RF Transmission

Radio Frequency Standards for Telemetry

- The IRIG 106 standards (especially Chapter 2 for RF) provide the criteria to determine equipment and frequency use requirements and are intended to ensure efficient and interference-free use of the radio frequency spectrum and interchange of operations and data.

- The radio frequency spectrum is a limited natural resource; therefore, efficient use of available spectrum is mandatory. In addition, susceptibility to interference must be minimized.

- The standards are derived from the National Telecommunications and Information Administration's (NTIA) Manual of Regulations and Procedures for Federal Radio Frequency Management.

Radio Frequency Standards for Telemetry

- IRIG 106 Chapter 2 – Transmitter and Receiver Systems
  - RF Standards for Telemetry
    - Ensure efficient, interference-free use of the aeronautical telemetry bands
    - Provide framework for Range interoperability
    - Tie-ins with NTIA Redbook *(“Manual of Regulations and Procedures for Federal Radio Frequency Management”)*
- Also
  - Appendix 2-A – “Frequency Considerations for Telemetry”
    - Detailed technical guidance on spectrally efficient ways of utilizing the aeronautical telemetry bands
  - Appendix 2-B – “Properties of the Differential Encoder Specified in IRIG Standard 106 for OQPSK Modulations”
  - Appendix 2-C – “Telemetry Transmitter Command and Control Protocol”
- IRIG 120-08 - TM Systems Radio Frequency Handbook

TM Bands

Frequency Range (MHz)	Unofficial Designation	Comments (Note: service in USA)
1435 - 1525	Lower L Band	Primary - Telemetry (part of mobile service)
1525 - 1535	Lower L Band	Primary - Mobile Satellite Service (MSS) Secondary - Telemetry
2200 - 2290	Lower L Band	Telemetry co-primary service
2310 - 2360	Upper S Band	Primary - Wireless Communications Service, Broadcast Satellite Service Secondary - Telemetry
2360 - 2395	Upper S Band	Primary - Telemetry
4400 - 4940	Lower C Band	Telemetry allowed, bi-directional telemetry
5091 - 5150	Middle C Band	Telemetry allowed
5925 - 6700	Upper C Band	Telemetry not allowed yet

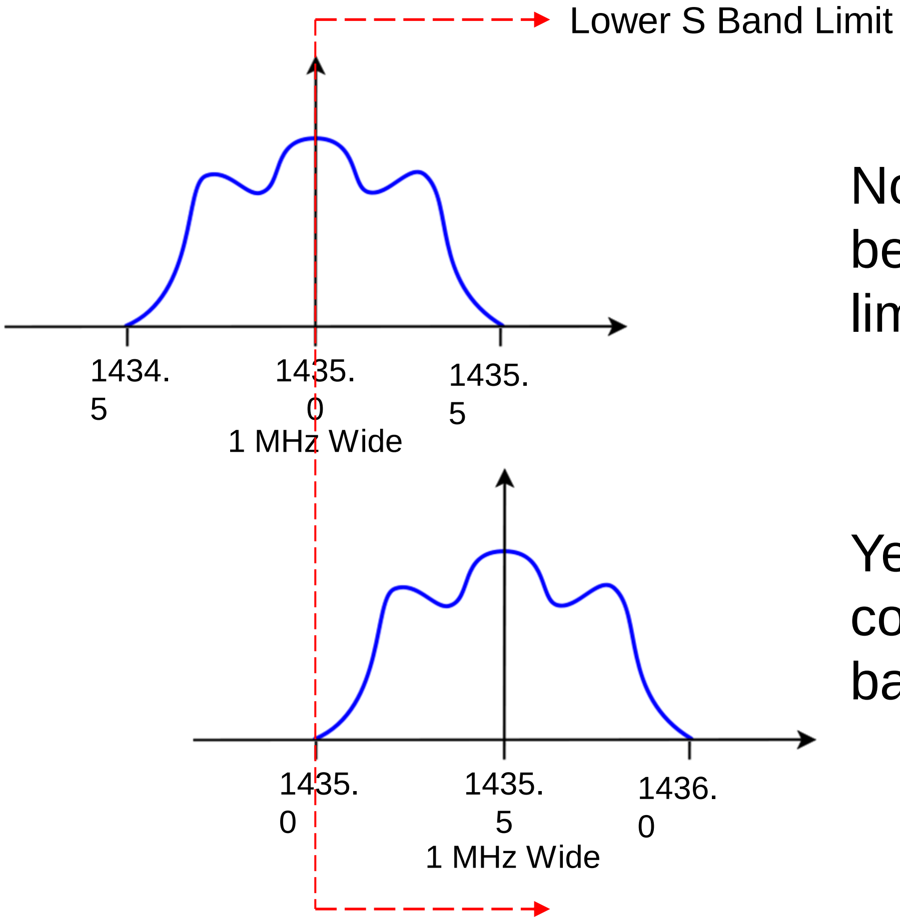
TM Bands

- While these band designations are common in the telemetry community, they may have no specific meaning to anyone else.
- Telemetry assignments are made for testing of manned and unmanned aircraft, missiles, space vehicles, rocket sleds, and systems carried on such sleds for testing or their major components.

Digital Signal Transmission

- **Standard Bandwidth Channel**
  - Spacing is in increments of 1 MHz, beginning 500 kHz from the lower band edge such as 1435.5, 1436.5, and 1437.5 MHz.
  - By definition, the band edges of a standard bandwidth channel cannot fall outside the allocated band.
- **Wide Bandwidth Channels**
  - Channels with bandwidths greater than 1 MHz are assigned channels on spacing as standard bandwidth channels.
  - The resulting spectrum is not allowed to fall outside the allocated band.

Digital Signal Transmission



No! Signal power extends beyond telemetry band limit.

Yes! All signal power contained within telemetry band limit.

Digital Signal Transmission, cont.

- Output Power
  - The output power of a telemetry transmitter shall be the minimum possible required for the specific application and should not exceed 25 watts.
  - The output power of a telemetry transmit system and the effective isotropic radiated power (EIRP) should be the minimum possible required for the specific application.
  - The EIRP should not exceed 25 watts.

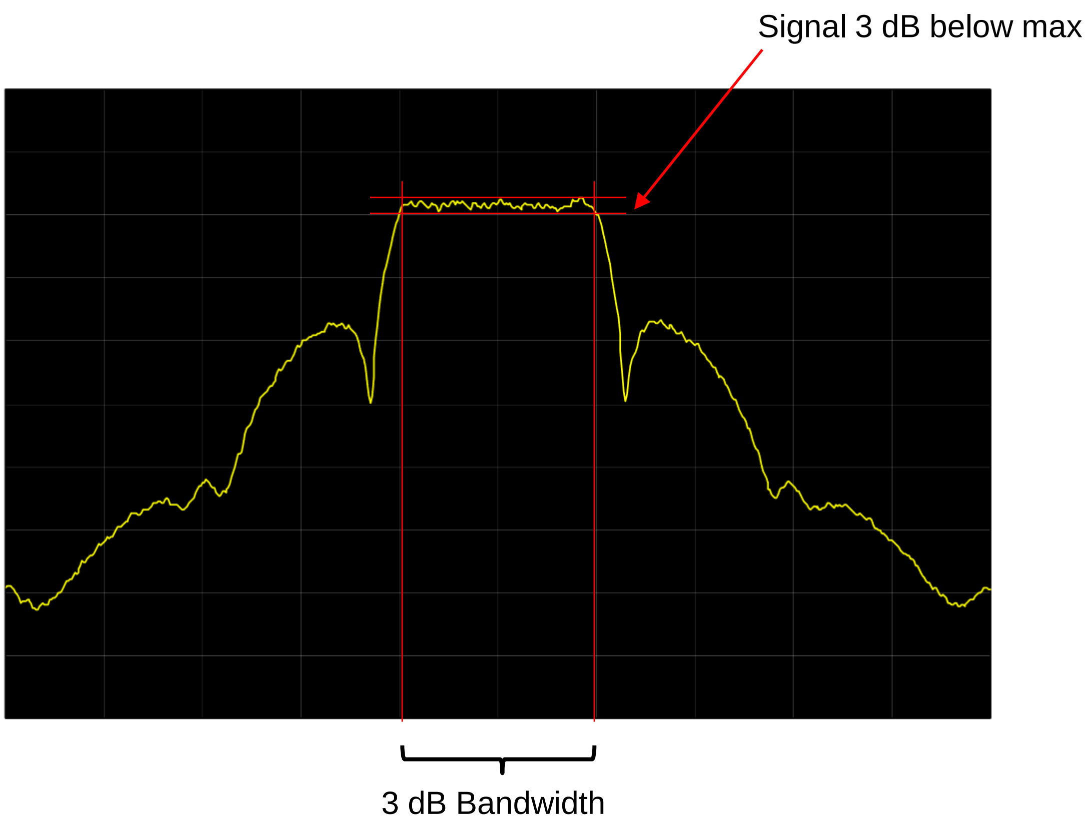
Digital Signal Transmission, cont.

