The case for Multiple MCS

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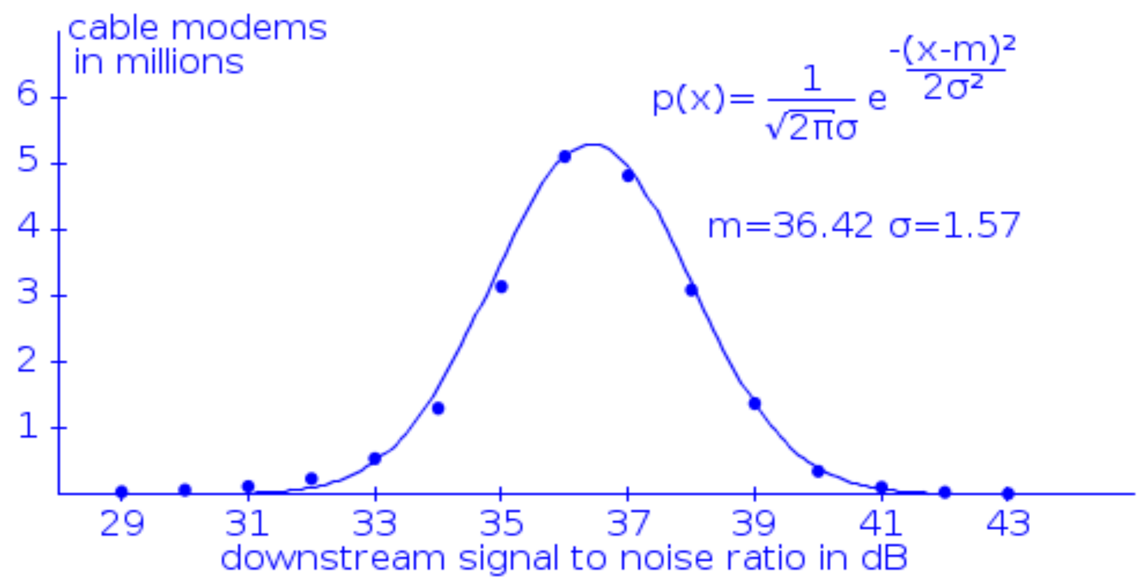
Histogram of Downstream SNR measured by 20 million cable modems

- The solid dots are measured values
- The dot at 36 dB shows that a little over 5 million cable modems reported a downstream SNR of 36 dB
- The bin size for the histogram was 1 dB
- The solid line is a gaussian distribution with mean and standard deviation shown



percent cable modems with 15 dB to 29 dB is 0.1%
these modems assigned 256-QAM LDPC .9 24 dB threshold

percent cable modems 30 dB 31 dB or32 dB is 2.0%
these modems assigned 512-QAM LDPC .9 27 dB threshold

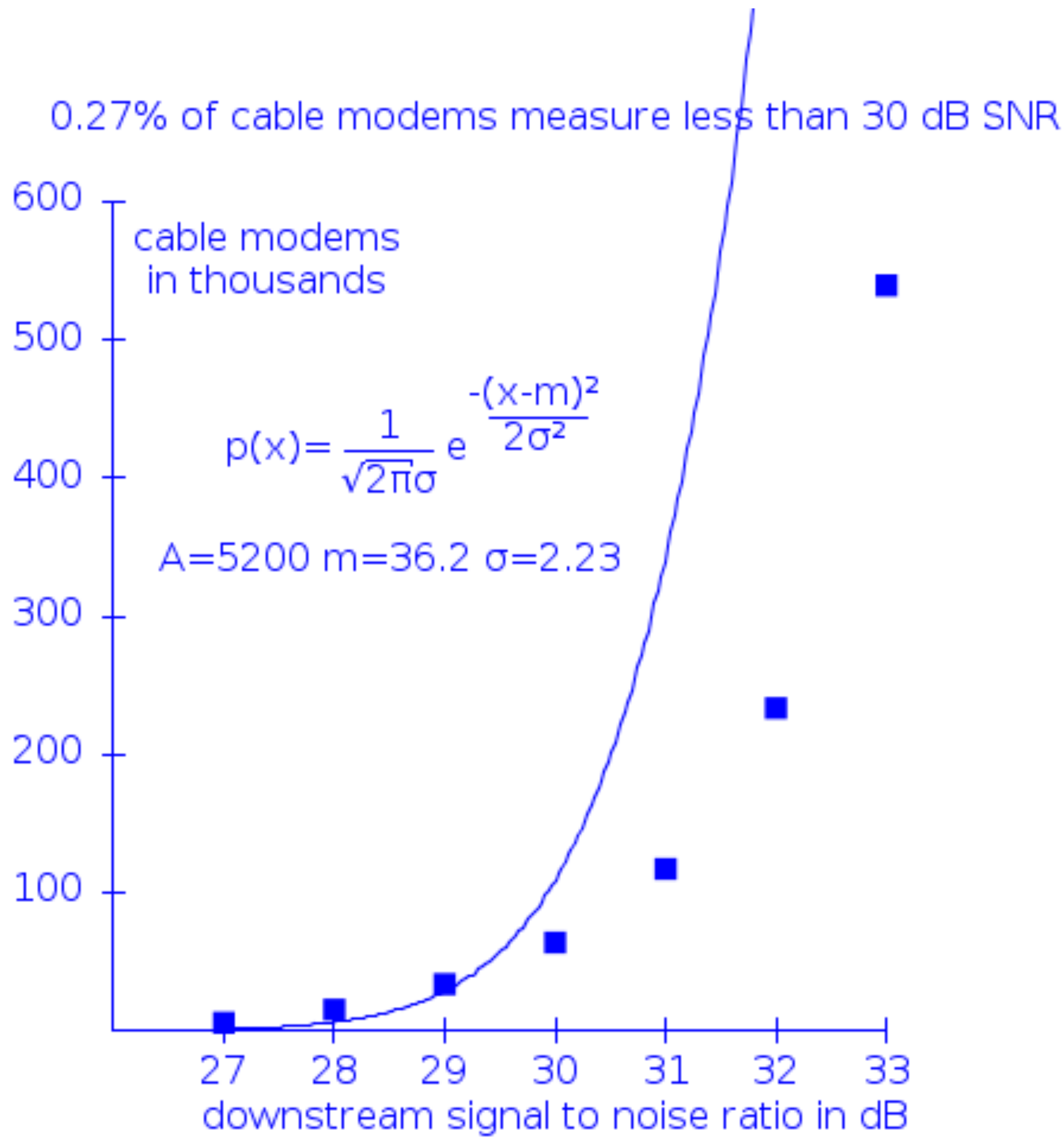
percent cable modems 33 dB 34 dB or 35 dB is 24.5%
these modems assigned 1024-QAM LDPC .9 30 dB threshold

