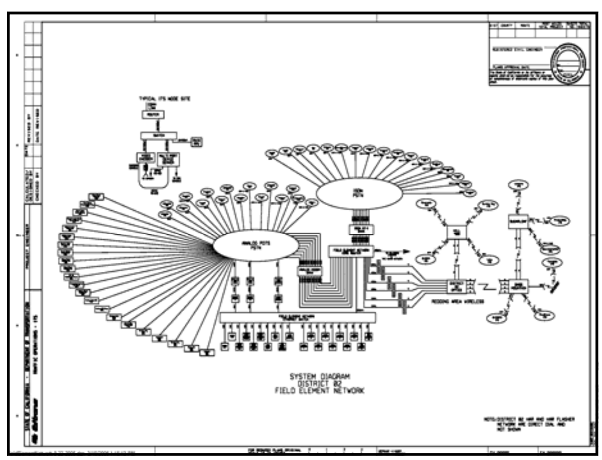
- Must stream video to the TMC w/ PTZ control
- Must operate in remote areas with harsh environments
- Must be perceived as reliable
- Must be “quickly” deployable
- Must have ability to work with six different telcos within the district
- Must keep ongoing connection costs as low as possible while meeting other goals

Overview of ITS Field Element Communications Solution

- All Internet Protocol (IP) based Field Element Network
- Design to support a constant 384 Kbps video data rate from each CCTV
- Primary network is one-to-many Dial on Demand Routed (DDR) network
- Allows establishment of “ITS Nodes” along the highway to transport all traffic from any IP field element back to TMC over a common communications infrastructure

Overview of ITS Field Element Communications Solution

- Allows quick installation and turn-up of new ITS Nodes
- Can be built with off-the-shelf reliable network communications equipment
- Allows seamless migration of an ITS Node site from DDR to microwave (“wireless”) as facilities are constructed
- Takes advantage of the fact that mountaintop communications sites are distributed along the main highway corridors in rural areas



What are the advantages of migrating to microwave?

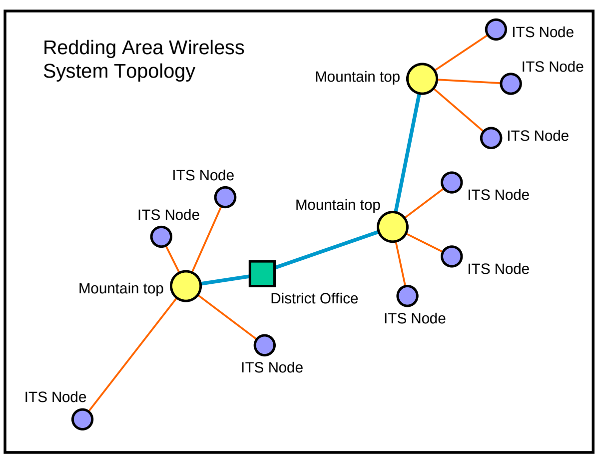
- More transport bandwidth than ISDN or POTS (512 Kbps versus ISDN at 128 Kbps or POTS at 9600 bps to 33.6 Kbps)
- Always connected to the network (DDR spoofs the routes and connects on “interesting traffic”)
- More reliable than rural telcos (paths must be engineered to meet objectives and mountain top back-up power must be installed)

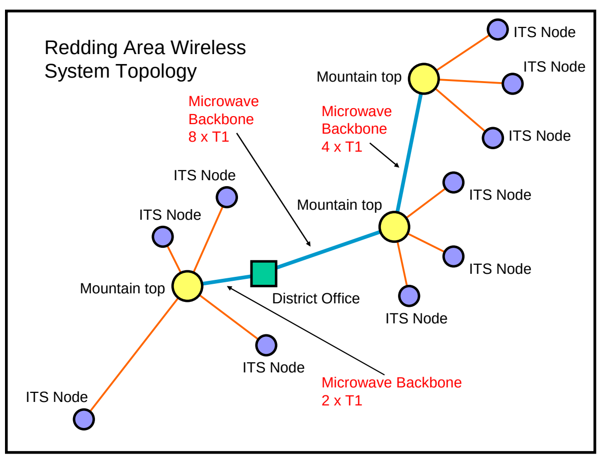
What are the advantages of migrating to microwave?

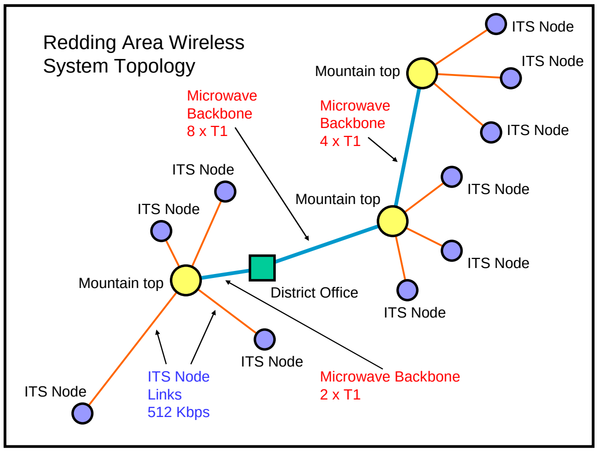
- More reliable during a crisis that PSTN (public switched networks are under an extreme load during a disaster)
- Lower ongoing costs (capital dollars are easier to get than operating dollars)

What is the system design and deployment strategy?

- Build a high bandwidth “backbone” between mountain tops and serve ITS Nodes with moderate bandwidth field element links
- Take advantage of the low population density (therefore interference potential) of rural areas and build initial deployment with 5.8 GHz and 2.4 GHz ISM (Industrial, Scientific, Medical) band microwave technology
- ISM band requires no FCC license

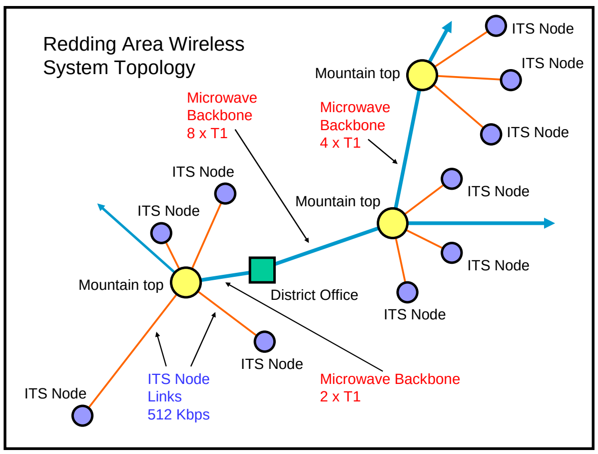


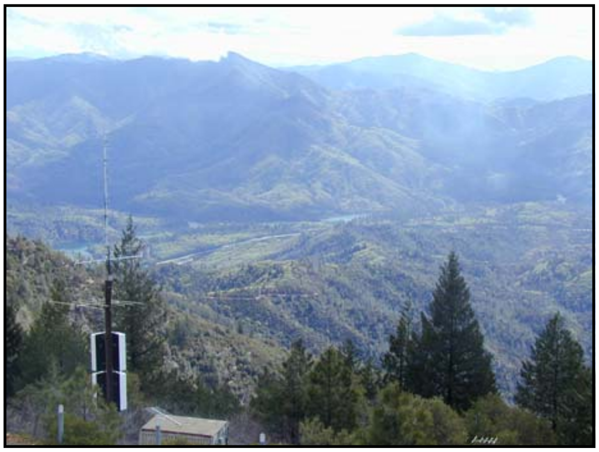




What is the system design and deployment strategy?

- Migrate the backbone to licensed microwave over time to provide better interference protection and free up spectrum for use to link more field elements
- Put time and energy into developing the access to mountain top sites - difficult and time consuming but worth the effort
- Move ISM band backbone equipment to the next hop edge site and repeat the process





What is the system design and deployment strategy?

