

Modern Digital Satellite Television: How It Works

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Outline

- 1 Satellite Television Standards
- 2 DVB-S2 Modulation
- 3 LDPC Coding
- 4 Tricks for Improving Performance
- 5 Conclusion

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Digital Satellite Television in the United States

DirecTV

- Spinoff of Hughes Network Systems.
- Began operations in 1994.
- 19.2 million U.S. subscribers in 2010.
- 23,000 employees in U.S. and Latin America.
- \$33.6 billion market cap.

Dish Network.

- Spinoff of EchoStar.
- Began operations in 1996.
- 14.1 subscribers in 2010.
- 22,000 employees.
- \$10.9 billion market cap.

The DVB Family



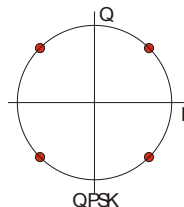
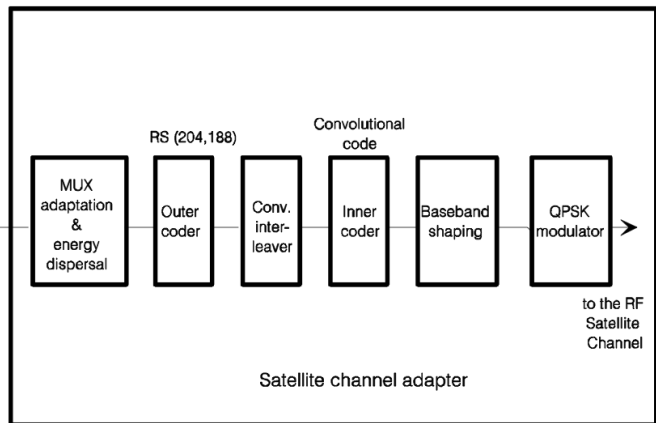
DVB is a family of open standards for digital video broadcasting.

- Maintained by 270-member industry consortium.
- Published by ETSI.

Modes of transmission

- Satellite: DVB-S, DVB-S2, and DVB-SH
- Cable: DVB-C, DVB-C2
- Terrestrial: DVB-T, DVB-T2, DVB-H

DVB-S



- Modulation: QPSK with $\alpha = 0.35$ rolloff.
- Channel coding: Concatenated Reed Solomon and convolutional.

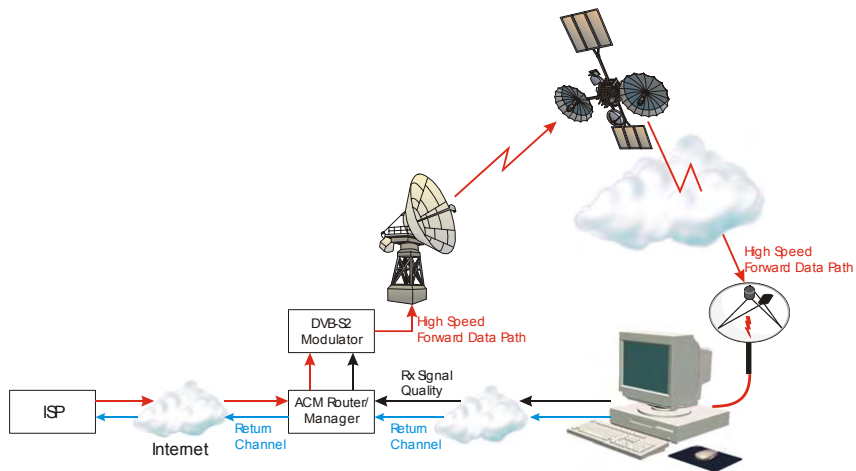
DVB-S2

DVB-S2 was introduced in 2003 with the following goals:

- Improve spectral efficiency by 30% through better modulation and coding.
 - Modulation: QPSK, 8PSK, 16/32 APSK.
 - Channel coding: LDPC with outer BCH code.
- Offer a more diverse range of services.
 - HDTV broadcast television.
 - Backhaul applications, e.g., electronic news gathering.
 - Internet downlink access.
 - Large-scale data content distribution, e.g., electronic newspapers.