percent cable modems 36 dB 37 dB or 38 dB is 64.0%
these modems assigned 2048-QAM LDPC .9 33 dB threshold

percent cable modems 39 dB 40 dB or 41 dB is 8.96%
these modems assigned 4096-QAM LDPC .9 36 dB threshold

J.83B efficiency is 7.1 bps/Hz
adaptive OFDM 0.9 LDPC efficiency is 9.967 bps/Hz, up 40%
192 MHz channel width,
32 J.83B QAMs at 38.8 Mbps has a total data rate of 1,242 Mbps
14,816 OFDM data subcarriers with 82.5 µs
OFDM LDPC adaptive data rate is 1,790 Mbps

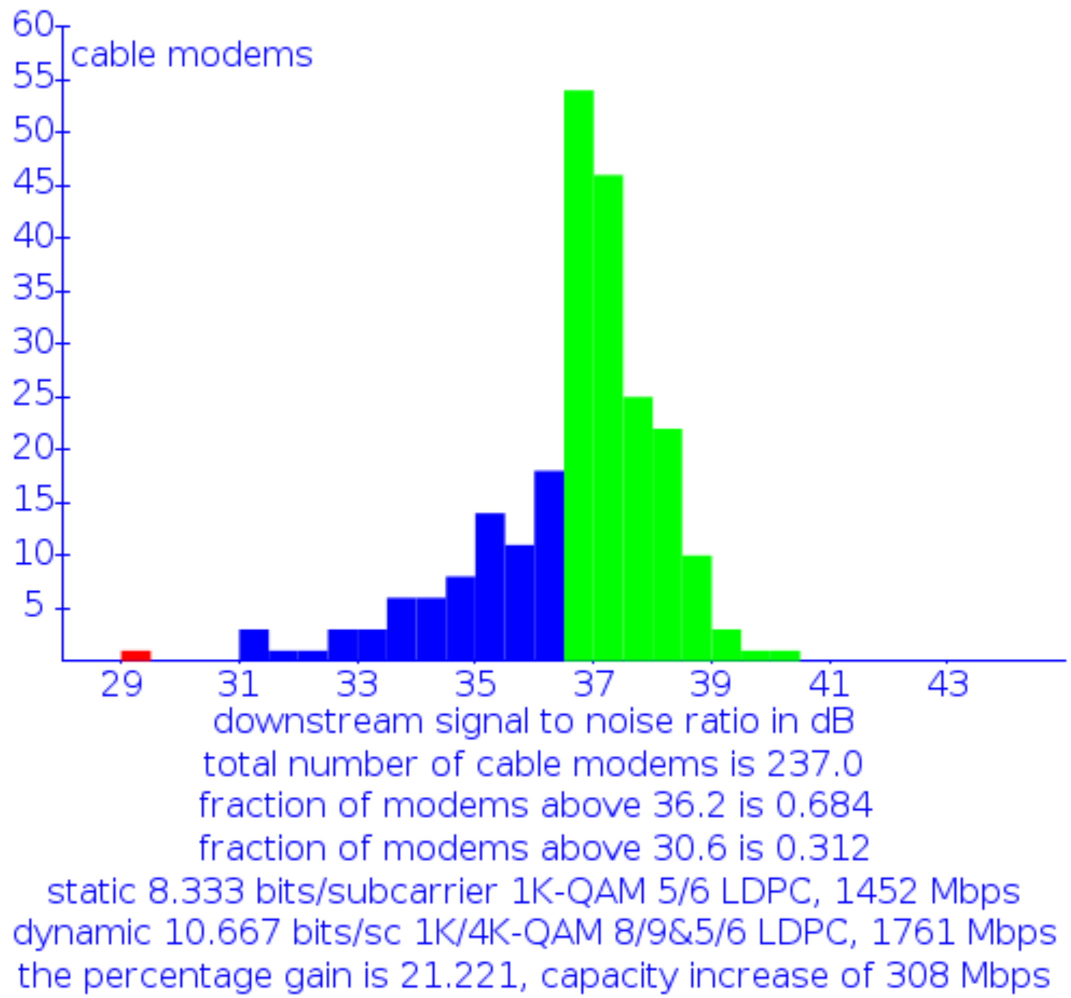
- The mean of 36.42 dB and standard deviation of 1.57 dB fit well with SNR above 33 dB
- But these values underestimate the number of modems below 30 dB SNR
- A mean of 36.2 dB and a standard deviation of 2.23 dB gives a better estimate for 27, 28, and 29 dB SNR
- Perhaps a two step model should be used



