**Class 3 Overview**

- Character transmission with parity
- Signal gain and loss: dB
- Signals and Transmission
- Switching
- ISDN
- Other Transmission Methods
- Homework & Project

**Sending Character Data: Parity**

- a simple error-checking code
- takes advantage of ‘spare’ bit in byte when using 7-bit ASCII
- even parity: make last bit in byte a 0 or a 1 so that the total number of 1’s is even
- odd parity: make last bit in byte a 0 or a 1 so that the total number of 1’s is odd
Sending Character Data: Parity

- e.g., the character 'K': in binary: \( \text{X100 1011} \)
- has an even number of 1's (4)
- so even parity version is: \( \text{0100 1011} \)
- odd parity version is: \( \text{1100 1011} \)

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Gain/Loss in dB

- decibel: dB
  - unit of signal strength based on ratio of power
  \[ S_d = 10 \log_{10} \left( \frac{\text{measured power}}{\text{reference power}} \right) \]
- signals strength is multiplied through cascaded blocks; using dB these strengths add
- note: 3dB gain means twice as "loud"
Using dB

1. Amplifier making a signal 100 times stronger has gain of:
   \(10 \log(100) = 20 \text{ dB}\)

2. Amplifier gain of 44 dB is a \(\sim 25,000\) X boost:
   \[\frac{P_m}{P_r} = 10^{44/10} = 25,119\]

Using dB

3. A signal reduced to 5% of original strength has:
   \(10 \log(0.05) = -13 \text{ dB}\)

4. An amplifier produces 1 watt for an input of 0.5 watts has gain:
   \(10 \log \left(\frac{1.0}{0.5}\right) = 10 \log(20) = 13 \text{ dB}\)

dB and electrical strength

- If signal intensity measured in volts, then:
  \[P = VI = V^2/Z\]
  So:
  \[10 \log \left(\frac{V^2}{V_r^2}\right) = 20 \log \left(\frac{V}{V_r}\right)\]
Signal Strength in dB, example

- Overall gain is: 15 dB + (-40 dB) + 22 dB = -3 dB
- So change in power over channel is: -3 dB = $10^{-3/10}$ = 0.5
- Input signal 0.5 watts X 0.5 gain factor = 0.25 watts

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Signals and Their Transmission

- what, exactly, do we put on 'the wire'?
  - directly:
    - what we start with (analog, digital)
      - digital pulse train
      - analog voice signal
  - often use indirect carrier: a signal whose properties we alter in order to carry our message
Signals and Their Transmission

- **Possibilities:**
  - Transmit as:
    - A: AM, FM, PM...
    - D: PCM, DM...
  - Input is:
    - A: ASK, FSK, PSK...
    - D: NRZ, AMI...

Analog to Analog

- **Use carrier to move message**
  - e.g., \( S(t) = A \sin(2\pi ft + \phi) \)
- **Signal content is in changes to the carrier**

Analog to Analog

- **Main types of modification:**
  - Amplitude modulation (AM)
  - Frequency modulation (FM)
  - Phase modulation (PM)
Amplitude Modulation

- Given some signal to send:
- and a carrier wave to carry it:

> figures ©ARRL, 1973

Amplitude Modulation

- we modulate the carrier with the amplitude of the signal we want to send:
  - envelope of carrier follows signal being sent
- dual sidebands
  - each can carry independent data

- what happens when signal amplitude is small?
- figures ©ARRL, 1973

Frequency Modulation

- start with carrier:
- signal to be transmitted:
- change $f_c$ as $m(t)$

> figures ©ARRL, 1973

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Phase Modulation

- start with carrier
- change \( \theta_c \) as \( m(t) \)
  - frequency deviation in PM proportional to both frequency and amplitude of \( m(t) \)
  - in FM, frequency deviation proportional only to amplitude of \( m(t) \)
- as \( |m(t)| \) increases, \( \Delta f \) increases, so does \( B \), but not overall overall power (both FM and PM)
- what about AM?

