6 June 2015

ETEC 303

5th Semester

[ECE + CSE] ONLY

DIGITAL COMMUNICATION

All of us have studied Analog Communication in the previous semester. In this semester, we would be studying Digital Communication. But before moving on, let us first review some of the questions mentioned below so that we can better appreciate the importance of this subject.

Q1 = What is the difference between Analog signal and Digital Signal?

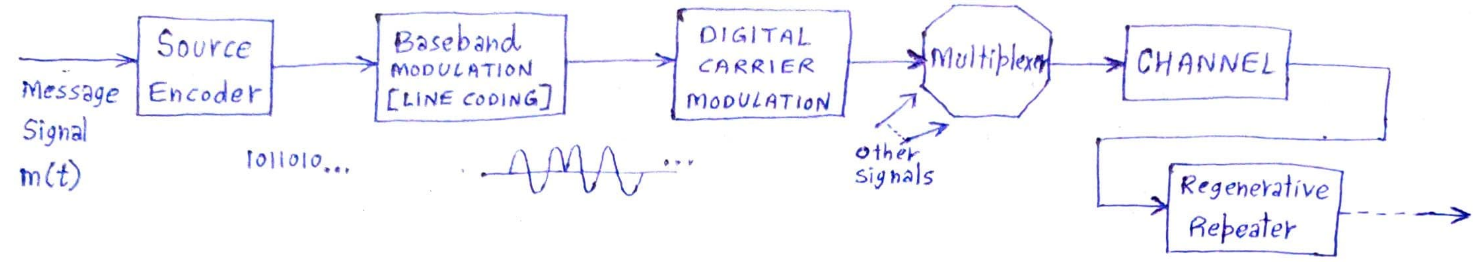
Q2 = What are the advantages of Digital Communication over Analog Communication? Are there any disadvantages also?

Q3 = In what way is the reception of analog signal different from a digital signal?

Q4 = Is it possible to completely sideline Analog Communication and use only and only Digital Communication in any given area of application?

Answers to Q1 and Q2 will help you to understand the necessity of LINE CODING, SAMPLING THEOREM and other related topics of UNIT-I. Answer to Q3 will give you an insight idea of why we need to study RANDOM VARIABLES, PDF, CDF, WSS, etc. etc., which are topics for UNIT II. And not only UNIT II, but also answer to Q3 will play an important role to understand UNIT III DESIGNING OF [DIGITAL] RECEIVER. Last but not the least, Q4 is there for a logical introduction to UNIT IV. For the kind information of all students, these notes are not all in all. YOU MUST READ THE TECHNICAL BOOKS ALSO. The only purpose of these notes is to enable you to achieve the level where it becomes relatively easier for understanding the contents of technical books. Answers for Q1 to Q4 will be discussed in class. Not here.

A digital communication system consists of several components as shown in the figure below. Now, we briefly outline their functionalities in the communication system.



<u>Source Encoder</u> The input to a digital system takes the form of a sequence of digits. The input could be the output from a data set, a computer, or a digitized audio signal (PCM, DM or LPC), digital facsimile or HDTV, or telemetry data and so on. Discussions pertaining to digital communication are generally confined to the binary case (communication schemes using only two symbols). However, the general case of M-ary communication which uses M symbols will also be discussed. The responsibility of source encoder is to assign least number of bits to the frequently occuring symbols and, the rarely occuring symbols may be assigned more number of bits. As an example, to encode, say, a sentence written in English language, the alphabet "Z" may be assigned more number of bits as compared to the alphabet "e". This will allow us to convey the information in lesser number of bits as against the case of assuming each symbol (such as any alphabet a to z) equally likely. A classical example of source encoding is the Morse Code where all the symbols are encoded using "~~mark~~" dashes and "~~space~~" dots. See any book for more on Morse Code.

<u>LINE CODING</u> The digital output of a source encoder is converted (or coded) into electrical pulses (waveforms) for the purpose of transmission over the channel. This process is called LINE CODING or TRANSMISSION CODING. There are many possible ways of assigning waveforms (or pulses) to the digital data. In the binary case (2 symbols), for example, conceptually the simplest line code is ON OFF, where a 1 is transmitted by a pulse $p(t)$ and a 0 is transmitted by no pulse (zero signal). Another commonly used code is POLAR, where 1 is transmitted by a pulse $p(t)$ and 0 is transmitted by a pulse $-p(t)$. The polar scheme is the most power efficient code because it requires the least power for a given noise immunity (error probability). Another popular code in PCM is BIPOLAR, also known as, PSEUDOTERNARY or ALTERNATE MARK INVERSION (AMI), where 0 is encoded by no pulse and 1 is encoded by a pulse $p(t)$ or $-p(t)$ depending on whether the previous 1 is encoded by $-p(t)$ or $p(t)$. In short, pulses representing consecutive 1s alternate in sign. This code has the advantage that if one single error is made in the detecting of pulses, the received pulse sequence will violate the bipolar rule and the error can be detected, although not corrected immediately. This assumes no more than one error in sequence.

