Variable Coded Modulation (VCM) with AR4JA/C2 LDPC Codes

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Objective of Current Effort

Conclusions from Spring 2012 presentation

- SCCC and LDPC are similar in many practical ways:
  - Code rates (SCCC 0.36 to 0.9, LDPC: 0.5 to 0.875)
  - Blocklengths (SCCC 5758 to 43678, LDPC: 1024 to 16384)
  - Both can be used with higher order modulations
  - Bandwidth/power efficiency performance (LDPC is a few tenths of a dB better)
- For a practical example, VCM+LDPC performs similar to VCM+SCCC
- The SCCC Red Book could serve as a baseline for a more general CCSDS VCM protocol that can be applied to any of the CCSDS codes.

This presentation:

- A description of how the VCM mode signaling mechanisms in the SCCC blue book can work as is for a VCM using the Turbo and AR4JA/C2 LDPC codes
- Check whether the VCM mode signaling mechanisms work down to Es/N0 = -8 dB, where the turbo codes operate

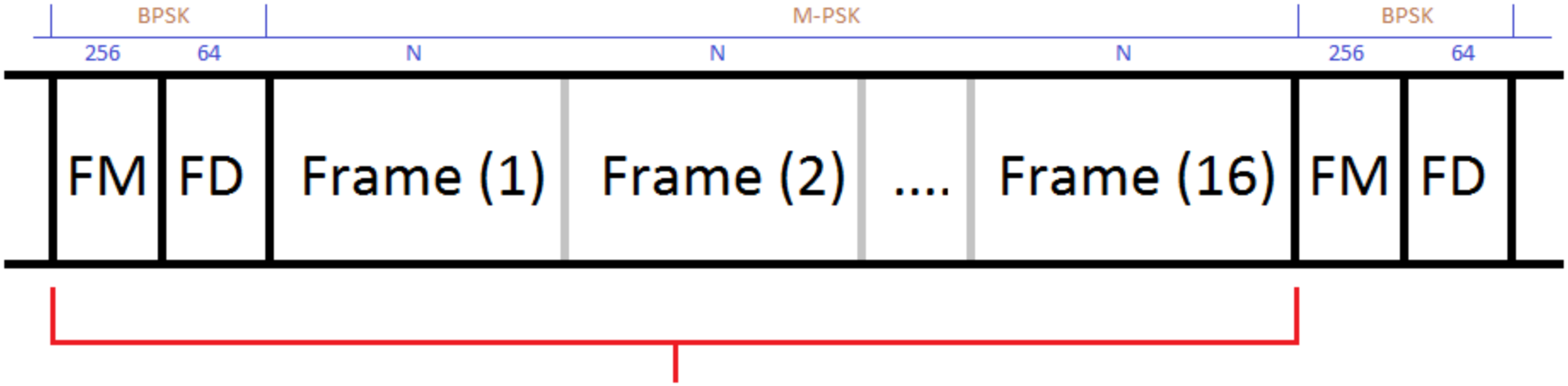
VCM Frame Descriptor

VCM "Frame descriptor" for SCCC [5] specifies which of 27 ACM formats is used:

Bit Number	Content
b_1-b_5	ACM Formats (Decimal values 1 to 27 are used with bit b_1 being the most significant bit)
b_6	Distributed Pilot On (=1) / Off (=0)
b_7	Reserved (set to 0)

The bits b1 – b5 could easily be extended or redefined to refer to other CCSDS codes.

The SCCC Physical Layer Frame



- Unique 256 bit Frame Marker (FM) (BPSK)
- Frame Descriptor (FD) bi-orthogonal (64,6) code (also in BPSK)
- 16 variable length codeword frames using one of 32 VCM modes (using modulation whose type is determined by VCM mode being used)