Quadrature Amplitude Modulation

- use 2 copies of carrier, one is 90° out-of-phase with the other
- input bit stream split in 2: bit \( i \) to one carrier, bit \( i + 1 \) to the other, sum and send
  - each sample represents 2 bits

Quadrature Amplitude Modulation

- if use multiple amplitude levels as well, can transmit more bits per signal sample
  - using 2 amplitudes, have 4 states
  - combinations: more amplitudes, different phase shifts
  - can get 64, even up to 256, states
Quadrature Amplitude Modulation

- more states ⇒ higher data rate for given B
- more states ⇒ less discriminability between parts of signal representing each state ⇒ higher error rates
- Given n levels of signal that can be discriminated in each sample based on amplitude, frequency or phase, the bit rate is: (b is sample rate or baud rate)

\[ C = b \log_2 n \]

QAM (with even parity)

QAM: 3 bits / baud

<table>
<thead>
<tr>
<th>Bit Combination</th>
<th>Phase Shift °</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>0</td>
<td>low</td>
</tr>
<tr>
<td>001</td>
<td>0</td>
<td>high</td>
</tr>
<tr>
<td>010</td>
<td>90</td>
<td>low</td>
</tr>
<tr>
<td>011</td>
<td>90</td>
<td>high</td>
</tr>
<tr>
<td>100</td>
<td>180</td>
<td>low</td>
</tr>
<tr>
<td>101</td>
<td>180</td>
<td>high</td>
</tr>
<tr>
<td>110</td>
<td>270</td>
<td>low</td>
</tr>
<tr>
<td>111</td>
<td>270</td>
<td>high</td>
</tr>
</tbody>
</table>
Analog to Digital

- Suppose we have true digital transmission, but an analog signal.
- Convert analog signal via digitizing, or analog-to-digital (A to D) conversion.
- Performed by a circuit that codes (A to D) and can decode (D to A): a codec.
- How to do the conversion?

A to D conversion

- We sample the analog signal at regular intervals.
  - We have $f_s$, sampling frequency or sample rate.
- If we sample analog signal $S(t)$ with $f_s \geq$ twice the highest frequency appearing in $S(t)$, then our samples contain all the information originally in $S(t)$: this is the Nyquist rate.
  - E.g., if voice signal is limited to 4,000 Hz, then sample at 8,000 samples/second.

A to D conversion

- If we sample $S(t)$ at regular intervals:

```
   \[ \begin{array}{c}
   t_1 \\
   t_2 \\
   \vdots \\
   t_n \\
   \end{array} \]
```

- And represent sample values as binary valued integers:

```
   \[ \begin{array}{c}
   0111 1111 0011 1011 \\
   \end{array} \]
```
A to D: PCM & Quantization Noise

- The number of bits per sample affects the accuracy (resolution) of the digitized version
  - Quantization error or quantization noise

- How improve?
  - More bits (~6dB improvement to SNR [quantization noise] per added bit)

\[
\text{SNR}_{\text{PCM}} = 20 \log_2 2^n + 1.76 \text{ dB}
\]

\[
= 6.02n + 1.76 \text{ dB}
\]

- Using non-linear coding: range of amplitudes is not even-stepped (e.g., Stallings Fig 5.11)
  - Used in voice telephony

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A to D: Delta Modulation

- approximate analog signal with 'staircase'
  - have sample time: width of a 'stair', $T_s$
  - have step size: height of a 'stair', $\delta$
- signal change in step, not sample value itself
  - each bit represents a change of $+\delta$ or $-\delta$
- generally poorer SNR performance than PCM at same data rate
- attractive because easy to build

A to D: Delta Modulation

- Fig 5.13
  - slope overload noise
  - quantization noise

A to D: Linear Predictive Coding

- used for digitized voice communication
- represent speech as progression of component speech sounds
- can achieve VDR (voice data rate) as low as 2.4 kbps
Digital Transmission of Voice

- sample analog speech at Nyquist rate $2f_h$.
  - For phone, $\approx 4$ kHz, so sample at 8000 sps.
- Convert each sample to an 8 bit value (PCM).
- What bit rate do we need?
  - $8000$ samples/second $\times 8$ bits/sample $= 64,000$ bps.
- A group of $24$ such voice channels needs:
  - $24 \times 64,000$ bps $= 1,536,000$ bps.
  - This fits on a T1 carrier channel.

