10. Ethernet

10.1 Network-Access-Layer (TCP-IP-model)

Already in chapter 2 we have seen that the network-access-layer builds a SDU so called frame. The header of this frame contains amongst other information the destination and source-MAC-address.

The network-access layer has however a second task which is to convert the frame containing bits into a signal that can be transported over a medium.

medium	**signal used**
copper	voltage
air or vacuum	electromagnetic wave
optical fiber	light

The two tasks of the network-access-layer are divided into two different layers in the OSI-model.

10.2 DataLink- and Physical-Layer (OSI-model)

10.2.1 Data-Link Layer (Layer 2)

The data-link-layer builds the frame. It does not only add the MAC addresses to the header but also adds information to detect and may be correct transmission errors (channel coding).

10.2.2 Physical Layer (Layer 1)

The physical layer converts the frame into a signal.

10.3 Ethernet standards

Ethernet is a family of standard that define both the Layer 2 protocols and the Layer 1 technologies. Ethernet is the most widely used wire based LAN technology and supports transmission speed of 10, 100, 1000, or 10.000 Mbps.

Examples of Ethernet standards and characteristics:

standard	speed	cable	Conector	maximum length
10Base-T	10 Mbit/s	4 twisted pair min. cat. 3	RJ-45	100m
100Base-TX	100 Mbit/s	4 twisted pair min. cat. 5	RJ-45	100m
1000Base-T	1000 Mbit/s	4 twisted pair min. cat. 5	RJ-45	100m
10GBase-T	10.000 Mbit/s	4 twisted pair min. cat. 6	RJ-45	100m

10.4 Layer 2 in the Ethernet standards

The Ethernet frame does not only add a header to the packet but also a trailer. The trailer contains a 32bit FCS (frame check sequence). These 32bit allow detecting with a very high probability if a transmission error occurred or not. The technique used to calculate the FCS in all Ethernet standards is the CRC (cyclic redundancy check). See also:

http://en.wikipedia.org/wiki/Computation_of_cyclic_redundancy_checks

The CRC allows only detecting an error but not correcting it.

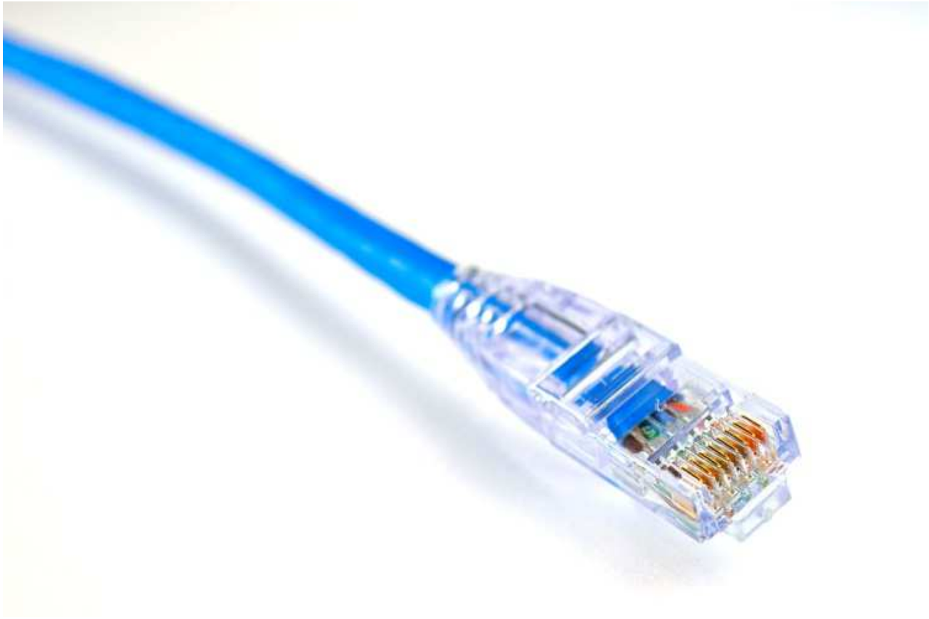
10.5 Layer 1 in the Ethernet standards

The layer 1 is called the physical layer. This layer defines the means of transmitting raw bits rather than logical data packets. Some of the points defined in the physical layer are:

- connector, cable and wiring
- voltage levels
- signal type

10.5.3 The Ethernet connectors

RJ45 connectors can be used up to frequencies of 500MHz. This corresponds to category 6a cables.

