The BPSK1000 Format for ARISSat-1

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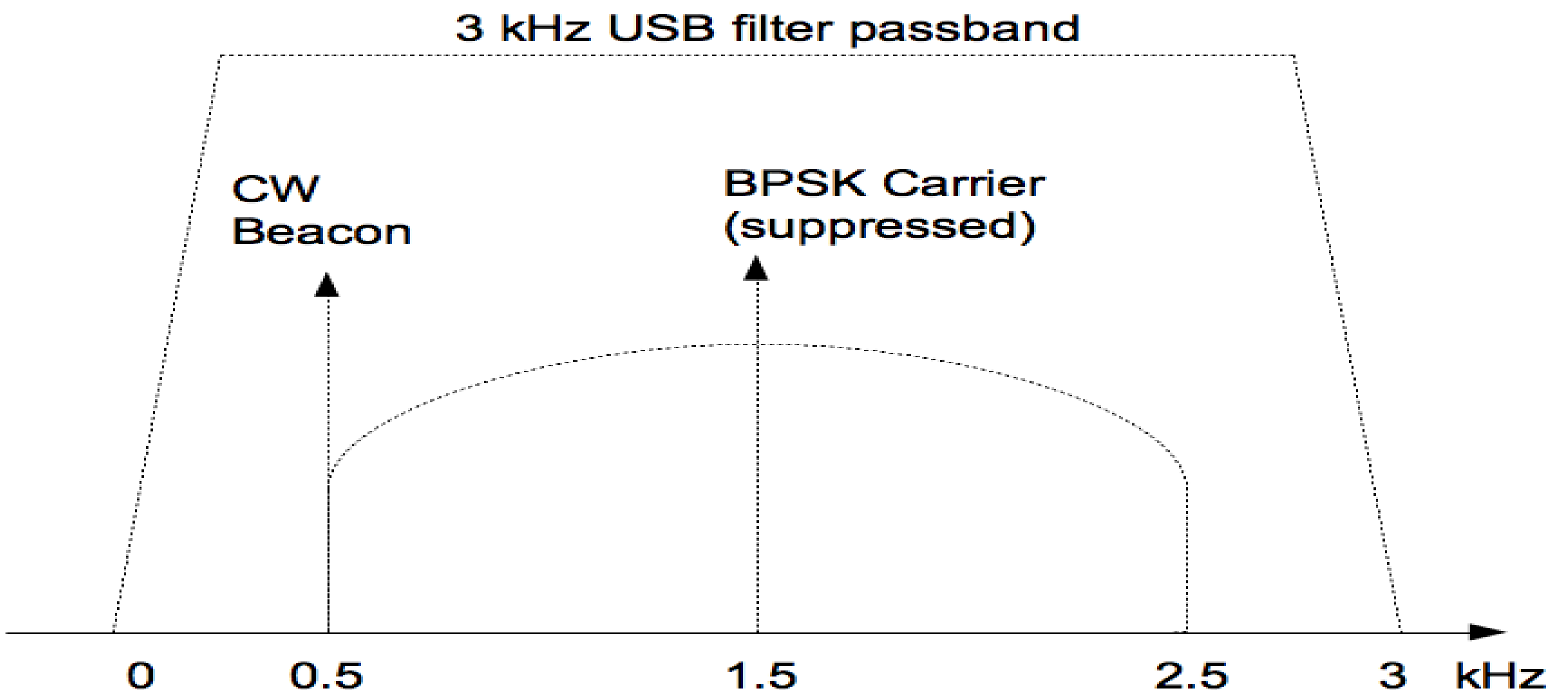
BPSK1000

- Framing, coding & modulation designed for ARISSat-1 telemetry downlink
- Fits in SSB bandwidth, CW beacon as pilot
- Optimized for severe fading → 16 sec delay
- 500 b/s user rate, variable size frame
- rate ½ FEC, Viterbi decoding → 1 kbaud
- DBPSK, $\alpha = 1.0$ → BW = 2 kHz
- $E_b/N_0 \geq 6.7$ dB on AWGN channel

BPSK1000 Spectrum with CW Beacon



1 kbaud BPSK with raised cosine spectrum,
100% excess bandwidth
(Nyquist BW = 1 kHz, we use 2 kHz)
BPSK spectral nulls @ 500 & 2500 Hz