- Bandwidth
  - Bandwidth is the amount of frequency spectrum occupied by a signal.
  - The precise definition of bandwidth depends on the context and application

What is the "Bandwidth" of this signal?

3 dB Bandwidth

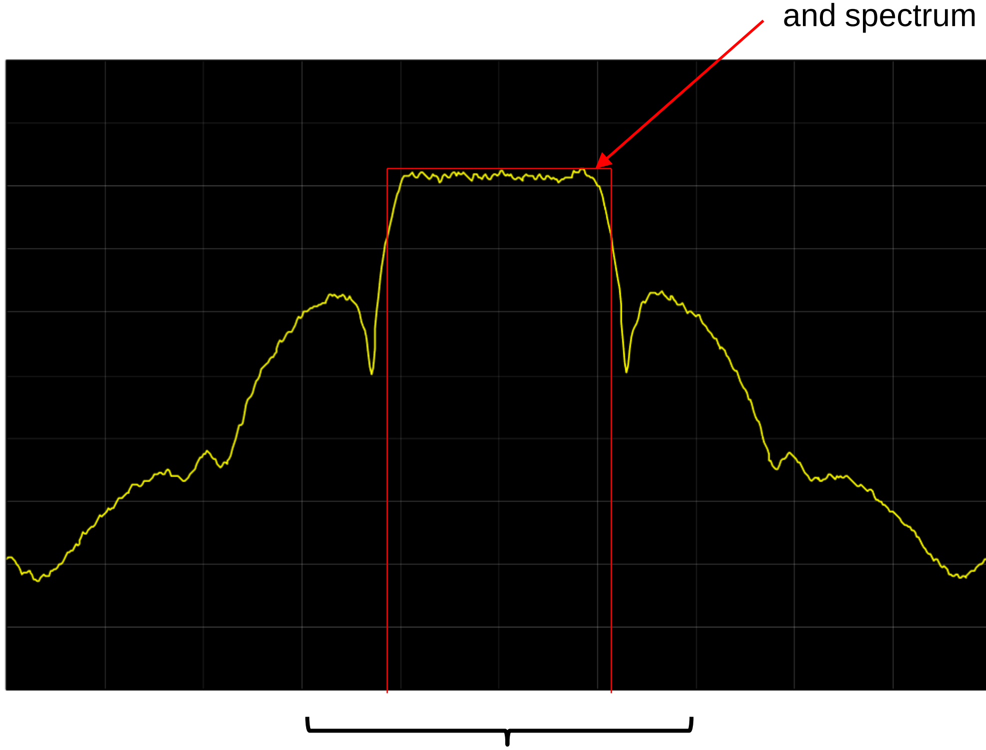
- Commonly used in receiver filter design
- There can be a lot of energy outside the defined band



What is the “Bandwidth” of this signal?

Noise Bandwidth

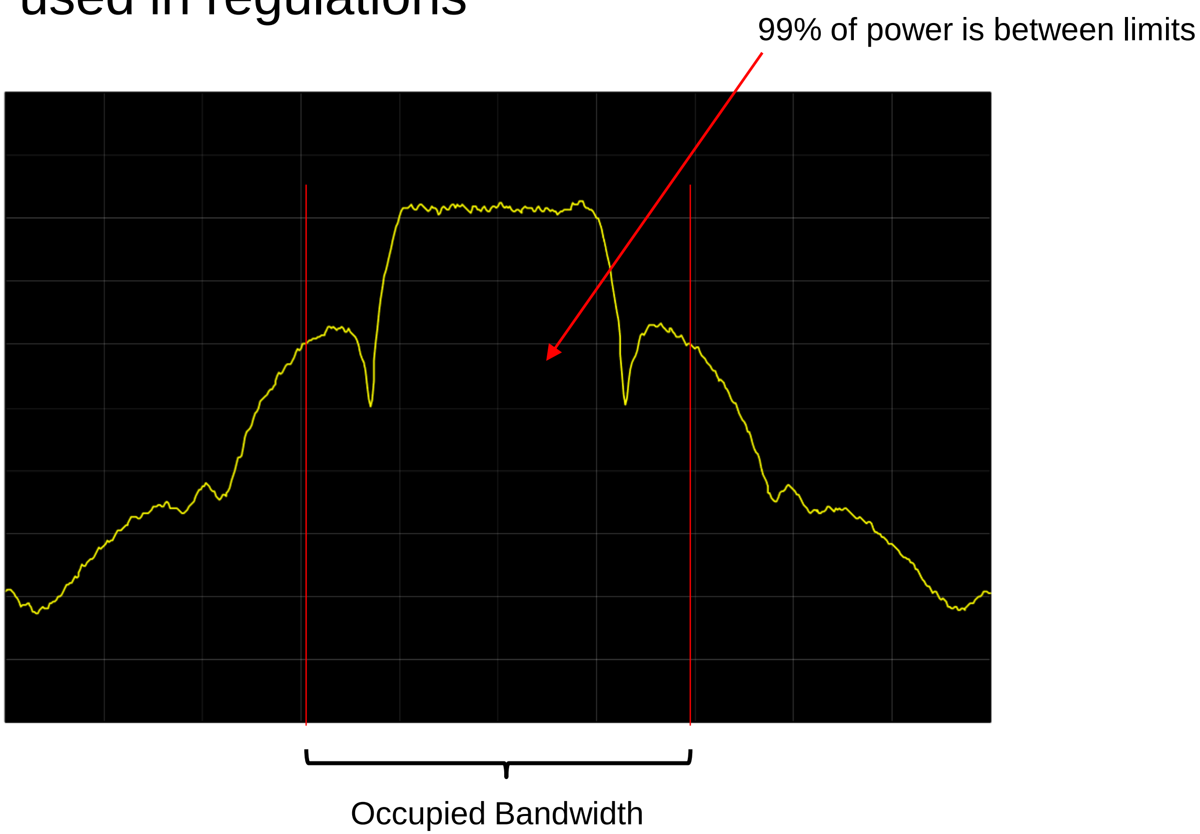
- All power falls between upper and lower limits and spectrum is flat
- Used in receiver sensitivity measurements



What is the “Bandwidth” of this signal?