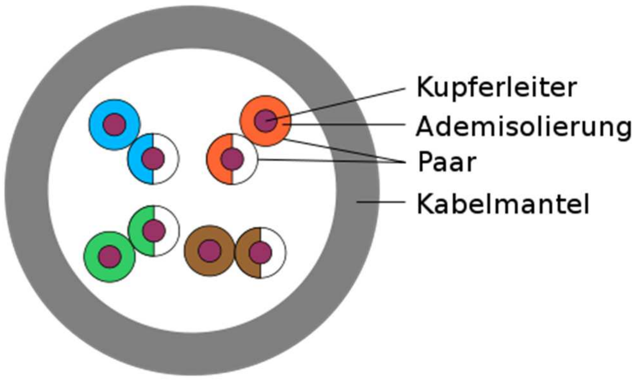


For frequencies higher than 500 MHz another connector must be used, for example a *GG45 connector*.

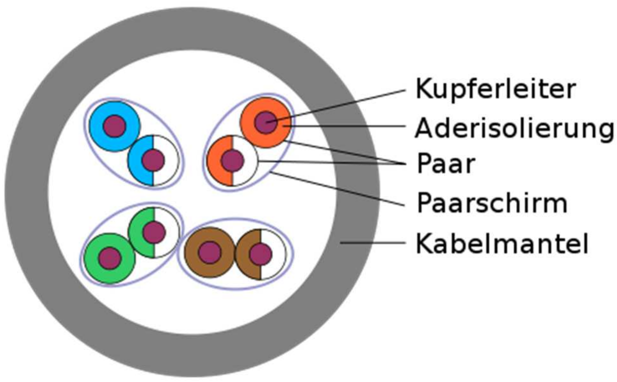
10.5.4 The Ethernet cables

The current Ethernet standards know 3 *types of cables.* All consists of 4 twisted pairs. Twisting the pairs is done in order to eliminate crosstalk (deut.: Übersprechen) and any other type of interference the cable might pick up from nearby electrical sources.

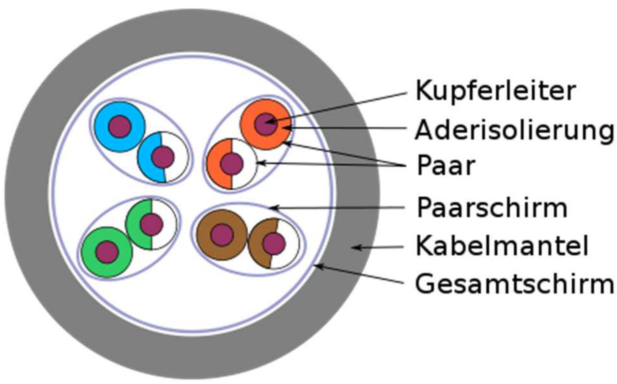
UTP



STP



S/FTP



Categories of cables:

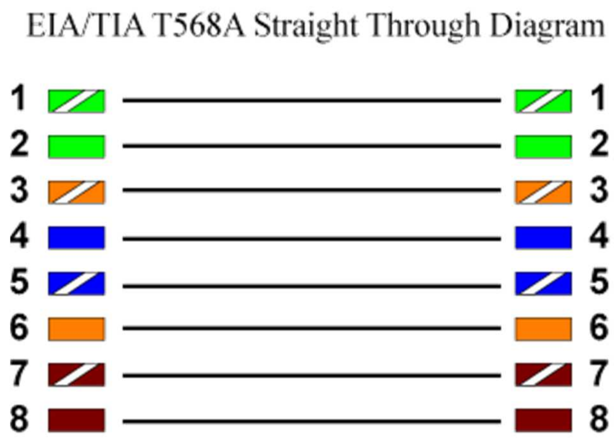
Name	Typ	Bandwidth	Application
Cat1	UTP	0,4 MHz	Telefon- und Modem-Leitungen
Cat2	UTP	4 MHz	Ältere Terminalsysteme, z. B. IBM 3270
Cat3	UTP	16 MHz	10BASE-T and 100BASE-T4 Ethernet
Cat4	UTP	20 MHz	16 Mbit/s Token Ring
Cat5	UTP	100 MHz	100BASE-TX & 1000BASE-T Ethernet
Cat5e	UTP	100 MHz	100BASE-TX & 1000BASE-T Ethernet
Cat6	UTP	250 MHz	10GBASE-TEthernet
Cat6a	STP	500 MHz	10GBASE-TEthernet
Cat7	STP	600 MHz	10GBASE-TEthernet
Cat7a	STP	1000 MHz	10GBASE-TEthernet
Cat7	S/FTP	600 MHz	Telefon, CCTV, 1000BASE-TX über dasselbe Kabel. 10GBASE-T Ethernet.
Cat7a	S/FTP	1000 MHz	Telefon, CATV, 1000BASE-TX über dasselbe Kabel. 10GBASE-TEthernet.
Cat8	S/FTP	1600 MHz – 2000 MHz	Telefon, PoE, 40GBASE-TEthernet.