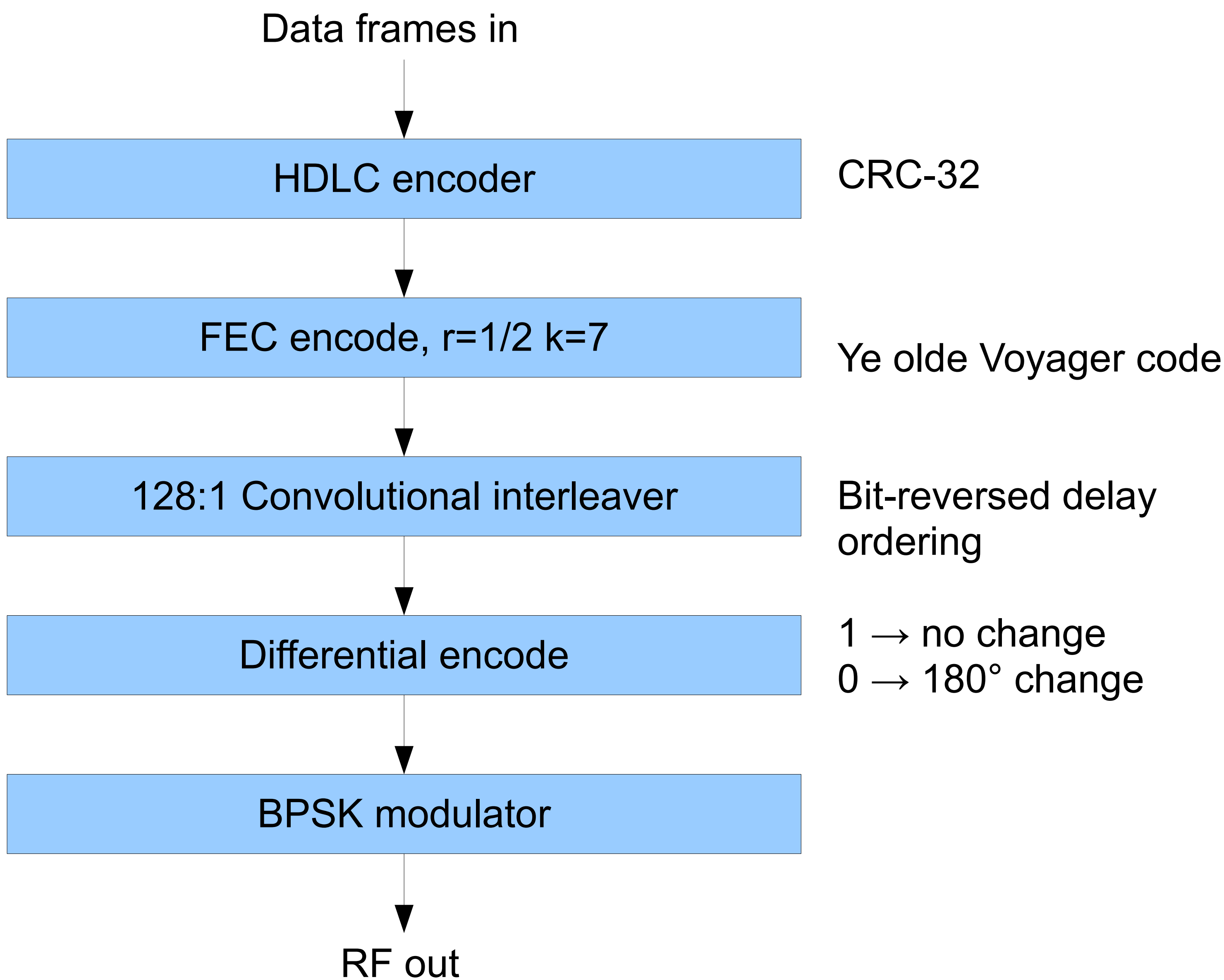
ARISSat Requirements

- No special receiving equipment
  - Just a generic SSB receiver & computer
- Efficient use of spacecraft power
- Tolerate deep, slow fading
- Easy manual Doppler tuning
  - Do not assume satellite experience
  - Automatic tracking nice but not required
- Simple generation by IHU and SDX