99% Occupied Bandwidth

- 99% of all power falls between upper and lower limits
- Hard to measure, usually calculated from modulation parameters
- Commonly used in regulations

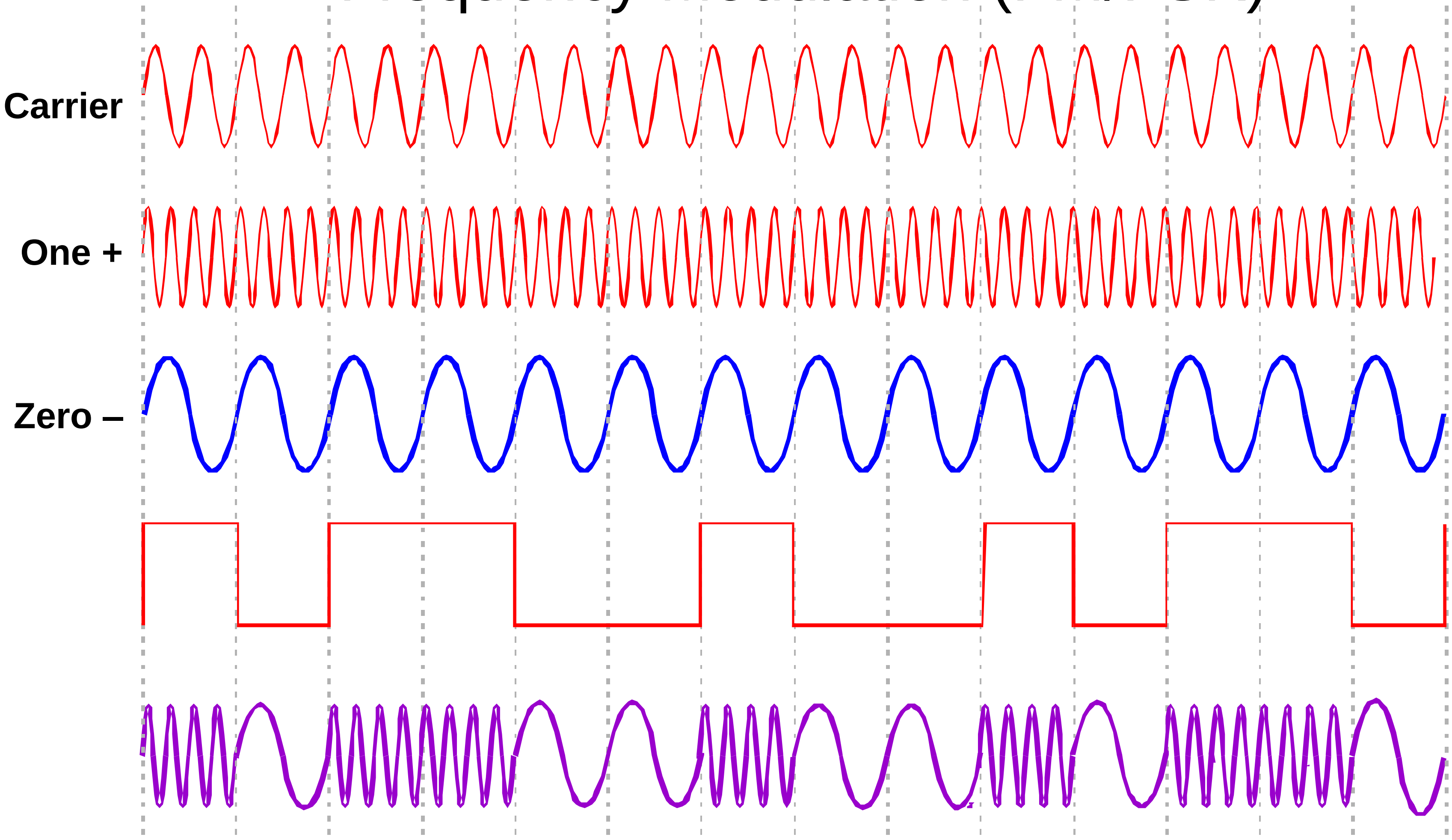


Digital Signal Transmission, cont.

- Modulation Techniques
  - An increasing voltage will cause an increase in the output power of an amplitude modulated (AM) transmitter.
  - An increasing voltage at the input of a frequency modulated (FM) transmitter will cause an increase in output carrier frequency.
  - An increase in voltage at the input of a phase modulated (PM) transmitter will cause advancement in the phase (i.e. left or right shift) of the output carrier.

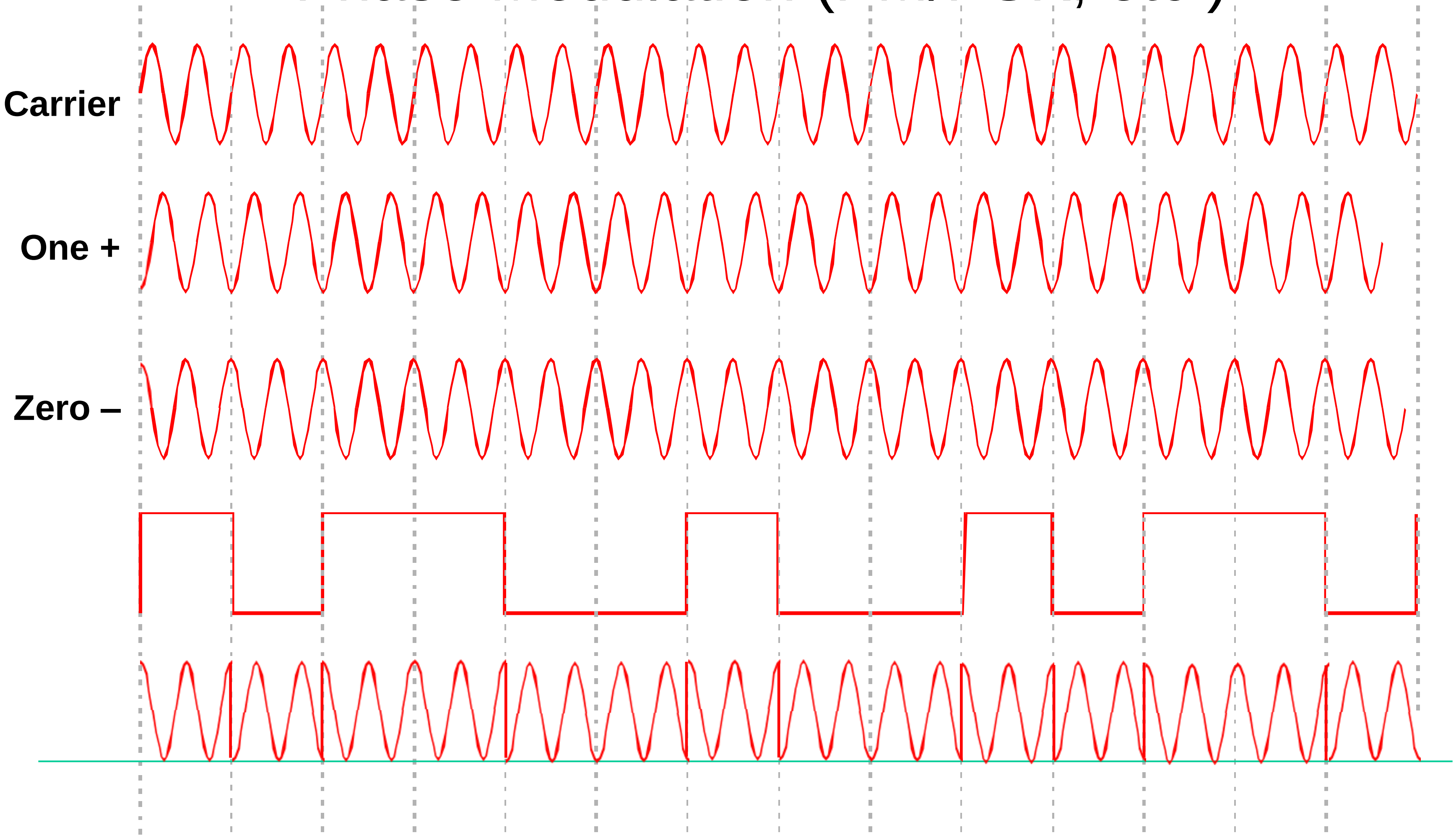
Digital Signal Transmission, cont.

Frequency Modulation (FM/FSK)



Digital Signal Transmission, cont.

Phase Modulation (PM/PSK, etc.)



Popular Modulation Types

- FM – Frequency Modulation
- PSK – Phase Shift Keying
- QPSK – Quadrature (i.e. 4 different shifts) Phase Shift Keying
- SOQPSK – Shaped Offset QPSK
- ARTM CPM - Continuous Phase Modulation

- In space applications, PSK and QPSK are preferred as they are more spectrally efficient.