- Just put Ethernet everywhere and make up for the inability to provide real QOS by massively overbuilding the bandwidth of every link.
- FALSE
- How many times have you heard this?
- This mentality came out of the corporate and educational campus environment where it was easy to put high-bandwidth fiber everywhere.

What is the system design and deployment strategy?

- In the RF environment the on-air spectrum is limited
- There is an intimate relationship between on-air spectrum bandwidth and payload bandwidth (as one increases, so does the other)
- In general, the more payload bandwidth you need the more spectrum you must occupy (all else being equal)

What is the system design and deployment strategy?

- In general also, the more spectrum you occupy the higher the receiver threshold (and therefore the shorter the path has to be to support a given reliability)
- The way this is traditionally dealt with is by using a transmission medium that is high-bandwidth (like fiber) or dividing up the RF spectrum spatially by using a cell or mesh approach

What is the system design and deployment strategy?

- Cell or mesh approaches allow frequency reuse by limiting the range of the cell and spatially separating them to avoid co-channel interference
- While this has the potential to work very well in densely populated urban settings, this is not practical in most rural areas due to the vast distances to be covered

What is the system design and deployment strategy?

- So for a rural environment where the mountain top to ITS Node links need to be in the 2 to 15 mile range you need to carefully consider what kind of payload bandwidth you really need and keep it to a reasonable compromise

What is the system design and deployment strategy?

- Use a point-to-point approach with quality antennas and transmission line to minimize potential interference from “off axis” sources
- Also use a point-to-point approach to increase the testability of the system (so there are clear points of evaluation and test and segments can be easily isolated)
- Remember that it will likely be a multi-hour drive to get to the other end of a link to test - so make remote testing as easy as possible

What is the system design and deployment strategy?

- Use a conservative design approach that emphasizes reliability (99.999% path reliability)
- Use only “Class A” (cellular / utility grade) radio equipment
- Stick with standard WAN interfaces on the backbone (N x T1) and for the ITS Node links, they are well known and easy to sectionalize and test

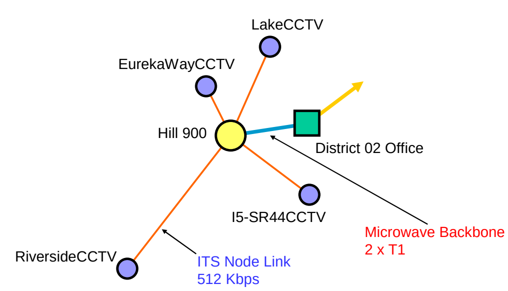
What is the system design and deployment strategy?

- Unless you have a “system-wide” way of controlling video bandwidth usage (like a gatekeeper) design backbone for worst case video usage
- Place routers at traffic aggregation points, consistent with traditional leased-line WAN design (each mountain top and each ITS Node)

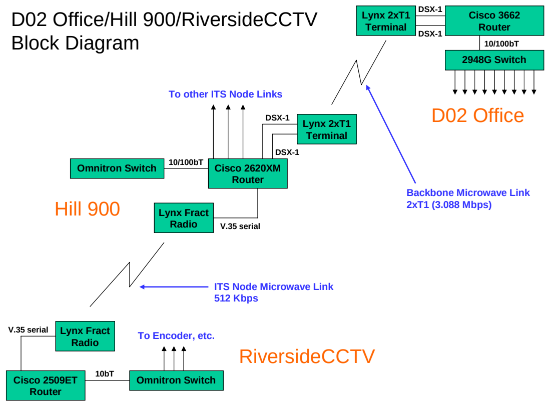
What is the system design and deployment strategy?

- Routers provide reliable interconnection, buffering and good diagnostic capabilities to time-tested WAN interfaces
- Place an Ethernet switch at the ITS Node to create a “roadside LAN” that connects to nearby field elements using copper, fiber and 802.11x wireless
- Place an Ethernet switch at the mountain top for test access and integrating a mountain top CCTV

Hill 900 Detailed System Topology



D02 Office/Hill 900/RiversideCCTV Block Diagram



ITS Node link - serial interface diagnostics

ITS Node end

RiversideCCTV#show int s0
Serial0 is up, line protocol is up
Hardware is HD64570
Internet address is 10.20.42.6/30
MTU 1500 bytes, BW 512 Kbit, DLY 20000 usec,
reliability 255/255, **txload 200/255, rxload 5/255**
Encapsulation PPP, loopback not set
Keepalive set (10 sec)
LCP Open
Open: IPCP
Last input 00:00:00, output 00:00:00, output hang never
Last clearing of "show interface" counters 5d04h
Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
Queueing strategy: fifo
Output queue: 0/40 (size/max)
5 minute input rate 11000 bits/sec, 26 packets/sec
5 minute output rate 403000 bits/sec, 48 packets/sec
10787932 packets input, 606731860 bytes, 0 no buffer
Received 0 broadcasts, 0 runts, 0 giants, 0 throttles
0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort
20727655 packets output, 1046809952 bytes, 0 underruns
0 output errors, 0 collisions, 0 interface resets
0 output buffer failures, 0 output buffers swapped out
0 carrier transitions
DCD=up DSR=up DTR=up RTS=up CTS=up
RiversideCCTV#

ITS Node link - serial interface diagnostics

Mountain top end

Hill900#show int s1/0
Serial1/0 is up, line protocol is up
Hardware is DSCC4 Serial
Internet address is 10.20.42.5/30
MTU 1500 bytes, BW 512 Kbit, DLY 20000 usec,
reliability 255/255, **txload 4/255, rxload 200/255**
Encapsulation PPP, LCP Open
Open: IPCP, loopback not set
Last input 00:05:47, output 00:00:00, output hang never
Last clearing of "show interface" counters 5d04h
Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
Queueing strategy: fifo
Output queue: 0/40 (size/max)
5 minute input rate 402000 bits/sec, 46 packets/sec
5 minute output rate 10000 bits/sec, 23 packets/sec
20734385 packets input, 1054040459 bytes, 0 no buffer
Received 0 broadcasts, 0 runts, 8 giants, 0 throttles
1278 input errors, 313 CRC, 965 frame, 0 overrun, 0 ignored, 0 abort
10791696 packets output, 606943512 bytes, 0 underruns
0 output errors, 0 collisions, 0 interface resets
0 output buffer failures, 0 output buffers swapped out
12 carrier transitions
DCD=up DSR=up DTR=up RTS=up CTS=up

Hill900#

ITS Node - Ethernet interface diagnostics

Note - no CXR transition indication

RiversideCCTV#show int e0
Ethernet0 is up, line protocol is up
Hardware is Lance, address is 0050.5480.74fe (bia 0050.5480.74fe)
Internet address is 10.20.201.25/29
MTU 1500 bytes, BW 10000 Kbit, DLY 1000 usec,
reliability 255/255, **txload 1/255, rxload 10/255**
Encapsulation ARPA, loopback not set
Keepalive set (10 sec)
ARP type: ARPA, ARP Timeout 04:00:00
Last input 00:00:00, output 00:00:00, output hang never
Last clearing of "show interface" counters 5d04h
Input queue: 3/75/0/0 (size/max/drops/flushes); Total output drops: 0
Queueing strategy: fifo
Output queue: 0/40 (size/max)
5 minute input rate 408000 bits/sec, 46 packets/sec
5 minute output rate 13000 bits/sec, 24 packets/sec
20726173 packets input, 1261139057 bytes, 0 no buffer
Received 0 broadcasts, 0 runts, 0 giants, 0 throttles
0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
0 input packets with dribble condition detected
10835389 packets output, 719742478 bytes, 0 underruns
0 output errors, 342 collisions, 0 interface resets
0 babbles, 0 late collision, 3628 deferred
0 lost carrier, 0 no carrier
0 output buffer failures, 0 output buffers swapped out
RiversideCCTV#

