CONTENT

Sources

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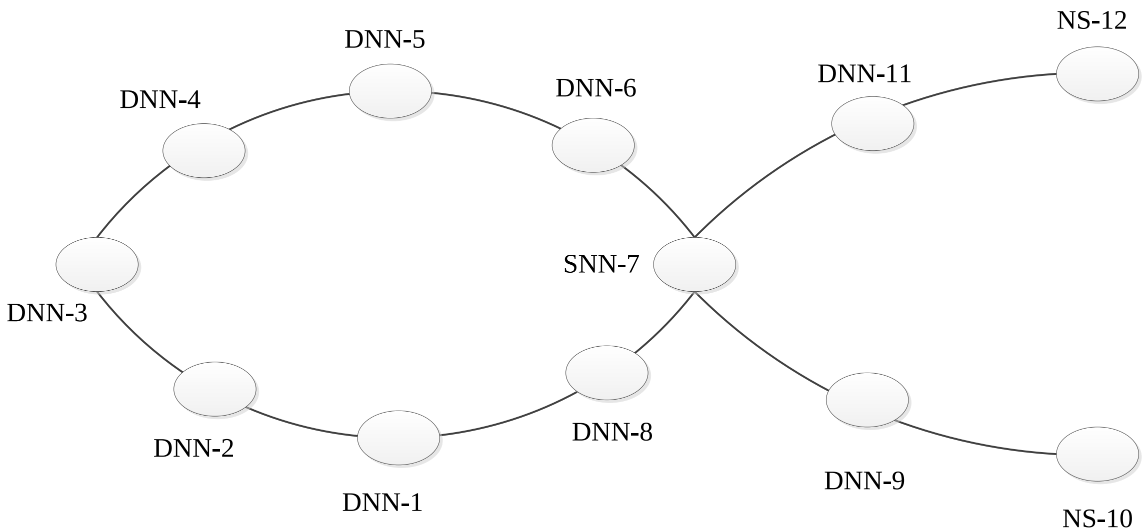
ASSIGNMENT

Develop a segment of a multiservice telecommunication network with the radially-ring architecture with using of PDH, SDH and DWDM technologies. Connect nodes from 1 to 8 by means of ring topology. One ring node is a switched network node (SNN) and all others are dedicated network nodes (DNN). Compare two variants of construction of a ring: 1) by means of SDH DTS only; 2) sharing of SDH and DWDM DTS. Organize branch line from a SNN to nodes 9 and 10 by means of PDH hardware. Develop block diagrams of transmission lines of corresponding network sections.

Input data

1. Architecture of a network is a ring type with branch line. Branch line from the network switched node № N_{SNN} to dedicated network nodes № 9 and №10 are organized.



1. The PCM-1920 which works on cable КМБ-4 on the branch line N_{SNN} = 7-10 is used.
2. Quantity of primary digital streams between nodes of branch line is equal to:

Section	SNN 7 – DNN9/ DNN9 – DNN10	SNN 7 – DNN10	DNN10 – DNN8 of SDH ring
Quantity of PDS	6	58	64 (all others E1 streams – calculate and

			write to this cell in the input data)

3. The type of SDH ring bi-directional
4. Type of SDH ring reservation 1) SNCP / BR / 1:1 / 2OF
5. Quantity of primary digital streams between nodes of SDH ring:

Number of PDB between DNN and SNN								Number of primary digital streams between DNN
1	2	3	4	5	6	7	8	
13	12	12	14	22	19	-	19	14

6. Distance between network nodes of ring:

1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-1
19	82	94	50	48	112	51	18

7. Break in section 6-7.
8. Parameters of the optical transmitter:
   - The transmission level p_{tr} = 8 dBp;
   - The emission wavelength of laser λ_0 = 1310 nm;
   - The width of laser emission line $\Delta\lambda$ = 0,18 nm.
9. Parameters of the optical cable in the SDH ring:
   - The attenuation coefficient α = 0,38 dB/km;
   - The chromatic dispersion σ_{01} = 3,50 ps/(nm·km);
   - The factory cable length l_f = 6,4 km;
10. Parameters of the optical receiver:
    - Optical sensitivity p_{rec} = -31 dBp.
11. Ethernet bitrate B_{eth} = 2 Gbps
12. The coder RS (239,255) is used in DWDM transponders.

(*) The symmetrical cable of MKC type with specified quantity of quads is used for PCM-120. The coaxial cable MKT-4 and KM-4, KM-8 are used for PCM-480 and PCM-1920. The symmetrical pairs in the cable of KM type are not used.

In **introduction** list the benefits of DTS and fiber-optic transmission systems. Give a brief description of the course project and its sections content.

Subsection 1.1

Give a description of the architectural elements of the transport network fragment given by the initial data. The ring structure with branches from the node «X» is given by initial data in the course project.

The others network nodes placed in a ring, 9 and 11 are dedicated network nodes - DNN.

Network node 3 is a switching network node - SNN. Equipment, which allows cross connection of large number of different digital streams, is usually installed there.

Finally, the network nodes 10 and 12 are network stations NS (terminal equipment) of this network fragment.

The ring is constructed using the FOTS - SDH. Transmission systems in the branches are given by the initial data:

DTS-PDH is used at the branch SNN-X – DNN-9 – NS-10

RRTS is used at the branch SNN-X – DNN-11– NS-12

Write the basic parameters of PDH transmission system correspondingly to the given input data (see Table 1) and main characteristics of the transmission system frame (see [1-2]).

INTRODUCTION

PDH or the plesiochronous digital hierarchy is a popular technology that is widely used in the networks of telecommunication in order to transport the huge amounts of data over the digital equipment for transportation like microwave radio or fiber optic systems. The term plesiochronous has been derived from the Greek work ‘plesio’ that means ‘near’ and ‘chronos’ meaning time. This means that the PDH works in a state when the various different parts of a network are clearly synchronized. But with the change in technology, the PDH is now being replaced by the SDH or what is popularly called as synchronous digital hierarchy. The SDH is useful equipment that is used in most of the telecommunications networks.

The DTS changed the ATS. DTS have a lot of advantages (reliability, the Terminal station costs, production fabric ability, small dimension and weight), but the important disadvantage is the short regeneration section length. The line path cost rise comparing with the ATS.

PDH DTS have next important disadvantages:

- System justification difficulty when asynchronous digital bit stream (DBS) multiplexing, the higher transmission rate the higher difficulty.
- “slip” type mistakes presence that lead to the frame alignment signal failure that causes the commutation channel break.
- difficulty and bulkiness of DBS extracting from the higher hierarchy level group DBS.
- Control system absence.

These disadvantages were solved in new SDH DTS.

The 1st SDH DTS was developed in America in 1986 and was named as SONET (Synchronous Optical Network).

SONET and SDH are standardized protocols that transfer multiple digital bit streams synchronously over optical fiber using lasers or highly coherent light from light-emitting diodes (LEDs).At low transmission rates data can also be transferred via an electrical interface.

The method was developed to replace the Plesiochronous Digital Hierarchy (PDH) system for transporting large amounts of telephone calls and data traffic over the same fiber without synchronization problems. SDH were originally designed to transport circuit mode communications from a variety of different sources, but they were primarily designed to support real-time, uncompressed, circuit-switched voice encoded in PCM format. The primary difficulty in doing this prior to SONET/SDH was that the synchronization sources of these various circuits were different. This meant that each circuit was actually operating at a slightly different rate and with different phase. SONET/SDH allowed for the simultaneous transport of many different circuits of differing origin within a single framing protocol.

SDH differs from Plesiochronous Digital Hierarchy (PDH) in that the exact rates that are used to transport the data on SONET/SDH are tightly synchronized across the entire network, using atomic clocks. This synchronization system allows entire inter-country networks to operate synchronously, greatly reducing the amount of buffering required between elements in the network. Both SONET and SDH can be used to encapsulate earlier digital transmission standards, such as the PDH standard, or they can be used to directly support either Asynchronous Transfer Mode (ATM) or so-called packet over SONET/SDH (POS) networking. Therefore, it is inaccurate to think of SDH or SONET as communications protocols in and of themselves; they are generic, all-purpose transport containers for moving both voice and data. The basic format of a SONET/SDH signal allows it to carry many different services in its virtual container (VC), because it is bandwidth-flexible.