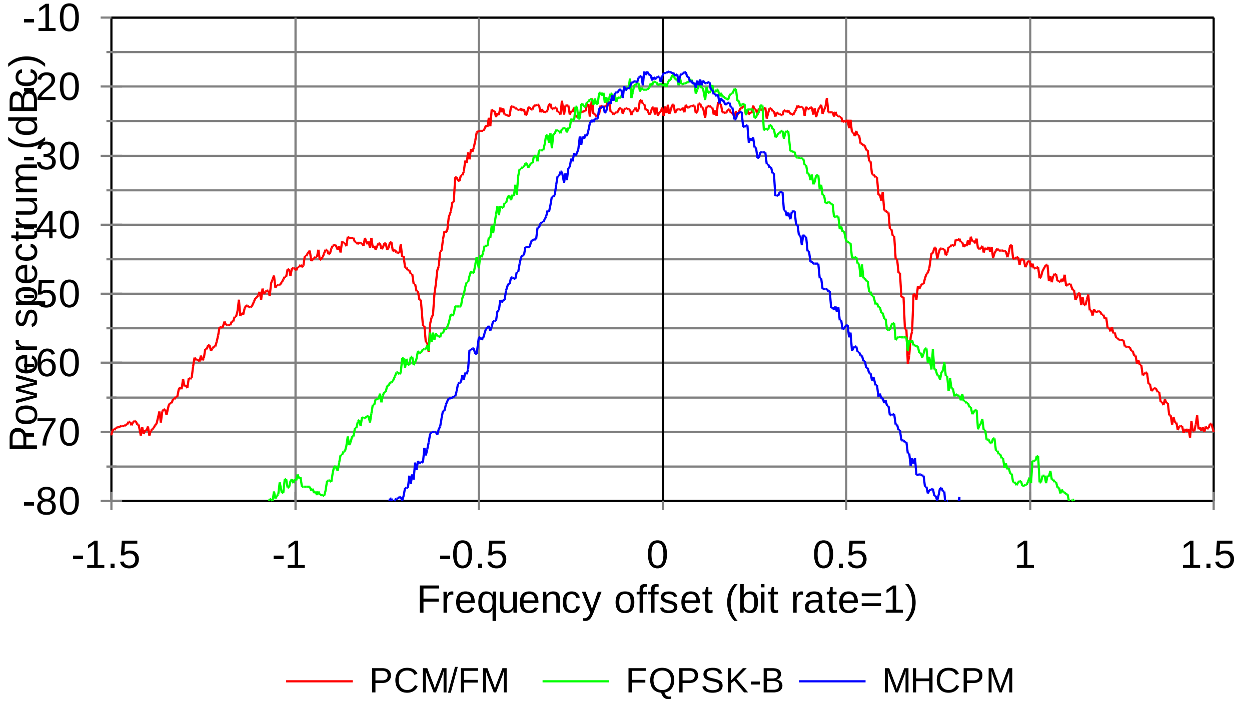
- In terrestrial applications, FM is preferred as it is more robust against dropouts. However, FM is very spectrally inefficient.

Popular Modulation Types

- **Tier 0 Modulation**
  - **A term used to reference the classical method of telemetering data which is PCM/FM.**
- **Tier 1 Modulation**
  - **A term used to group together a family of spectrally efficient waveforms, FQPSK-B, FQPSK-JR and SOQPSK-TG.**
- **Tier 2 Modulation**
  - **A term used to classify the most spectrally efficient modulation scheme ARTM CPM.**

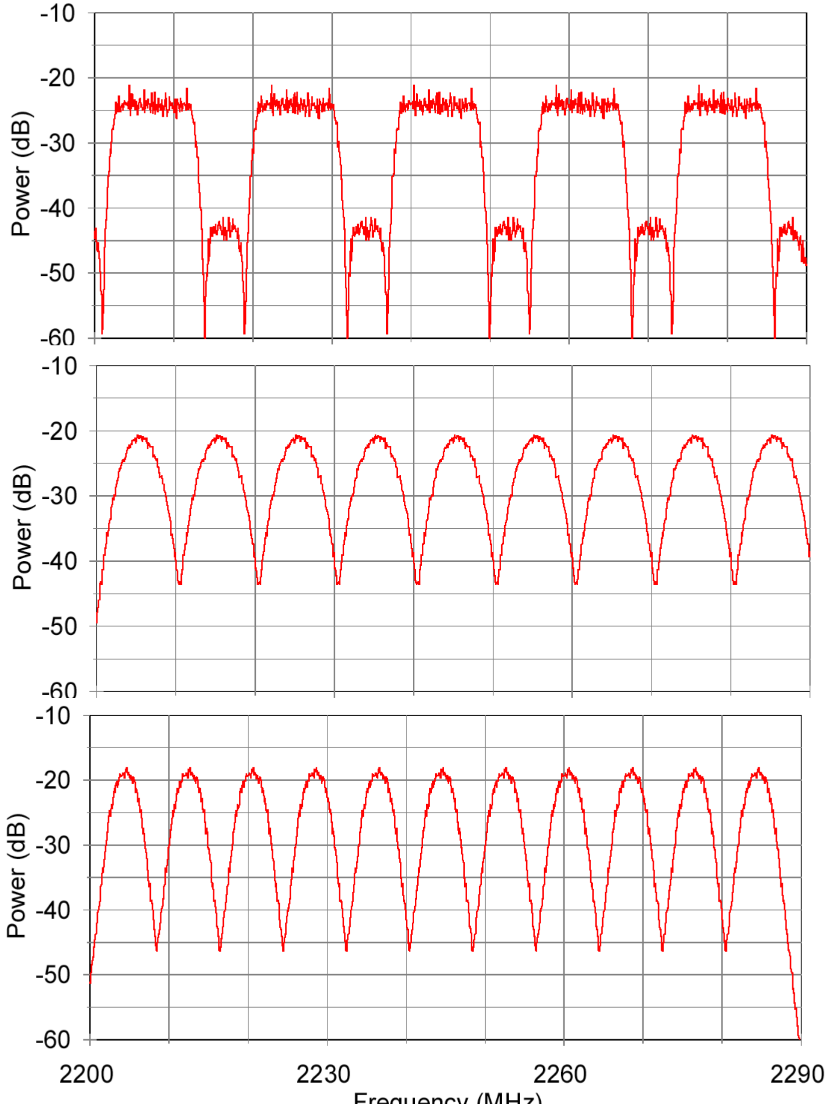
Popular Modulation Types, cont.

- Tier 0 – typical PCM/FM
- Tier 1 – FQPSK (proprietary) and SOQPSK
- Tier 2 – Multi-h CPM



Popular Modulation Types, cont.

Result:



- **PCM/FM**
- **5 Links**

- **SOQPSK**
- **9 Links**

- **CPM**
- **11 Links**

Popular Modulation Types, cont.

Considerations / Tradeoffs

- There are performance trade-off's with each type of modulation technique. Remember you don't get something for nothing.