Ratified 2005.

Adaptive Internet Downlink

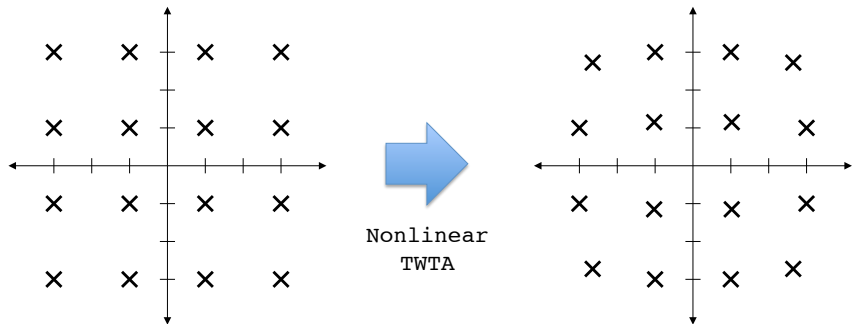


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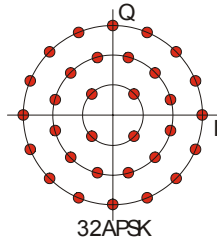
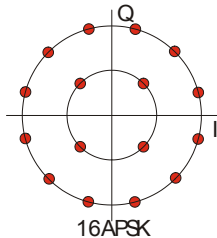
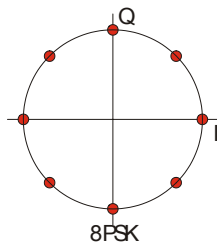
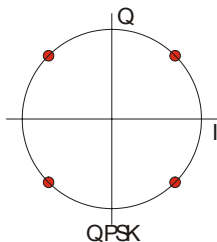
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Why Not Use QAM?

- A constellation with $M = 2^m$ conveys m bits per channel use.
- Higher spectral-efficiencies require larger signal constellations.
- Nonlinear satellite channels are not well suited to square QAM.



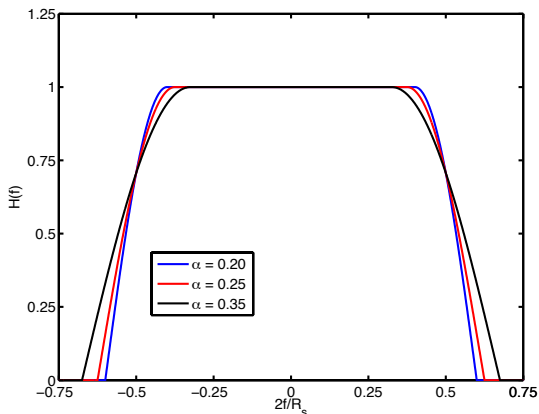
The DVB-S2 Signal Constellations



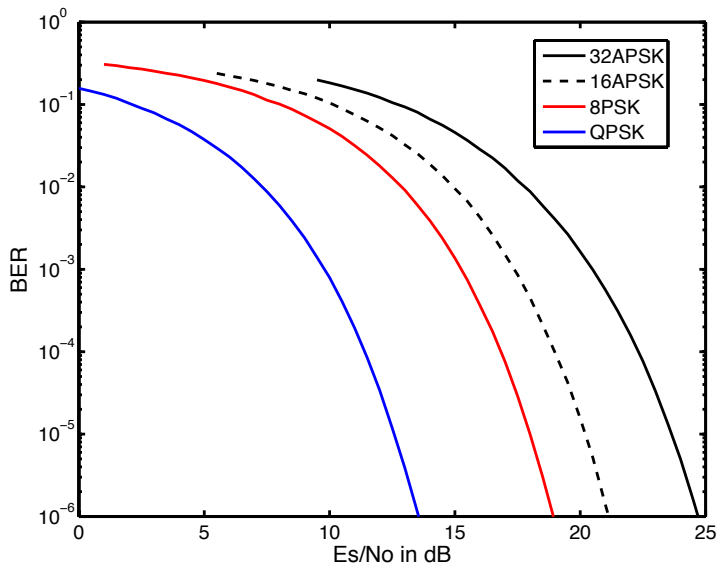
Raised-Cosine Rolloff Filtering

DVB-S2 uses a tighter root RC-rolloff filter.