We have the option of using both half width and full width pulses. Whenever full width pulses are used, the pulse amplitude is held to a constant value throughout the pulse interval. In other words, it does not have a chance to go to zero before the next pulse begins. For this reason, these schemes are called Nonreturn-to-Zero (NRZ) schemes in contrast to Return-to-Zero (RZ) schemes.

DIGITAL CARRIER MODULATION Till now, we have discussed baseband digital systems where signals are transmitted directly without any shift in the frequencies of the signal. Because baseband signals have sizable power at low frequencies, they are suitable for transmission over a pair of wires, co axial cables, or optical fibres. Much of the modern communication is conducted this way. However, BASEBAND SIGNALS CANNOT BE TRANSMITTED OVER A RADIO LINK OR SATELLITES because this would necessitate impracticably large antennas to efficiently radiate the low frequency spectrum of the signal. Hence, for such a purpose, the signal spectrum must be shifted to a high frequency range. A spectrum shift to higher frequencies is also required to transmit several messages simultaneously by sharing the large bandwidth of the transmission medium (FDM). There are several techniques used for Digital Carrier Modulation such as ASK, FSK, PSK, QPSK, MSK, etc. We shall later study these techniques in more detail as we progress through the semester.

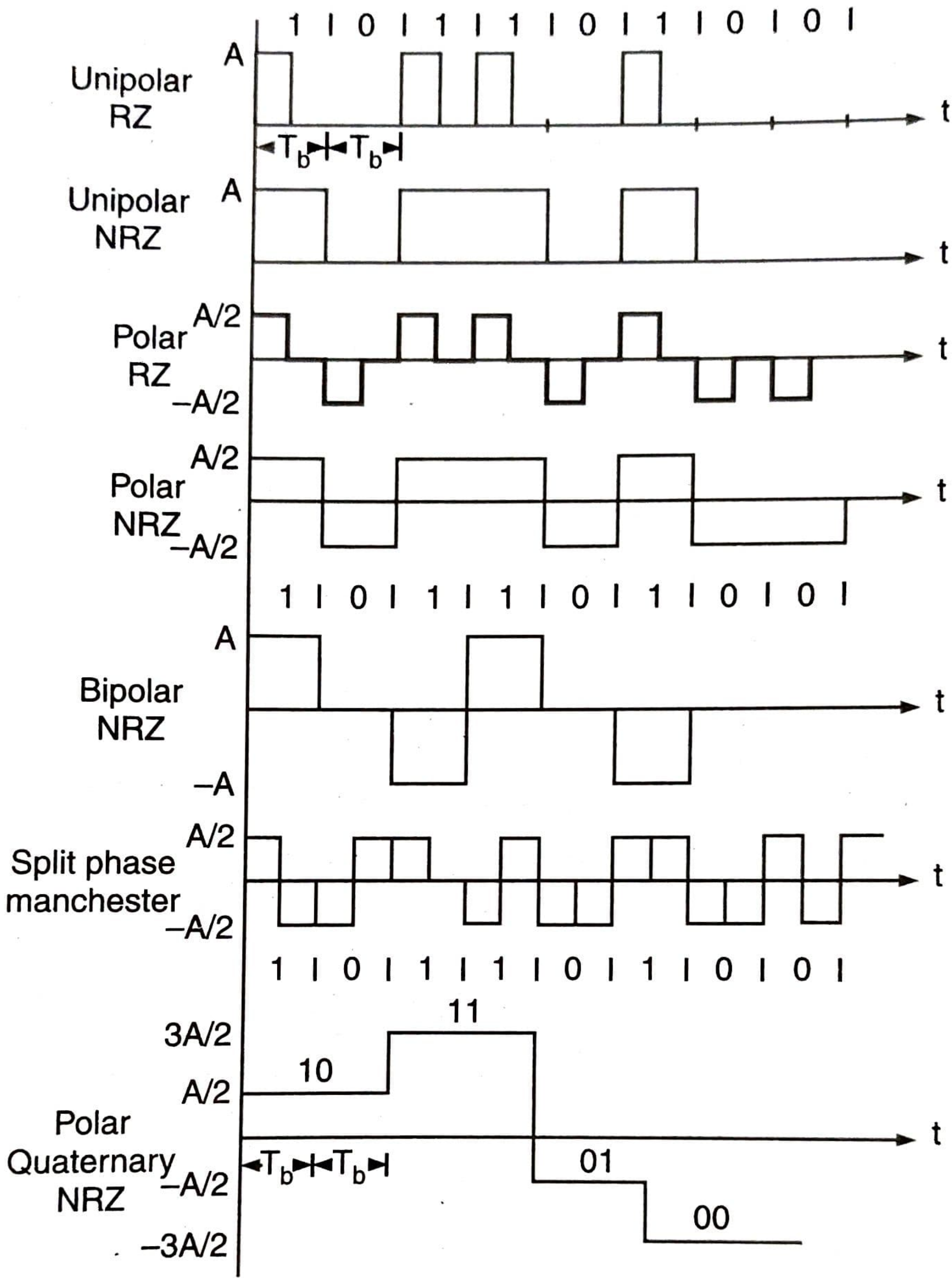
MULTIPLEXER The bandwidth occupied by a single information source is quite less as compared to the overall channel bandwidth. Therefore, we can multiplex several signals and transmit them simultaneously over the channel. We have just discussed FDM, a multiplexing technique, in the above written paragraph.