Tier	Difficulty (Design)	Drop-Outs	Power for 10^{-6} BER	BW Req.	Code
0	Simple	100	Best	Good	All
1	Harder	10K-50K	Better	Better	RNRZ-L
2	Complex	1,000,000	OK	Best	RNRZ-L

Decibels

- **A Decibel (dB) is a ratio of two quantities**
  - **Signal “A” is 100 times stronger than Signal “B”**
    - 20 dB stronger
  - **The signal coming out of the cable is half the power of the signal going in**
    - 3 dB of loss
  - **Signal “A” is 20 times more than a milliwatt (i.e. 20 mW)**
    - Signal “A” is 13 dBm
  - **An antenna provides a signal 50 times stronger than you would get from an isotropic antenna**
    - Antenna gain is 17 dBi

Decibels

- **Decibel uses a base 10 logarithmic scale**
  - **More convenient for wide dynamic range**

  $10^X = Y$ log (Y) = X
- **Decibel**
  - **10 log (A/B)**

Some Examples

X/Y		Log		dB
100	$= 10^2$	log (100)	= 2	20 dB
10	$= 10^1$	log (10)	= 1	10 dB
1	$= 10^0$	log (1)	= 0	0 dB
1/10	$= 10^{-1}$	log (1/10)	= -1	-10 dB
1/100	$= 10^{-2}$	log (1/100)	= -2	-20 dB
2		log (2)	= 0.30103	3 dB
1/2		log (1/2)	= -0.30103	-3 dB

Common Decibel Quantities

- dB Unitless ratio
- dBm Power compared to 1 milliwatt
- dBW Power compared to 1 watt

30 dBm = 1 dBW

- dBi Antenna gain compared to isotropic antenna
- dBc Power level compared to center frequency

Receiver Systems

- **Receiver receives RF energy from the transmitter and converts it to signal that can be decoded**
- **Receiver setup must match transmitter**
  - **Frequency**
  - **Modulation**
  - **Bandwidth**

Receiver Systems

Receiver Figures of Merit

- **Sensitivity - What is the weakest signal that can be received**
- **Selectivity - How good is the receiver at passing wanted signals and rejecting unwanted signals**
- **Noise Figure - How much additional noise does the receiver add to the received signal**
- **Linearity - Related to how well the receiver rejects strong unwanted signals.**

Receiver Systems

Receiver Sensitivity

- **Sensitivity depends on receiver bandwidth**
- **Receiver Thermal Noise Power is calculated**

$$P_n = kTB$$

where P_n **is power (watts)**

k **is Boltzmann constant**

T **is Noise Temperature (K)**

B **is bandwidth (Hz)**

Bandwidth (Hz)	Thermal Noise Power (dBm)
1 Hz	-174
10 Hz	-164
100 kHz	-124
1 MHz	-114
5 MHz	-107
10 MHz	-104
20 MHz	-101

Receiver Systems

Receiver Noise Figure

- **Noise figure is additional noise added by the receiver above thermal noise**
- **2 to 4 dB is typical**

Bandwidth (Hz)	Thermal Noise Power (dBm)	With 3 dB Noise Figure (dBm)
1 Hz	-174	-171
10 Hz	-164	-161
100 kHz	-124	-121
1 MHz	-114	-111
5 MHz	-107	-107
10 MHz	-104	-101
20 MHz	-101	-98

Receiver Systems

Minimum Detectable Signal

- Detecting and demodulating a signal requires a signal stronger than the noise floor (i.e. signal power margin)
  - Signal to Noise Ratio (SNR)
- More SNR means a better demodulated signal
  - Bit Error Rate (BER) depends on SNR
  - Around +10 dB SNR is a reasonable minimum

Bandwidth (Hz)	Thermal Noise Power (dBm)	With 3 dB Noise Figure (dBm)	Minimum Signal (dBm)
1 Hz	-174	-171	-161
10 Hz	-164	-161	-151
100 kHz	-124	-121	-111
1 MHz	-114	-111	-101
5 MHz	-107	-107	-97
10 MHz	-104	-101	-91
20 MHz	-101	-98	-88

RF Cable Loss

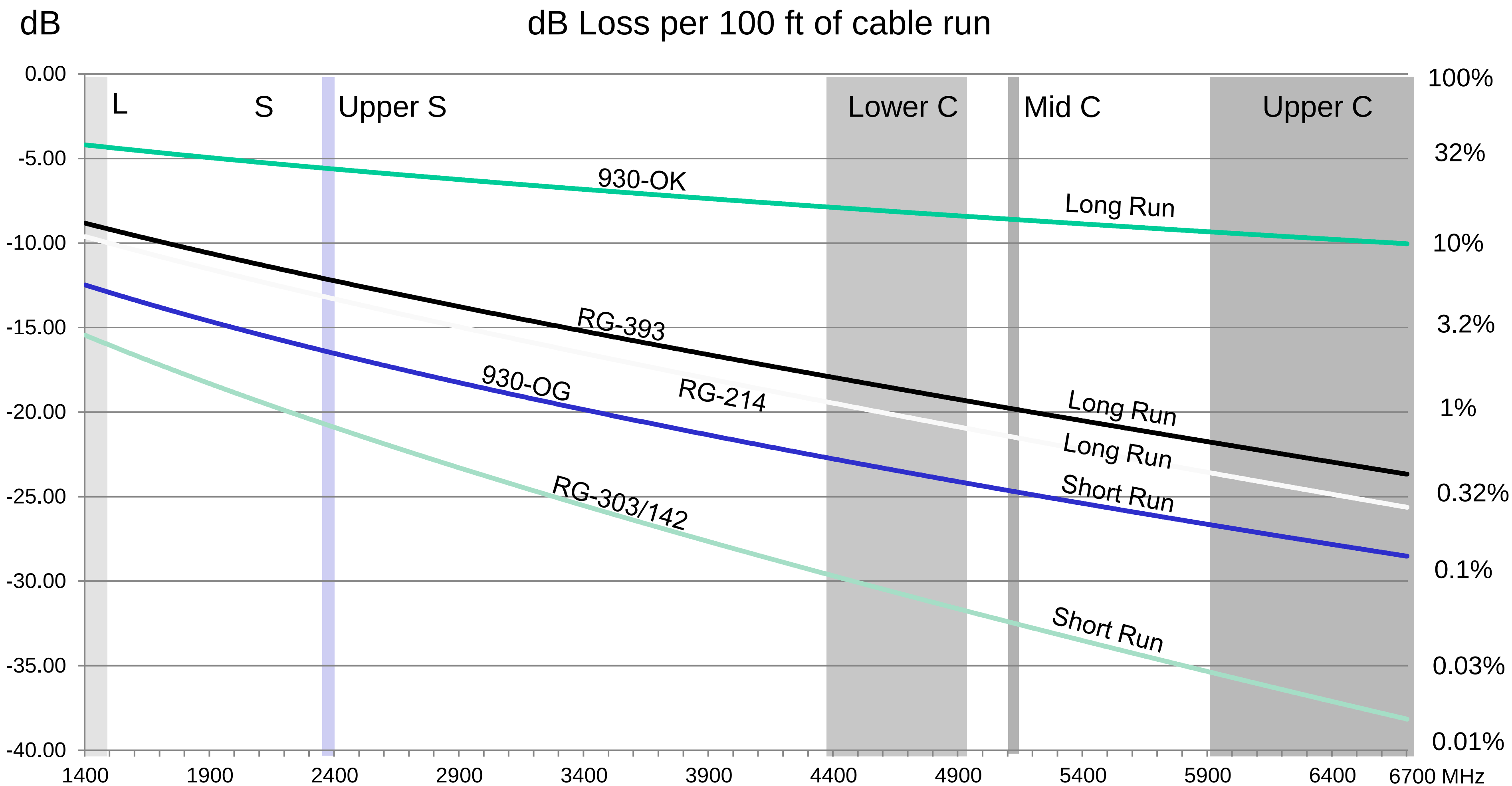
The attenuation of an RF cable at any frequency is determined by the equation:

$$\alpha = k_1\sqrt{f} + k_2 f$$

where…
α is the attenuation in dB/100ft
k_1, k_2 are the attenuation constants for a particular cable
f is the center frequency in MHz