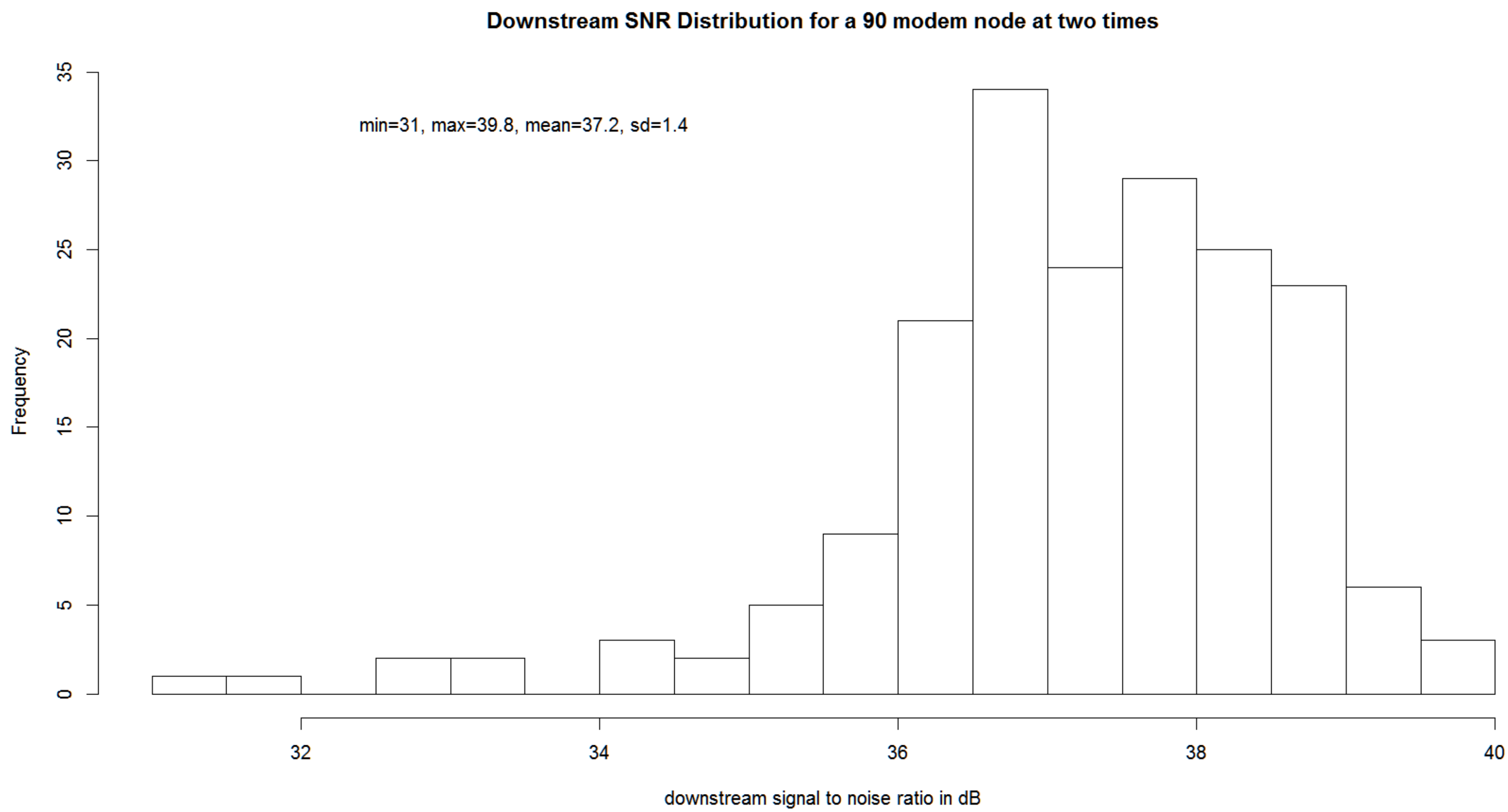
How many cable modems have 40 dB SNR?