Backbone - Multilink interface diagnostics

Hill900#show int m1
Multilink1 is up, line protocol is up
Hardware is multilink group interface
Internet address is 10.20.41.6/30
MTU 1500 bytes, BW 3072 Kbit, DLY 100000 usec,
reliability 255/255, **txload 100/255, rxload 2/255**
Encapsulation PPP, LCP Open, multilink Open
Open: IPCP, loopback not set
DTR is pulsed for 2 seconds on reset
Last input 00:00:00, output never, output hang never
Last clearing of "show interface" counters 5d04h
Input queue: 2/75/0/0 (size/max/drops/flushes); Total output drops: 0
Queueing strategy: fifo
Output queue: 0/40 (size/max)
5 minute input rate 32000 bits/sec, 72 packets/sec
5 minute output rate 1206000 bits/sec, 139 packets/sec
26967268 packets input, 1517418872 bytes, 0 no buffer
Received 0 broadcasts, 0 runts, 0 giants, 0 throttles
0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort
51850040 packets output, 410786479 bytes, 0 underruns
0 output errors, 0 collisions, 0 interface resets
0 output buffer failures, 0 output buffers swapped out
0 carrier transitions
Hill900#

Backbone - T1-A interface diagnostics

Hill900#show controller t1 0/0
T1 0/0 is up.
Applique type is Channelized T1
Cablelength is short 133
No alarms detected.
alarm-trigger is not set
Version info Firmware: 20030902, FPGA: 11
Framing is ESF, Line Code is B8ZS, Clock Source is Line.
CRC Threshold is 320. Reported from firmware is 320.
Data in current interval (204 seconds elapsed):
0 Line Code Violations, 0 Path Code Violations
0 Slip Secs, 0 Fr Loss Secs, 0 Line Err Secs, 0 Degraded Mins
0 Errored Secs, 0 Bursty Err Secs, 0 Severely Err Secs, 0 Unavail Secs
Data in Interval 1:
0 Line Code Violations, 0 Path Code Violations
0 Slip Secs, 0 Fr Loss Secs, 0 Line Err Secs, 0 Degraded Mins
0 Errored Secs, 0 Bursty Err Secs, 0 Severely Err Secs, 0 Unavail Secs
.
.
.
.
Data in Interval 96:
0 Line Code Violations, 0 Path Code Violations
0 Slip Secs, 0 Fr Loss Secs, 0 Line Err Secs, 0 Degraded Mins
0 Errored Secs, 0 Bursty Err Secs, 0 Severely Err Secs, 0 Unavail Secs
Total Data (last 24 hours)
0 Line Code Violations, 0 Path Code Violations,
0 Slip Secs, 0 Fr Loss Secs, 0 Line Err Secs, 0 Degraded Mins,
0 Errored Secs, 0 Bursty Err Secs, 0 Severely Err Secs, 0 Unavail Secs
Hill900#

Backbone - T1-B interface diagnostics

```
Hill900#show controller t1 0/1
T1 0/1 is up.
  Applique type is Channelized T1
  Cablelength is short 133
  No alarms detected.
  alarm-trigger is not set
  Version info Firmware: 20030902, FPGA: 11
  Framing is ESF, Line Code is B8ZS, Clock Source is Line.
  CRC Threshold is 320. Reported from firmware  is 320.
  Data in current interval (375 seconds elapsed):
    0 Line Code Violations, 0 Path Code Violations
    295 Slip Secs, 0 Fr Loss Secs, 0 Line Err Secs, 0 Degraded Mins
    295 Errored Secs, 0 Bursty Err Secs, 0 Severely Err Secs, 0 Unavail Secs
  Data in Interval 1:
    0 Line Code Violations, 0 Path Code Violations
    704 Slip Secs, 0 Fr Loss Secs, 0 Line Err Secs, 0 Degraded Mins
    704 Errored Secs, 0 Bursty Err Secs, 0 Severely Err Secs, 0 Unavail Secs
 .
 .
 .
 .
  Data in Interval 96:
    0 Line Code Violations, 0 Path Code Violations
    703 Slip Secs, 0 Fr Loss Secs, 0 Line Err Secs, 0 Degraded Mins
    703 Errored Secs, 0 Bursty Err Secs, 0 Severely Err Secs, 0 Unavail Secs
  Total Data (last 24 hours)
    0 Line Code Violations, 0 Path Code Violations,
    67488 Slip Secs, 0 Fr Loss Secs, 0 Line Err Secs, 0 Degraded Mins,
    67488 Errored Secs, 0 Bursty Err Secs, 0 Severely Err Secs, 0 Unavail
Secs
Hill900#
```

What information do I need to be able to frequency plan?

- What ISM band are you using ?
- 902 MHz to 928 MHz - generally highly used in most areas and available equipment is relatively low transport bandwidth
- 2400 MHz to 2483.5 MHz - Becoming more used in many areas (popular with WLAN) but still very viable in rural areas. Has 83.5 MHz of RF spectrum with good equipment available. Very good propagation characteristics.

What information do I need to be able to frequency plan?

- What ISM band are you using ?
- 5725 MHz to 5845 MHz - Very viable band in rural areas. Has 125 MHz of RF spectrum with good equipment available. Very good propagation characteristics.

What information do I need to be able to frequency plan?

- What is the interference potential?
- Do a careful visual inspection on each end of the link - look for antennas that are possibly using the band you are interested in. Trace the transmission line to the equipment and see what the operating frequency is. Take the time to do this carefully!
- You can also search the spectrum of interest with a spectrum analyzer to look for interfering emissions

What information do I need to be able to frequency plan?

- What is the interference potential?
- You must use an antenna with an LNA or LNB and then present that amplified band signal to the spectrum analyzer - most SA are not sensitive enough to see signals down at the level you need (-50 dBm to -100 dBm)
- Most of the interference I have encountered is infrequent and would have been missed with this type of a spectrum scan - so beware

What information do I need to be able to frequency plan?

- What radios are you using?
- In this case Lynx 5.8 GHz ISM band radios of several capacities
- True full-duplex radios
- Proven reliability all over the globe with telcos, cellular providers and utilities
- Various capacities available with good RF spectrum utilization

What information do I need to be able to frequency plan?

- What type of emission is transmitted?
- In this case DSSS (Direct Sequence Spread Spectrum)
- Relatively low spectral power density
- Traditional channelization and filtering to allow for more predictable frequency planning

2.2 Specifications

Transmitter

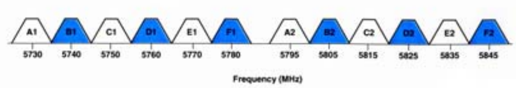
	All Models	
Frequency Selection	Rear Panel DIP switches; 7-cavity RF filter assembly	
Modulation	OQPSK	
Coding	Direct Sequence	
Number of Codes	4 (Rear Panel DIP switch selectable)	
	2.4 GHz Fractional	**5.8 GHz Fractional**
Output Power (typical)	+30 dBm	+23 dBm
Output Power (minimum)	+27 dBm	+20 dBm
Output Power Control Range	16 dB minimum	20 dB minimum
Frequency Range	2407-2471 MHz (occupies 2400-2483.5 MHz)	5730-5845 MHz (occupies 5725-5850 MHz)

Receiver

	All Models	
Nominal Receive Level	-30 to -60 dBm	
Maximum Receive Level	0 dBm error free, +10 dBm no damage	
Frequency Selection	Rear Panel DIP switches; 7-cavity RF filter assembly	
Processing Gain	10 dB minimum	
	2.4 GHz Fractional	**5.8 GHz Fractional**
Threshold Receive Level	-95 dBm (BER = 10^{-6})	-95 dBm (BER = 10^{-6})
Frequency Range	2400 - 2483.5 MHz	5725 - 5850 MHz

What information do I need to be able to frequency plan?