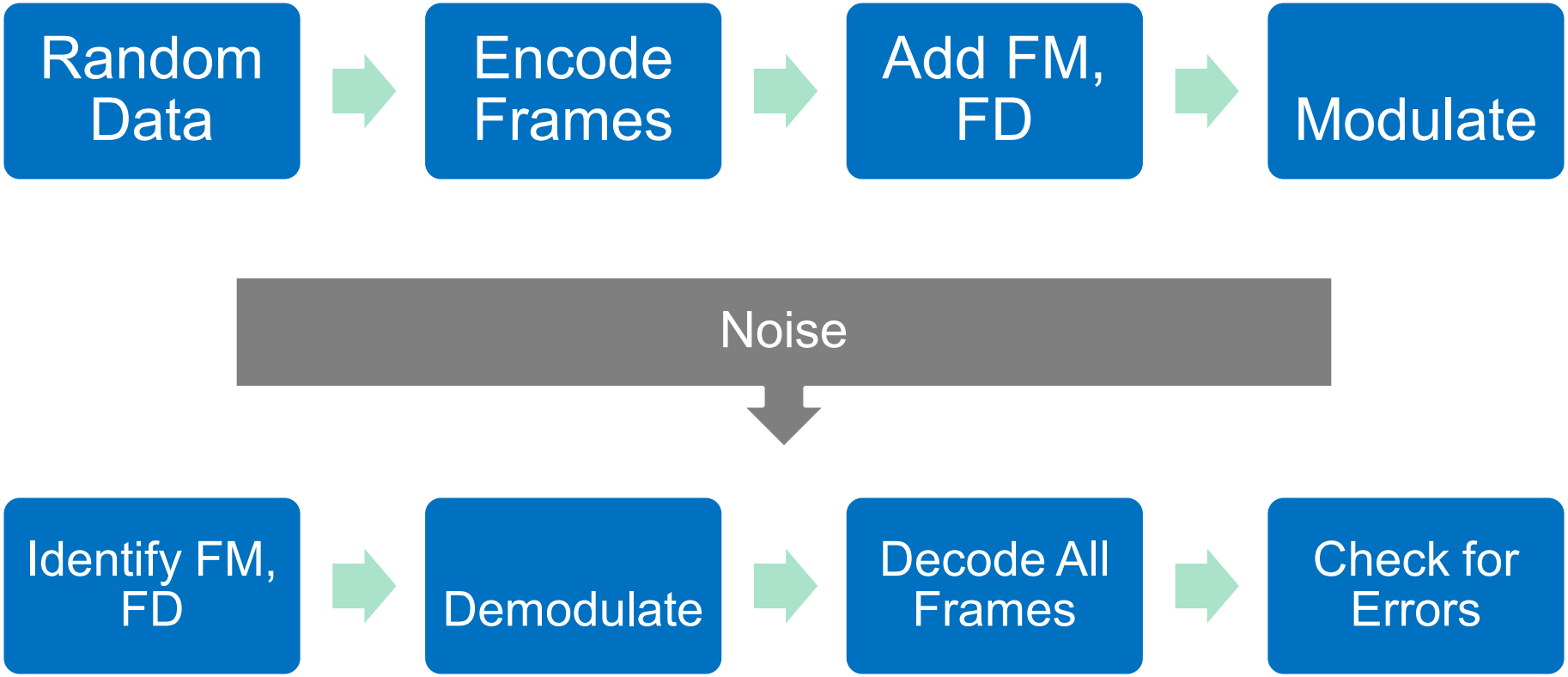
VCM Modes

Instead of the SCCC codes, we use AR4JA/C2 codes with the various modulations:

VCM #	Modulations	Coding	Length	Rate	Enc Length
0-7	BPSK, QPSK	Turbo	8920	1/6	53544
			8920	1/4	35696
			8920	1/3	26772
			8920	1/2	17848
8 - 27	QPSK, 8PSK, 16APSK, 32APSK, 64APSK	LDPC	16384	1/2	32768
			16384	2/3	24576
			16384	4/5	20480
			7136	*7/8*	8160
28-31			Unused		