- $B = R_s(1 + \alpha)$
- Assuming a 6 MHz transponder channel...
- DVB-S Example:
 - $\alpha = 0.35$.
 - QPSK: $R_b = 2R_s$
 - $2(6)/(1.35) = 8.9$ Mbps
- DVB-S2 Example:
 - $\alpha = 0.20$.
 - 32-APSK: $R_b = 5R_s$
 - $5(6)/(1.2) = 25$ Mbps



BER in AWGN

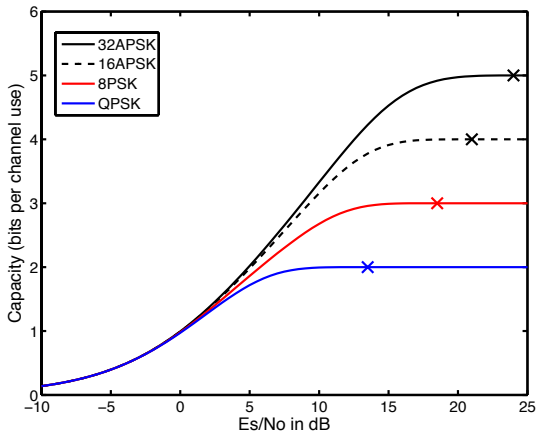


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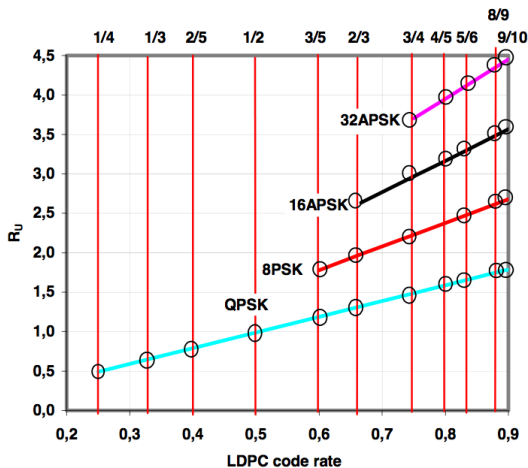
Capacity

- Performance can be improved by using error control coding.
- Gains are limited by the modulation-constrained capacity.
- LDPC codes are capable of approaching capacity.



Available Code Rates

- The encoder maps length- k messages to length- n codewords.
- The code rate is $R = k/n$.
- Useful bit rate is $R_u = R \log_2(M)$.
- Two codeword lengths:
 - 16, 200.
 - 64, 800.



Coding by Example: Single Parity-Check Codes

- Consider the following rate $R = 5/6$ single parity-check code:

$$\mathbf{c} = [\underbrace{1 \ 0 \ 1 \ 0 \ 1}_{\mathbf{u}} \ \underbrace{1}_{\text{parity bit}}]$$

- One error in *any* position may be detected:

$$\mathbf{c} = [1 \ 0 \ X \ 0 \ 1 \ 1]$$

- Problem with using an SPC is that it can only detect a single error.

Product Codes

- Place data into a k by k rectangular array.
 - Encode each row with a SPC.
 - Encode each column with a SPC.
 - Result is a rate $R = k^2/(k + 1)^2$ code.
- Example $k = 2$.

$c_1 = u_1$	$c_2 = u_2$	$c_3 = c_1 \oplus c_2$
$c_4 = u_3$	$c_5 = u_4$	$c_6 = c_4 \oplus c_5$
$c_7 = c_1 \oplus c_4$	$c_8 = c_2 \oplus c_5$	$c_9 = c_3 \oplus c_6$

 $=$

1	0	1
1	1	0
0	1	1

- A single error can be corrected by detecting its row and column location

1	0	1
0	1	0
0	1	1

 \Rightarrow

1	0	1
1	1	0
0	1	1

Linear Codes

$c_1 = u_1$	$c_2 = u_2$	$c_3 = c_1 \oplus c_2$
$c_4 = u_3$	$c_5 = u_4$	$c_6 = c_4 \oplus c_5$
$c_7 = c_1 \oplus c_4$	$c_8 = c_2 \oplus c_5$	$c_9 = c_3 \oplus c_6$