- What is the occupied channel bandwidth of the different links in your system?
- For fractional radios - 10 MHz channel in each direction
- For 2 x T1 radios - 31.5 MHz channel in each direction



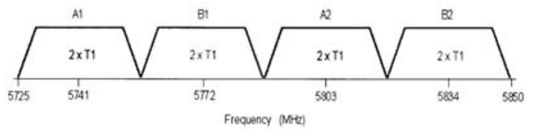
Channel plan for Lynx Fractional radios

ITS Node links (512 Kbps)

Channel Pairs

A1		A2
Tx 5730	→	Rx 5730
Rx 5795	←	Tx 5795
B1		B2
Tx 5740	→	Rx 5740
Rx 5805	←	Tx 5805
C1		C2
Tx 5750	→	Rx 5750
Rx 5815	←	Tx 5815
D1		D2
Tx 5760	→	Rx 5760
Rx 5825	←	Tx 5825
E1		E2
Tx 5770	→	Rx 5770
Rx 5835	←	Tx 5835
F1		F2
Tx 5780	→	Rx 5780
Rx 5845	←	Tx 5845

Figure 3-2: Channel Plan, 5.8 GHz Fractional Radio



Channel plan for Lynx 2 x T1 radios

Channel Pairs		
A1		A2
TX 5741	→	RX 5741
RX 5803	←	TX 5803
B1		B2
TX 5772	→	RX 5772
RX 5834	←	TX 5834

Backbone link from D.O. to Hill 900 (2 x 1544 Kbps)

Figure 3-4: Channel Plan, 5.8 GHz 2xT1

What information do I need to be able to frequency plan?

- What is the antenna cross-pol rejection?
- In this case about 30 dB - This means that a horizontally polarized signal will be 30 dB weaker when received with an antenna that is vertically polarized
- Use this to further isolate adjacent channel signals that have the potential to cause interference due to filter overlap

Terrestrial Microwave Antenna Products

P2F-52 Antenna

0.6m (2ft) Parabolic Antenna

Andrew 52 series antennas are designed to meet the requirements of the 5 GHz unlicensed bands. This antenna uses proprietary technology to deliver superior electrical performance.

Andrew antennas satisfy the widely accepted EIA 195C and 222E standards for electrical, mechanical and structural characteristics and are backed by a 3 year warranty.

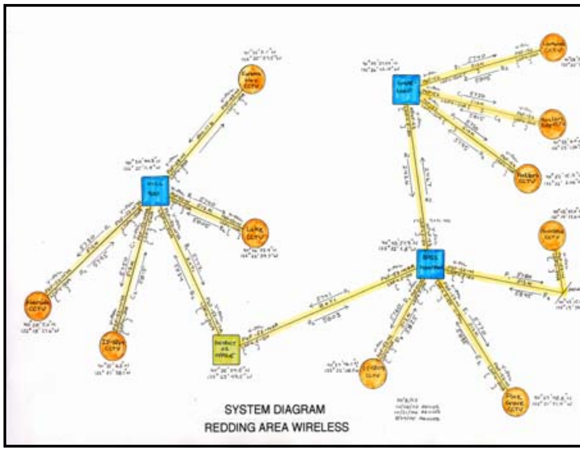
In order to reduce shipping costs and delivery times to sites worldwide, microwave antennas are available from Andrew locations at Lochgelly, Scotland; Denton, Texas; Melbourne, Australia and Sorocaba, Brazil.

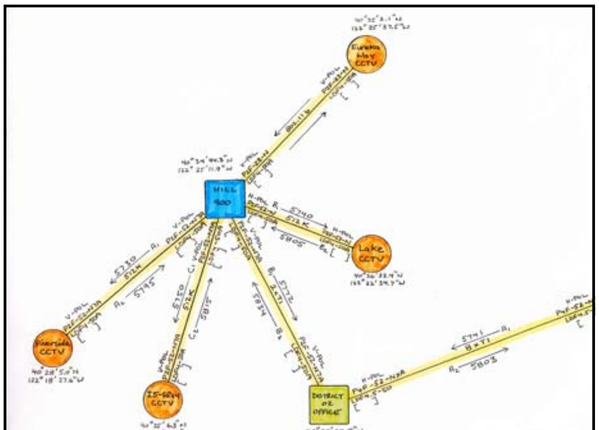
Flange Options	
Standard	
'N' FEMALE	

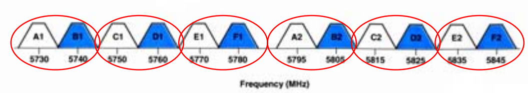
Radome Options	
Standard	None
Optional	Moulded ABS

Regulatory Compliances				
U.S. FCC			ETSI	
101	74	78	CLASS	GAIN
-	-	-	-	-

Electrical Characteristics		
Antenna Type		P2F-52
Frequency Band (GHz)		5.25 - 5.85
Gain (dBi)	Bottom	29.0
	Middle	29.4
	Top	30.1
3dB Beamwidth (deg.)		5.4
Cross Polar Disc. (dB)		30
F/B Ratio (dB)		41
VSWR (R.L. dB)		1.5(14.0)
R.P.E Number		4528





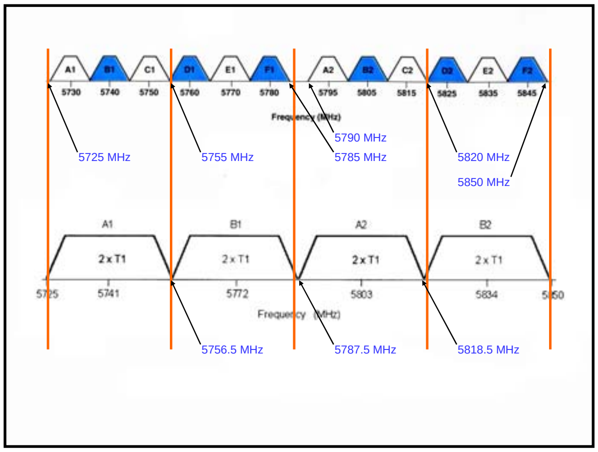


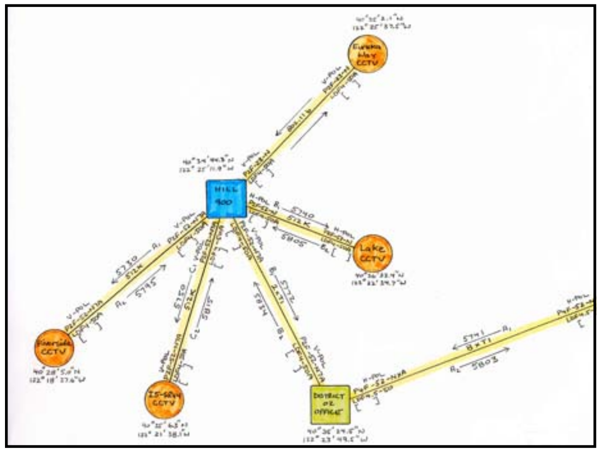
Filter overlap for Lynx Fractional radios

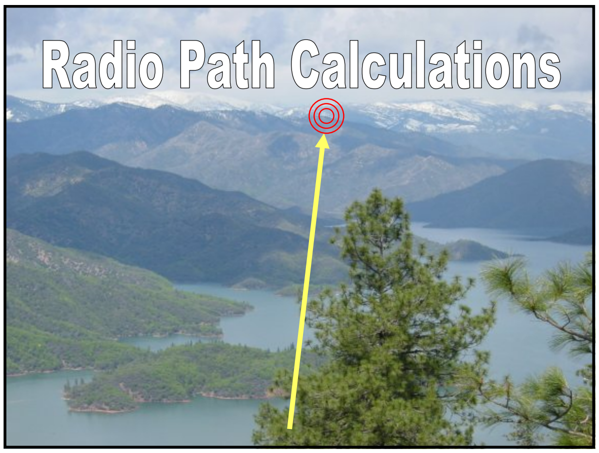
Channel Pairs		
A1		A2
Tx 5730	→	Rx 5730
Rx 5795	←	Tx 5795
B1		B2
Tx 5740	→	Rx 5740
Rx 5805	←	Tx 5805
C1		C2
Tx 5750	→	Rx 5750
Rx 5815	←	Tx 5815
D1		D2
Tx 5760	→	Rx 5760
Rx 5825	←	Tx 5825
E1		E2
Tx 5770	→	Rx 5770
Rx 5835	←	Tx 5835
F1		F2
Tx 5780	→	Rx 5780
Rx 5845	←	Tx 5845

ITS Node links (512 Kbps)

Figure 3-2: Channel Plan, 5.8 GHz Fractional Radio







Do I have a path?