SDH is a transport hierarchy based on multiples of 155.52 Mbit/s

The basic unit of framing in SDH is a STM-1

STM-1 = 155.52 Mbit/s

STM-4 = 622.08 Mbit/s

STM-16 = 2588.32 Mbit/s

STM-64 = 9953.28 Mbit/s

Subsection 1.1

Table 1.1 – Basic parameters of PCM- 1920

№	Parameter	Value
1	Bitrate of input digital streams, kbps	34368
2	Bitrate of a group digital stream, kbps	139264
3	Cable type	КМБ - 4
4	Maximal length of communication link, km	2500
5	Quantity of digital streams	64
6	Quantity of voice-band channels	1920
7	Frame rate, kHz	64
8	Re-sync time of frame alignment signal, ms	0,15
9	Maximal frequency of justification, Hz	870
10	Line coder type	HDB-3
11	Length of: - regeneration section, km - section of distance supply, km	 2,75±3,15 240

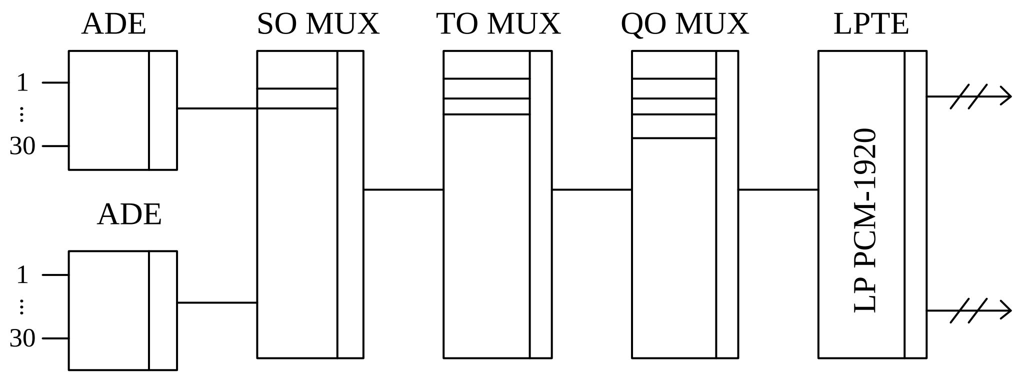
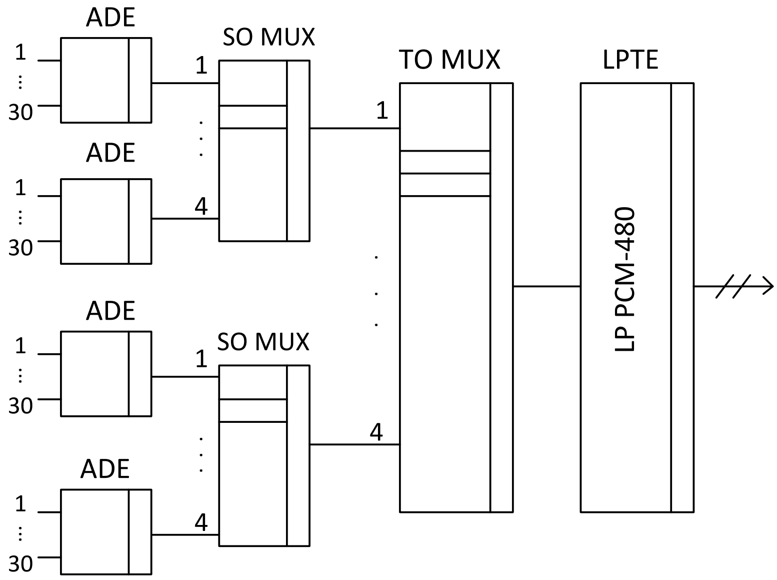
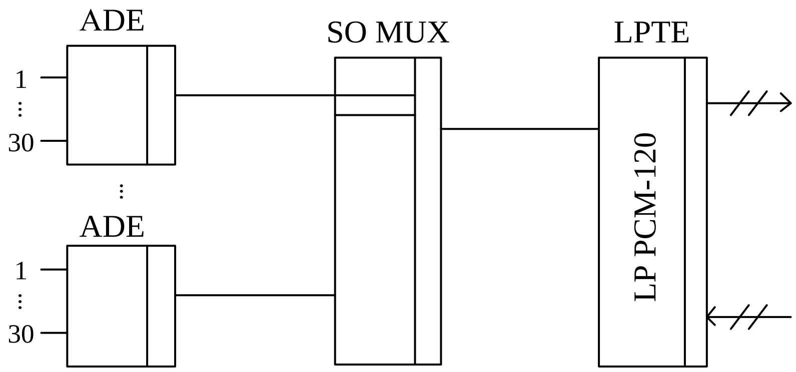


Fig. 1.1 – TS structure chart

Example for PCM-480:



Example for PCM-120:



ADE – Analog-Digital Equipment

SO MUX –Secondary Order Multiplexer

LPTE – Linear Path Terminal Equipment

LP PCM – Linear Path Pulse Code Modulation

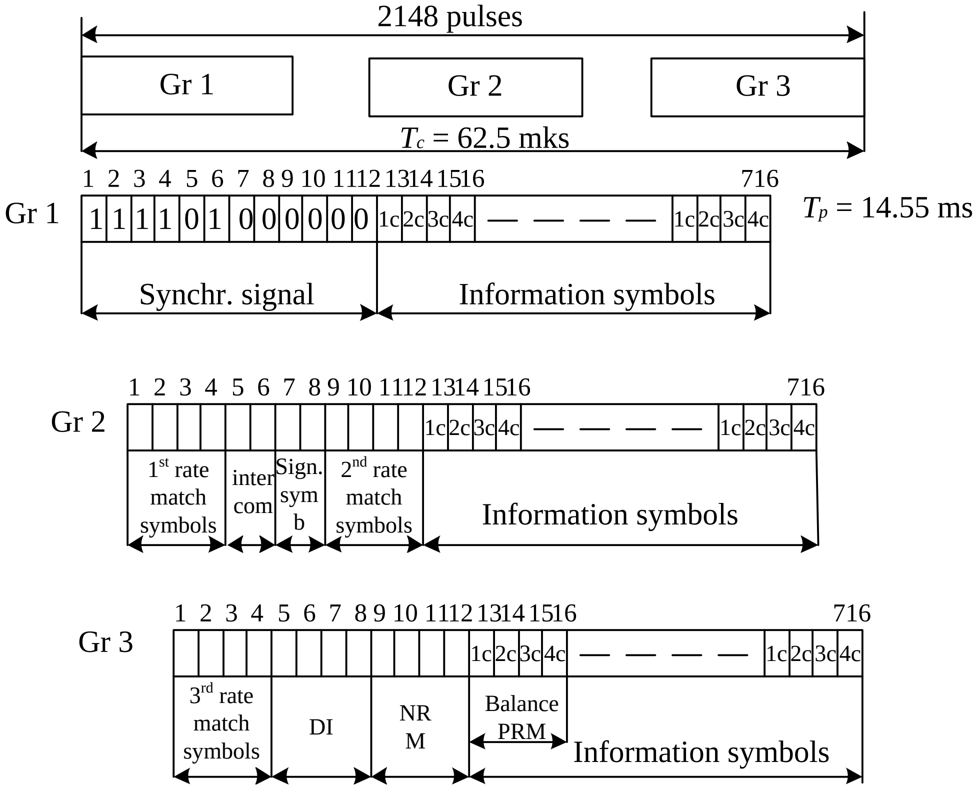


Fig. 1.2 – TDTS frame forming for PCM-480

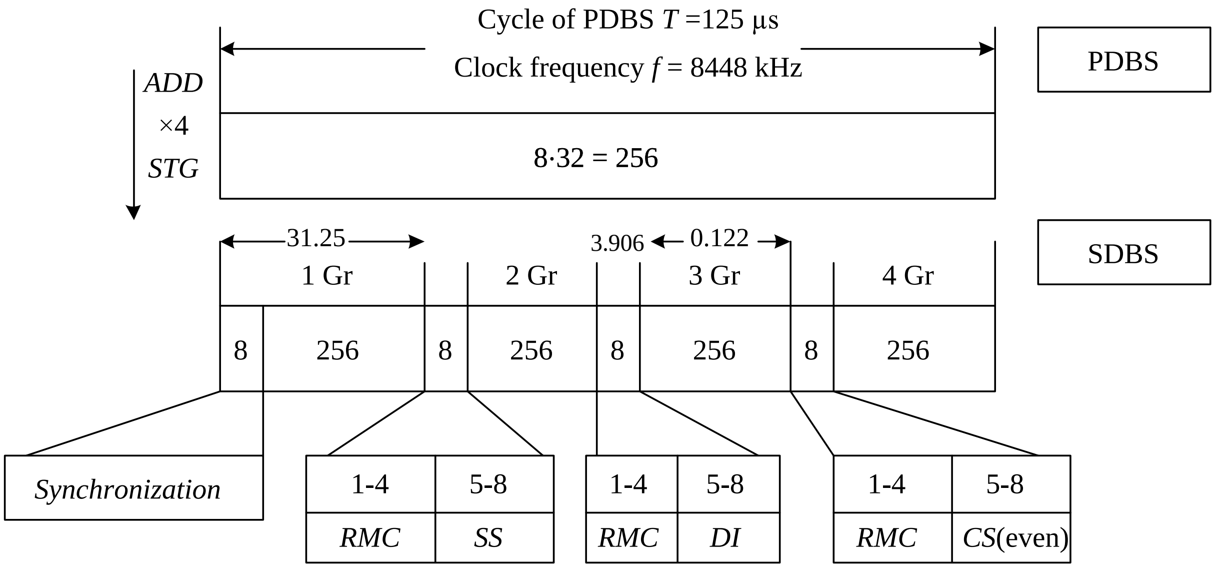
Tc – cycle period

DI – Discrete information

NRM – Negative Rate Matching

PRM – Positive Rate Matching

Structure frame of PCM-120:



PDBS – Primary Digital Bit Stream

SDBS – Secondary Digital Bit Stream

GR –Group

STG – Secondary Time Grouping

In **subsection 1.2** calculate the number of DBS in the transmission line when full filling of the cable. Use a single-cable duplex for DTS working over coaxial cable and two-cable duplex for DTS on the symmetric cable. Determine the number DBS in the DNN 10 - DNN (N_{SNN}+1) of the SDH ring and fill the input data table of the CP. Show the distribution of DBS between network nodes and general location plan of the transmission line scheme.

Design with all explanations network organization diagram on the branch SNN N_{SNN} – DNN-10 **subsection 1.3.**

Subsection 2.1

Provide an overview of SNN, explaining that:

– ring and branch traffic is coming to it (SNN) and through it;

– all the necessary cross connections are performed by the ring cross connector DxC;

– Operative SNN channel commutation is performed by digital switching station (DWS);

– DWS trunks have E1 interface.

In **Section 2.2** provide a SNN network organization diagram with an explanation of all traffic to the node.