CHANNEL It is a medium through which the multiplexed signal propagates. Channel can be wired or wireless. Example of wired channel includes copper cables, twisted pair, co axial cable, optical fibre, etc. Wireless channels propagate the signal through free space such as a radio link, satellite link, etc. Free space refers not only to over the air communication but also through vaccum, water, etc. As an example, in a satellite link, the signal travels through the atmosphere as well as in deep space (vaccum).

REGENERATIVE REPEATER They are used at regularly spaced intervals along a digital transmission line to detect the incoming digital signal and regenerate new clean pulses for further transmission along the line. This process periodically eliminates, and there by combats, the accumulation of noise and signal distortion along the transmission path. This is one of the most significant advantage of digital communication over analog communication. Basically, a regenerative repeater performs three functions:

1. Reshaping incoming pulses by means of an equaliser.
2. The extraction of timing information required to sample incoming pulses at optimum instants.
3. Decision making based on the pulse samples.

The student may find it difficult to understand these three points at the moment. Things will get clear (hopefully) as the semester progresses. As far as point 2 written above is concerned, it will get more clear if point 5, adequate timing content, is read from the next topic LINE CODING PROPERTIES. Point 3 written above means that if pulse amplitude is detected to be positive, then it is logic 1, otherwise it is logic 0 and the value of pulse amplitude is a factor which tells us about the reliability of our decision.



1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
A
Unipolar RZ
t
T_b T_b
A
Unipolar NRZ
t
A/2
Polar RZ
t
–A/2
A/2
Polar NRZ
t
–A/2
1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
A
Bipolar NRZ
t
–A
A/2
Split phase manchester
t
–A/2
1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
11
3A/2
10
A/2
Polar Quaternary NRZ
t
T_b T_b
01
–A/2
00
–3A/2

LINE CODING PROPERTIES

Digital data can be transmitted by various transmission or line codes such as ON OFF, POLAR, BIPOLAR and so on. Each has its advantages and disadvantages. A Line Code should have the following properties:

① **Transmission Bandwidth** It should be as small as possible.

② **Power Efficiency** For a given bandwidth and a specified detection error probability, the transmitted power should be as small as possible.

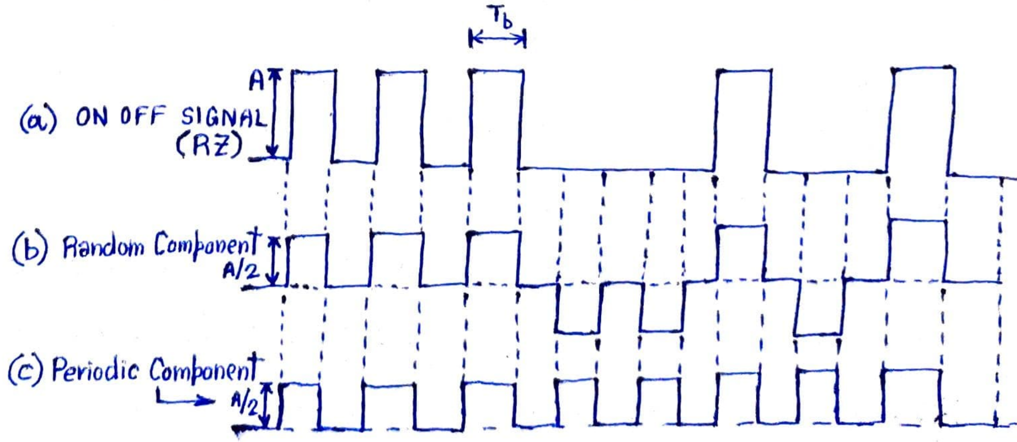
③ **Error Detection and Correction Capability** It should be possible to detect, and preferably correct, detection errors. In a bipolar (AMI) case, for example, a single error will cause bipolar violation and can easily be detected.