- First step - Can I see the distant end?
- Try using:
- A bucket truck if you are at a roadside location and the antenna will actually be up feet in the air (say 30 feet)
- Binoculars
- A mirror to flash the path - it is often very hard to pick out a terminal location amongst vegetation

Required path clearance

- Understand that the microwave beam is not a line but a wave front
- The clearance required along the path in order to not interfere (block) this wave front varies along the path
- This clearance is a function of the length of the path, the position along the path and the frequency of operation

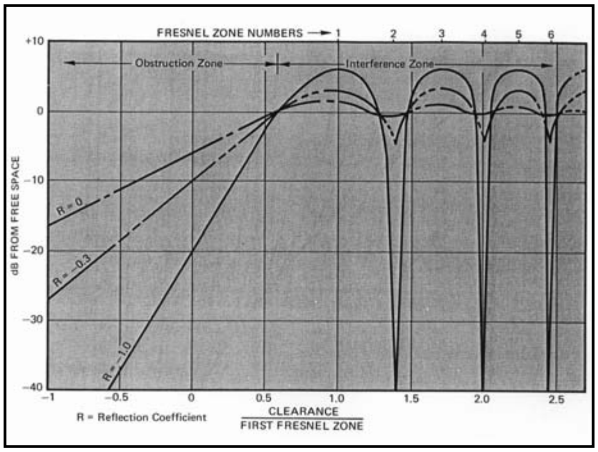
Required path clearance

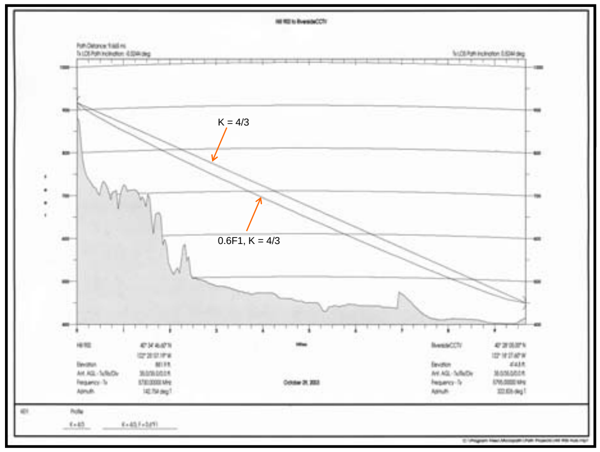
- The required clearance creates a cigar shape between the endpoints and is described by 0.6 of the first Fresnel zone

$$0.6F1 = 43.2\sqrt{(d1xd2)/(FxD)}$$

Where:

- d1 and d2 define the point along the path and are in miles
- D is the total path length in miles
- F is the frequency in GHz





Required path clearance

- That wave front is affected (bent) by various atmospheric phenomenon
- Under "normal" conditions the index of refraction is lower at the top of the wave front and higher at the bottom
- This causes the wave front to "bend" downward slightly as it traverses the path
- Under "abnormal" conditions the beam can be bent to coincide with the curvature of the earth or be bent into an obstruction

Required path clearance

- An accepted way to model this phenomenon is to use a coefficient (K) that "modifies" the mean radius of the earth
- If the departure from a line tangent to the surface of the earth is "h" then:

  h = (d1xd2)/1.5xK
- K = Infinity is a "flat earth" (supernormal) condition
- K = 4/3 is "normal" propagation conditions
- K = 1/2 is an "earth bulging" (subnormal) condition

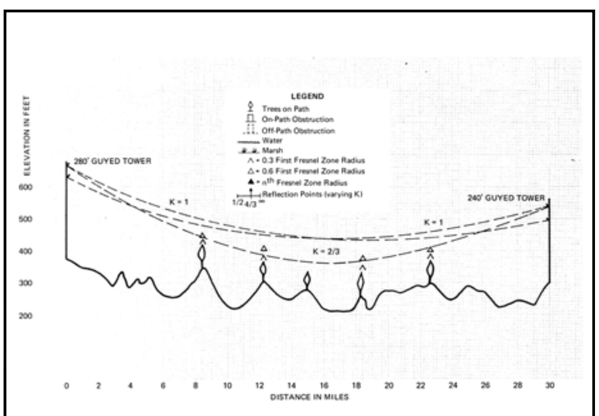
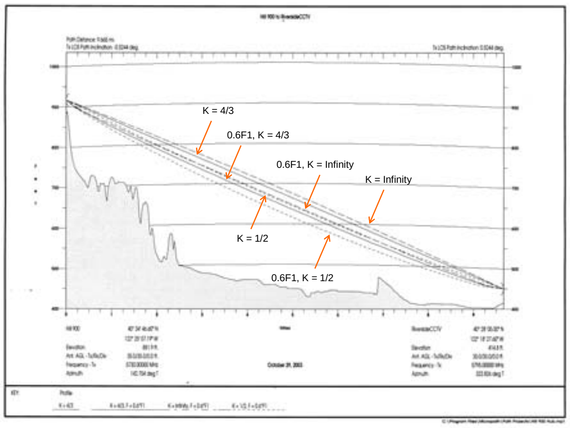


Figure 5. Path Profile Example (Flat Earth)

Required path clearance

- In order to prevent an obstructed path (power fade) under certain propagation conditions you want to verify that you have 0.6F1+15 feet clearance for all expected values of K
- For this area check K = Infinity, K = 4/3, K = 1 and K = 1/2
- Be sure to consider trees and tree growth
- Consideration of reflection points under all expected values of K are also important - for this discussion a non-reflective path is assumed



Reliability Objectives

- You need to decide what path reliability you need for your system
- This is the reliability of the path with respect to Rayleigh-distributed multipath fading
- At 5.8 GHz, rain effects (fading) are negligible
- Rain effects become a consideration at frequencies above 8 GHz.
- Reliability and outage times should be considered in the context of system-wide objectives - That is beyond the scope of this presentation

Table D. Relationship Between System Reliability And Outage Time

RELIABILITY %	OUTAGE TIME %	OUTAGE TIME PER YEAR	OUTAGE TIME PER MONTH (Avg.)	OUTAGE TIME PER DAY (Avg.)
0	100	8760 hours	720 hours	24 hours
50	50	4380 hours	360 hours	12 hours
80	20	1752 hours	144 hours	4.8 hours
90	10	876 hours	72 hours	2.4 hours
95	5	438 hours	36 hours	1.2 hours
98	2	175 hours	14 hours	29 minutes
99	1	88 hours	7 hours	14.4 minutes
99.9	0.1	8.8 hours	43 minutes	1.44 minutes
99.99	0.01	53 minutes	4.3 minutes	8.6 seconds
99.999	0.001	5.3 minutes	26 seconds	0.86 seconds
99.9999	0.0001	32 seconds	2.6 seconds	0.086 seconds