In **Section 3.1** it is necessary to describe:

–operation description of the given SDH protection scheme;
– traffic table of the SDH ring and branches with counting the number of input and output streams in the network nodes;
– multiplex plans (node cross-connect maps) for normal and failure mode on given section;
–considerations for the STM level selecting.

In **section 3.2** calculate:

– the regenerator section length;
– cable lengths from the known length of the sections;
– the regenerators' number at each section.

In **subsection 3.3** the communication organization diagram in the ring with SDH with designation of:

– numbers of nodes;
– types of used equipment (TM / ADM / DxC / SMR);
– section length;
– the number of input and output streams in nodes (don't forget about the Ring-DNN 10);
– level STM.

CP with schemes without explanation will not be checked!

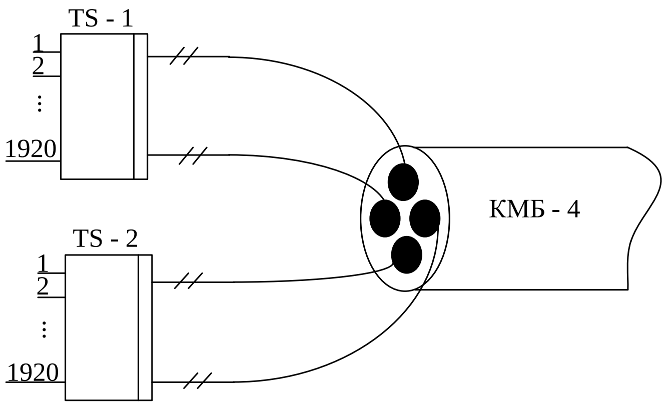
Example of the section 1 and 2 of the course project

1.2 Characteristic of the PDH DTS transmission line.

The capacity of transmission line on the base of a КМБ-4 cable is equal two PCM-1920 $(nDTS = 2)$:

$$nDTS = \frac{(\text{number of pairs} \cdot 2 \cdot \text{number of cables})}{\text{number of wires}}$$

$$nDTS = \frac{4 \cdot 2 \cdot 1}{4} = 2$$



The total quantity of E1 streams in the transmission line is:

$NE1$ line$=NDTS \cdot 64 = 2 \cdot 64 = 128$ E1

Let's calculate quantity of the remained E1 streams to the SDH ring:

$Nring-10 = NE1$line - $(NSNN{-}7 + NSNN{-}9) = 128 - (6 + 58) = 64$ E1

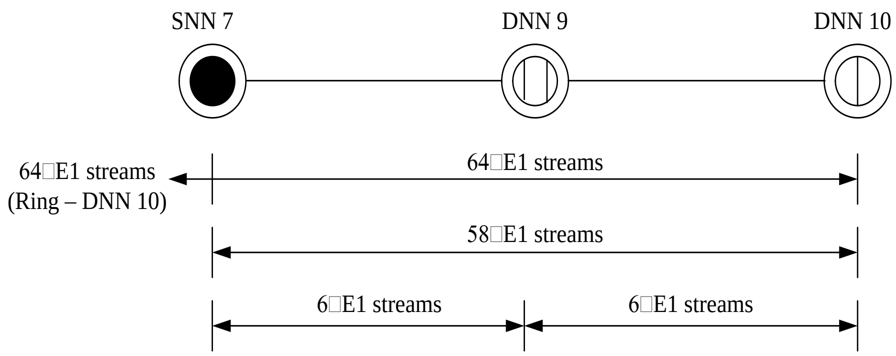


Figure 1.3 – Distribution of E1 streams between network nodes

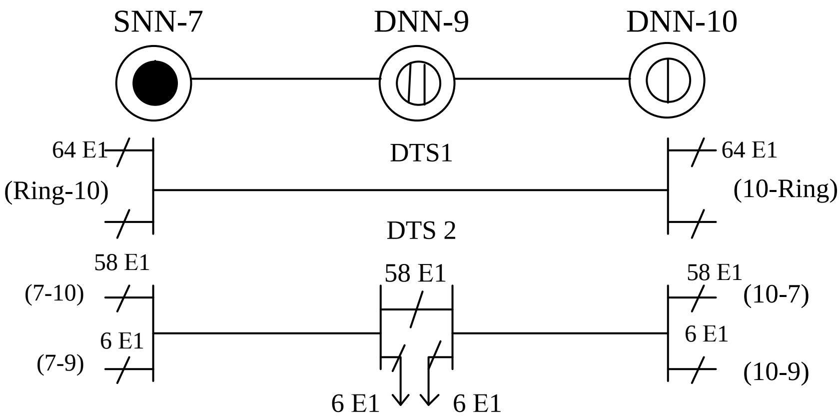


Figure 1.4 – Situational diagram of transmission line

Examples for another variants:

1) For PCM-480:

$$nDTS = \frac{(\text{number of pairs} \cdot 2 \cdot \text{number of cables})}{\text{number of wires}}$$

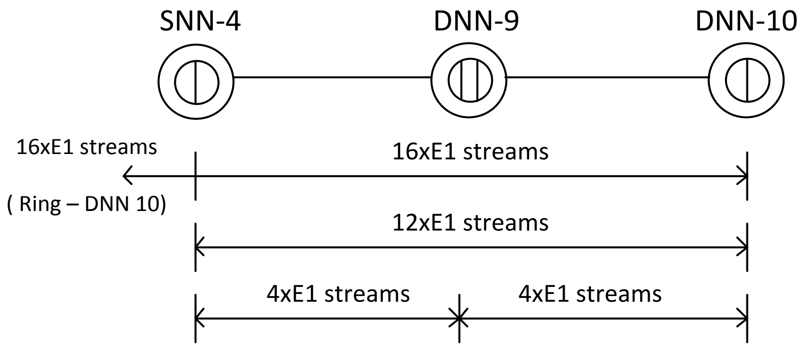
$$nDTS = \frac{4 \cdot 2 \cdot 1}{4} = 2$$

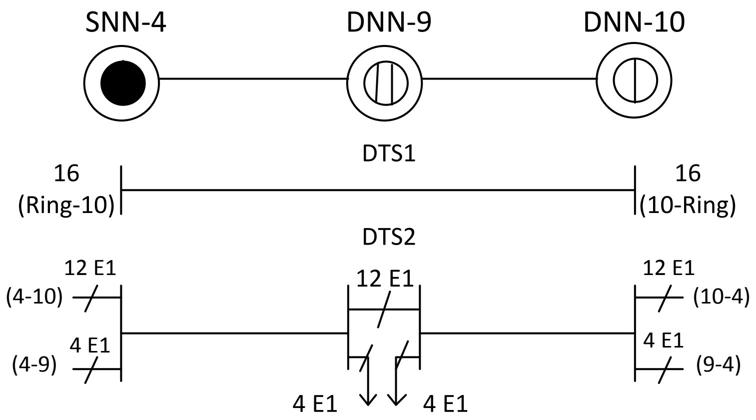
The total quantity of E1 streams in the transmission line is:

$$NE1\ \text{line} = NDTS \cdot 16 = 2 \cdot 16 = 32\ \text{E1}$$

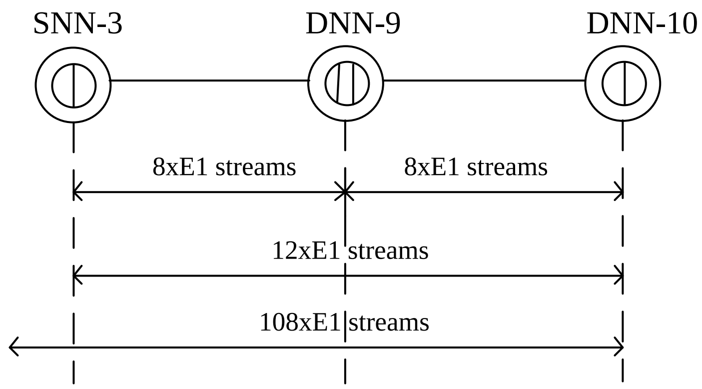
Let’s calculate quantity of the remained E1 streams to the SDH ring:

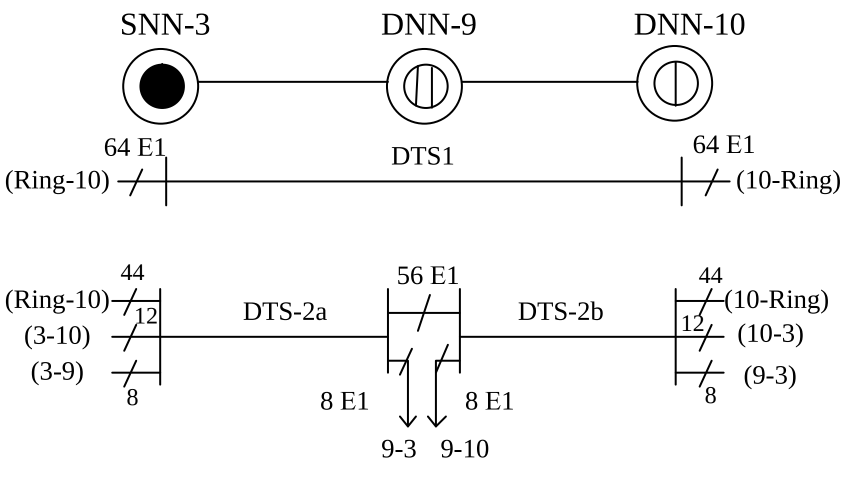
$$Nring - 10 = NE1\text{line} - (NSNN - 9 + NSNN - 10) = 32 - (4 + 12) = 16\ \text{E1}$$




SNN-4
DNN-9
DNN-10
DTS1
16
(Ring-10)
16
(10-Ring)
DTS2
12 E1
(4-10)
4 E1
(4-9)
12 E1
4 E1
4 E1
12 E1
(10-4)
4 E1
(9-4)