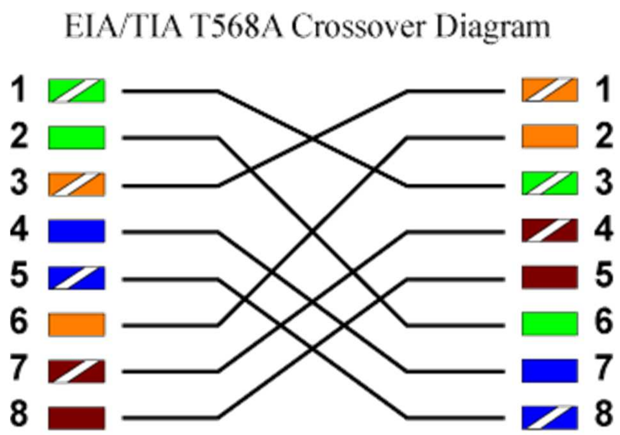
Relation between bandwidth and transmission speed:

10.5.5 Wiring the RJ45 connector

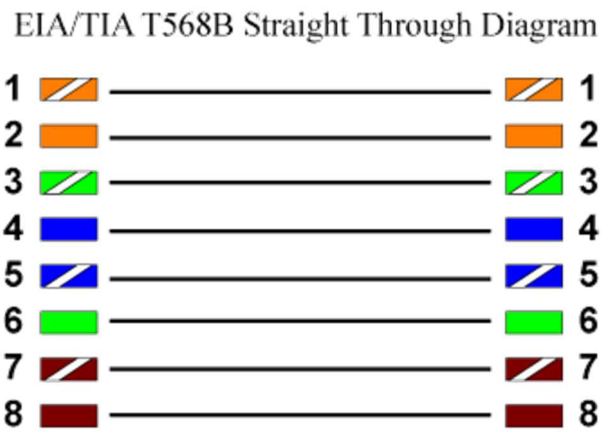
There are two standards for RJ45 connector wiring:

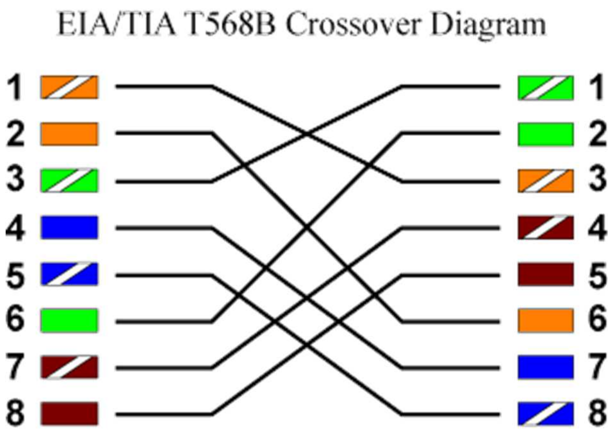
T568A





T568B (most commonly used)





Use of crosscables:

10.5.6 Signals in 100Base-TX

In the 100Base-TX standard only 2 of the 4 twisted pairs are used. On a host pin 1 and 2 are used to transmit and pin 3 and 6 are used to receive data.

Exercise 1:

Complete the following drawings with the pin numbers, signals and connections:

Host	
1	TXD+
2	TXD-
3	RXD+
4	NC
5	NC
6	RXD-
7	NC
8	NC
	GND

Switch	
	1
	2
	3
	4
	5
	6
	7
	8
GND	

Host	
1	TXD+
2	TXD-
3	RXD+
4	NC
5	NC
6	RXD-
7	NC
8	NC
	GND

Host	
	1
	2
	3
	4
	5
	6
	7
	8
GND	

Switch	
1	
2	
3	
4	
5	
6	
7	
8	
	GND

Switch	
	1
	2
	3
	4
	5
	6
	7
	8
GND	

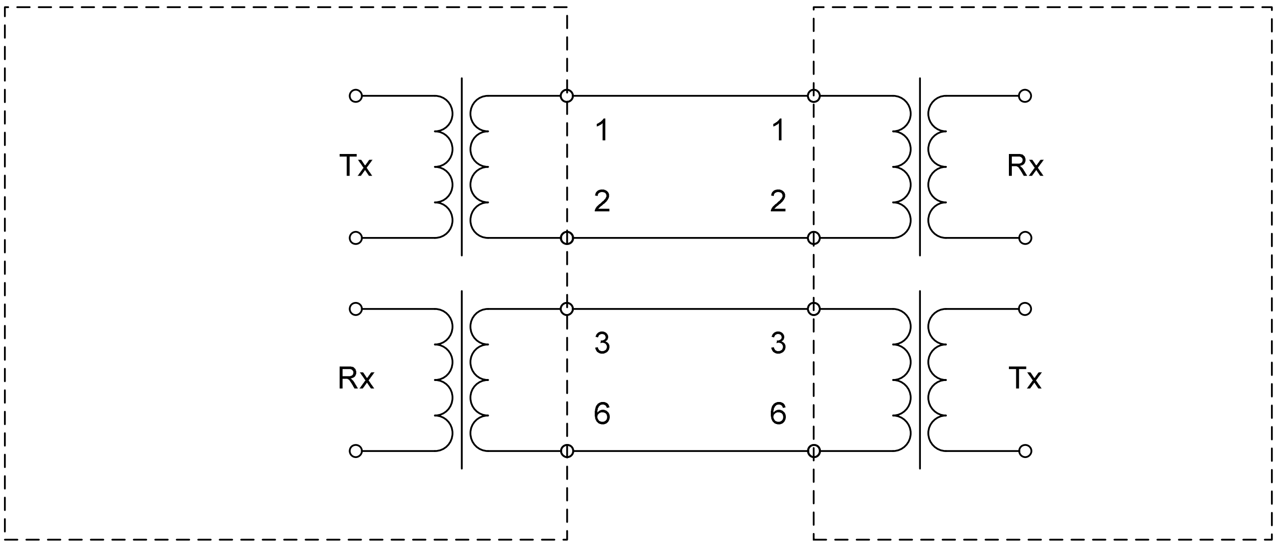
10.5.7 Signals in 1000Base-T

1000Base-T uses all 4 twisted pairs for *bidirectional transmission*.

Host	
1	BI_DA+
2	BI_DA-
3	BI_DB+
4	BI_DC+
5	BI_DC-
6	BI_DB-
7	BI_DD+
8	BI_DD-
	GND

Switch	
BI_DA+	1
BI_DA-	2
BI_DB+	3
BI_DC+	4
BI_DC-	5
BI_DB-	6
BI_DD+	7
BI_DD-	8
GND	

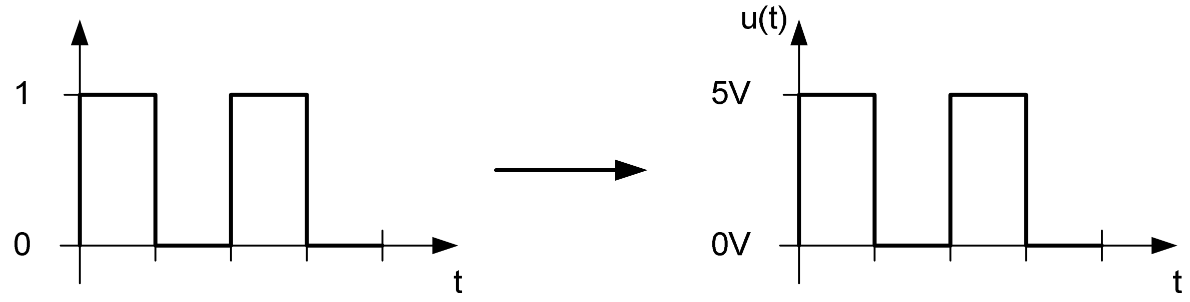
10.6 Galvanic separation and Power over Ethernet (POE)