Reliability Objectives

- For the ITS Node link in this example, the path reliability objective is 99.999%
- The outages due to multipath fading for the entire year occur during the "fade season"
- This is defined as a 3 month period (8.04x10E06 seconds) when fading activity is dominant
- These objectives constrain what the link fade margin needs to be and that fade margin constrains your choices of radios, antennas and transmission line

Reliability Objectives

- Some quick definitions:
- The "fade margin" is the difference (in dB) between the unfaded receive signal level and the receiver threshold
- This is an oversimplification, but for the radios chosen (with good dispersive fade margin characteristics) it is adequate
- The receiver threshold is the signal level at the receiver port that will yield a given bit error rate (BER) - use 1x10E-06 consistently

Reliability Objectives

- It is convenient to use one-way path outage probability or "unreliability", U, to find one-way path "reliability", A
- A = (1 - U), where A is a fraction (x100 for %)

For a non-diversity path, the equation for determining the "unreliability" during the fade season is as follows:

$$U_{ndp} = (c)(f/4)(10^{5})(D^{3})(10^{(-F/10)}) \, .$$

where
- U_{ndp} = U, one-way outage probability for non-diversity path
- f = frequency in GHz
- D = path length
- F = composite or flat fade margin in dB (see below)
- c = climate/terrain factor (see APPENDIX E)
  - = 6.0 :influenced by surface ducting
  - = 4.0 :flat terrain and humid climate
  - = 2.0 :average terrain and humid climate
  - = 1.0 :average terrain and climate
  - = 0.25 :rough terrain and dry climate.

Outage Objectives

- Ultimately what we are interested in for a given link is the annual outage time
- Design for a particular path reliability and then calculate the annual outage and verify that it is better than 5.3 minutes (99.999%)
- Note that this is an iterative process of adjusting antenna gains and transmission line losses to arrive at a fade margin that will give you the reliability and thereby outage time you desire

Outage Objectives

- The path reliability speaks to how reliable the path is during the fade season
- The annual outage time speaks to how many seconds the path will be down due to multipath fading during a year

MULTIPATH PROPAGATION OUTAGE TIMES AND OBJECTIVES

The annual outage time due to multipath fade activity in a microwave link is defined, occurring over a 2-5 month "fade season," as:

$$\text{Outage}_{sec} = U_{ndp} \times T_o \times t/50 ,$$

where T_o = fade season, usually taken as three months (a combination of two severe and two moderate fade months), or 8.04×10^6 seconds.

t = Average annual temperature, °F extends the fade season in warmer areas, and $35° \leq t \leq 75°$.

Outage Objectives

- Note that the outage time is a function of the average annual temperature of the region
- Note also that the definition of fade season is "by convention" and somewhat arbitrary

MULTIPATH PROPAGATION OUTAGE TIMES AND OBJECTIVES

The annual outage time due to multipath fade activity in a microwave link is defined, occurring over a 2-5 month "fade season," as:

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t = Average annual temperature, °F extends the fade season in warmer areas, and $35° \leq t \leq 75°$.

Where are we at?

- What are the knowns in this path design?
- We know we have an unobstructed path
- We know what path reliability we want and the fade margin needed to obtain it
- We know what radios we are using and have already done the frequency planning
- Since we have chosen the radios, we also know the transmit output power and the receiver threshold

Link Budget Calculations

- The last major activity we need to do is to develop the link budget
- This will allow us to choose the antennas and transmission line such that we get the fade margin we need to get the reliability we want
- We want to determine the unfaded receive signal level
- This becomes an exercise of adding and subtracting the different gains and losses (in dB) from the transmitter output power (in dBm)

Link Budget Calculations

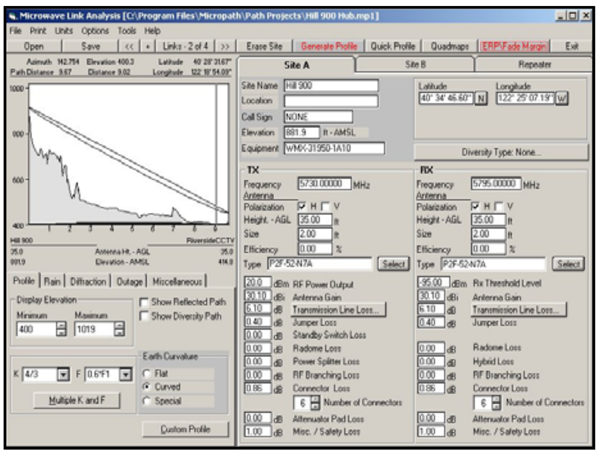
- The link budget in its simplest form is:
- RSLb = Pta - TLa + AGa - FSPL + AGb - TLb
- Where:
  - RSLb is the received signal level at Site B (in dBm)
  - Pta is the transmit power output at Site A (in dBm)
  - TLa is the transmission line loss at Site A (in dB)
  - AGa is the antenna gain over isotropic at Site A (in dB)
  - FSPL is the free space path loss (in dB)
  - AGb is the antenna gain over isotropic at Site B (in dB)
  - TLb is the transmission line loss at Site B (in dB)

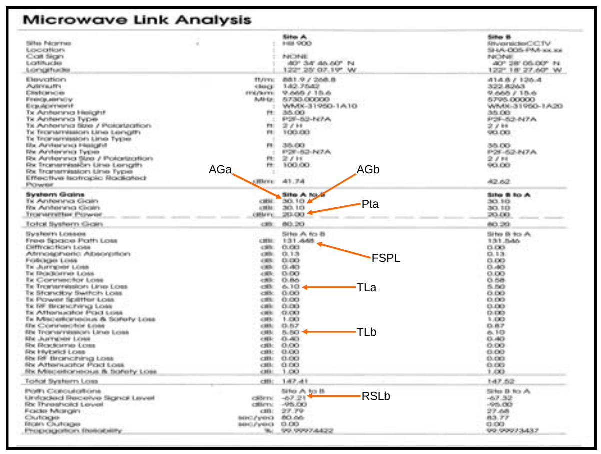
Link Budget Calculations

- The Free Space Path Loss is a function of the frequency of operation and the path distance
- FSPL = 96.6 + 20 LOG(f) + 20 LOG(D)
- Where:
  - FSPL is the free space path loss (in dB)
  - f is the frequency of operation (in GHz)
  - D is the path distance (in miles)
- This loss is due to the “expanding sphere” nature of an isotropic radiator wavefront

Link Budget Calculations

- The actual calculations for our link in question are fairly tedious and are best handled by a spreadsheet or path design software
- We will be repeatedly changing values for antenna gain and transmission line loss
- As stated before, we want to choose the antennas and transmission line such that we get the fade margin we need to get the reliability we want
- I normally use Micropath 2001 VHF / UHF / Microwave Link Analysis Program