2)


SNN-3
DNN-9
DNN-10
8xE1 streams
8xE1 streams
12xE1 streams
108xE1 streams


SNN-3
DNN-9
DNN-10
64 E1
(Ring-10)
DTS1
64 E1
(10-Ring)
44
(Ring-10)
12
(3-10)
(3-9)
8
DTS-2a
56 E1
8 E1
8 E1
9-3
9-10
DTS-2b
44
(10-Ring)
12
(10-3)
(9-3)
8

1.3. Organizational scheme of SNN7 – DNN10 transmission line

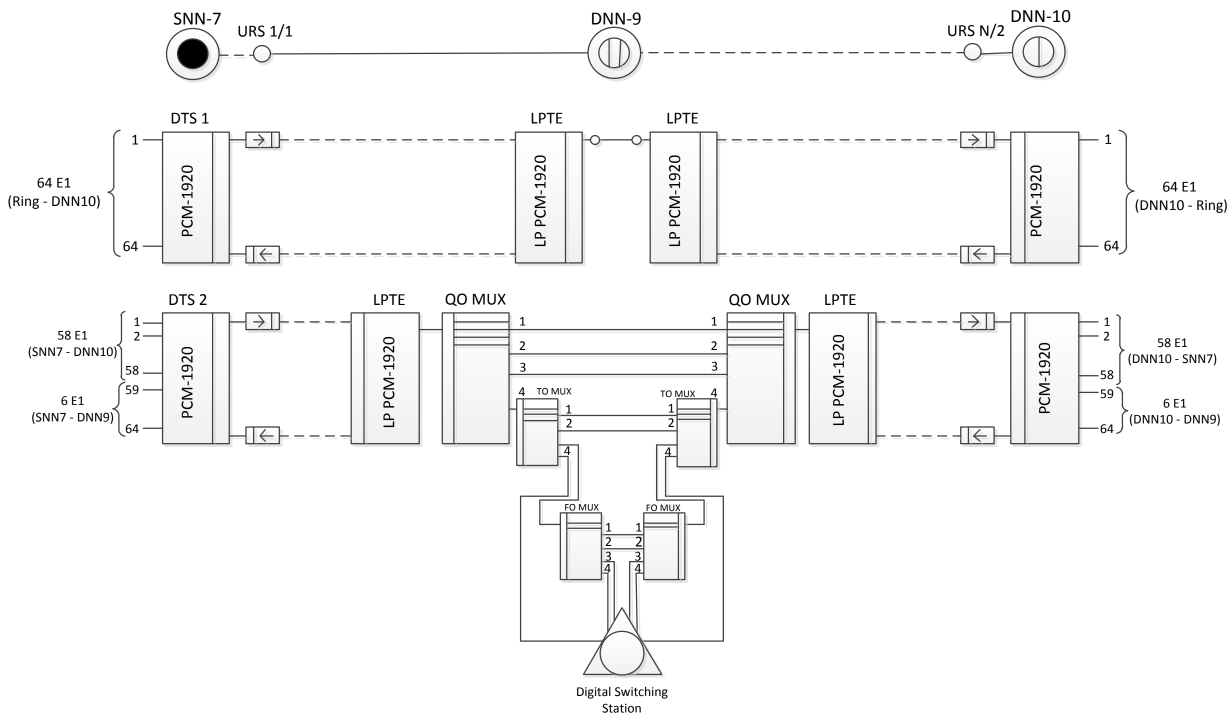


Figure 1.5 -_Organizational scheme of SNN7 – DNN10 transmission line

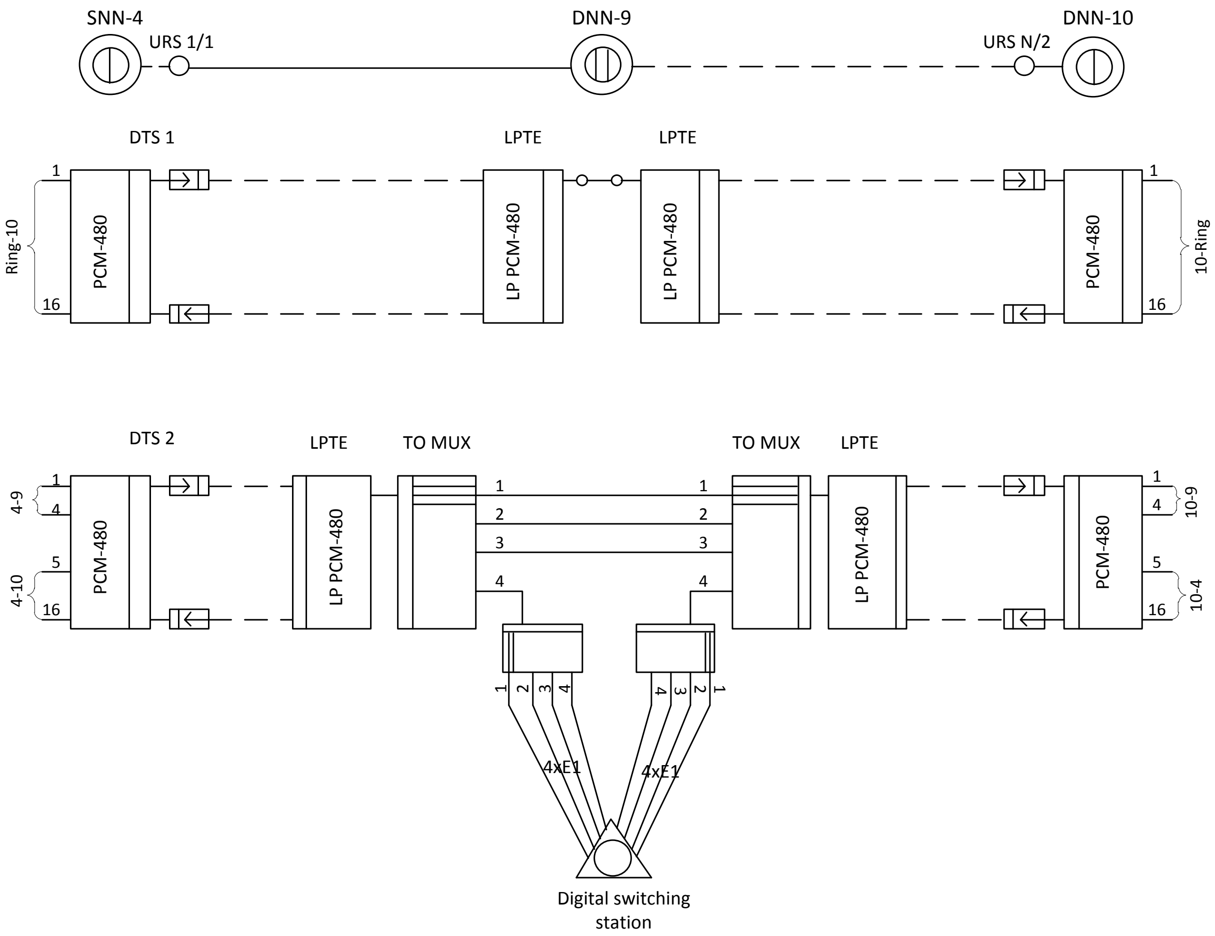
SO MUX – is secondary multiplexing, which performs the merging of four primary streams.

TO MUX - tertiary multiplexing, which performs the merging four secondary flows.

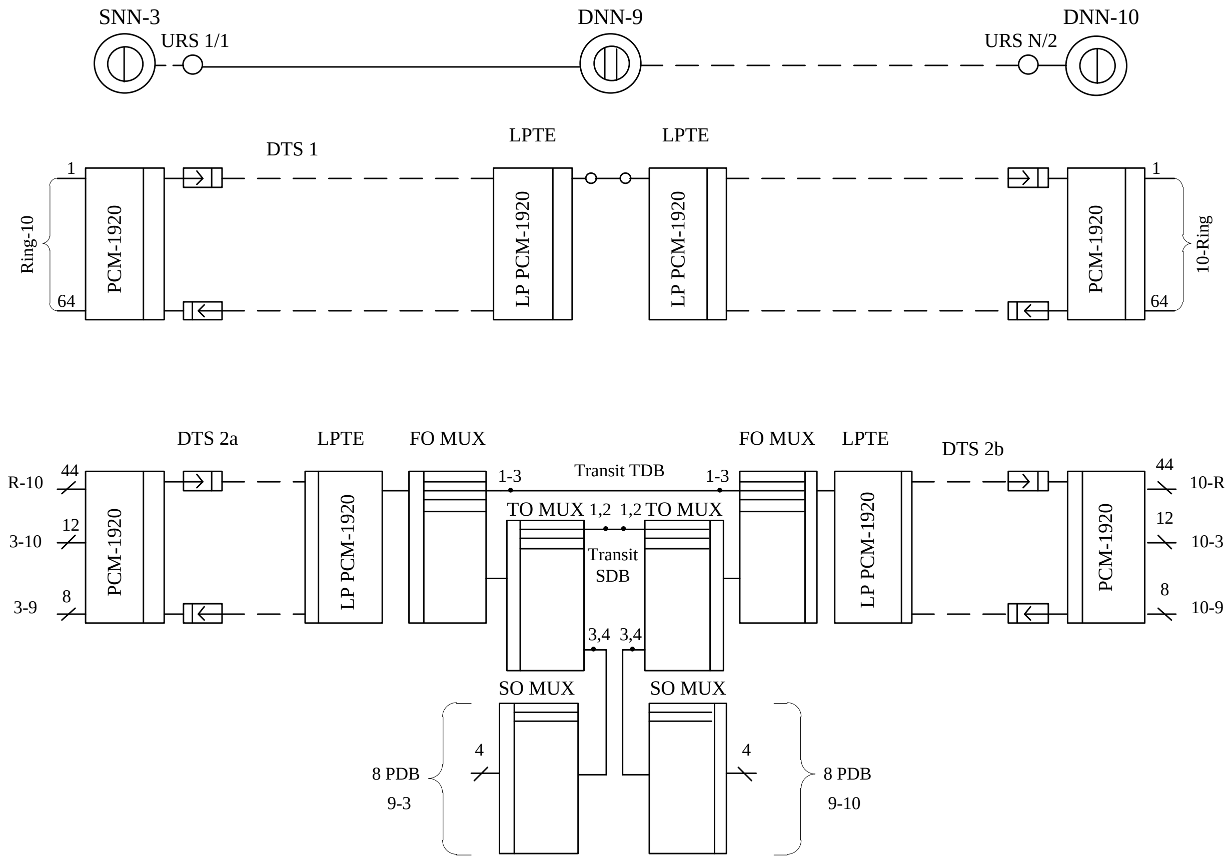
LPTE – Line Path Terminal Equipment

URS – Unattended regeneration station (НРП рус.)