- 2.4% of cable modems have SNR 40 dB or better
- 97.6% of cable modems report SNR less than 40 dB
- Since a small percentage of modems have SNR below 33 dB and a small percentage of modems have SNR above 40 dB, a single modulation and coding scheme will either lose many modems or under utilize many modems
- Static 4096-QAM would appear to lose at least a quarter of all modems
- For a single modulation and coding scheme even going above 256-QAM RS would lose some modems
- 1024-QAM with high rate LDPC may be the highest static MCS possible

Does it hold for a node? Yes



Distribution for a single node



How about just Gateway Data?

- A sample of 16.8 million set top boxes showed an average SNR of 35.5 dB with a standard deviation of 1.95 dB
- A sample of 1.9 million D2 MTAs showed an average level of -0.38 dBmV, median level of -0.2 dBmV, level standard deviation of 5.75 dB, average SNR of 37.51 dB, median SNR of 37.6 dB, SNR standard deviation of 1.47 dB
- So STBs which are more dependent on home wiring have about 2 dB lower average SNR and a half dB higher standard deviation

The need for Multiple MCS

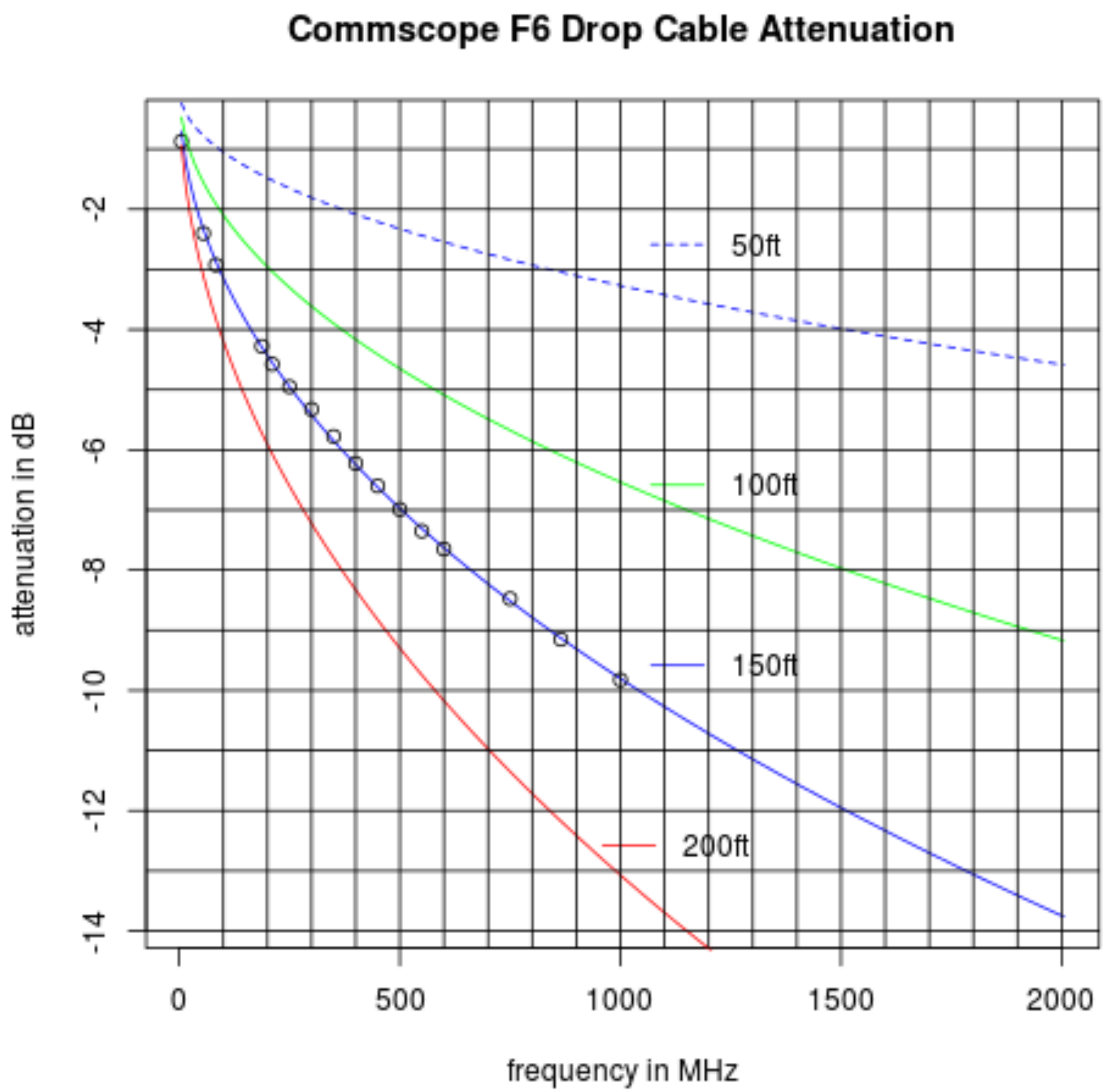
- The objective is to get very high data rates over coaxial cable on par with fiber
- Gbps service over coax requires high spectral efficiency
- Transmit power is limited
- Loss over coax increases with frequency
- 4K-QAM with LDPC has 11 bps/Hz with 36 dB SNR threshold
- We want to have most modems running 4K-QAM at launch with this number going up over time
- We do not want to be prevented from offering 4K-QAM to a customer who needs it because of a low level or interference from a customer that can operate fine at lower modulation