Microwave Link Analysis

		Site A	Site B
Site Name	:	Hill 900	RiversideCCTV
Location	:		SHA-005-PM-xx.xx
Call Sign	:	NONE	NONE
Latitude	:	40° 34' 46.60" N	40° 28' 05.00" N
Longitude	:	122° 25' 07.19" W	122° 18' 27.60" W
Elevation	ft/m:	881.9 / 268.8	414.8 / 126.4
Azimuth	deg:	142.7542	322.8263
Distance	mi/km:	9.665 / 15.6	9.665 / 15.6
Frequency	MHz:	5730.00000	5795.00000
Equipment	:	WMX-31950-1A10	WMX-31950-1A20
Tx Antenna Height	ft:	35.00	35.00
Tx Antenna Type	:	P2F-52-N7A	P2F-52-N7A
Tx Antenna Size / Polarization	ft:	2 / H	2 / H
Tx Transmission Line Length	ft:	100.00	90.00
Tx Transmission Line Type	:		
Rx Antenna Height	ft:	35.00	35.00
Rx Antenna Type	:	P2F-52-N7A	P2F-52-N7A
Rx Antenna Size / Polarization	ft:	2 / H	2 / H
Rx Transmission Line Length	ft:	100.00	90.00
Rx Transmission Line Type	:		
Effective Isotropic Radiated Power	dBm:	41.74	42.62
System Gains		**Site A to B**	**Site B to A**
Tx Antenna Gain	dBi:	30.10	30.10
Rx Antenna Gain	dBi:	30.10	30.10
Transmitter Power	dBm:	20.00	20.00
Total System Gain	dB:	80.20	80.20
System Losses		Site A to B	Site B to A
Free Space Path Loss	dB:	131.448	131.546
Diffraction Loss	dB:	0.00	0.00
Atmospheric Absorption	dB:	0.13	0.13
Foliage Loss	dB:	0.00	0.00
Tx Jumper Loss	dB:	0.40	0.40
Tx Radome Loss	dB:	0.00	0.00
Tx Connector Loss	dB:	0.86	0.58
Tx Transmission Line Loss	dB:	6.10	5.50
Tx Standby Switch Loss	dB:	0.00	0.00
Tx Power Splitter Loss	dB:	0.00	0.00
Tx RF Branching Loss	dB:	0.00	0.00
Tx Attenuator Pad Loss	dB:	0.00	0.00
Tx Miscellaneous & Safety Loss	dB:	1.00	1.00
Rx Connector Loss	dB:	0.57	0.87
Rx Transmission Line Loss	dB:	5.50	6.10
Rx Jumper Loss	dB:	0.40	0.40
Rx Radome Loss	dB:	0.00	0.00
Rx Hybrid Loss	dB:	0.00	0.00
Rx RF Branching Loss	dB:	0.00	0.00
Rx Attenuator Pad Loss	dB:	0.00	0.00
Rx Miscellaneous & Safety Loss	dB:	1.00	1.00
Total System Loss	dB:	147.41	147.52
Path Calculations		Site A to B	Site B to A
Unfaded Receive Signal Level	dBm:	-67.21	-67.32
Rx Threshold Level	dBm:	-95.00	-95.00
Fade Margin	dB:	27.79	27.68
Outage	sec/year	80.66	83.77
Rain Outage	sec/year	0.00	0.00
Propagation Reliability	%:	99.99974422	99.99973437

For More Information

- Microwave transmission engineering is a complex field of study - the two main references used in preparation of this presentation are recommended reading
- “Engineering Considerations for Microwave Communications Systems” by Robert F. White and Staff, GTE Lenkurt, 1975
- “Microwave Radio Path Calculations Plus” by the Staff at Harris Farinon Division, 1989
- The references cited in both publications above

Typical ITS Node

Microwave antenna installation

CCTV-45 Pole (Modified Caltrans Standard Plans ES-16A)

ITS Node electronics cabinet

Camera (Cohu 3955-3100-PEDD)

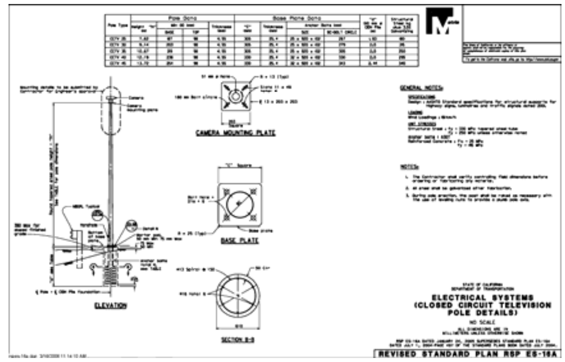
Microwave antenna (5.8 GHz ISM band)

ITS Node BBS cabinet

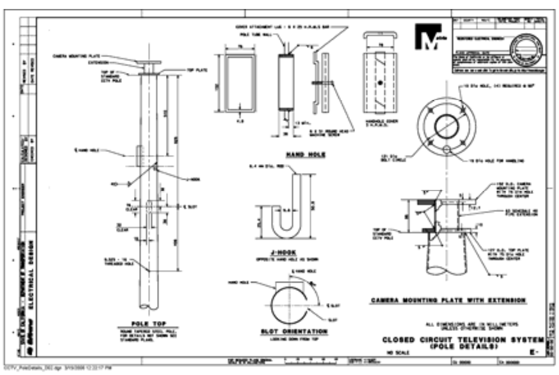
Power subpanel

Pull box area

Caltrans Standard CCTV Pole



Modified Camera Mount and Transmission Line Slot



Radome (Andrew VR2-1)

Parabolic antenna reflector (Andrew P2F-52-N7A)

1/2" Heliax (Andrew LDF4-50A)

Antenna elevation adjustment

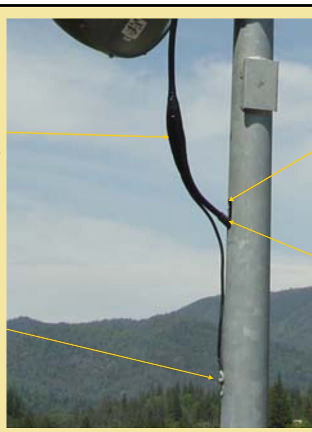
Antenna azimuth adjustment

N-connector weatherproofing (3M Cold Shrink 8426-9 & Butyl)

CCTV pole handhole

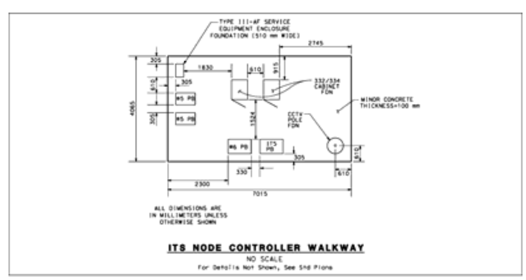
Ground kit (Andrew SGL4-06B2)

