ELEX 3525 : Data Communications
2014 Winter Session

Solutions to Assignment 3

Corrected April 13, 2014 to change the number of guard time samples in answer to Question 5 (from 3 to 4) and added diagrams to explain the answer of Question 7.

Question 1

This channel's frequency response has odd symmetry around a frequency of 500 kHz. Thus it meets the Nyquist no-ISI condition for a symbol rate of 1 MHz[1]

However, the shape of the signal can be, and normally is, distorted even when there is no ISI at the sampling points. It is common for pulses to be distorted by being "rounded off" as can be seen in eye diagrams.

There will be no interference between symbols if the transmitted symbols are impulses. But for common types of transmitted symbols there will be ISI. In order to avoid this ISI the channel needs to be corrected for the fact that we are transmitting something other than impulses.

Since the question does not state the type of symbols being transmitted the correct answer is "yes, except for impulses." However, the description of a Nyquist "channel" in textbooks often includes the transmitter's pulse-shaping filter as part of the channel and in this case the answer would be "yes." Either answer will be accepted.

Question 2

In this case the impulse response of the channel is not zero at multiples of the symbol period for a 2 MHz symbol rate (500 ns) so there will be ISI.

If the symbol rate were 1 MHz and the transmitted symbols were impulses then there would be no ISI at multiples of the symbol period (1 μs). This will not be the case for other symbols unless the "channel" is considered to also include the pulse-generating filter that converts impulses to the transmitted symbols.

Question 3

The Shannon capacity theorem only applies to channels with AWGN (additive white Gaussian noise). It does not apply to channels with other types of noise. If the channel is impulsive we cannot apply the Shannon capacity theorem. For example, since there is no noise in-between impulses there is (theoretically, from the information given in the question) no limit to the data rate we could transmit at these times and there is no limit to the data rate we could achieve over this channel.

If the noise is AWGN the we can apply the Shannon capacity theorem and calculate the maximum error-free rate as:

$$C = B \log_2 \left(1 + \frac{S}{N}\right)$$

$$= 10^6 \log_2 \left(1 + \frac{0.1}{0.01}\right) \approx 3.5 \times 10^6$$

Question 4

The symbol rate exceeds the channel bandwidth by a factor of 4 and the minimum Nyquist bandwidth by a factor of 2 so we could not transmit over this channel without ISI.

However, there are types of receivers, such as a sequence-estimation receiver, that could recover the transmitted signal given a knowledge of the channel impulse response and the absence of noise.

The use of partial-response signalling would allow data transmission over the channel without necessarily recovering the transmitted levels.

Question 5

The OFDM symbol duration is the number of samples per symbol times the sample period:

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[1] To avoid ISI the channel should also have symmetry in phase. For example, it could have linear phase (equal delay at all frequencies).

$$T_{\text{symbol}} = N \times T_s = N \times \frac{1}{f_s}$$

and the subcarrier spacing is the inverse of the symbol duration:

$$\Delta f = \frac{1}{T_{\text{symbol}}}$$

substituting the first equation into the second:

$$\Delta f = \frac{1}{N \times \frac{1}{f_s}} = \frac{f_s}{N}$$

from which:

$$f_s = N\Delta f = 256 \times 4\,\text{kHz} = 1024\,\text{kHz}$$

If the duration of the ISI is $T_{\text{ISI}} = 3\ \mu$ s and the duration of each sample is $1/f_s$ then we need $T_{\text{ISI}}/(1/f_s) = 3 \times 10^{-6} s/(1/1.024 \times 10^6) = 3.072\,\mu$ s. The number of samples must be an integer so we need to round up this number. We thus need a minimum of 4 samples to avoid ISI from one symbol from affecting the following one.

Question 6

One of the advantages of a current loop is that it indicates a failure of the communication link; for example, that the link has been disconnected or cut. It would be useful for a security alarm system to have an indication that the communication link had failed in order avoid failures of the system involving link disconnection.

Note that a current loop can be bypassed by shorting the loop. More sophisticated methods are required to protect against this type of failure or intentional attack.

Question 7

The termination should: have an impedance that matches that of the transmission line, minimize the average power consumption, and maintain differential signalling (equal and opposite currents).

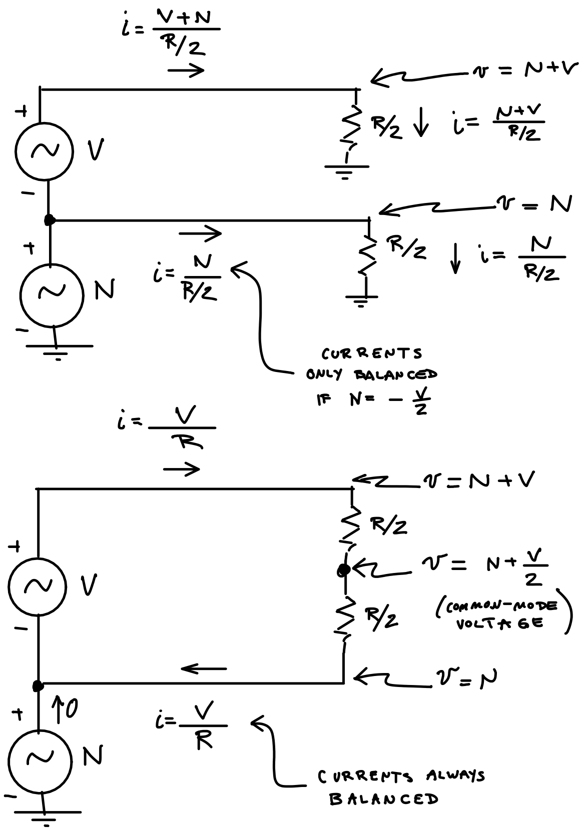
All three terminations present a 100 Ω impedance between the pairs.