④ **Favorable Power Spectral Density** It is desirable to have zero PSD at $\omega = 0$ (dc), because ac coupling and transformers are used at the repeaters. Significant power in low frequency components causes dc wander in the pulse stream when ac coupling is used. The ac coupling is required because the dc paths provided by the cable pairs between the repeater sites are used to transmit the power required to operate the repeaters.

⑤ **Adequate Timing Content** It should be possible to extract timing or clock information from the signal. If the pulses are transmitted at a rate of R_b pulses per second, we require the periodic timing information (the clock signal at R_b Hz.) to sample the incoming pulses at a repeater. This timing information can be extracted from the received signal itself if the line code is chosen properly. The POLAR SIGNAL (Fig 1 on previous page), for example, when rectified, results in a periodic signal of clock frequency R_b Hz. which contains the desired periodic timing signal of frequency R_b Hz.. When this signal is applied to a resonant circuit tuned to frequency R_b, the output, which is a sinusoid of frequency R_b Hz, can be used for timing.

As shown in Fig. 2, an ON OFF RZ signal can be expressed as the sum of a periodic signal (of clock frequency) and a polar signal. Because of the presence of the periodic component, we can extract the timing information from this signal using a resonant circuit tuned to the clock frequency.

A BIPOLAR SIGNAL when rectified becomes an ON OFF SIGNAL. Hence, its timing information can be extracted the same way as that for an ON OFF SIGNAL.



ON OFF RZ SIGNAL (Waveform (a)) = POLAR SIGNAL (Waveform (b)) + Clock Frequency Periodic Signal (Waveform (c))

Fig. 2

⑥ Transparency It should be possible to transmit a digital signal correctly regardless of the pattern of 1's and 0's. The timing signal (the resonant circuit output) is sensitive to the incoming bit pattern. In the ON OFF or BIPOLAR case, a 0 is transmitted by "no pulse". Hence, if there are too many 0's in a sequence (no pulses), there is no signal at the input of the resonant circuit and the sinusoidal output of the resonant circuit starts decaying, thus causing error in the timing information. To solve this problem, several methods are available, out of which two methods are written below.

(i) High Density Bipolar (HDB) Code.
(ii) Binary with N Zero Substitution Code.

Next, we will study the above written two methods in detail ahead. To conclude, a line code in which the bit pattern does not affect the accuracy of the timing information is said to be a TRANSPARENT line code. The POLAR scheme is transparent. ON OFF and BIPOLAR schemes are non transparent.

(i) HIGH DENSITY BIPOLAR (HDB) CODE

In this scheme, the problem of the bipolar signal being nontransparent is eliminated by adding pulses when the number of consecutive 0's exceeds n. It is denoted by HDBN, where N can take on any value 1,2,3,... . The most important of the HDB codes is the HDB3 format, which has been adopted as an international standard.

The basic idea of the HDBN code is that when a run of N+1 zeros occur, this group of zeros is replaced by one of the special N+1 binary digit sequences. The sequences are chosen to include some binary 1's in order to increase the timing content of the signal. The 1's included deliberately violate the BIPOLAR RULE for easy identification of the substituted sequence. In HDB3 coding, for example, the special sequences used are 000V and B00V, where B=1 conforms to the BIPOLAR RULE and V=1 violates the BIPOLAR RULE.

The choice of sequence 000V or B00V is made in such a way that consecutive V pulses alternate signs in order to avoid DC WANDER and to maintain the dc null in the PSD. This requires that,

① The sequence B00V be used when there is an even number of 1's following the last special sequence.
② The sequence 000V be used when there is an odd number of 1's following the last sequence.

Consider the following example:

INPUT DIGITS 0 1 0 1 1 1 0 0 0 0 1 0 1 1 0 1 0 0 0 0 0 0 0 0 0 0 1 0 1 1 0 1 0 1 0 0 0 0 1

CODED DIGITS 0 1 0 1 1 1 0 0 0 V 1 0 1 1 0 1 1 0 0 V 1 0 0 V 0 0 1 0 1 1 0 1 0 1 0 0 0 V 1

TRANSMITTED WAVEFORM

Note that in the sequence B00V, B and V are both encoded by the same pulse. The decoder has to check two things: the BIPOLAR violations and the number of 0's preceding each violation to determine if the previous 1 is also a substitution.