Example for PCM-480:



Example for PCM-1920:



2.1 Organization scheme in the switched network node.

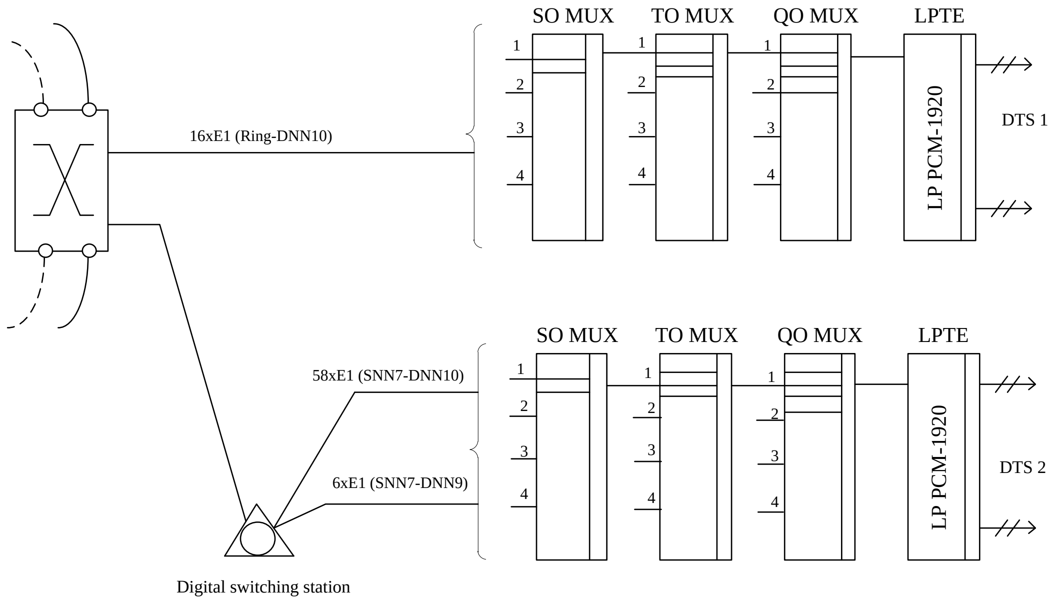
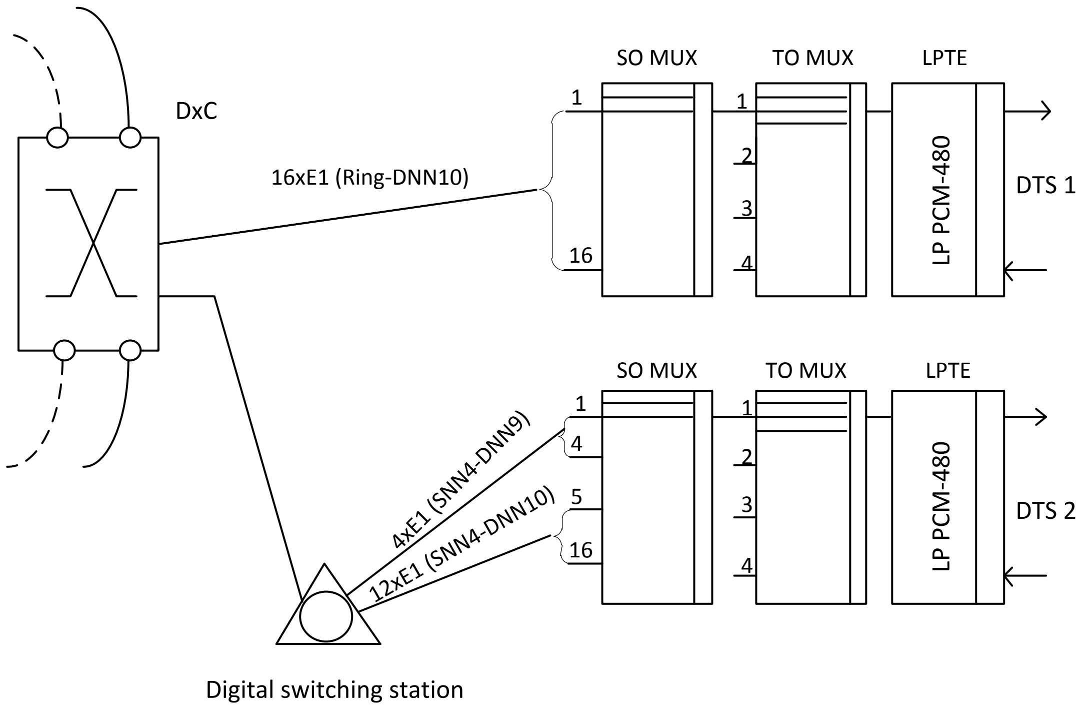


Figure 2.1 - Organization scheme in the switched network node

Organization scheme in the switched network node for **PCM-480:**



Example of the section 3 of the course project

3.1 Levels of the synchronous transport modules in SDH ring

Input data:

1) $N_{SNN} = 7$;
2) Quantity of primary digital streams between nodes of SDH ring:

Number of PDB between DNN and SNN								Number of primary digital streams between DNN
1	2	3	4	5	6	7	8	
13	12	12	14	22	19	-	19	14

3) Quantity of primary digital streams $N_{ring\text{-}\mathrm{DNN10}} = 64$ (**see part 2** of your course project).
4) Break in section — 6-7.

Solution

1) Fill cells in the N_{SNN}-th row and column;
2) All others empty cells must contain a quantity of E1 digital streams between DNN only (14xE1 in our example);
3) Write $N_{ring\text{-}\mathrm{DNN10}}$ to a corresponding cell of column 10;
4) Sum up cells in every row and column, and write a result to the corresponding cell in the last row of table.

Table 3.1 – Traffic in the SDH ring

	1	2	3	4	5	6	7	8	10
1	-	14	14	14	14	14	**13**	14	
2		-	14	14	14	14	**12**	14	
3			-	14	14	14	**12**	14	
4				-	14	14	**14**	14	
5					-	14	**22**	14	
6						-	**19**	14	
7							-	**19**	**64**
8								-	
10									-
Quantity of E1 streams in the node	97	96	96	98	106	103	175	103	-

After this operation see examples 1-4 from lections in the module 4.1 for building of node cross-connect map.

SNCP 1:1

In SNCP is protected not the concrete route, but the connection between two points (a traffic entry point in a network and its exit from a network). And in case of accident on any segment of the main path switching on completely alternative reserve path which doesn't have a common ground with the main path (except the input and the output) is carried out.

This method in a normal mode provides transmission of a working traffic also as well as MS SPRing. Difference consists in protective switching at the moment of accident situation emergence. The same example is considered – the accident between DNN-3 and DNN-4. The traffic doesn't go to the place of accident through the working channels, but at once switches to protective channels in a network node, in which it comes in a ring. I.e. there is no double traffic passing through the same section that is the advantage of this scheme in comparison with MS SPRing.

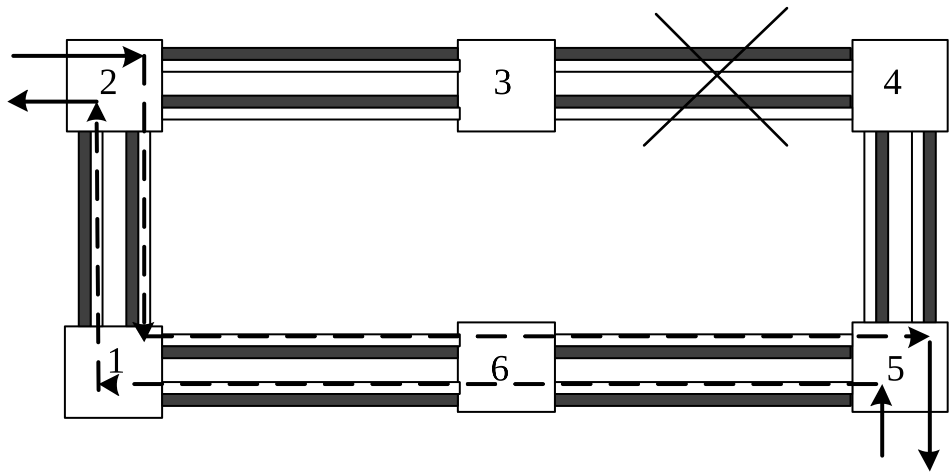


Fig. 3.1 – Traffic transmission at the accident at SNCP 1:1 protection method

At calculation of hierarchy level for this method of protection it is necessary to consider the fact that at accident on any of the sections its traffic will be added to the traffics not of all sections, but only through which it didn't pass before accident, it will be subtracted from the other sections. This condition leads to complication of hierarchy level calculations: it is necessary to consider not only the distribution of streams in a normal state of a ring, but also at the accident on each of the sections.