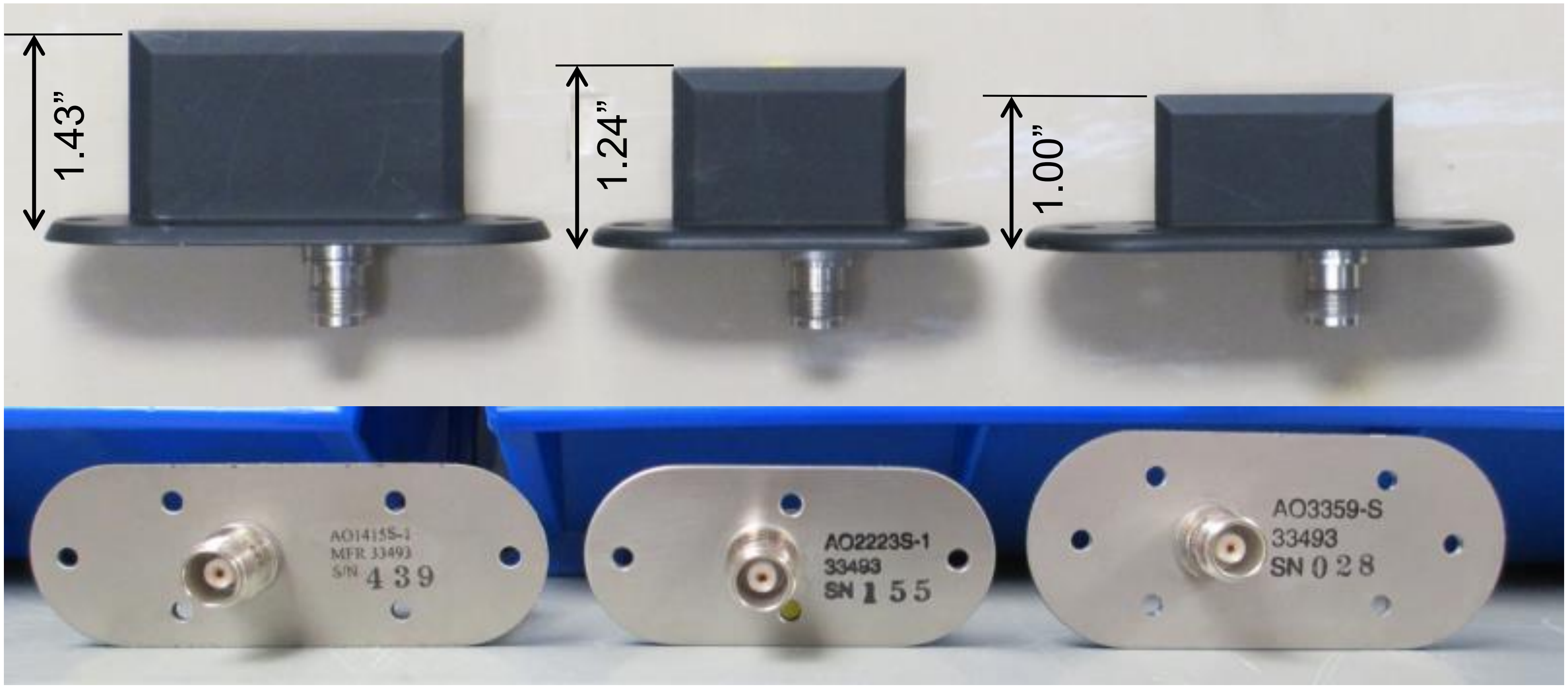
Cable Type	k1	k2
RG-303/142	0.368	0.0012
RG-393	0.191	0.0012
RG-214	0.210	0.00126
930-OG	0.321	0.000336
930-OK	0.103102	0.000239

RF Cable Frequency Response



The graph shows the dB loss per 100ft for each of the RF cable types in each of the telemetry bands. Larger diameter cable also has lower losses than the thinner cable which is why they are used for longer runs in the aircraft.

Antennas



L-Band Antenna
1.35 - 1.9 GHz

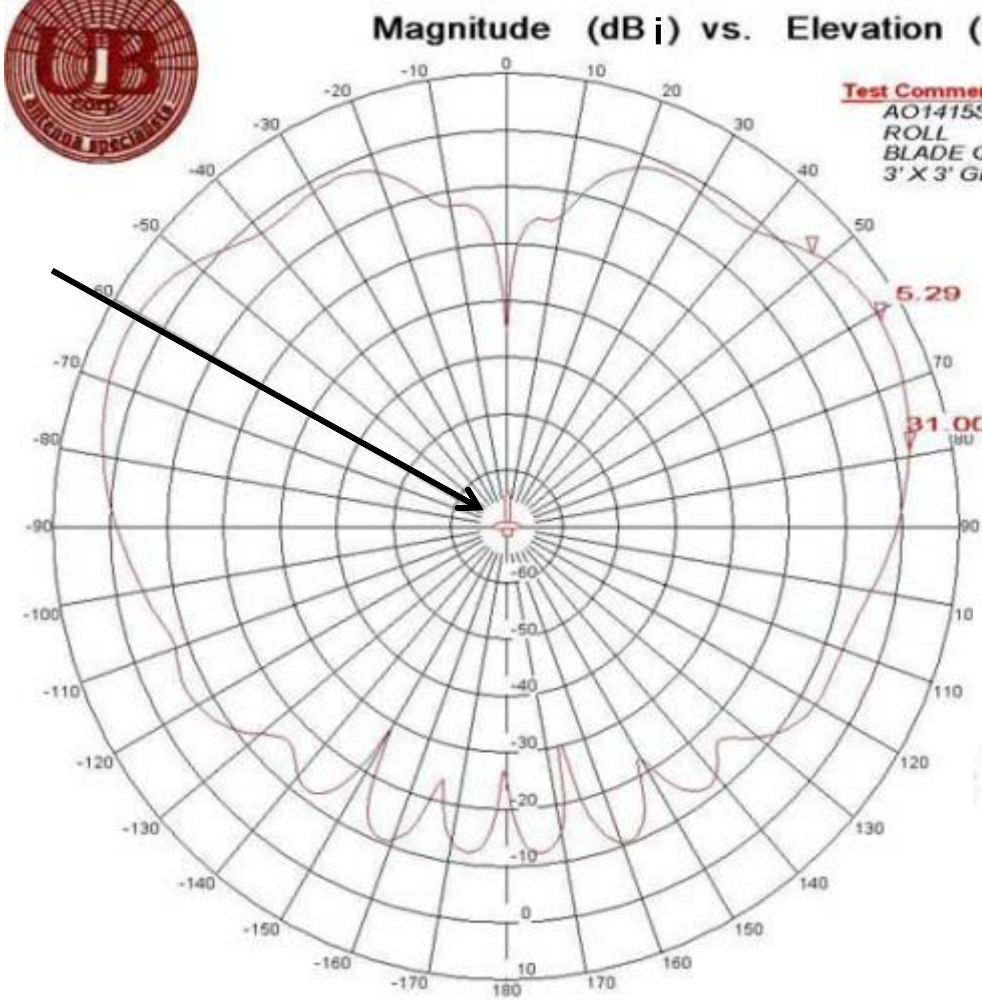
S-Band Antenna
2.2 - 2.4 GHz

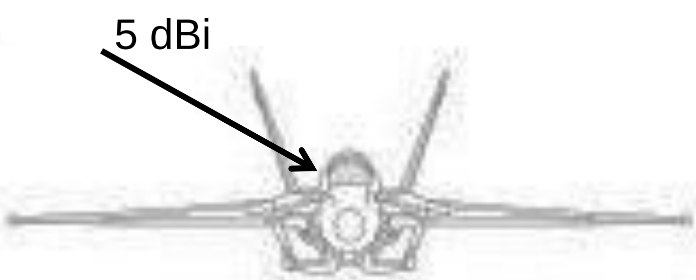
C-Band Antenna
3.0 – 6.0 GHz

Higher frequencies have shorter wavelengths, which result in shorter antenna heights. Make sure the appropriate antenna is used for the frequency band used.