Despite deliberate bipolar violations, HDB signalling retains error detecting capability. Any single error will insert a spurious bipolar violation (or will delete one of the deliberate violations). This will become apparent when, at the next violation, the alternation of violations does not appear. This also shows that deliberate violations can be detected despite single errors.

(ii) BINARY WITH N-ZERO SUBSTITUTION CODE

A class of line codes similar to HDBN is the BNZS code, where if N zeros occur in succession, they are substituted by one of the two special sequences containing some 1's to increase timing content. There are deliberate BIPOLAR violations just as in HDBN.

Binary with eight zero substitution (B8ZS), is such a scheme used in DS1 signals. It replaces any string of eight zeros in length with a sequence of 1's and 0's containing two BIPOLAR violations. Such a sequence is unlikely to be counterfeited by errors, and any such sequence received by a digital channel bank is replaced by a string of eight logical zeros prior to decoding. The sequence used as a replacement consists of the pattern 000VB0VB. Similarly, in B6ZS code used in DS2 signals, a string of six zeros is replaced with 0VB0VB, and DS3 signal features a three zero B3ZS code. The B3ZS code is slightly more complex than the others in that either B0V or 00V is used, the choice being made so that the number of B pulses between consecutive V pulses is odd. These BNZS codes with N = 3, 6 or 8 involve bipolar violations and must therefore be carefully replaced by their equivalent zero strings at the receiver.

DIFFERENTIAL CODING

In Differential Coding a 1 is transmitted by a pulse identical to that used for the previous bit and a 0 is transmitted by a pulse negative of that used for the previous bit. Basically this method is used to encode information in terms of Signal Transitions. A Differentially Encoded signal may be inverted without affecting its interpretations. We will see this with the help of an example. Such a coding is useful in systems that have no sense of absolute polarity. Note that Differential Encoding requires the use of a reference bit before initiating the encoding process. Since polarity is not an issue over here, it wont matter whether we select a 1 or 0 as the reference bit.

	Reference Bit								
Let original binary data be :		0	1	1	0	1	0	0	1
Then the corresponding encoded data will be :	1	0	0	0	1	1	0	1	1

Here we have just started the encoding process. The first bit in the original data is logic 0. Since we have just started the encoding process, our reference bit serves as the "previous bit", which is logic 1. Now, as per the rule a 0 is transmitted by a pulse negative of that used for the previous bit. That is why we have written 0 over here.

ORIGINAL	0	1	0
ENCODED	1	?	0

Bit under consideration

Previous Bit

What should come here?

As per the rule, a 1 is transmitted by a pulse identical to that used for the previous bit. Hence we write logic 1 in place of "?" mark.

Now suppose had we used logic 0 as our reference bit, what would be our answer?

	Reference Bit								
Let original data be same as above :		0	1	1	0	1	0	0	1
Corresponding Encoded Data :	0	1	1	1	0	0	1	0	0

This is actually the inverted version of the answer we got above.

Next we discuss how to decode the differentially encoded data. As discussed above, the signal or the binary data is encoded in terms of signal transitions. In particular, a transition is used to designate symbol 0 in the incoming binary data stream while no transition is used to designate symbol 1. Let us consider that we have received the following bit stream at the receiver :

$\boxed{1\ 0\ 0\ 0\ 1\ 1\ 0\ 1\ 1}$

This bit stream is the same as calculated above. How to recover original binary data from this? Before moving ahead, it is again reiterated that: A transition is used to designate symbol 0 }
No transition is used to designate symbol 1 } AT THE Receiver

Received Bit Stream :	1	0	0	0	1	1	0	1	1
Decoded Data :		0	1	1	0	1	0	0	1

$1 \Rightarrow 0$

0

Here, we observe that there is a transition from 1 to 0. A transition is designated by symbol 0 and hence the first bit in decoded data is 0.

$1 \Rightarrow 1$

0 | ?

Here, we observe that there is no transition as both the next and previous bits are logic 1. Since no transition is designated by symbol 1, logic 1 will come in place of "?" mark.

Observe that the decoded data is exactly the same as original data written on the previous page of this notes. As we have just read, a differentially encoded signal may be inverted without affecting its interpretation. To prove this, we invert the received bit stream written above and again decode it. We should get the same answer after decoding.

Received Bit Stream (INVERTED) :	0	1	1	1	0	0	1	0	0
Decoded Data :		0	1	1	0	1	0	0	1

Hence, we see that decoded data is the same even if received bit stream is inverted.