Simulation Software

- MATLAB simulation
  - Using C encoders/decoders for speed



Receiver Synchronization

1. Initial Lock onto unique Frame Marker sequence by finding best correlation over 857204 symbols

2. Decoding the Frame Descriptor yields VCM mode, telling receiver location of next Frame Marker

3. Check for next Frame Marker after 16th codeword

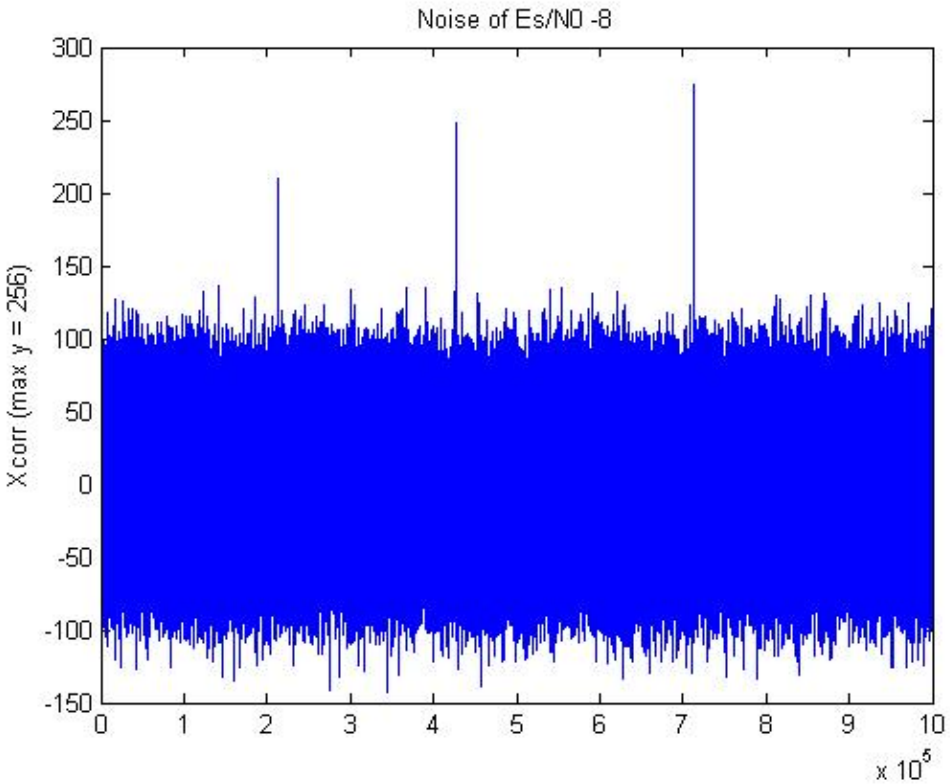
   If error return to step 1, and reacquire lock