Antenna Patterns

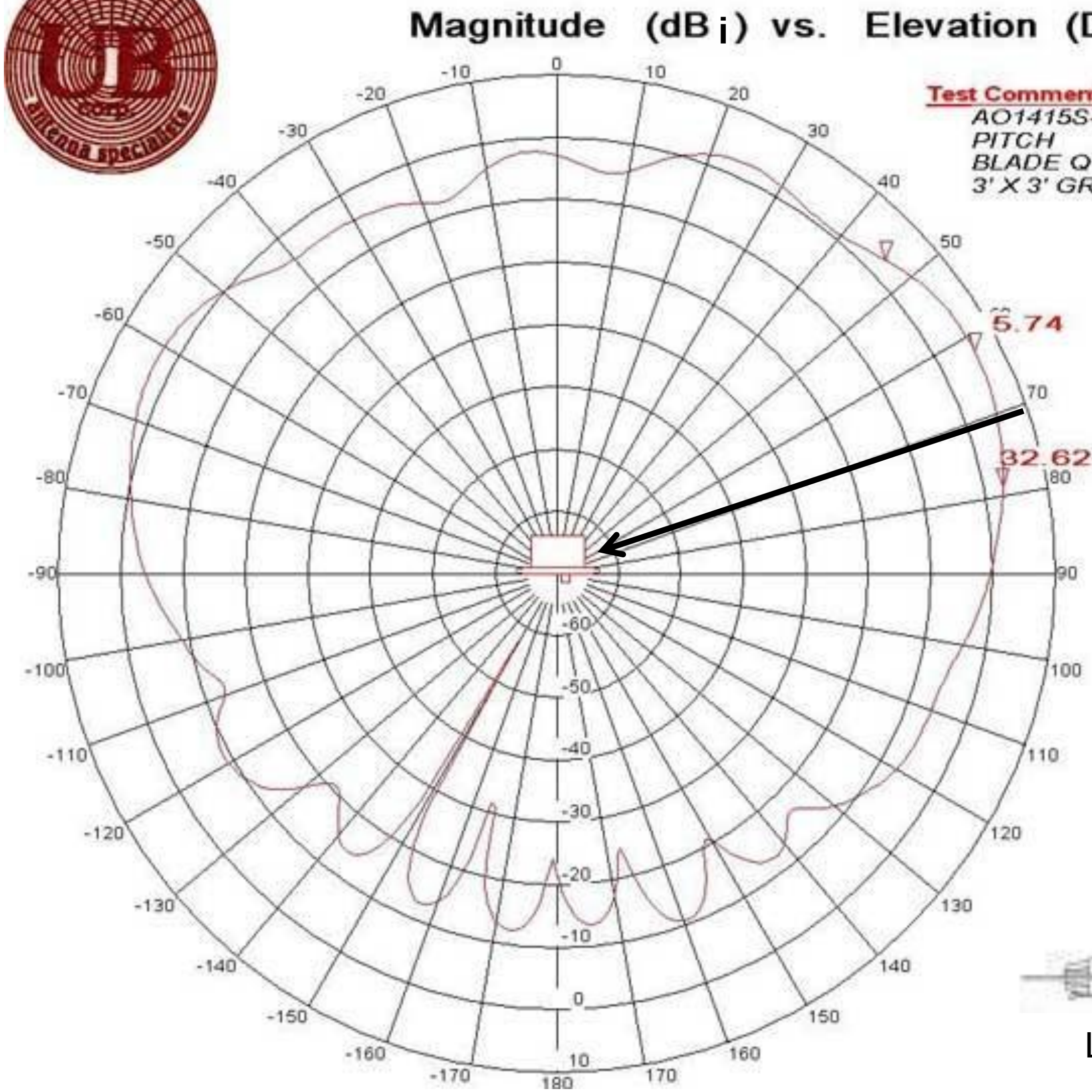
This and the following slide shows the antenna patterns for the AO1415S-1 (L-band antenna). The antenna gain is shown in both the ROLL and PITCH elevations. The units dBi refer to an isotropic (or point) source.



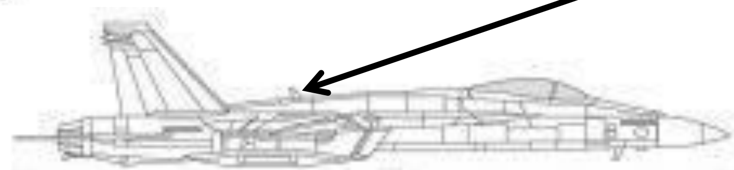


Looking towards the nose of the aircraft

Antenna Patterns



5 dBi

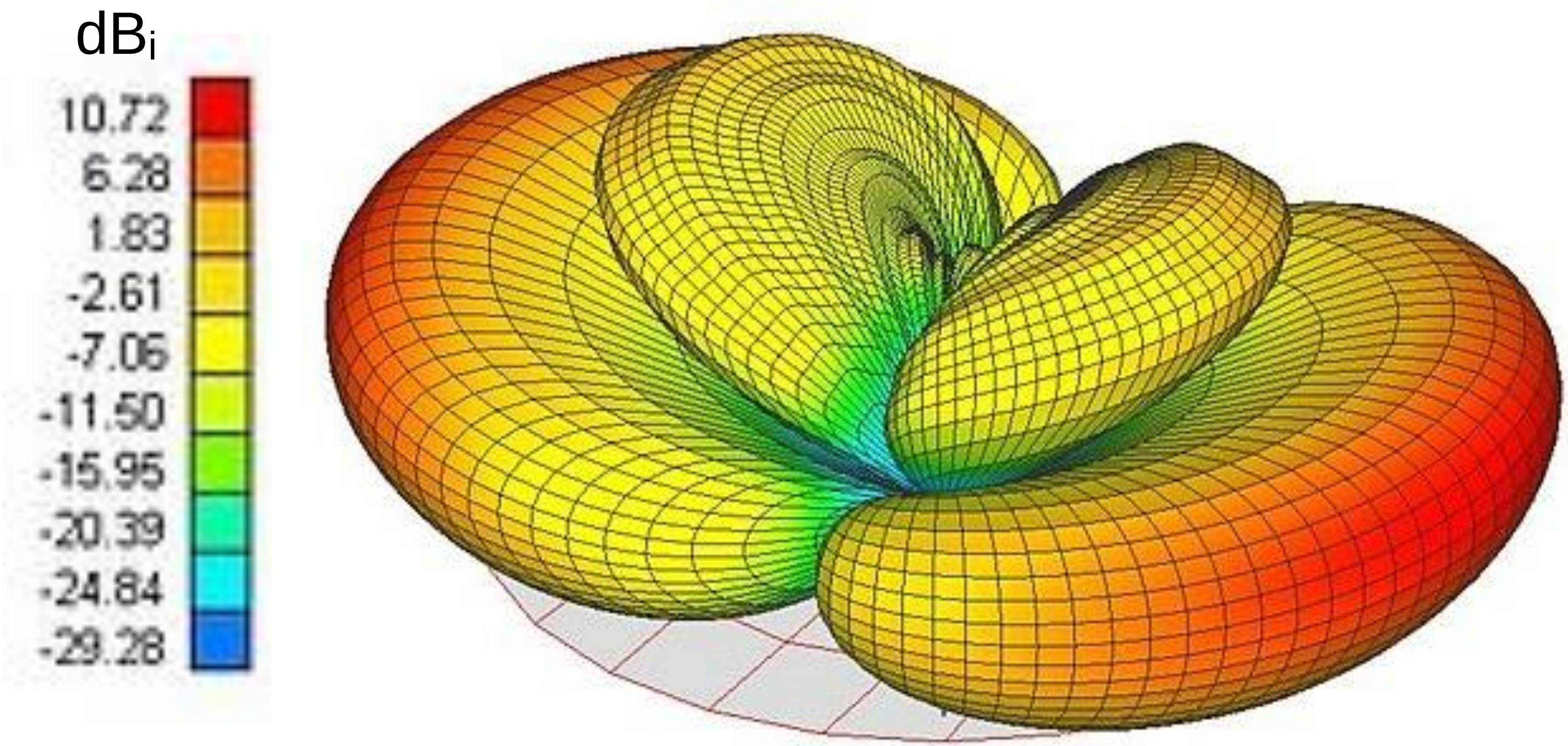


Looking towards the side of the aircraft

Antenna Patterns

Sometimes it is difficult to visualize the antenna strength from two dimensional plots. This plot shows an antenna pattern in three dimensions.