The hierarchy level is defined by the section with the maximum traffic from a normal state and the accident on each section N_{max}.

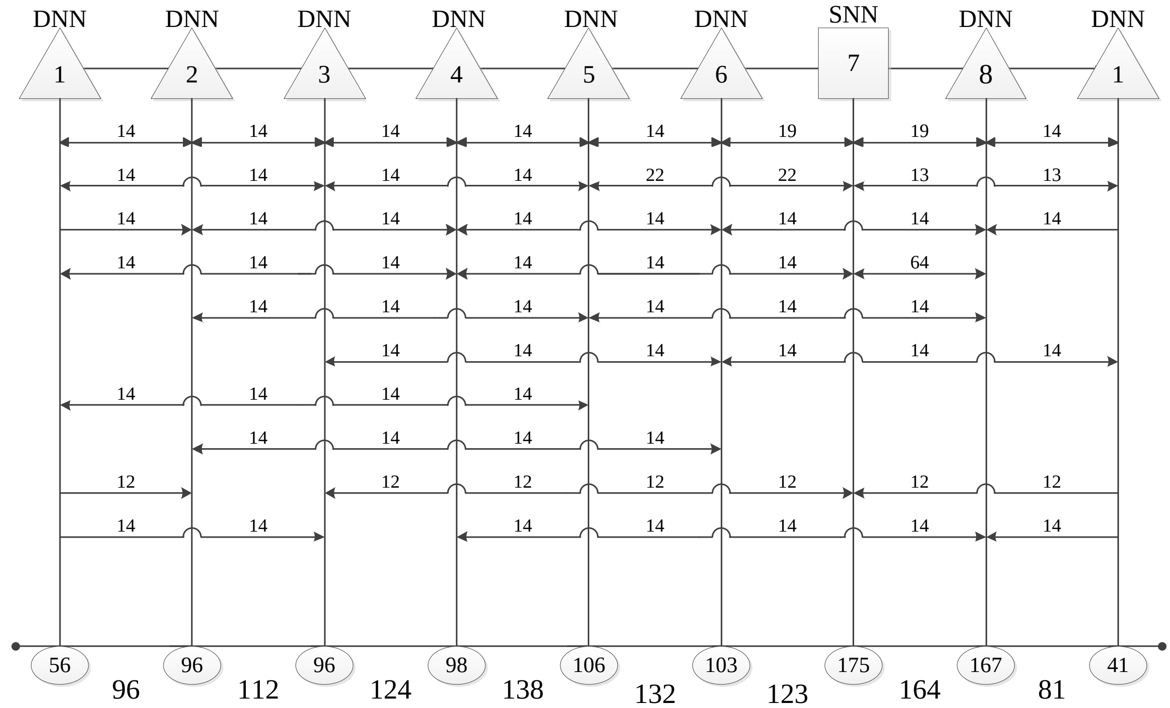


Fig. 3.2 – Multiplexing plan of SDH ring work in normal operation mode

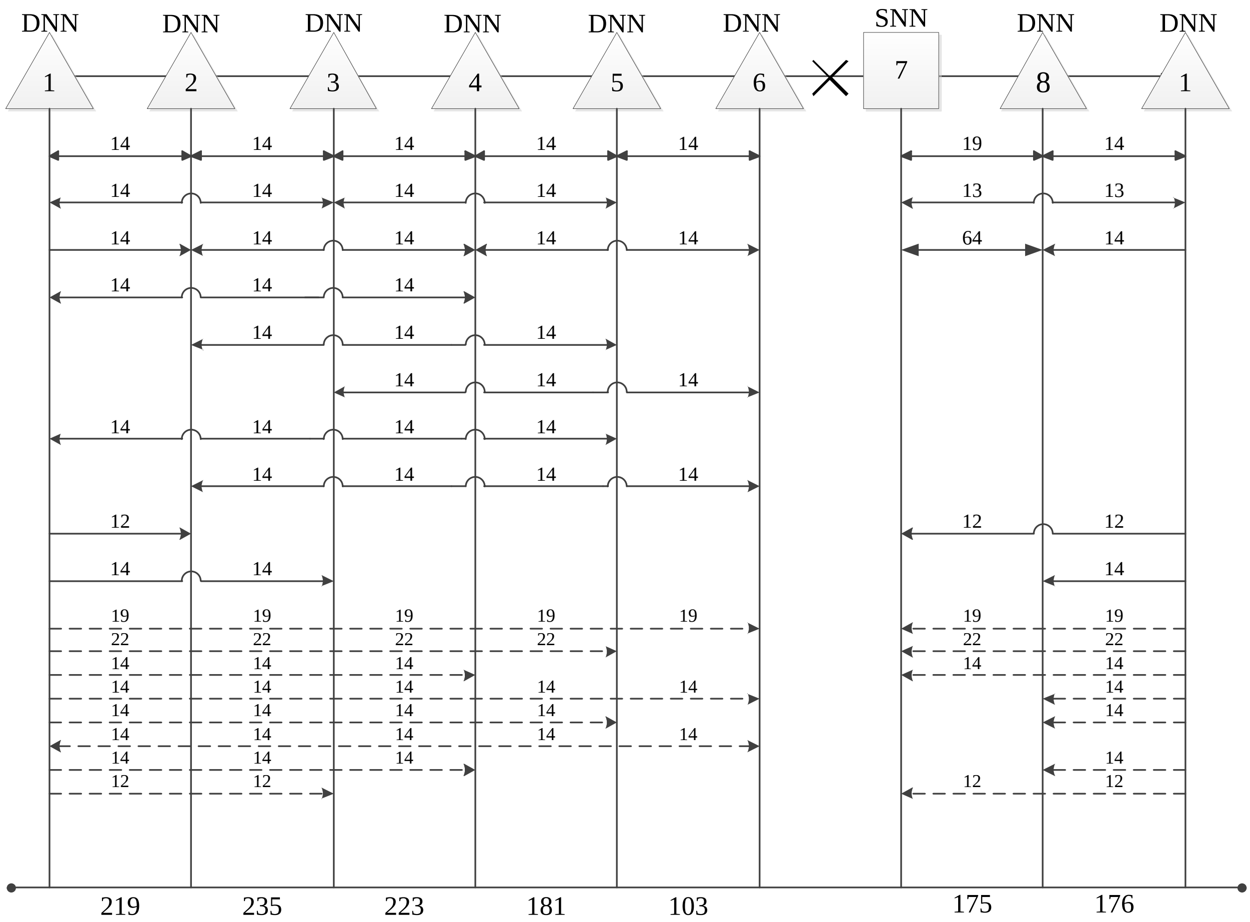


Fig. 3.3 – Multiplexing plan of SDH ring work in emergency operation mode

$N_{STM-4}=252<138+132=270<N_{STM-16}=1008$, in this case we have to use STM-16.

SNCP 1+1

This method differs from SNCP 1:1 that transmission both through the main and reserve channels is carried out simultaneously, and the receiving part chooses a signal with the best quality (which, in fact, is the basic, the second according to the reserve) (see fig. 3.4).

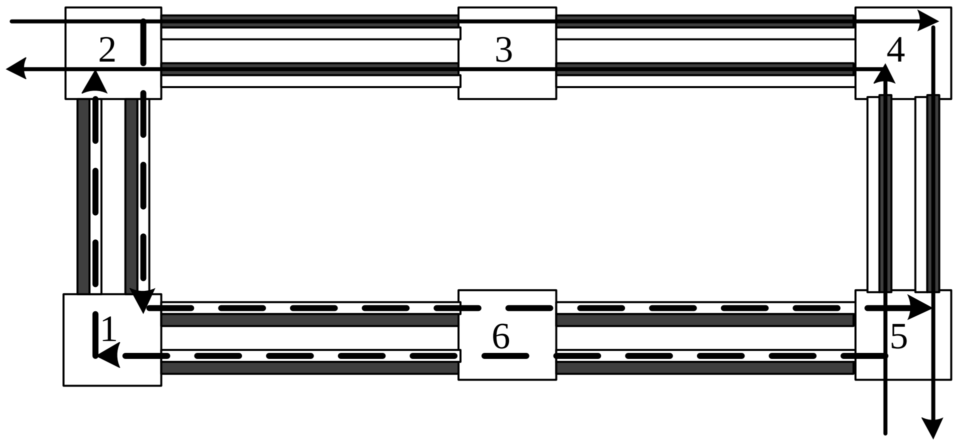


Fig. 3.4 – Traffic transmission in the normal mode at SNCP 1+1 protection method

At the accident one of the transmission directions disappears, and communication between network nodes is provided in the remained direction similar to the SNCP 1:1 scheme (see fig.3.1).From the figure 3.1 it is visible that each of streams transmitted through a ring loads all the sections (working or reserve channel), i.e. hierarchy level calculation is reduced to the determination of the total number of streams in a ring. So, this method differs from other that for the definition of hierarchy level it is not necessarily to build the multiplexing plan, it is quite enough to summarize streams according to the table of inter-nodal network traffic $N_{\Sigma PDS}$.

So in this case $N_{\Sigma PDS}$ =469, and it is necessary to use the STM-16 equipment .

On the figure 3.5 we will give the multiplexing plan for SNCP 1+1 protection method.