   Otherwise return to step 2

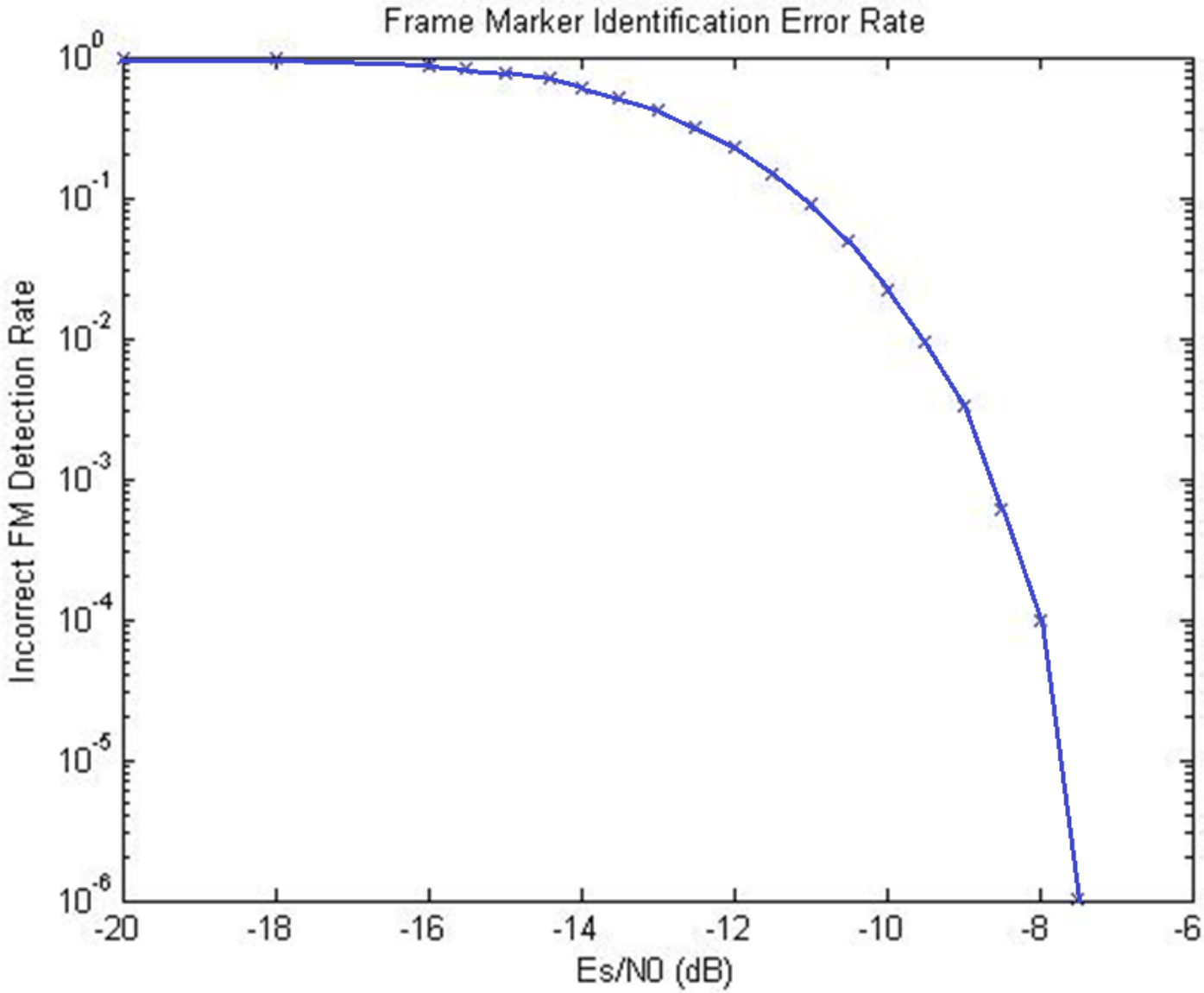
Correlation of Frame Marker

Even at Es/N0=-8 dB, the periodic Frame Marker is readily distinguishable:

(Three FM correlation peaks are seen here, well above noise floor)