Variation in optimum Modulation and Coding Schemes amongst cable modems on a fiber node

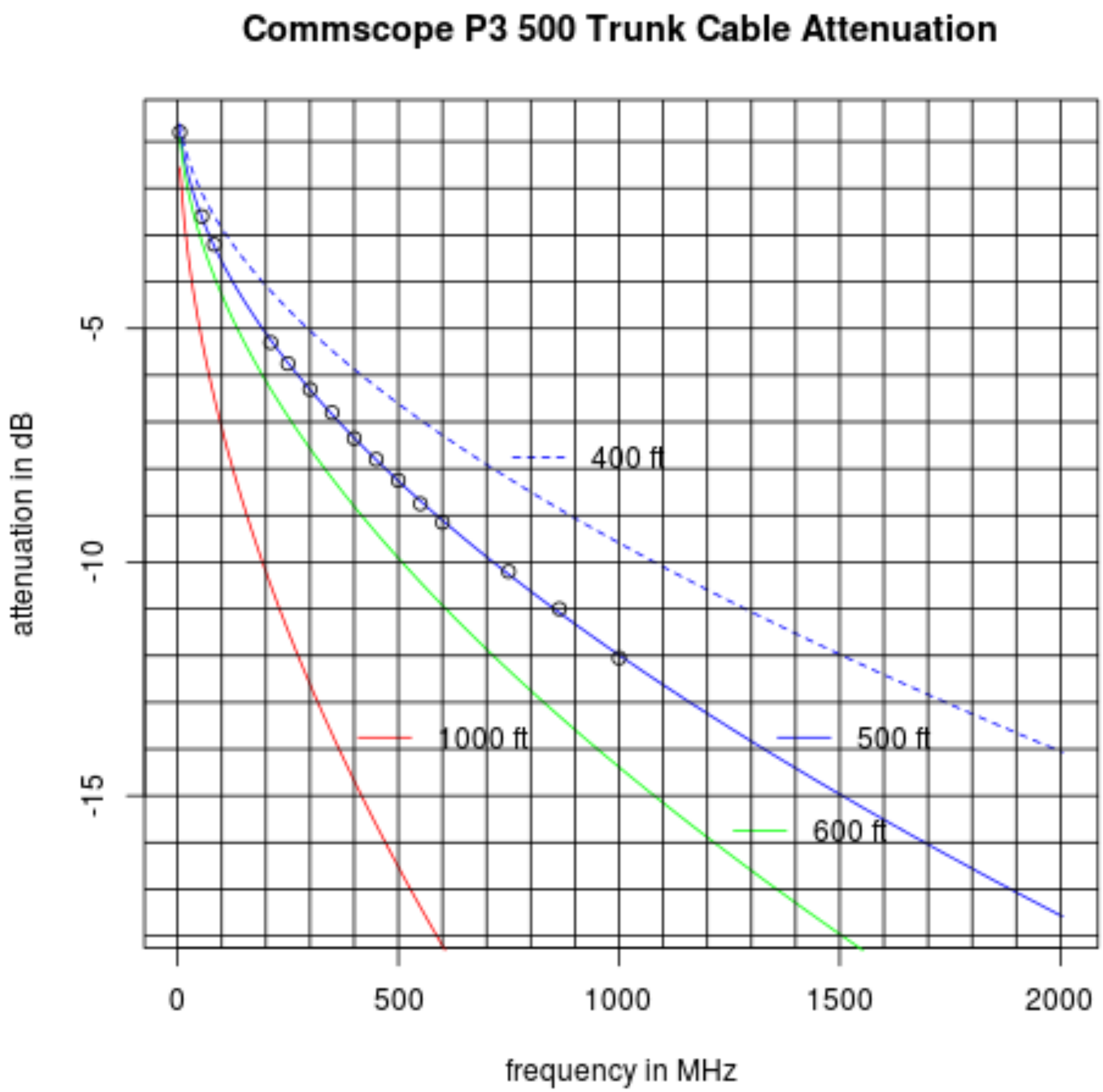
- The length of the cable drop will vary
- The length of the trunk cable will vary
- The receiver parameters such as gain and noise figure will vary
- The reflections will vary (short CP)
- In home splitters, cable length and quality will vary (self install)

HFC network

- A long cascade under worst case conditions may have an analog SNR of 48 dB and digital SNR of 42 dB
- Using the noise figure and minimum input level specifications of a typical amplifier, the QAM signal level to amplifier cascade noise level for N +6 is 57 dB analog and 50 dB QAM
- Thus, even for N+6 the amplifier cascade is designed to have a negligible impact of cable modem SNR distribution for 256-QAM