- The example product code is characterized by the set of five linearly-independent equations:

$$c_3 = c_1 \oplus c_2 \Rightarrow c_1 \oplus c_2 \oplus c_3 = 0$$

$$c_6 = c_4 \oplus c_5 \Rightarrow c_4 \oplus c_5 \oplus c_6 = 0$$

$$c_7 = c_1 \oplus c_4 \Rightarrow c_1 \oplus c_4 \oplus c_7 = 0$$

$$c_8 = c_2 \oplus c_5 \Rightarrow c_2 \oplus c_5 \oplus c_8 = 0$$

$$c_9 = c_3 \oplus c_6 \Rightarrow c_3 \oplus c_6 \oplus c_9 = 0$$

- In general, it takes $(n - k)$ linearly-independent equations to specify a *linear* code.

What is a Parity-Check Matrix?

- The system of equations may be expressed in matrix form as:

$$\mathbf{c}H^T = \mathbf{0}$$

where H is a *parity-check* matrix.

- Example:

$$\begin{array}{l}
 c_1 \oplus c_2 \oplus c_3 = 0 \\
 c_4 \oplus c_5 \oplus c_6 = 0 \\
 c_1 \oplus c_4 \oplus c_7 = 0 \\
 c_2 \oplus c_4 \oplus c_8 = 0 \\
 c_3 \oplus c_6 \oplus c_9 = 0
 \end{array}
 \Leftrightarrow
 H =
 \begin{bmatrix}
 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\
 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\
 0 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\
 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1
 \end{bmatrix}$$

Parity-check matrix

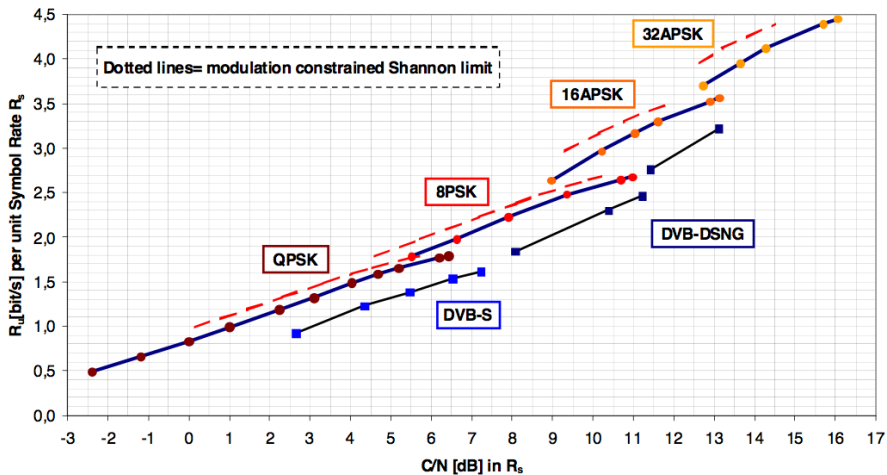
LDPC Codes

- An LDPC code is a code with a large, sparse H matrix.
- A code from MacKay and Neal (1996):

$$\mathbf{H} = \left[\begin{array}{cccc|cccc|ccc} 1 & & & & 1 & & 1 & & 1 & & & \\ 1 & & & & 1 & & & & & & 1 & \\ & 1 & & & 1 & & 1 & & 1 & & & 1 \\ & & 1 & & & 1 & & 1 & & 1 & 1 & \\ & & & 1 & & & 1 & 1 & & & & 1 \\ & & & & 1 & & & & 1 & & 1 & \\ 1 & & & & & & 1 & & & 1 & & \\ & 1 & & & & & & 1 & & & & \\ & & 1 & 1 & & 1 & & & 1 & & & \\ & & & & 1 & & 1 & & & & & \\ & & & & & & & & 1 & & & \\ & & & & & & & & & & 1 & \\ & & & & & & & & & & & 1 \end{array} \right]$$

- The code called a $(3, 4)$ *regular* code because:
 - Each column has exactly 3 ones.
 - Each row has exactly 4 ones.
- The DVB-S2 LDPC codes are *irregular*.