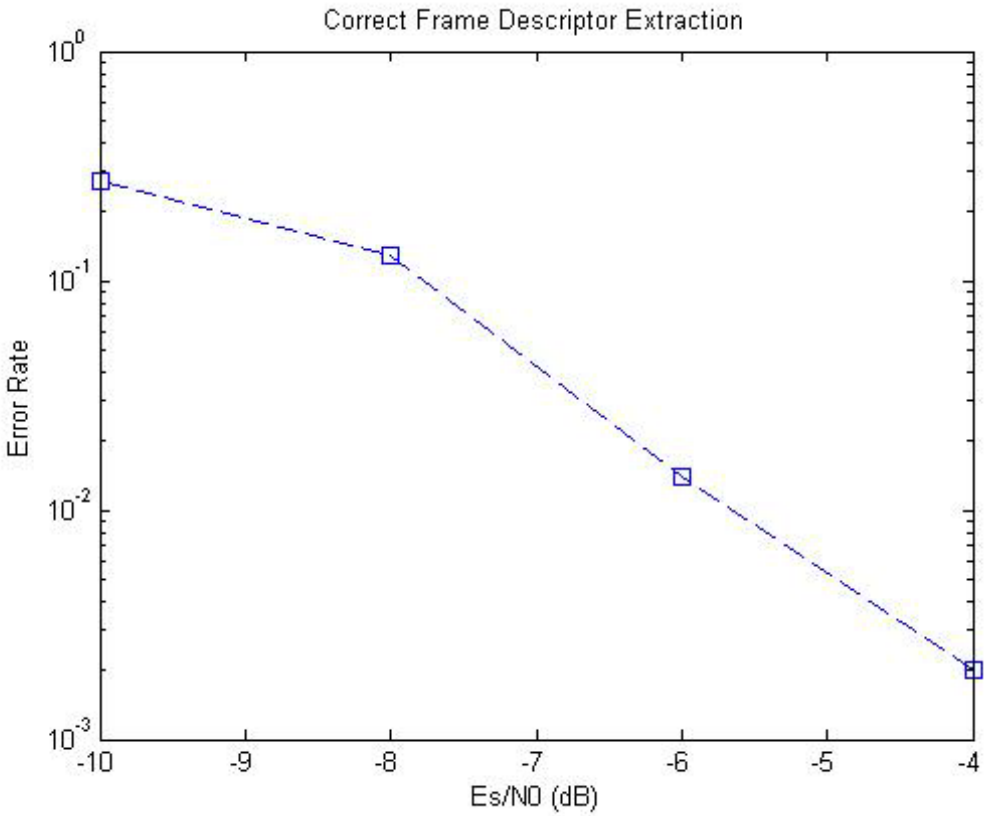


Frame Marker Identification Error Rate

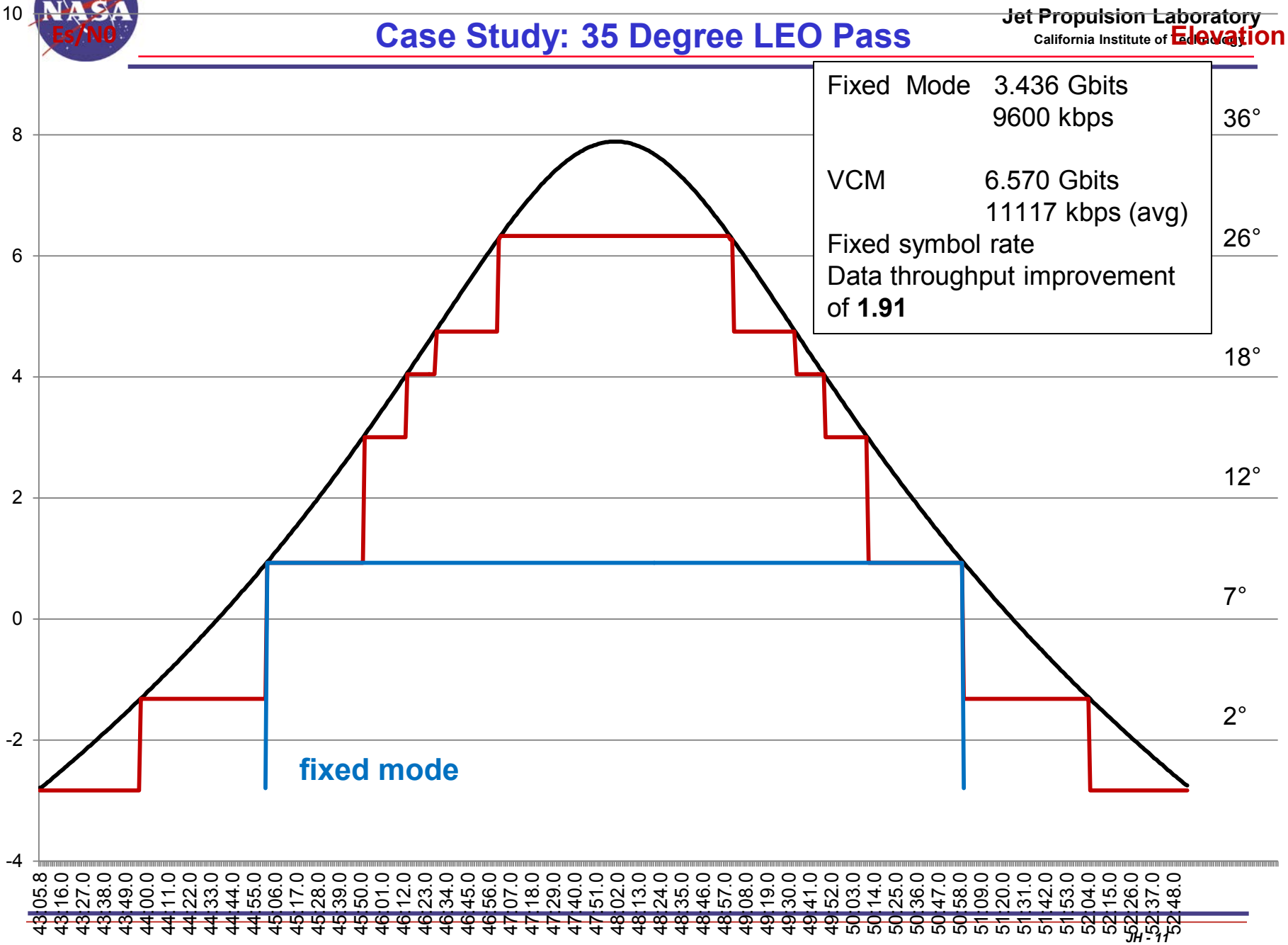


Frame Descriptor (64,6)