dB$_i$



Link Budget

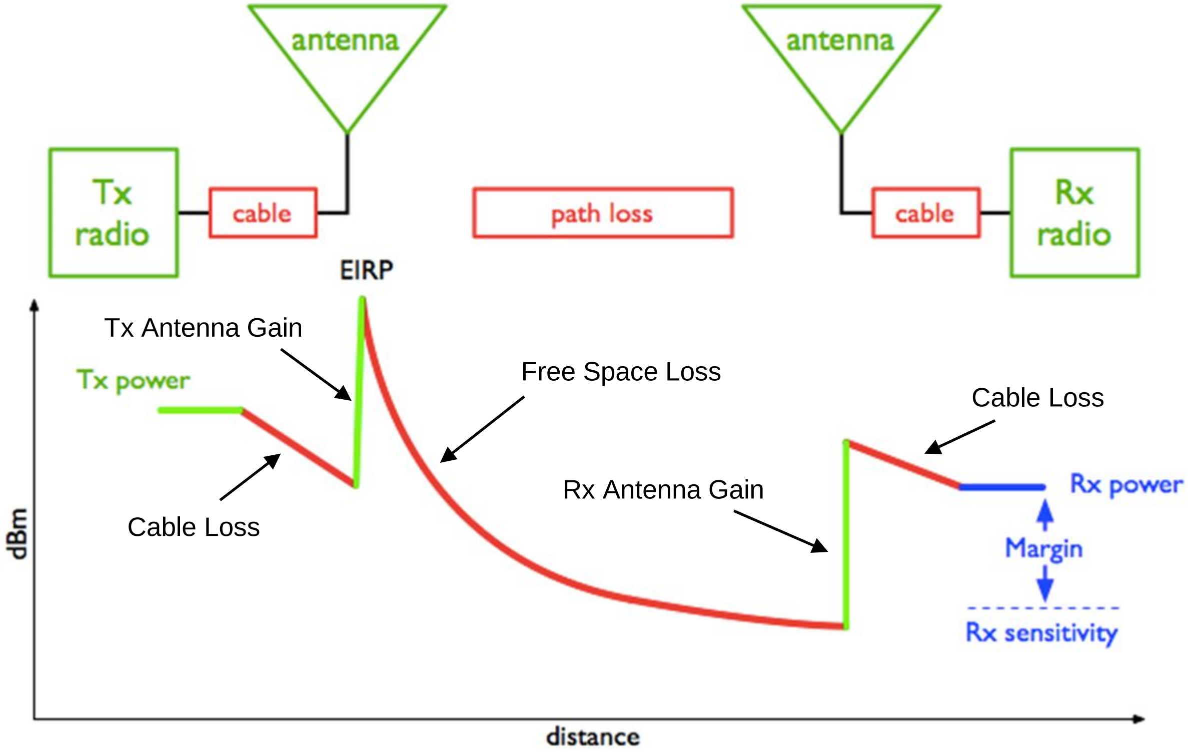
A link budget accounts for all the power gains and losses in a system to insure sufficient signal power at the receiver.

There are many components within the system that will affect the receiver power:

- Antenna Gains
- Cable – attenuation determined by cable type and center frequency
- Connectors – contribute -0.1dB for each connector (a barrel connector will count as two connectors)
- Splitter – divides the power to each output.
- Distance

Draw out your telemetry system and determine the drops along each element of the system.

Link Budget



Tx Power + Gains − Losses = Rx Power

Free Space Path Loss

- **Free Space Path Loss depends on**
  - **Frequency**
  - **Distance**

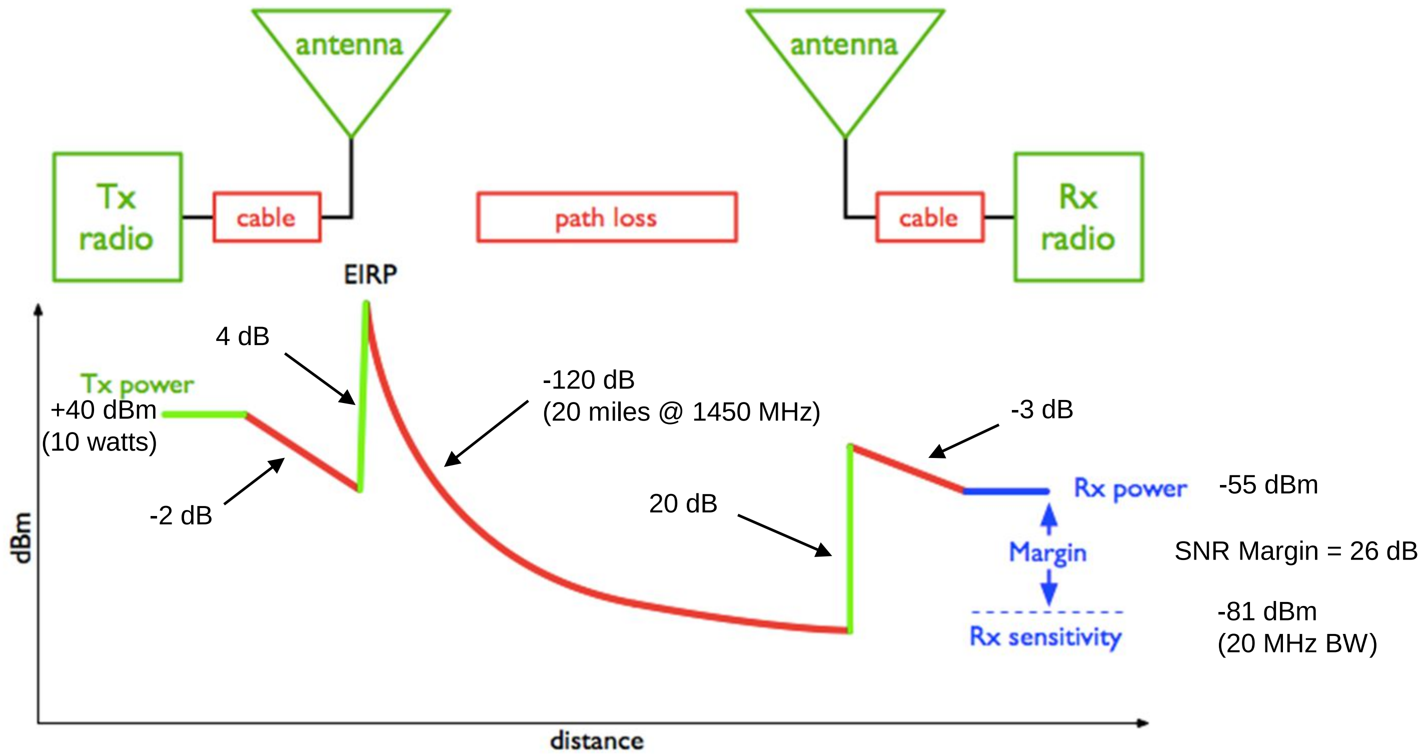
$$L_{db} = 20log_{10}\left(\frac{4\pi d}{\lambda}\right)$$

- **Loss can be estimated by**

$$L_{db} = 36.6 + 20log_{10}D(miles) + 20log_{10}F(MHz)$$

	1450 MHz	2300 MHz
5 Miles	114 dB	118 dB
500 Miles	154 dB	158 dB

Link Budget – An Example



+40 dBm – 2 dB + 4 dB – 120 dB + 20 dB – 3 dB = -55 dBm

For 20 MHz bandwidth minimum signal level is -81 dBm
SNR = (-55 dBm) – (-81 dBm) = 26 dB

State of the art …

- Classic PCM/FM will continue to be the workhorse for years to come, however…
- The newer more spectrally efficient modulations are prevalent due to increased TM data requirements:
  – Tier 1: SOQPSK – In common use
  – Tier 2: MhCPM – Not commonly used
- TM Receivers will continue to shrink in size (14” rack mount box with 4 receivers and 2 diversity combiners)
- Much more integration with
  – Integral Bit Sync
  – Ethernet Network (TMoIP)