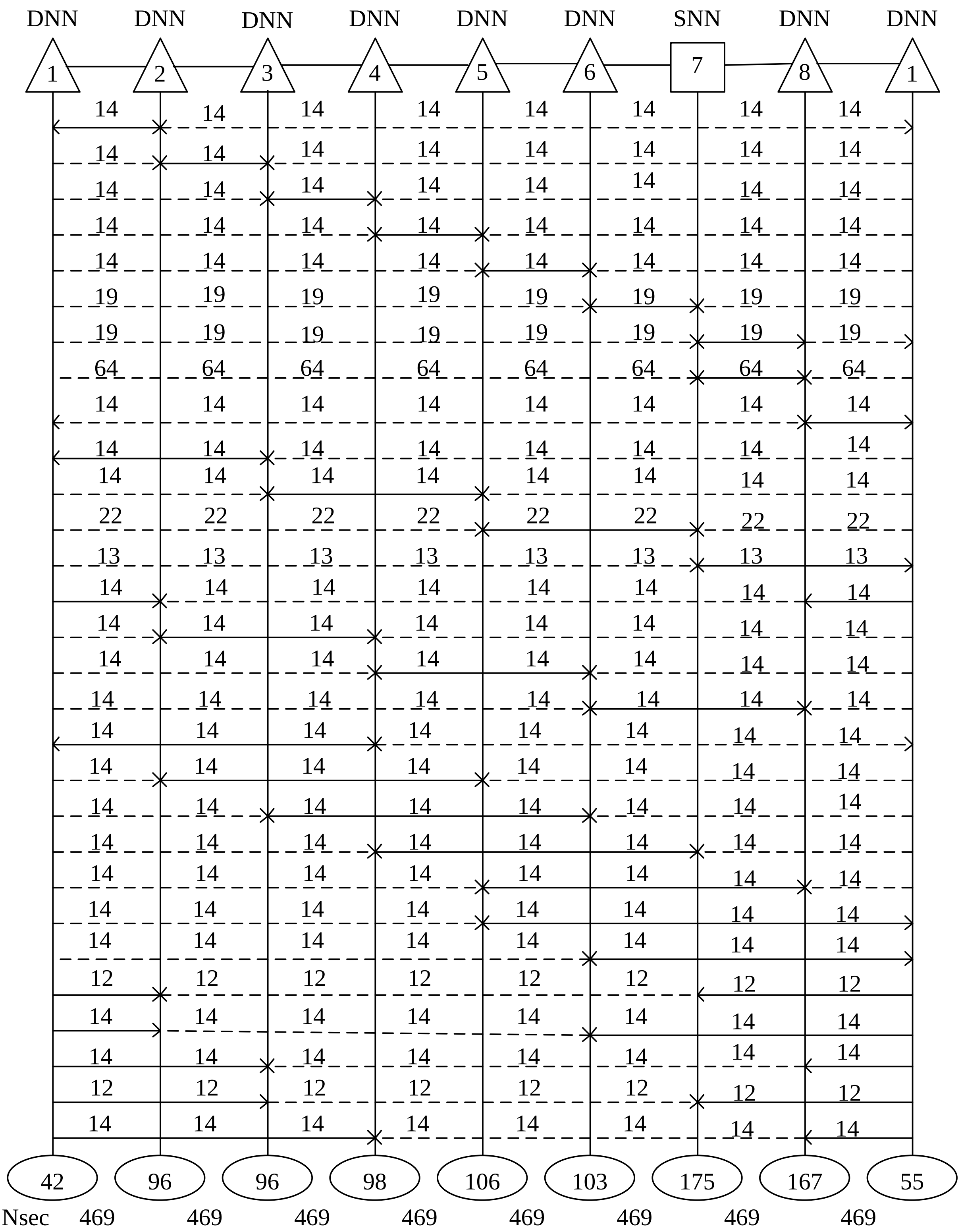


Fig. 3.5 – Multiplexing plan of SDH ring work in normal operation mode for SNCP 1+1

MS SPRing on 2 OF

In this variant each fiber resources are divided between working and protective channels approximately equally, so that at accident on any of the sections the main (working) traffic could be switched to protective channels. The scheme of traffic transmission between DNN-2 and DNN-5 through DNN-3 and DNN-4 is given in the fig.3.6. As we can see from the drawing the ring consists of two fibers, in each fiber resources are divided between working (dark color) and protective (light color) channels. In the normal mode traffic transmission takes place at both fibers through the working channels.

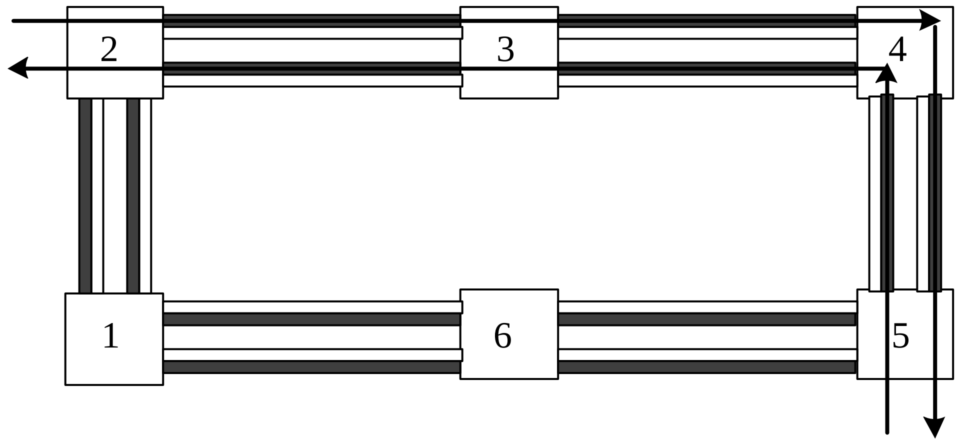


Fig. 3.6 – Traffic transmission in the normal mode at MS SPRing protection on 2 OF

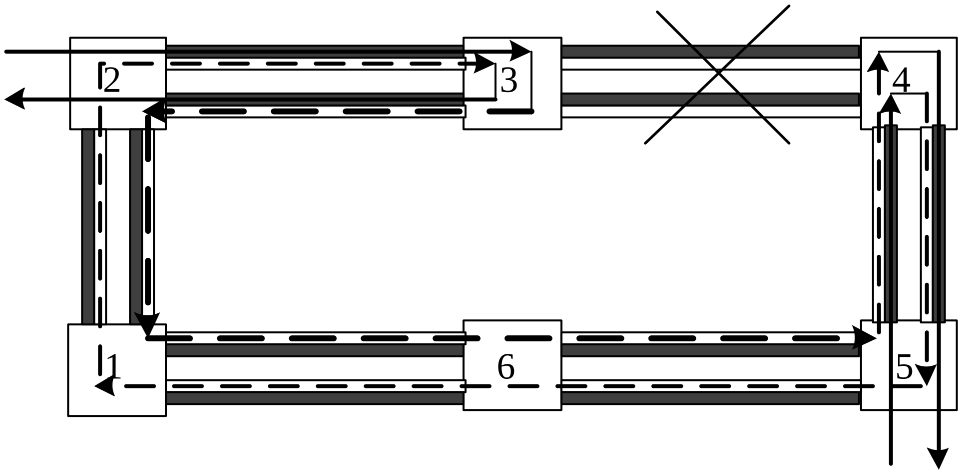


Fig. 3.7 – Traffic transmission at the accident at MS SPRing protection on 2 OF

Proceeding from all above-stated it is possible to conclude that this method uses the protective ring switching (RS) with the division of stream resources (SR) according to the scheme 1:1.

As we can see from the multiplexing plan in normal mode – $N_{\text{DNN6-SNN7}}$ = =123. At the accident on the section DNN-6-SNN-7 this traffic will go through the protective channels of other sections (i.e. an external short circuit of the damaged section will take place), then the common traffic for each section will be defined as a sum of working channels (of this section) and protective channels (for emergency section). So, the STM level is defined as a sum of two sections with the maximum traffic: $N_{\max 1} + N_{\max 2}$

For our example these sections are DNN-4 – DNN-5 and SNN-7 – DNN-8

$$N_{STM-4} = 252 < 261 + 287 = 548 < N_{STM-16} = 1008$$

I.e. to provide the traffic protection with usage of MS SPRing on 2 OF method it is required to use the STM-16 equipment.