Speech Coding: non-linear

- Speech is coded using non-linear scale: $\mu$-law.
- 7 bits gives effect of 13.
Digital Transmission of Music

- 8000 samples/second inadequate
- 8 bits per sample inadequate

CD uses:
- 44,100 samples/sec
- 16 bit samples
- 2 channels for stereo (interleaved channels)
- what is bit rate of a CD player?

More Quantization Noise

- for speech encoded using 8-bit samples, what is SNR PCM?
  - SNR PCM = 20 log 2^n + 1.76 dB
  - SNR PCM = 20 log 2^8 + 1.76 dB
  - 128 dB
  - noise can never be better than 49.9 dB below maximum signal level
- how about for a CD?
  - SNR CD = 20 log 2^16 + 1.76 dB
  - 98.1 dB

Digital to Analog

- most familiar use: digital data xfer through voice-grade analog telephone lines
  - what bandwidth? spectrum?
- many signals (e.g., voice) that may have been digitized for transmission must be converted back to analog at receiver
- use device to receive digital and generate modulated analog (and vv): modulator-demodulator, or, modem
D to A

- analog signal to carry digital info: properties to use?
  - amplitude: ASK amplitude shift keying
  - frequency: FSK frequency shift keying
  - phase: PSK phase shift keying

- resulting signal occupies B centered on $f_c$

D to A: ASK

- use 2 amplitude levels, typically:
  - for bit value 0: 0
  - for bit value 1: $A \cos(2\pi f_1 t)$

- good to ~1200 bps on voice grade lines

- used for driving LED transmitters on fibre optic
  - also for lasers, though these usually have low-level
    analogous of DC offset (‘bias’)

D to A: FSK

- use 2 frequencies typically:
  - for bit value 0: $A \cos(2\pi f_1 t)$
  - for bit value 1: $A \cos(2\pi f_2 t)$
  
    where $f_1$ and $f_2$ are offset from $f_c$ by fixed amount
    in opposite directions

- less susceptible to error than ASK
- on voice-grade lines, used up to 1200 bps
- also used for radio transmission (3 to 30 MHz)
- use at higher frequencies in LANs using coax
D to A: PSK

- Use 2 phases typically:
  - For bit value 0: \( A \cos(2\pi f_c t) \)
  - For bit value 1: \( A \cos(2\pi f_c t + \pi) \)

To signal new bit value relative to previous one:
- This is differential PSK

- If bit is 0, send burst in same phase as previous
- If bit is 1, send burst 180 out of phase as previous

D to A: QPSK

- Can also use quadrature to increase bit rate:
  - Multiple phase angles
  - Multiple amplitudes

  E.g., V.32 modem standard does 9600 bits per second at 2400 baud:

In general, quadrature allows increased bit rate per sample:

\[
D = R \frac{b}{L} \leq R
\]

- \( D \) is modulation rate in baud
- \( R \) is data rate in bps
- \( b \) is # bits per signal element
- \( L \) number of different signal elements
Digital to Digital

- How represent, as EM signals, digital quantities?
- Need clocks to agree at sender and receiver

- Simplest:
  - Use one fixed voltage level for a 0
  - A different fixed level for a 1
  - Hold those fixed voltages for one 'pulse time'
    - Short: higher bit rates
    - Long: lower error rates
  - Called NRZ: non-return to 0

D to D: NRZ, NRZ-L, NRZI

- In practice, implement NRZ as:
  - Negative voltage for 1 bit
  - Positive voltage for 0 bit
  - This is called NRZ-L (non-return-to-zero-level)

- Another variant: NRZI (NRZ, invert on 1s)
  - Is a differential coding
  - If current bit is 0, use same level as preceding bit
  - If current bit is 1, use different level from previous

D to D: NRZ family

- Intolerant to synchronization drift
  - What happens with long string of 1s or 0s?