DVB-S2 vs. Shannon

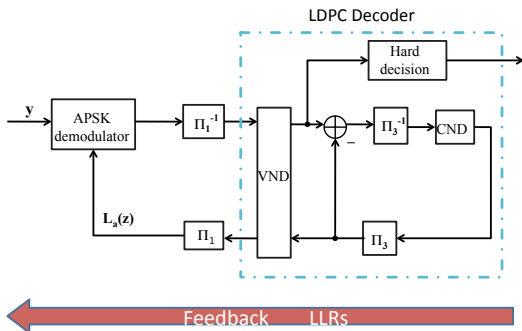


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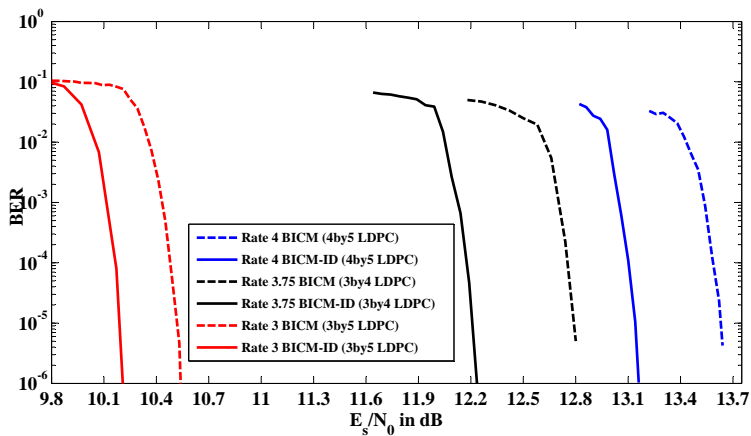
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Iterative Demodulation and Decoding

- Conventional receivers first demodulate, then decode.
- Performance is improved by iterating between the demodulator and decoder.
- BICM-ID: bit-interleaved modulation with iterative decoding.



AWGN Performance of 32APSK with BICM-ID



Constellation Shaping

- Capacity curves assume equiprobable signaling.
- It is possible to increase capacity by transmitting higher-energy signals less frequently than lower-energy signals.

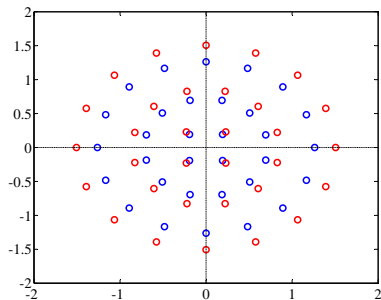


Figure: Uniform 32APSK \circ vs. shaped 32APSK \circ . Both constellations have the same energy.

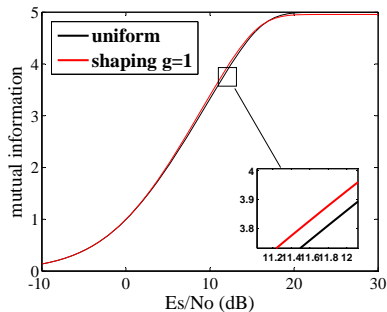


Figure: The capacity of shaped 32APSK is about 0.3 dB better than uniform 32APSK.

Sub-constellations

- The 32APSK is partitioned into two equal-sized sub-constellations.
- A *shaping bit* selects the sub-constellation, while the remaining bits select a symbol from the chosen sub-constellation.
- The lower-energy sub-constellation is selected more frequently.