BPSK1000 Summary

- HDLC framing with 32-bit CRC
- R=1/2, k=7 convolutional FEC with Viterbi decoding
- 128-way convolutional interleaving with bit-reversed delay line ordering
- Differentially coherent binary phase shift keying
  - Noncoherent detection (implementation choice)

BPSK1000 Encoding



HDLC Frame Format

01111110	Data (variable)	CRC-32	01111110

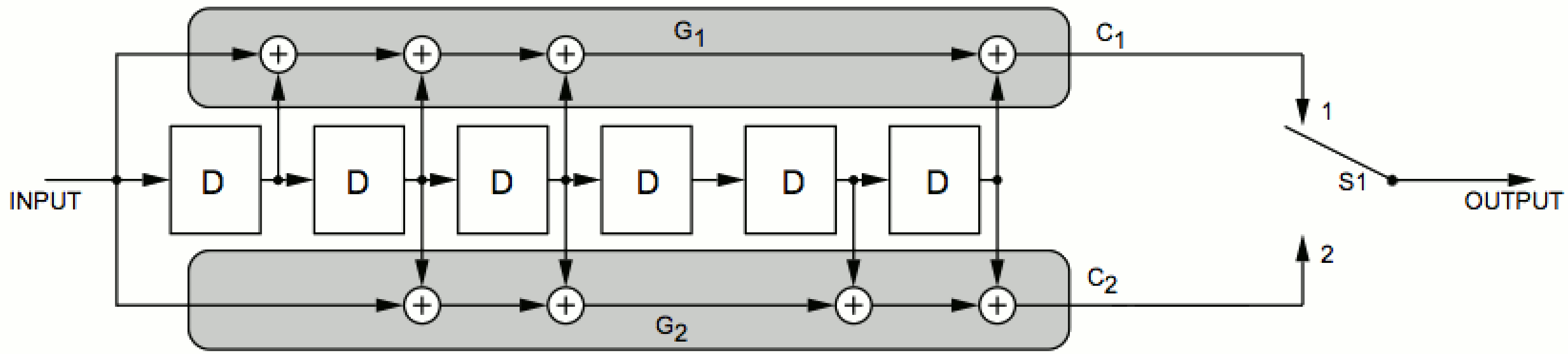
HDLC with CRC-32

- HDLC with 16-bit CRC part of AX.25 Layer 2
  - Basis of amateur packet radio since 1982
  - Variable length frames
- CRC-32 essentially eliminates spurious frames
  - allows Viterbi decoding without Reed-Solomon

Convolutional FEC

- Rate ½ k=7 with Viterbi decoding
  - Same as in AO-40 FEC
- Like all convolutional codes, requires interleaving to tolerate burst errors
- Very fast vectorized software decoders
  - 20-40 Mb/s on reasonably modern PCs

Convolutional encoder



Convolutional Interleaving

- Not to be confused with convolutional *coding*
  - Vs block interleaving on AO-40FEC
- Operates on a continuous bit stream
  - De-interleaver priming required
- Half the delay and memory for given depth
  - Usual rule: maximum fade < 10% of depth
- BPSK1000 uses 128:1; 128^2=16,384
  - Delay of 16.384 sec at 1 kbaud