Assuming both bit values are equally likely (probability = 0.5), the first termination will result in currents of 0 and 100 mA for an average power consumption of $0.5 \times I^2R = 0.5 \times (0.1)^2 \times 100 = 0.5$ W compared to currents of ±50 mA for an average power consumption of $I^2R = 0.05^2 \times 100 = 0.25$ W.

The third termination will not result in balanced currents unless the source voltages are also balanced relative to ground (not stated in the question and not always the case).

Therefore the second termination is the best choice since it has a lower average power consumption than the first choice and results in balanced currents regardless of the source voltages relative to ground.

The following diagrams show the currents flowing along the two conductors when there is a common-mode voltage. When there are two terminations to ground and there is a common-mode voltage the currents will not be balanced (equal in magnitude and opposite in direction).



Question 8

Does a typical line driver:

(a) provide impedance matching: T. In the sense that the line driver output should have an output impedance suitable for the type of transmission line being used.

(b) detect parity errors: F. This is normally a function of the receiver hardware that handles the link-layer protocol (a serial interface UART or Ethernet network interface) rather than the line driver which is a physical-layer transmitter.

(c) provide a logic-level output: F. The logic-level outputs are provided by the receiver.

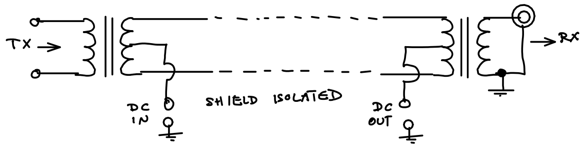
(d) provide a logic-level input: T. The line driver turns logic-level inputs into line-level outputs.

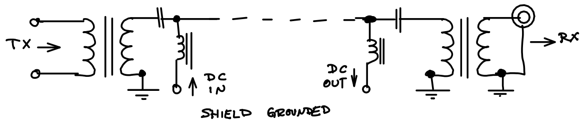
Question 9

Transformers can be used at the transmit end to connect the differential line driver to the unbalanced transmission line. A transformer can be also be used at the receiver to provide isolation against line voltage.

In this question the transmission line is co-ax cable. To use the technique described in the lectures notes and shown in the first figure below the shield would have to be isolated from ground.

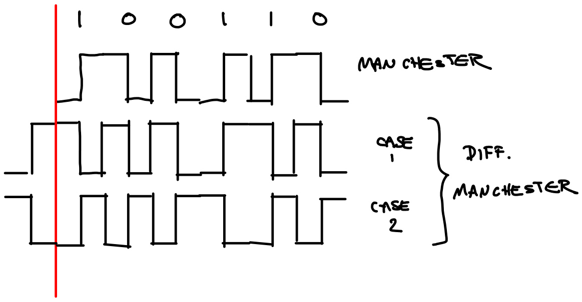
However, in most cases co-ax cable is used with the shield grounded. In that case the second circuit shown below can be used. The capacitors prevent current from flowing to ground through the transformers but allow the signal through. Chokes (the inductors) prevent the signal from flowing to ground through the power supply but allow the DC power through. In this second case an optoisolator could also be used at the receiver to provide protection.





Question 10

The first waveform is the Manchester encoding (0 is a high-to-low transition, 1 is a low-to-high transition). The differential Manchester encoding transmits the same waveform for a '0' bit and the opposite waveform for a '1' bit. Since the previous values (zeros) could have been transmitted as either waveform, there are two possible answers.



Question 11

A [bipolar] Return to Zero (RZ) line code is usually described as a three-level signal using negative and positive voltage levels in addition to zero. However, the question did not state this explicitly. RZ can also refer to "unipolar RZ" in which the signal returns to zero from either a positive voltage or zero. In this case the line code is using a pulse to indicate a '1' and no pulse to indicate a '0'.

(a) NRZ, AMI (without zero substitution) and unipolar RZ all have the minimum number of guaranteed level transitions per bit (zero).

(b) Bipolar RZ or Manchester have the maximum guaranteed number of transitions per bit (two and one respectively).

(c) Manchester, NRZ and unipolar RZ all have the minimum number of signal levels (two).

Question 12

The HDLC frame begins with a flag sequence and has a '0' bit-stuffed after every 5 '1' bits. An HDLC frame typically contains a header and trailer but they were not specified in the question and are not included the answer below.

```
0 1 1 1  1 1 1 0        <- the starting flag
1 0 1 1  0 1 1 1  1 1  <- the original data up
                          until 5 1's are seen
0                       <- the 'stuffed' bit
1 1  0 1               <- the rest of the bits
0 1 1 1  1 1 1 0        <- the ending flag
```

Question 13

The byte-oriented encapsulation as described in the question would result in a starting STX, an ending ETX and an ESC character preceding every STX (0x02), ETX (0x03) or ESC (0x1b) character within the frame:

```
02    <- STX start of frame
00 01 <- data
1B 03 <- escaped ETX
51 2A <- data
1B 1B <- escaped ESC
10    <- data
1B 02 <- escaped STX
11    <- data
03    <- ETX for end of frame
```

Question 14

At 4 bits/symbol it will be necessary to transmit $\lceil 1795/4 \rceil = 449$ symbols. The frame will thus carry a total $449 \times 4 = 1796$ bits. The remaining $1796 - 1795 = 1$ bits will be padding bit(s).