- The FD describes which VCM mode is being used
- The (64,6) code for the FD as described in SCCC does not perform well enough on its own
- It was never designed to work with turbo 1/6 at Es/N0=-8 dB
- But simulation can overcome FD errors
  - VCM mode can be determined by # symbols between Frame Markers and modulation type classifier
  - This is unique for each mode
  - This makes FD unnecessary to transmit, in fact



Case Study: 35 Degree LEO Pass

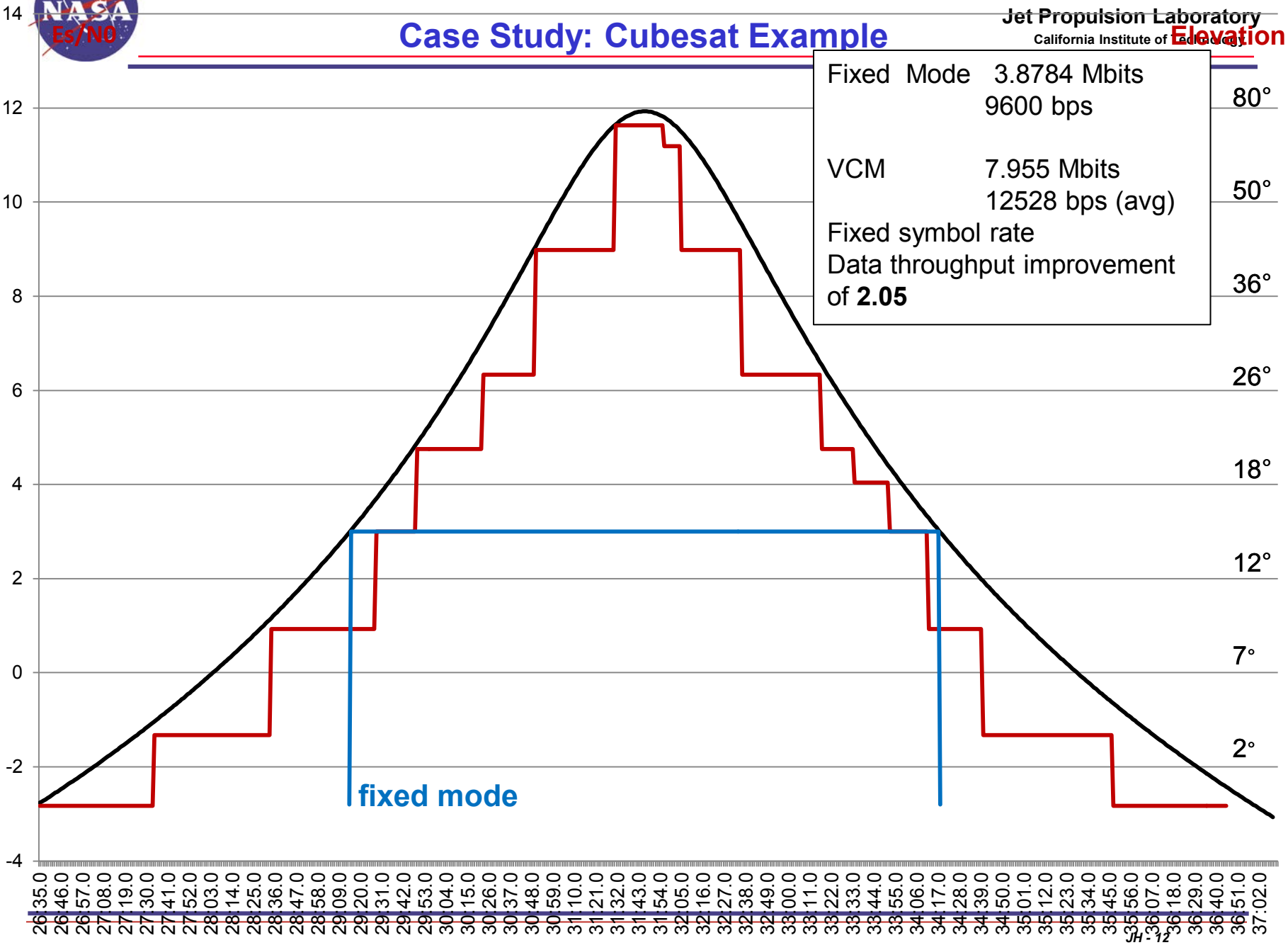


Fixed Mode 3.436 Gbits
9600 kbps

VCM 6.570 Gbits
11117 kbps (avg)

Fixed symbol rate
Data throughput improvement of **1.91**

Case Study: Cubesat Example



Fixed Mode 3.8784 Mbits
9600 bps

VCM 7.955 Mbits
12528 bps (avg)

Fixed symbol rate
Data throughput improvement of **2.05**

Conclusions

- The VCM physical layer framing mechanisms outlined in the SCCC blue book are generally applicable for VCM using CCSDS turbo and AR4JA codes as well

- Varying links utilize VCM and deliver more data throughput,
  - **Twice** the data throughput for simulated cubesat satellite pass
  - 8% more data throughput than similar SCCC codes

- Overhead of VCM accounts for 0.18% of the transmitted data

- Special handling of Frame Descriptor or Frame Identification required for the low rate Turbo codes, such as by considering the length between frame markers.