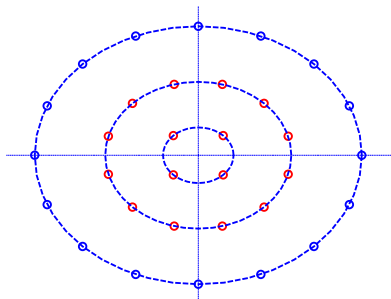


Figure: 32APSK w/ 2 sub-constellations

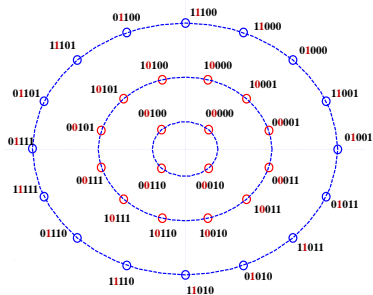


Figure: 32APSK symbol-labeling map

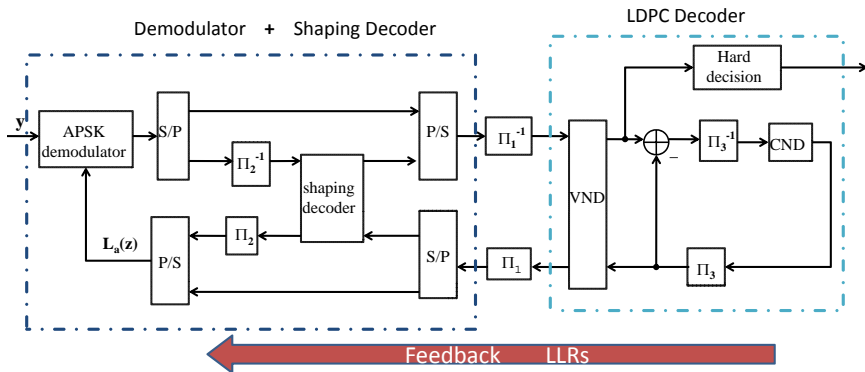
Shaping Encoder

- The shaping encoder should produce more zeros than ones.
- Example: $(n_s, k_s) = (5, 3)$

3 input data bits	5 output codeword bits
0 0 0	0 0 0 0 0
0 0 1	0 0 0 0 1
0 1 0	0 0 0 1 0
0 1 1	0 0 1 0 0
1 0 0	0 1 0 0 0
1 0 1	1 0 0 0 0
1 1 0	0 0 0 1 1
1 1 1	1 0 1 0 0

- $p_0 = 31/40$: fraction of zeros.
- $p_1 = 9/40$: fraction of ones.

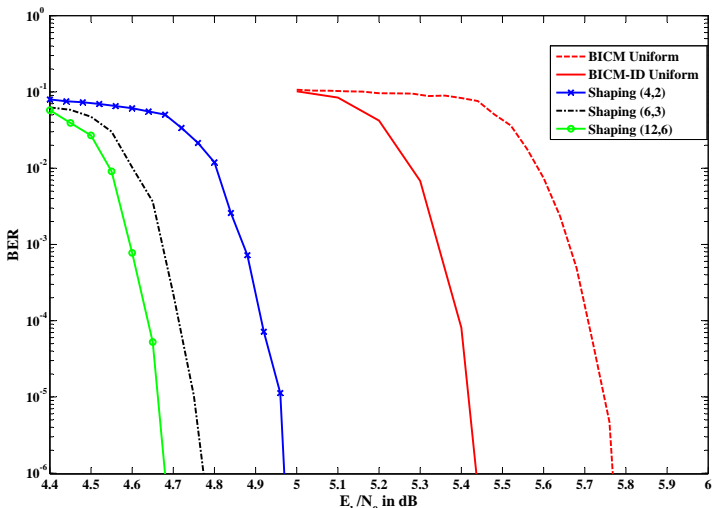
Receiver Implementation



- Additional complexity relative to BICM-ID due to shaping decoder.
- MAP shaping decoder compares against all 2^{k_s} shaping codewords.

BER of Shaping in AWGN

BER of 32-APSK in AWGN at rate $R=3$ bits/symbol



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Conclusion

- DVB-S2 is a highly efficient system, thanks to
 - APSK modulation.
 - Tight RC-rolloff filtering.
 - Capacity-approaching irregular LDPC codes.
- The performance of DVB-S2 can be improved by
 - BICM-ID.
 - Constellation shaping.
- Future work:
 - Optimize the LDPC code with respect to shaped modulation.
 - Extension to 64APSK and beyond.

Thank You.