Convolutional Interleaver

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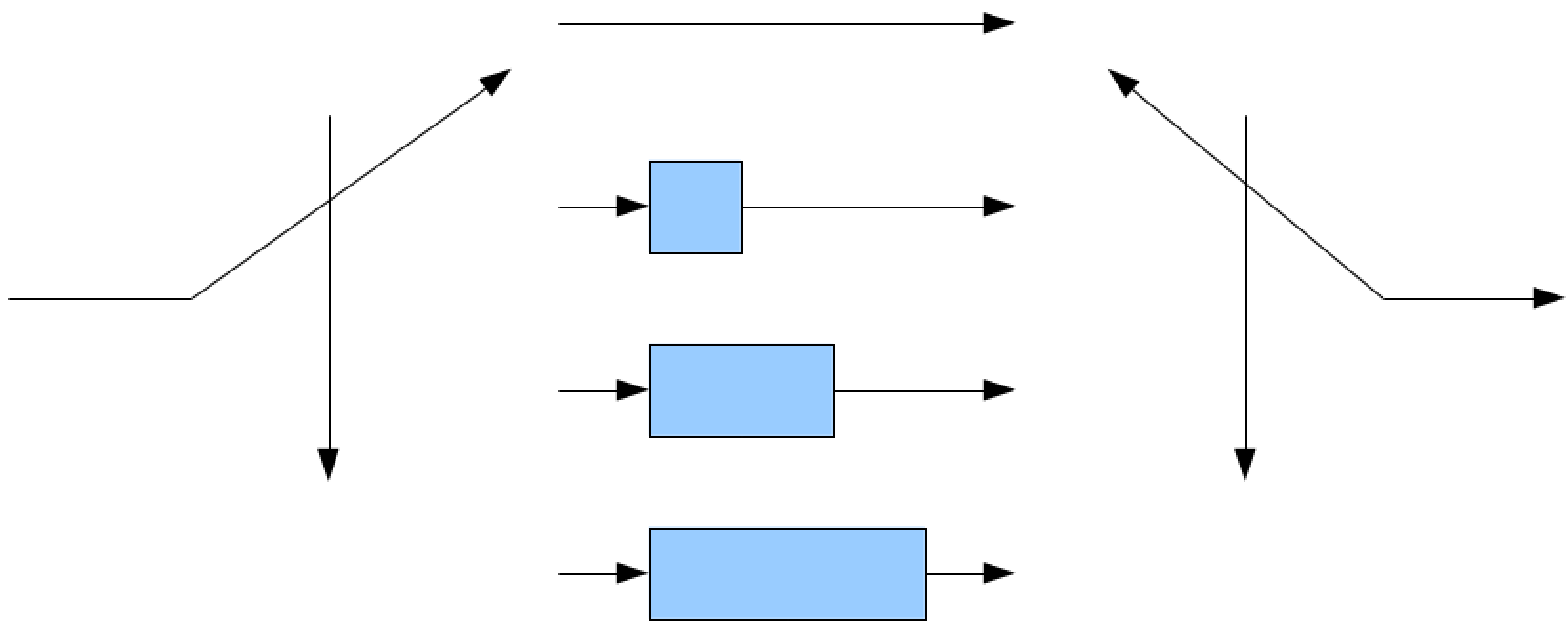
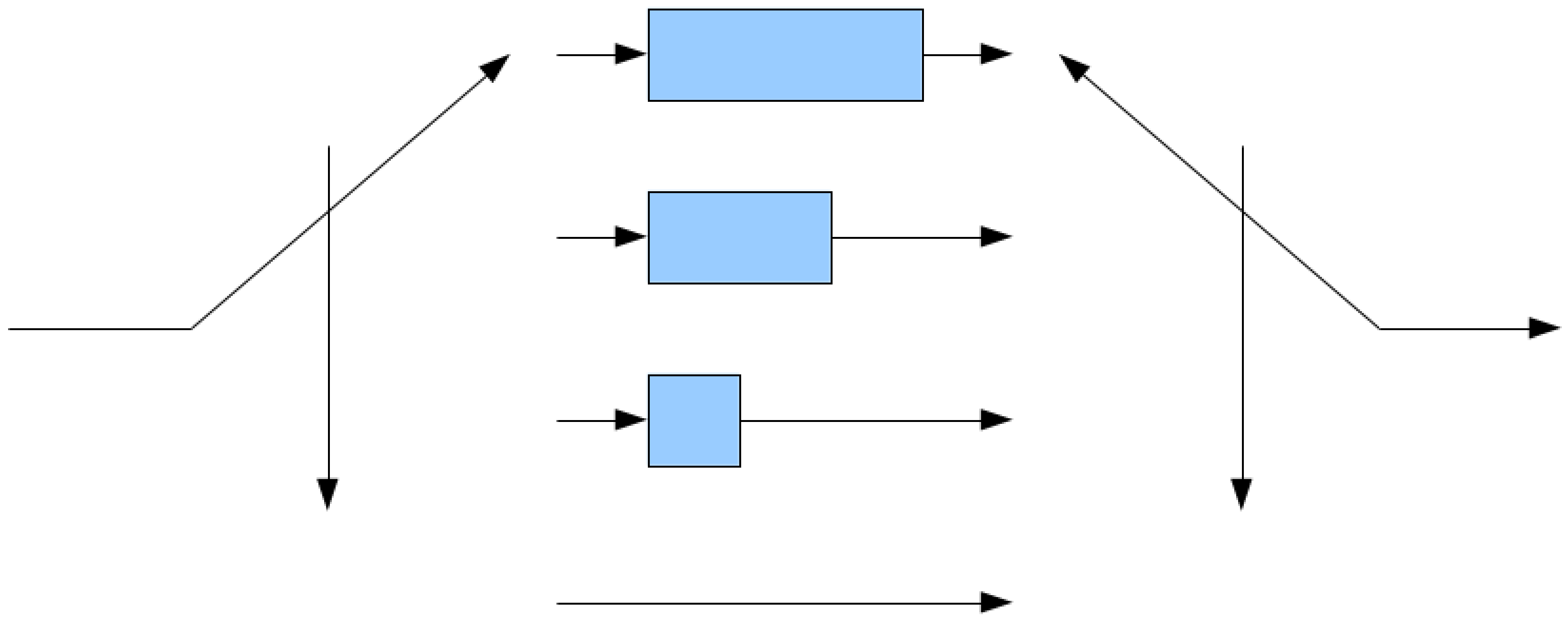