Backup

Modes

VCM #	Modulation	Coding	Length K	Rate	Enc Bits N	# Info Bits / Symbol	PLF Length (SYM)
0	BPSK	Turbo	8920	1/6	53544	0.1666	857024
1	BPSK	Turbo	8920	1/4	35696	0.2499	571456
2	BPSK	Turbo	8920	1/3	26772	0.3332	428672
3	BPSK	Turbo	8920	1/2	17848	0.4998	285888
4	QPSK	Turbo	8920	1/6	53544	0.3332	428672
5	QPSK	Turbo	8920	1/4	35696	0.4998	285888
6	QPSK	Turbo	8920	1/3	26772	0.6664	214496
7	QPSK	Turbo	8920	1/2	17848	0.9996	143104

VCM #	Mod.	Coding	Length K	Rate	Enc Bits N	# Info Bits / Symbol	PLF Length (SYM)
8	QPSK	LDPC	16384	1/2	32768	1.0000	262464
9	QPSK	LDPC	16384	2/3	24576	1.3333	196928
10	QPSK	LDPC	16384	4/5	20480	1.6000	164160
11	QPSK	LDPC	7136	*7/8*	8160	1.7490	65600
12	8PSK	LDPC	16384	1/2	32768	1.5000	175083
13	8PSK	LDPC	16384	2/3	24576	2.0000	131392
14	8PSK	LDPC	16384	4/5	20480	2.4000	109547
15	8PSK	LDPC	7136	*7/8*	8160	2.6235	43840

VCM #	Mod.	Coding	Length K	Rate	Enc Bits N	# Info Bits / Symbol	PLF Length (SYM)
16	16APSK	LDPC	16384	1/2	32768	2.0000	131392
17	16APSK	LDPC	16384	2/3	24576	2.6667	98624
18	16APSK	LDPC	16384	4/5	20480	3.2000	82240
19	16APSK	LDPC	7136	*7/8*	8160	3.4980	32960
20	32APSK	LDPC	16384	1/2	32768	2.5000	105178
21	32APSK	LDPC	16384	2/3	24576	3.3333	78964
22	32APSK	LDPC	16384	4/5	20480	4.0000	65856
23	32APSK	LDPC	7136	*7/8*	8160	4.3725	26432