- Usually used for digital magnetic recording
  - Not so well suited to transmission
D to D: Bipolar-AMI

- bipolar with alternate mark inversion
- use 0 volts for 0 bit
- use ±v to signal 1 bit, alternating between +v and –v on successive 1s
  - avoid sync problems on long strings of 1s
  - what about long strings of 0s?
- allows for simple error detection
  - any erroneous insertion or deletion of a pulse violates alternating ±v property

D to D: NRZ vs. Bipolar-AMI

- how do these compare?
  - bipolar-AMI less sync error prone, provides simple error detection, has no net DC component
  - but uses 3 levels instead of NRZ’s 2:
    - \( \log_2(2) = 1 \)
    - \( \log_2(3) = 1.58 \)
  - bipolar-AMI receiver needs 3dB stronger signal for same error rate as NRZ
    - or, for same SNR, NRZ has lower error rate

D to D: Manchester

- a biphase technique: do transition at mid-point of each bit period
  - acts as clocking mechanism
  - signals data:
    - low to high for 1 bit
    - high to low for 0 bit
- requires 2X bandwidth in medium
D to D: Differential Manchester

- Do transition at mid-point of each bit period
  - Midbit transition acts as clocking mechanism only
  - Signals data:
    - If transition at start of bit period: 0 bit
    - If no transition at start of bit period: 1 bit

D to D: Biphase

- Advantages of biphase techniques:
  - Self-clocking: mid-bit transition assures sync
  - No DC component in signal
  - Error detection: missing transitions indicate errors
    - How could an error be missed?
    - Good speed locally (10 Mbps), but inefficient for transmission over long distance (high D to R)

D to D: Biphase

- Manchester used in IEEE 802.3
  - Baseband coax and twisted pair CSMA/CD bus LANS

- Differential Manchester used in IEEE 802.5
Data Compression

- If compress data to be sent, then re-expand on receipt, can get higher effective data rate for fixed signal rate (companding).

- Introduces processing overhead at sender and receiver.

Data Compression

- **RLE (run length encoding)**
  - replace long sequence of 1s or 0s with something like: `<tag><count>`
  - tag indicates what follows is not plain data but count of repeating 1s or 0s
  - count is number of 1s or 0s in a sequence

- **Ziv-Lempel compression** used in V .42 bis modems
Concentrators
- Used to obtain high-utilization of links
  - Let multiple stations share links
  - All senders served in turn (older technology)

Multiplexing
- Multiplexing (muxing) allows multiple flows to share a channel within limits of overall capacity

Muxing
- FDM: Frequency division multiplexing
  - Analogous to radio spectrum within a cable
  - Not good for data due to noise from 'baseband loading'
  - Subcarrier modulator
  - Subcarrier already band-limited
    - E.g., voice telephony: 3 kHz
Muxing: FDM

- separate bands may slightly overlap
  - hence need for ‘guardbands’ at sides

Muxing

- **TDM**: time division multiplexing
  - interleave bits from different slower streams into one faster stream

- **STDM**: statistical time division multiplexing
  - take advantage of idle time on link to run more TDM streams
  - not good for data, good for voice

- **TDMA**: time division multiple access
  - used with radio and satellite
  - transmitters take turns sending in closely spaced slots
  - wasteful of spectrum

Muxing

- **WDM**: wavelength division multiplexing
  - send multiple λ through fiber concurrently
  - up to 96 commonly used today
An application: FAX machines

- scanner + printer + modem in-a-box
- scanner digitizes page image
- digitalized page image converted (back to) analog (but different kind) in modem for transmission over voice-grade telephone
  - why does computer-generated fax look better?
- extensive use of compression (e.g., RLE)
- can use protocols that take advantage of document characteristics (e.g., “group 3”)

Modern Transmission Systems

- most commercial systems are digital end-to-end
  - analog data converted to digital at or near sender
  - every amplifier along path restores digital signal to clean bits
  - digital data converted to analog at or near receiver
- what advantages from this?