Sample 4:1 interleaver
Delays: 0, 1, 2, 3

Convolutional De-interleaver

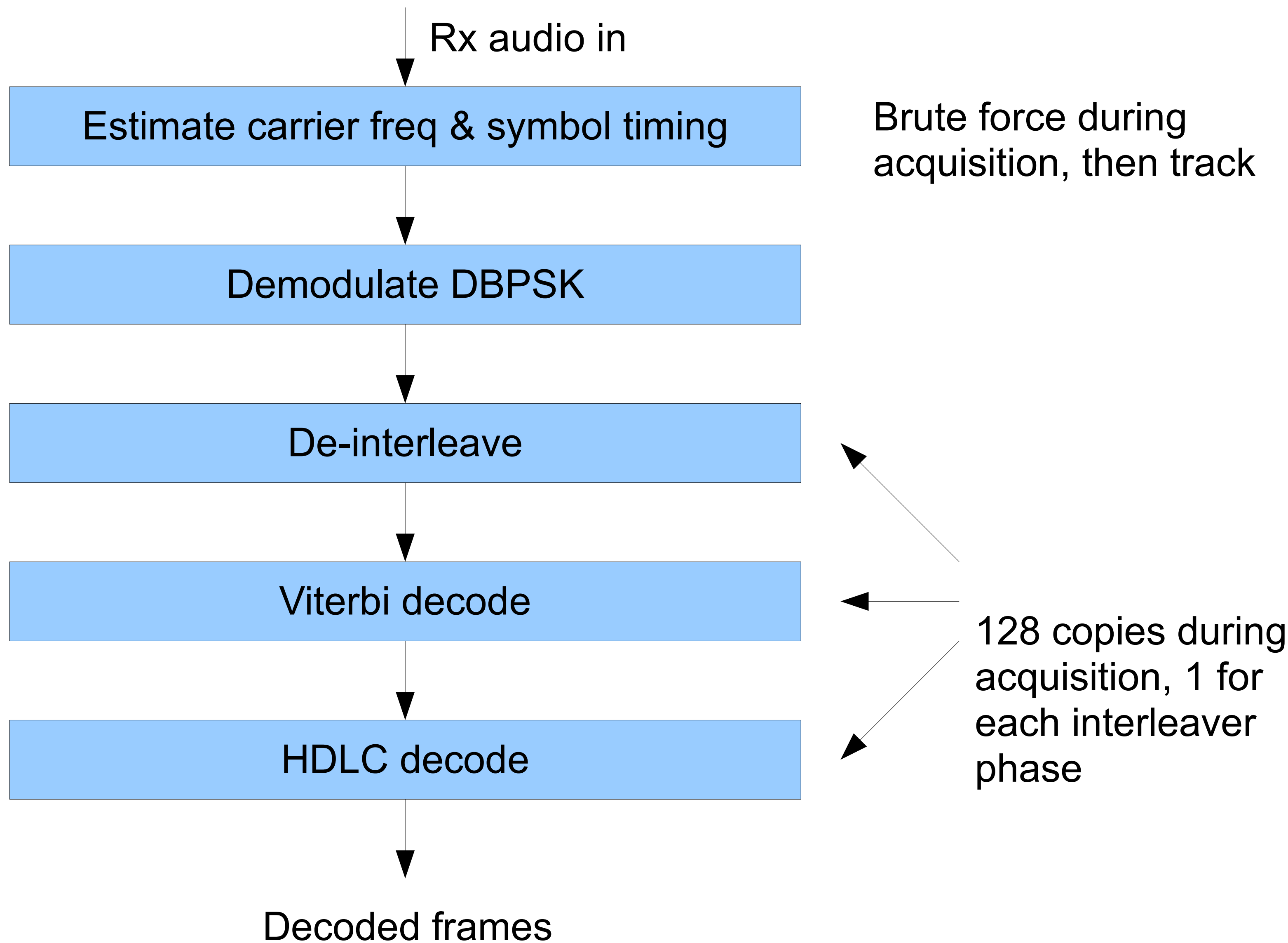


Delays: 3, 2, 1, 0

Bit-reversed ordering

- The delay elements can be in any order
  - As long as sum of delays constant for each row
- Bit-reversed ordering seems to improve distance properties
  - 000 001 010 011 100 101 110 111 →
  - 000 100 010 110 001 110 011 111
  - i.e., 0, 1, 2, 3, 4, 5, 6, 7 →
  - 0, 4, 2, 6, 1, 5, 3, 7