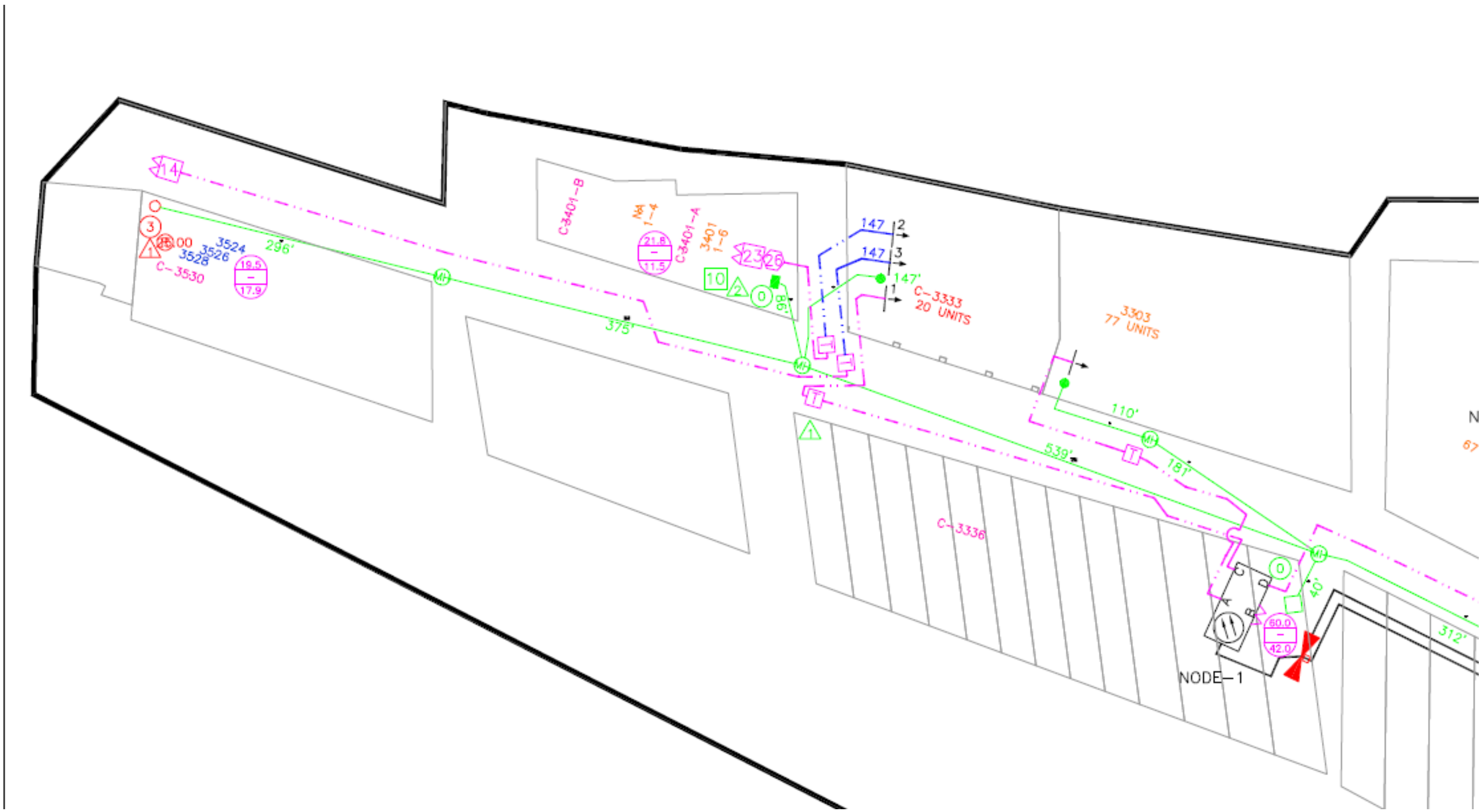


Commscope F6 Drop Cable Attenuation
50ft
100ft
150ft
200ft
attenuation in dB
-2
-4
-6
-8
-10
-12
-14
frequency in MHz
0
500
1000
1500
2000



Commscope P3 500 Trunk Cable Attenuation
400 ft
1000 ft
500 ft
600 ft
-5
-10
-15
attenuation in dB
0
500
1000
1500
2000
frequency in MHz

Node + 0 network architecture
Trunk cable is about 1000 feet to end of line, loss of 20 dB at 750 MHz, 2 µs echo
High frequency level is 60 dBmV at fiber node output and 19.5 dBmV at end of line
Low frequency level is 42 dBmV at fiber node output and 19.9 dBmV at end of line



Product Consistency Distribution Charts [6, 7]