Advantages of all-digital transmission

- result:
  - immunity to noise
  - lower cost
  - uniform data format
  - better security
  - better reliability
  - better control
- application:
  - 56 kbps modem: is digital from provider to user, all digital (hdx); is 33.6 kbps analog from user to provider... doesn't work everywhere!
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Circuit Switching

- Establishes temporary connections among communicating elements

Hub Switching

- Connects multiple devices in a network
Hierarchical Switching

Trunk Circuit Switching

Inside a Circuit Switch
Circuit Switching for Data

- Real-time capability
- Call setup delay
- End system must place call
- Blocking (e.g., busy signal) possible
- Once you have a circuit you can use it until to choose to release it

A Familiar Circuit Switched Network

- subscriber: device attached to network (at endpoint), e.g., a telephone
- subscriber loop: link between subscriber and network
  most are twisted-pair
  typical range: few km to few 10s of km
- exchange: switching center on the network
  exchanges directly supporting subscribers are end-offices
- trunk: links between exchanges
  multiple voice frequency circuits
  using FDM or synchronous TDM
Private Branch Exchange (PBX)

- A PBX is a small circuit switch providing:
  - local dial-up service
  - access to large system, like public switched system

- New PBXs are fully digital
  - Interfaces for (analog) plain old telephone system (POTS) available
  - What would such an interface have to do?

Digital Line Hierarchy
(North America & Japan)

- Normally available as leased service
- Europe uses different digital hierarchy, also based on 64 Kbps voice channels
  - E1 is 2.048 Mbps, 32 channels

<table>
<thead>
<tr>
<th>Name</th>
<th>Capacity</th>
<th>Voice Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS0</td>
<td>56 Kbps</td>
<td>1</td>
</tr>
<tr>
<td>DS1 (<em>T1</em>)</td>
<td>1.544 Mbps</td>
<td>24</td>
</tr>
<tr>
<td>DS2</td>
<td>6.312 Mbps</td>
<td>96</td>
</tr>
<tr>
<td>DS3 (<em>T3</em>)</td>
<td>44.736 Mbps</td>
<td>672</td>
</tr>
<tr>
<td>DS4</td>
<td>1.536 Mbps</td>
<td>2,016</td>
</tr>
</tbody>
</table>

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Integrate Services Digital Network (ISDN)

- common standard for “dial-up digital” circuits:
  - B channel: 64 kbps
  - D channel: 16 kbps (used for signaling)

- packaged as:
  - basic rate: 2B + D
  - primary rate: 23B + D (30B + D in Europe)

- “broadband ISDN”: 155 Mbps and up
  - using ATM
  - slowly becoming available

ISDN Components

- TA: Terminal Adapter
  - for non-ISDN directly compatible equipment
- NT1: Network Terminator
- Stallings Appendix A has details on ISDN

Synchronous Optical Network (SONET)

- a network of optical carriers installed by the common carriers for most long-distance trunks
- data rates occur at multiples of 51.84 Mbps, called Optical Carrier 1 (OC-1)

- commonly available data rates include:
  - OC-3 ~155 Mbps
  - OC-12 ~622 Mbps
  - OC-24 ~1.2 Gbps
  - OC-48 ~2.4 Gbps
Broadband ISDN

- operates over SONET
- uses cell-switching technique: asynchronous transfer mode (ATM)
- sends 53-byte cells (fixed-sized packets) across SONET links between cell switches
- cell paths requested using ISDN call setup
- cells sent into network, switched at cell switches, then brought out of network at dest.

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ATM and AAL

- ATM Adaptation Layers (AAL) integrate application data with cell structure
  - AAL1: constant bit rate
  - AAL2: variable bit rate
  - AAL5: available bit rate
- more on ATM later in course...(stay tuned)
Asymmetric Digital Subscriber Line (ADSL, DSL)

- approach new in 1995
- basic idea: asymmetric speeds reflect usage:
  - high capacity to subscriber (≤ 9 Mbps)
  - low capacity from subscriber (≤ 1 Mbps)
- may also provide voice telephony by muxing
- runs on std copper wire up to ~ 3 miles/5 km from telephone office
  - longer distance, lower data rate
  - 3 miles/5km: 1.5 Mbps
  - 1.5 miles/2.5 km: 9 Mbps

Cable Modem

- cable TV originally unidirectional
  - all signals flow from "head end" through tree of wire, fibre, and distribution amplifiers
  - practically no capacity for flow back to head
- contemporary cable TV bidirectional
  - competing for Internet service to home
- subscriber (at home) connects via cable modem

- the cable modem:
  - bypasses (is independent of) home cable converter
  - provides bit rates of hundreds of kbps to/from Internet
  - upstream transmissions contend for shared channel
  - mechanism similar to Ethernet (we see later)
Physical Interfaces