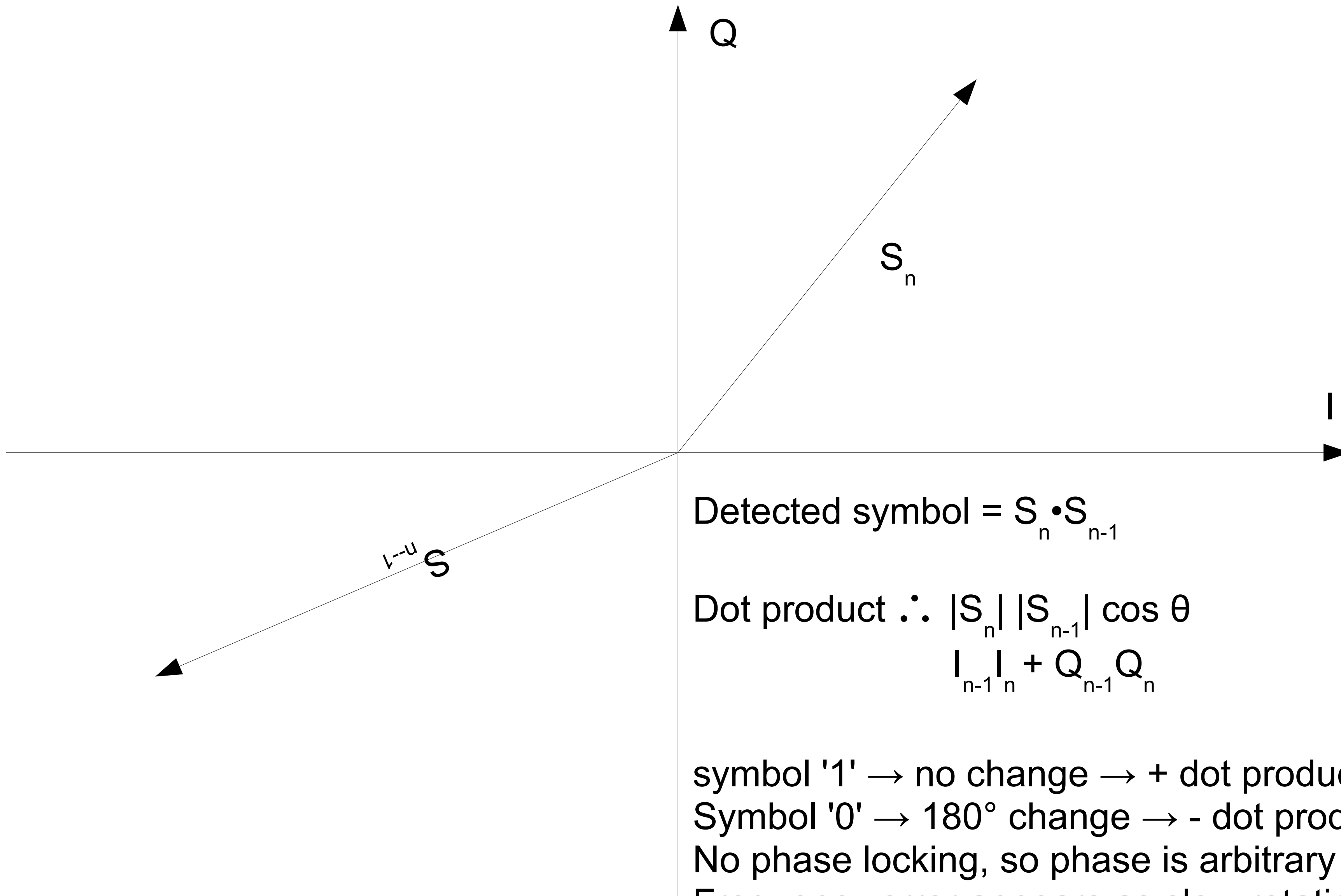
Demodulating BPSK1000



Demodulating DBPSK

- No carrier phase tracking needed!
  - Impossible on fading channels
- Still need:
  - symbol timing
  - approx carrier frequency

Dot Product Detection



Detected symbol = $S_n \bullet S_{n-1}$

Dot product ∴ $|S_n|\,|S_{n-1}| \cos\theta$

$I_{n-1} I_n + Q_{n-1} Q_n$

symbol '1' → no change → + dot product
Symbol '0' → 180° change → - dot product
No phase locking, so phase is arbitrary
Frequency error appears as slow rotation

Frequency errors in DBPSK

- Frequency errors cause slow rotation of signal phasor.
- Effective signal loss in dB = $20 \log_{10} \cos(2\pi E/R)$
  - E = frequency error, R = baud rate
  - e.g., 50 Hz error @ 1 kbaud → 0.44 dB loss
  - 100 Hz error @ 1 kbaud → 1.84 dB loss

Nonfading channel performance

Differential encoding	Demod	FEC	Eb/No 10^{-5} BER	Fade tolerance
Yes	non-coherent	None	10.3	Good
No	coherent	None	9.6	Bad
Yes	non-coherent	r=1/2, k=7	6.7	Good
Yes	coherent	r=1/2, k=7	5.9	Bad
No	coherent	r=1/2, k=7	4.4	Bad
No	coherent	R=1/2 k=7, (255,223)RS	2.5	Bad