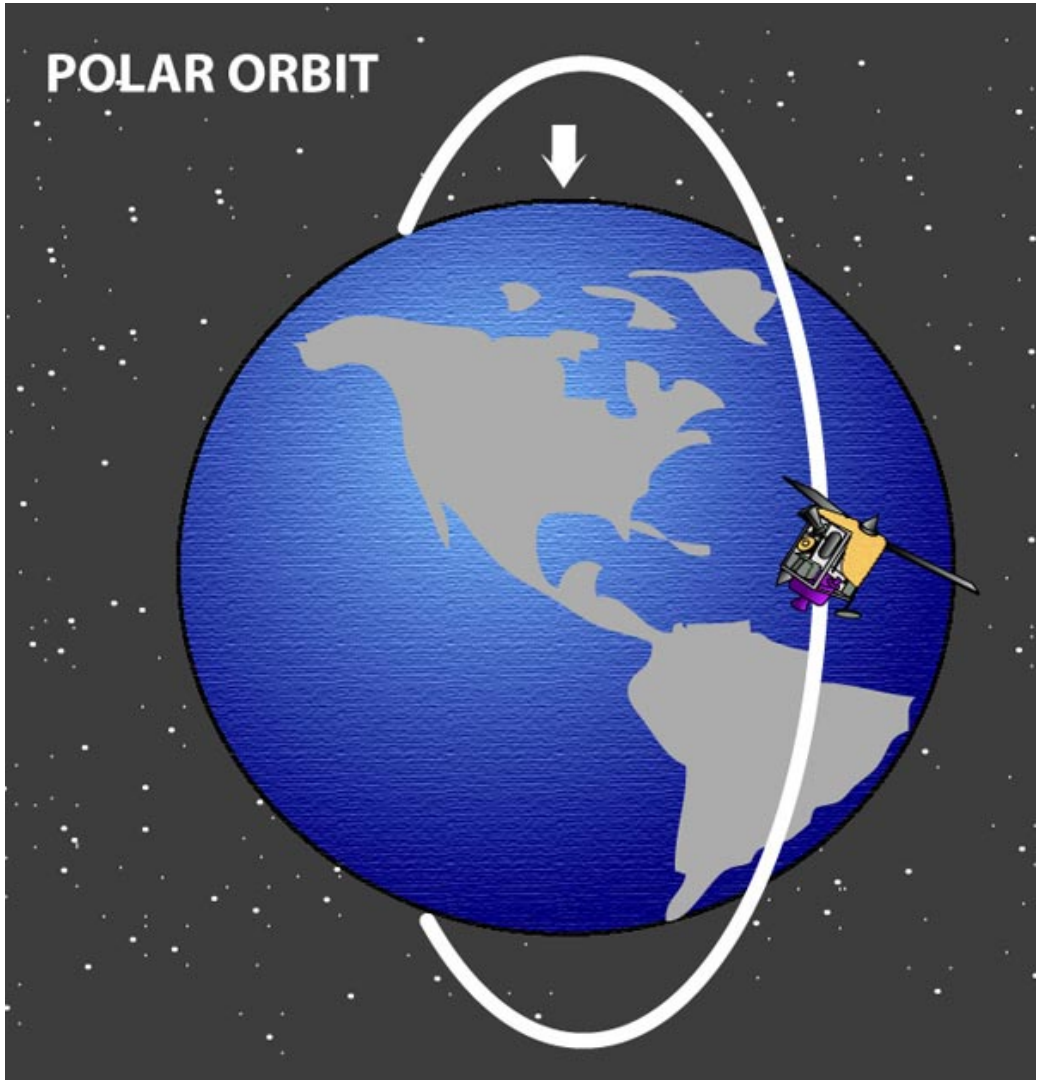
VCM #	Modulation	Coding	Length K	Rate	Enc Bits N	# Info Bits / Symbol	PLF Length (SYM)
24	64APSK	LDPC	16384	1/2	32768	3.0000	87702
25	64APSK	LDPC	16384	2/3	24576	4.0000	65856
26	64APSK	LDPC	16384	4/5	20480	4.8000	54934
27	64APSK	LDPC	7136	*7/8*	8160	5.2471	22080

Cubesat Link Alaska

Fairbanks, AK

S-band

- Patch antenna
- 1.6 meter dish

9600 bps

Nearly 15 dB of SNR swing for highest passes