10.7 Converting a series of bits to an electrical signal

The simplest way to convert a bit stream to an electrical signal would be to assign two voltage levels to the two binary states, for example:

logical state	voltage level
0	0V
1	5V

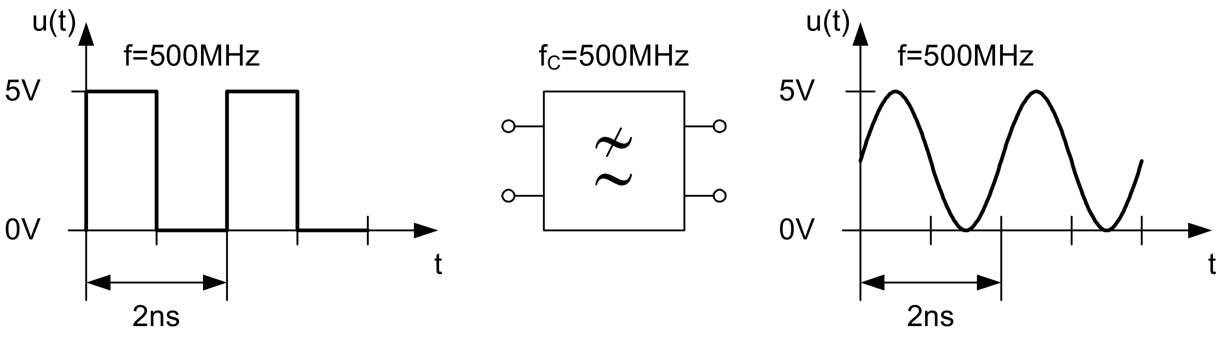


The *first problem* with this approach is that the signal has a DC part which cannot be transmitted through the transformers seen in the previous chapter. In addition the DC part of the signal would be added to the DC part of the Power over Ethernet.

The *second problem* is that the spectrum of this signal contains harmonics with frequencies much higher than the cable bandwidth allows. Explanations:

The "worst case" signal that can be imagined in regards of its spectrum, is a continuous series of a 01 sequence. This signal has the lowest possible periodic time T. At 1GBit/s a single bit will need 1ns to be transmitted. The periodic time will then be 2ns which correspond to a frequency of 500MHz. Thus the fundamental contained in our worst case signal has a fundamental frequency of 500MHz. The next spectral line in a rectangular signal is the third harmonic having a frequency of 1500MHz. However the bandwidth of a CAT6a cable will only allow transmitting up to 500MHz.

distortion caused by the low pass behaviour of a CAT6a cable to a 01 series:



Theoretically we could still retrieve the binary information out of the distorted signal but in practice noise will lead to unacceptable high error rates.

The *third problem* is that on Ethernet no clock signal is transmitted with the signal so that the receiver needs to reconstruct the clock signal out of the data signal. If the data signal contains long series of zeros or ones, no clock signal can be extracted and the receiver clock will start to desynchronize from the transmitter clock.

10.7.8 Channel coding

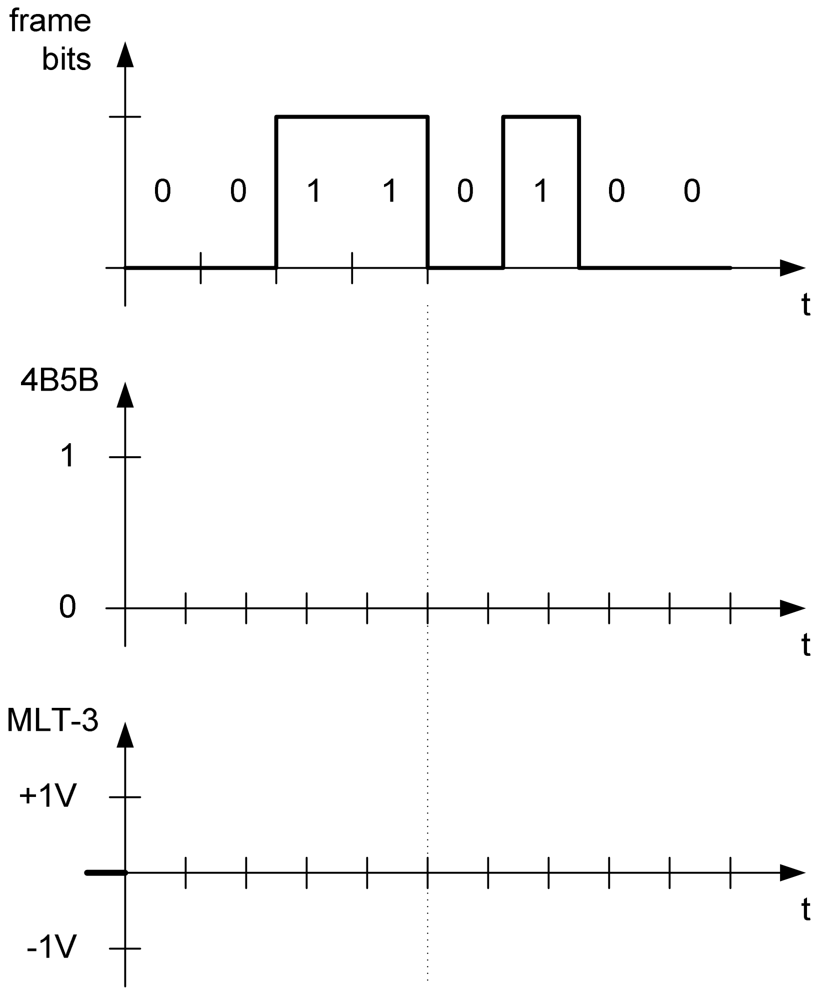
Channel coding is a technique that allows avoiding one or several of the above mentioned problems. 100Base-TX Ethernet uses for example the *4B5B-code* in order to assure that within every 4 bit sequence at least one level change is assured. To do this a 5th bit is added to every 4 bit sequence according to the following translation table:

4B	5B	4B	5B
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

In order to reduce the maximal fundamental frequency of the 4B5B-signal this one will be coded a second time with the *MLT-3 code*. This code uses three voltage levels +1V, 0V and −1V. Only when a logical 1 appears in the input signal then the output signal will change its state in the following order: 0V, +1V, 0V, -1V, 0V, etc.

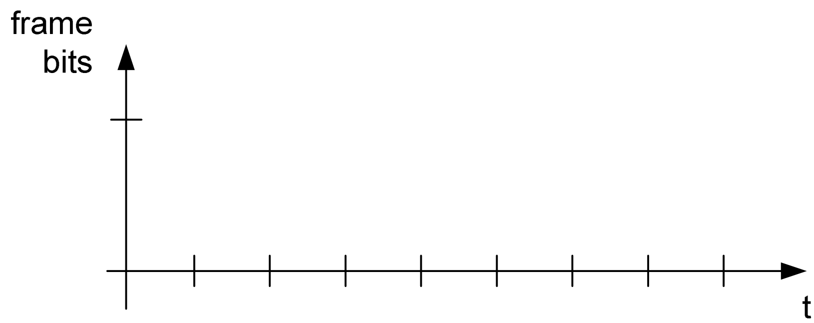
Exercise 2:

Draw the 4B5B signal of the frame bit series. Then draw the MLT-3 signal of the 4B5D signal.

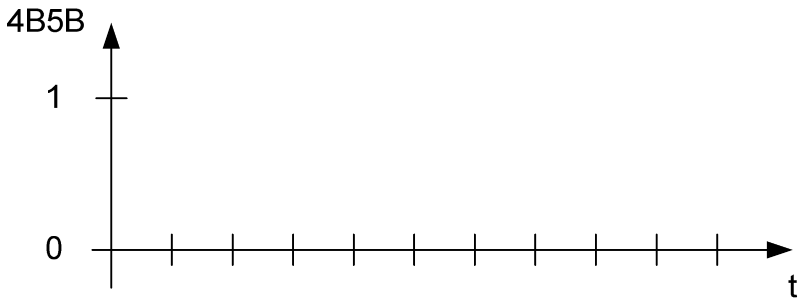


Exercise 3:

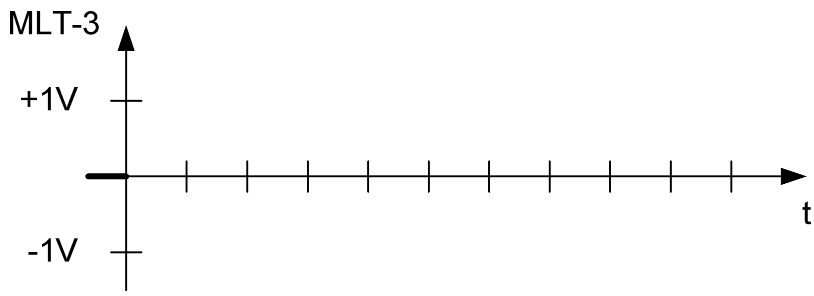
Draw for each of the following codes the worst case signal in regards of its frequency spectrum for a 100Mbit/s stream. What will be the fundamental frequency of the signal?



$f_{0,MAX}$= ____________



$f_{0,MAX}$= ____________



$f_{0,MAX}$= ____________