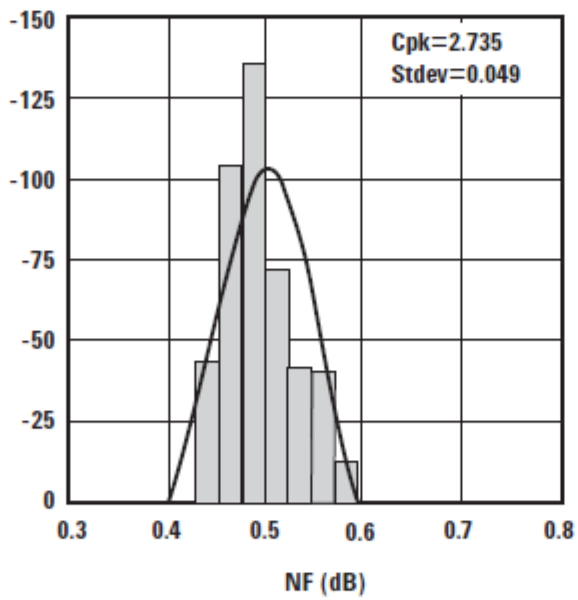


Figure 2. NF @ 3V, 30 mA.
USL = 0.9, Nominal = 0.5

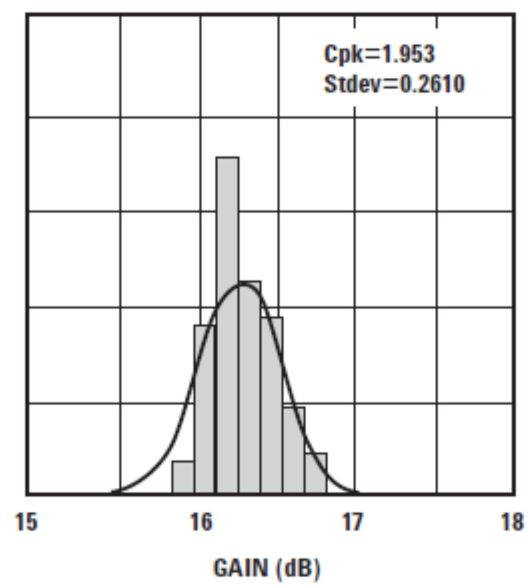


Figure 3. Gain @ 3V, 30 mA.
USL = 18.5, LSL = 15, Nominal = 16.5

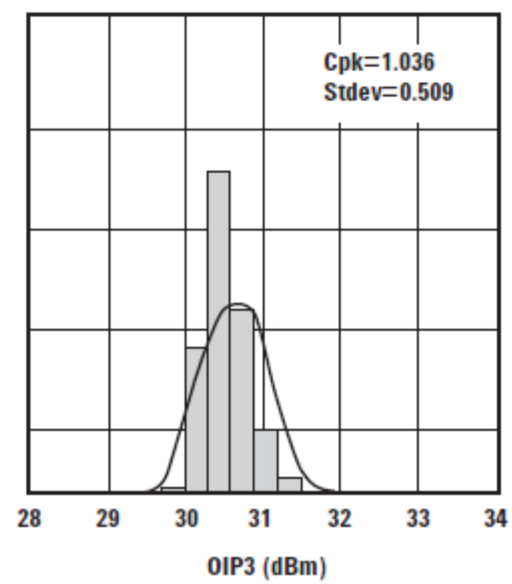
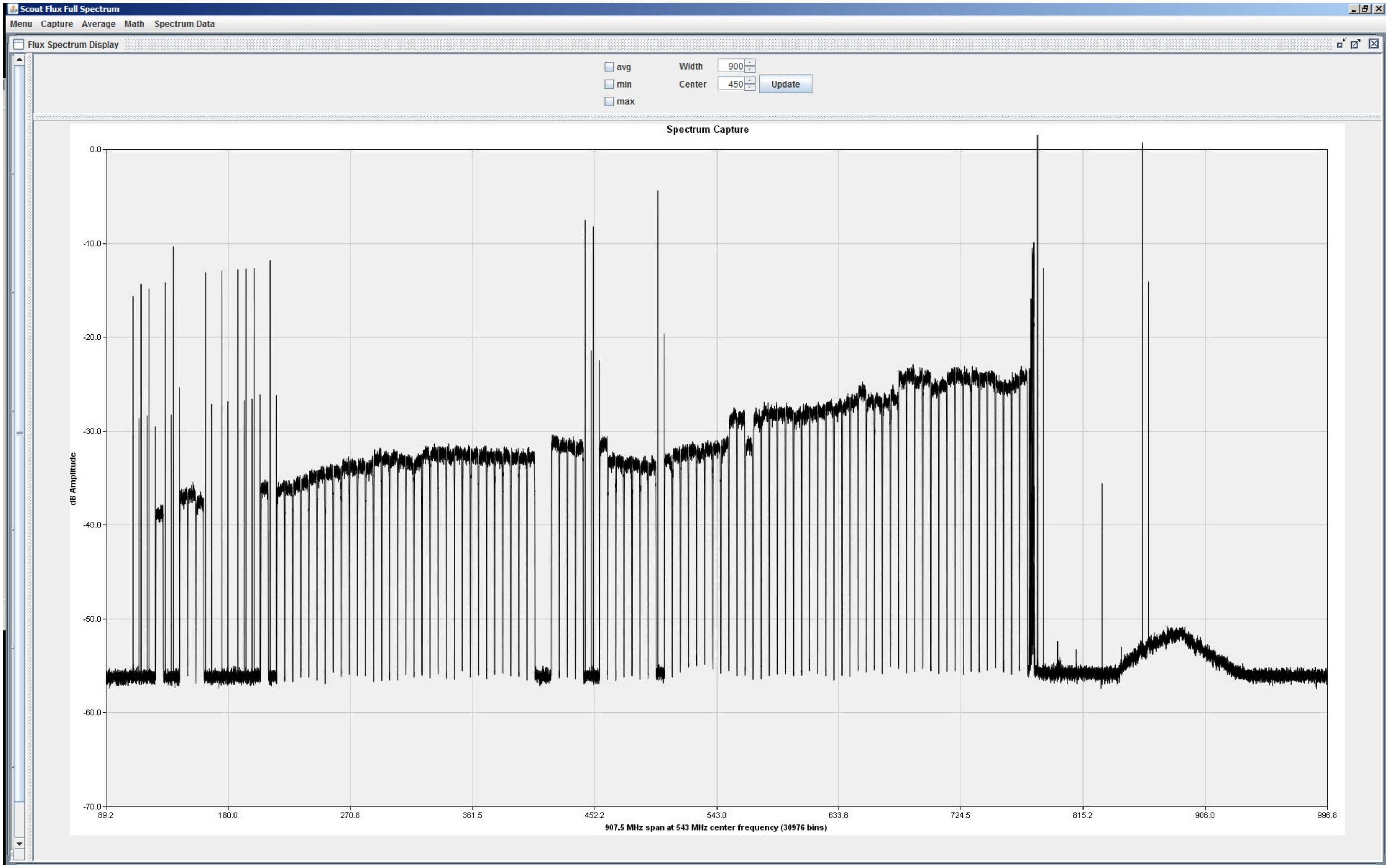