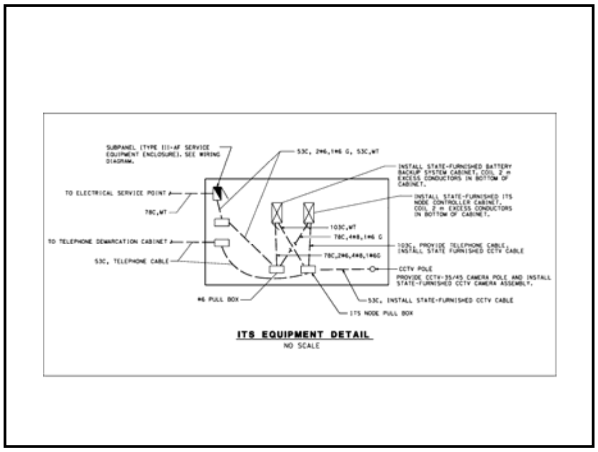
Ground point

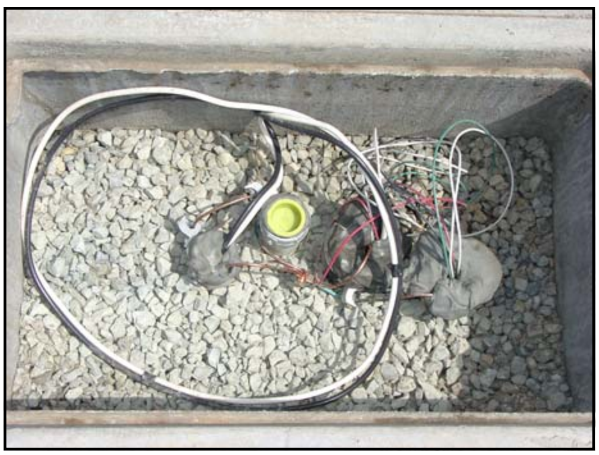


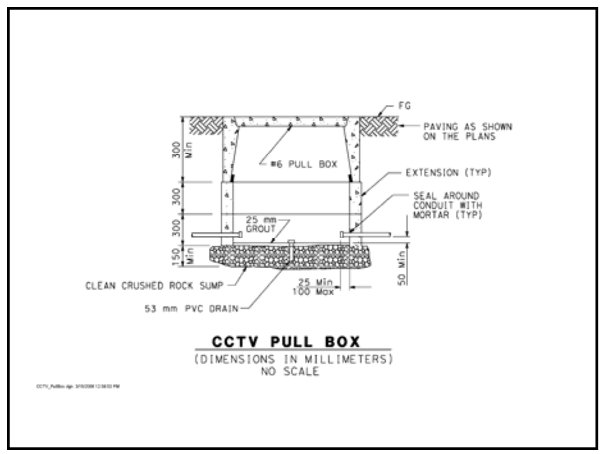
Pole slot for Heliax

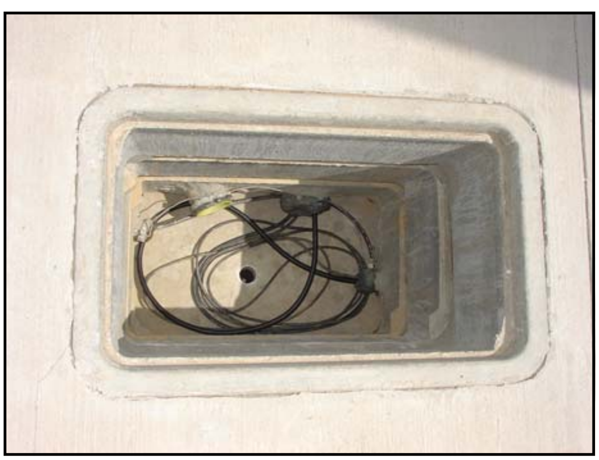
Heliax protection (3M Cold Shrink 8424-8)

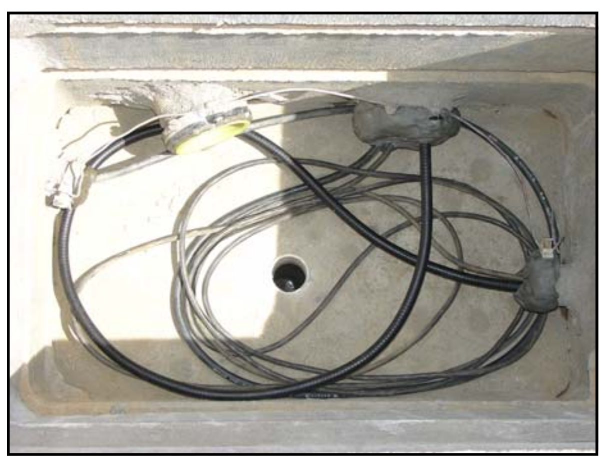


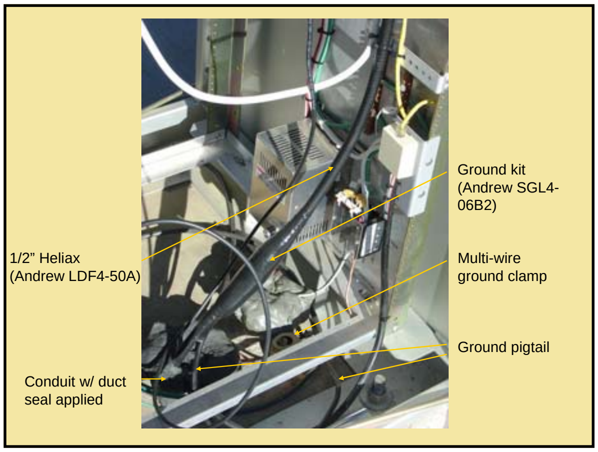

SUBPANEL (TYPE III-AF SERVICE EQUIPMENT ENCLOSURE). SEE WIRING DIAGRAM.
53C, 2#6,1#6 G, 53C,WT
INSTALL STATE-FURNISHED BATTERY BACKUP SYSTEM CABINET. COIL 2 m EXCESS CONDUCTORS IN BOTTOM OF CABINET.
TO ELECTRICAL SERVICE POINT
78C,WT
INSTALL STATE-FURNISHED ITS NODE CONTROLLER CABINET. COIL 2 m EXCESS CONDUCTORS IN BOTTOM OF CABINET.
103C,WT
78C,4#8,1#6 G
TO TELEPHONE DEMARCATION CABINET
103C, PROVIDE TELEPHONE CABLE. INSTALL STATE FURNISHED CCTV CABLE
78C,2#6,4#8,1#6G
53C, TELEPHONE CABLE
CCTV POLE
PROVIDE CCTV-35/45 CAMERA POLE AND INSTALL STATE-FURNISHED CCTV CAMERA ASSEMBLY.
#6 PULL BOX
53C, INSTALL STATE-FURNISHED CCTV CABLE
ITS NODE PULL BOX
ITS EQUIPMENT DETAIL
NO SCALE

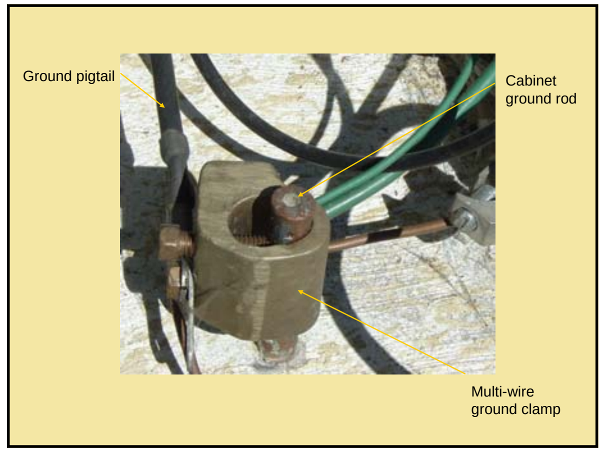


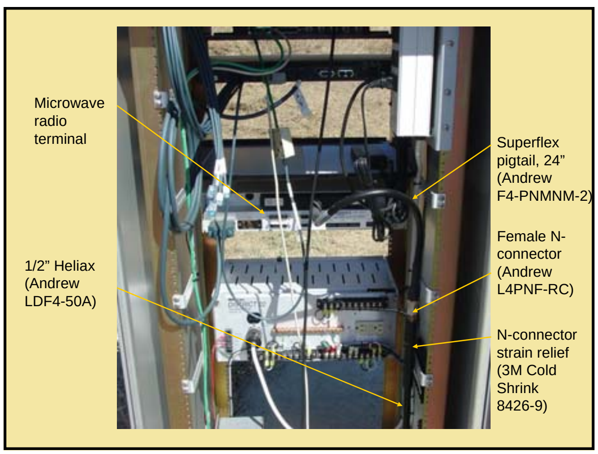

FG
PAVING AS SHOWN ON THE PLANS
300 Min
#6 PULL BOX
EXTENSION (TYP)
300
SEAL AROUND CONDUIT WITH MORTAR (TYP)
25 mm GROUT
300
150 Min
CLEAN CRUSHED ROCK SUMP
25 Min
100 Max
50 Min
53 mm PVC DRAIN
CCTV PULL BOX
(DIMENSIONS IN MILLIMETERS)
NO SCALE






Ground kit (Andrew SGL4-06B2)
1/2” Heliax (Andrew LDF4-50A)
Multi-wire ground clamp
Ground pigtail
Conduit w/ duct seal applied


Ground pigtail
Cabinet ground rod
Multi-wire ground clamp


Microwave radio terminal
Superflex pigtail, 24” (Andrew F4-PNMNM-2)
Female N-connector (Andrew L4PNF-RC)
1/2” Heliax (Andrew LDF4-50A)
N-connector strain relief (3M Cold Shrink 8426-9)


Antenna Alignment
• Iterative process
• Make sure you are on the main lobe
• Verify measured RSL is close to calculated value


Any Questions?