No	coherent	R=1/6 turbo, 8920 bit blk	-0.1	Bad

ARISSat-1 vs AO-40

- Faster Doppler
- Stronger average signal
- Random fading
- Variable data frames
- IHU/SDX software

- Slow Doppler
- Weaker signal
- Periodic spin fading
- Fixed frame size
- Hardware restrictions: 400 baud, BPSK, Biphase

AO40/ARISSat comparison

	AO40FEC	ARISSat
Baud rate	400	1000
Data rate	160	500
Error control	r=1/2, k=7 convolutional (160,128) Reed-Solomon Overall rate = 0.4	r=1/2, k=7 convolutional CRC-32 Overall rate =~ 0.5
Baseband	Biphase	NRZI
Interleaving	Block, 5200 symbols	128:1 convolutional
Interleaver depth	13 sec	16.384 sec
Sync vector	Yes	No
Block size	256 bytes	variable
Differential coding	Yes	Yes
Modulation	BPSK	BPSK
Scrambling	Yes	No

Future Formats

- AMSAT needs a *family* of modulation & coding schemes
  - HEO, LEO, telem, comms, freq, BW, speed...
  - There's no one-size-fits-all!
- Broadcast vs Interactive
  - Broadcast – long interleavers
  - Interactive – short interleavers, hybrid ARQ
- Uplink is a different, unaddressed problem
  - multiple access
  - greater power