Figure 4. OIP3 @ 3V, 30 mA.
LSL = 29, Nominal = 30.5

Measurement of Home STB

level	frequency	SNR	AGC	PreRSBER	F
dBmV	MHz	dB	%		dB
-23.1	711	27.5	96	4.83E-04	7.2
-20.4	711	29.7	92	3.3W-7	8.1
-17.5	711	32.3	87	0	8.1
1.4	711	39.1	58	0	20.3
4.7	711	38.9	53	0	23.7

The level vs frequency within a home can vary by 15 dB



High Spectral Efficiency

- Nfft=2^14=16,384 OFDM subcarriers
- Sampling rate is 204.8 MHz
- Subcarrier spacing is 12.5 kHz
- Useful symbol time is 80 μs
- CP is 2.5 μs
- Channel width is 190 MHz
- 15,200 available subcarrier
- 384 pilots
- Data subcarriers = 1482
- Data rate = 1.97 Gbps

1.99 Gbps in 192 MHz

$N_{FFT} := 2^{14}$ $N_{FFT} = 16384$ $R_{sampling} := 204.8\ \mathbf{MHz}$ $\delta f := \frac{R_{sampling}}{N_{FFT}}$

$\delta f = 12.5\ \mathbf{kHz}$ $CW := 190\ \mathbf{MHz}$ $N_a := \frac{CW}{\delta f}$

$N_a = 15200$ $pilots := 256$ $N_{data} := N_a - pilots$ $N_{data} = 14944$

$T_u := \frac{1}{\delta f}$ $T_u = 80\ \boldsymbol{\mu s}$ $CP := 2.5\ \boldsymbol{\mu s}$ $T_{symbol} := T_u + CP$ $T_{symbol} = 82.5\ \boldsymbol{\mu s}$

$\varepsilon := 11\ \frac{\frac{\mathbf{bit}}{\mathbf{s}}}{\mathbf{Hz}}$ $R_{data} := \frac{\varepsilon \cdot N_{data}}{T_{symbol}}$ $R_{data} = 1.993\ \frac{\mathbf{Gbit}}{\mathbf{s}}$

Minimum input level -7 dBmV per 6 MHz met for 88.6% of modems

$k = (1.381 \cdot 10^{-23}) \frac{1}{K} \cdot \frac{W}{Hz}$ $T_0 := 290\ K$ $T_0 = 16.85\ °C$ $T_0 = 62.33\ °F$

$N_0 := 10 \cdot \log\left(\frac{k \cdot T_0 \cdot 1\ Hz}{1\ mW}\right)$ $N_0 = -173.975$ dBm/Hz

$SNR_{threshold} := 35.2$ $margin := 6$ $SNR_{threshold} + margin = 41.2$ dB

$NF := 9$ $ENB := \frac{N_a}{T_{symbol}}$ $ENB = 184.242\ MHz$

$$RX_{min} := 30 + 10 \cdot \log(75) + N_0 + NF + SNR_{threshold} + margin + 10 \cdot \log\left(\frac{ENB}{1\ Hz}\right)$$

$RX_{min} = 7.629$ dBmV $RX\_per\_6MHz_{min} := RX_{min} - 10 \cdot \log\left(\frac{ENB}{6\ MHz}\right)$

$RX\_per\_6MHz_{min} = -7.243$ $100 \cdot (1 - \text{pnorm}(-7.243, 0, 6)) = 88.6$ % above threshold