- **EIA-232-D (RS-232)**
  - most common serial interface
  - asynchronously: as few as 5 wires
  - normal limit 20 kbps (though some over 100 kbps)
  - see Stallings Fig 6.5, table 6.1
  - note variety of standards involved:
    - mechanical (ISO 2210)
    - electrical (V.28)
    - functional (V.24)
    - procedural (V.24)

---

**RS232 Interface Standard**

- 25 wire standard:

<table>
<thead>
<tr>
<th>Wire</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Common Ground</td>
</tr>
<tr>
<td>2</td>
<td>Signal Ground</td>
</tr>
<tr>
<td>3</td>
<td>Data terminal ready</td>
</tr>
<tr>
<td>4</td>
<td>Ring detector</td>
</tr>
<tr>
<td>5</td>
<td>Signal Ground</td>
</tr>
<tr>
<td>6</td>
<td>Ring detector</td>
</tr>
<tr>
<td>7</td>
<td>Data terminal ready</td>
</tr>
<tr>
<td>8</td>
<td>Ring detector</td>
</tr>
<tr>
<td>9</td>
<td>Signal Ground</td>
</tr>
<tr>
<td>10</td>
<td>Ring detector</td>
</tr>
<tr>
<td>11</td>
<td>Data terminal ready</td>
</tr>
<tr>
<td>12</td>
<td>Ring detector</td>
</tr>
<tr>
<td>13</td>
<td>Signal Ground</td>
</tr>
<tr>
<td>14</td>
<td>Ring detector</td>
</tr>
<tr>
<td>15</td>
<td>Data terminal ready</td>
</tr>
<tr>
<td>16</td>
<td>Ring detector</td>
</tr>
<tr>
<td>17</td>
<td>Signal Ground</td>
</tr>
<tr>
<td>18</td>
<td>Ring detector</td>
</tr>
<tr>
<td>19</td>
<td>Data terminal ready</td>
</tr>
<tr>
<td>20</td>
<td>Ring detector</td>
</tr>
<tr>
<td>21</td>
<td>Signal Ground</td>
</tr>
<tr>
<td>22</td>
<td>Ring detector</td>
</tr>
<tr>
<td>23</td>
<td>Data terminal ready</td>
</tr>
<tr>
<td>24</td>
<td>Ring detector</td>
</tr>
<tr>
<td>25</td>
<td>Signal Ground</td>
</tr>
</tbody>
</table>

---

Physical Interfaces

- **EIA-449 (RS-449)**
  - higher data rates (up to 2 Mbps)
  - balanced line capable
  - common on 56/64 kbps and T1/E1 links
  - built-in loopback capability
  - variations include:
    - RS-422
    - V.32
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Homework Problems

1. Express in dB the gain of an amplifier with output of 75W, when the input is 150 mW
2. If attenuation results in an output = .013 X input (measured in Watts), express this loss in dB.
3. Sketch the QAM signal for “Net” in 8-bit ASCII with even parity. Do also for Manchester.
4. Calculate the ratio of signal to quantization noise for 24-bit PCM encoding. How does this compare to ordinary audio CD?
5. For the figure below, (a) calculate the overall dB and (b) find the output.

Project DLC2

- FCS stack: generate_FCS(bit_frame* FCS_frame)
  
  Given a bit frame delimited by two flags and with a 16-bit CRC placeholder (immediately preceding the closing flag), compute a 16-bit Cyclic Redundancy Check Frame Check Sequence using the CCITT 0-5-12-16 polynomial. Return the 16-bit FCS.
  
  - Do not include the flags in the CRC computation.
- code/crc.cpp contains function stub and algorithm
- See UIP Chapter 4 for details.

<table>
<thead>
<tr>
<th>FLAG</th>
<th>Address</th>
<th>Control</th>
<th>Data</th>
<th>CRC-FCS</th>
<th>FLAG</th>
</tr>
</thead>
</table>

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Hardware CRC Generation Circuit
Polynomial: $D^{16} + D^{12} + D^5 + 1$

Input DATA: 0010 0101 1001 0100
open switch to shift out result
⊕ XOR gate

uncomment CRC_example(); in dlc2.cpp to see how this works