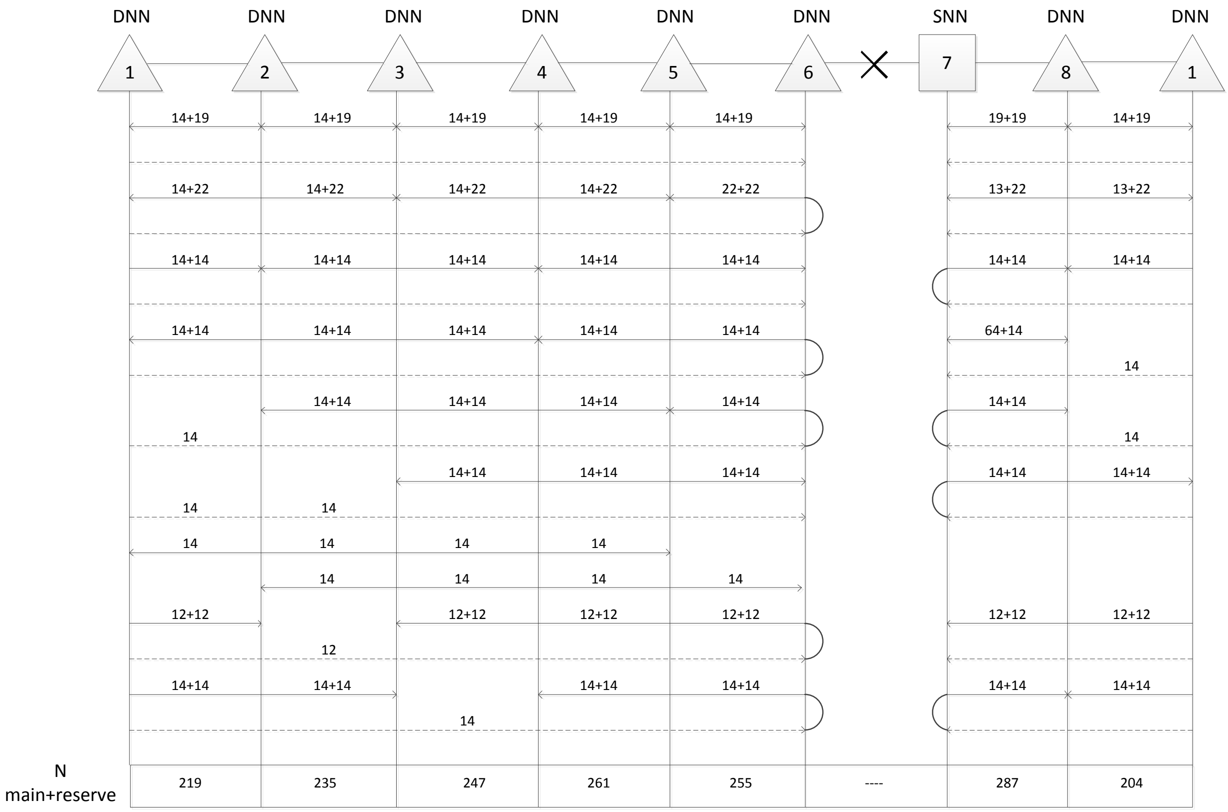


Fig. 3.8 – Multiplexing plan of SDH ring work in emergency operation mode for MS SPRing on 2 OF

MS SPRing on 4 OF

This variant differs that for transmission of working and protective channels different optical fibers (dark fibers for transmission of the main traffic, and light fibers – for reserve) are taken. As a result in a mode without accident the traffic is transmitted only through working fibers (see fig.3.9). At the accident the traffic in a place of damage switches to reserve couple of fibers on which the bypass of the damaged section is carried out (see fig.3.10).

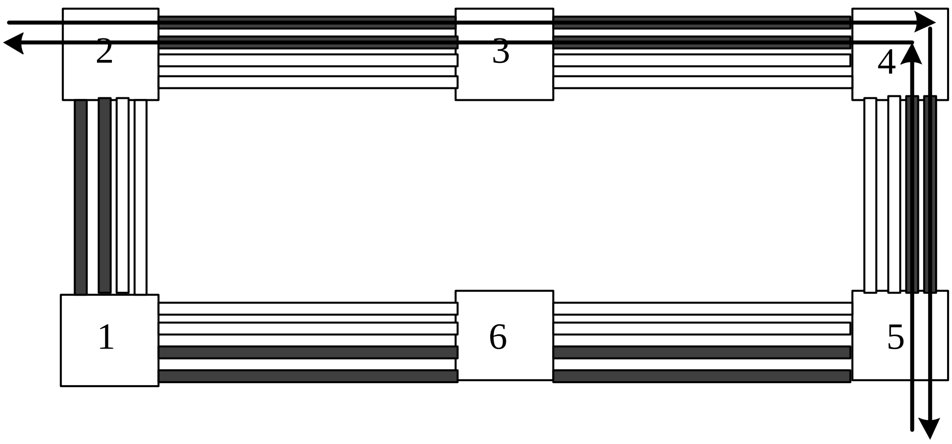


Fig. 3.9 – Traffic transmission in a normal mode at MS SPRing on 4 OF protection method

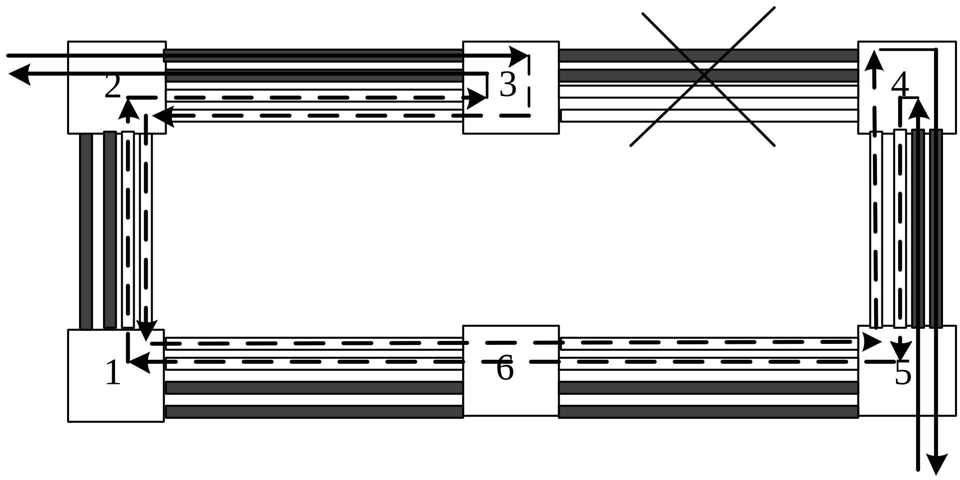


Fig. 3.10 – Traffic transmission at the accident at MS SPRing on 4 OF protection method

The example of hierarchy level calculation for MS SPRing on 4 OF protection method for the same input data is given on the fig.3.11.

During calculation of hierarchy level only working channels are considered, since through any of fibers can be transmitted either working or protective channels. So, the STM level is defined by the section with the maximum traffic N_{max}.

For our example it is a section SNN-7 – DNN-8:

$$164 < NSTM - 4 = 252$$

I.e. to provide the given traffic protection with usage of MS SPRing on 4 OF method it is required to use the STM-4 equipment.

During traffic calculation at the accident state working and protective channels should be considered separately since they are divided by different fibers (see fig.3.11).

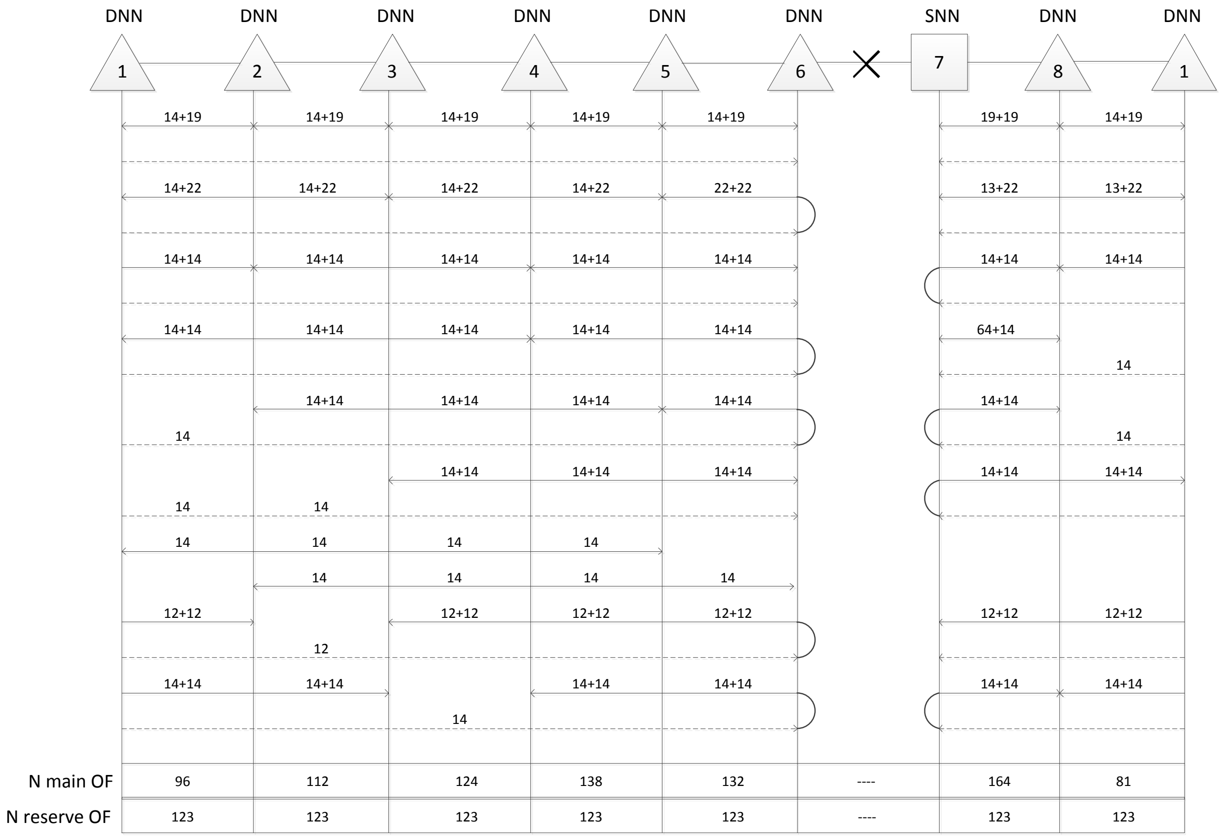


Fig. 3.11 – Multiplexing plan at the accident for MS SPRing on 4 OF protection method

3.2 Types of SDH modules in the ring

Possible indexes in marking of cables at public corporation “Одесскабель”. Symbol and designation.

Table 3.2 – Designation of cable marks

№	Name of the index or index tag	Marks in code	Designation of marks
1	Type of cable	ОК	An optical cable
2	Field of application	L	Linear
3	Type of armor (the index may be absent)	Б	The armor with flat steel bands
		Бг	The armor with the corrugated steel band
		К	The armor of a single-layer round steel wires
		КК	The armor of two-layers round steel wires
		С	The armor of a single-layer dielectric rod

4	A hose made of a flame-retardant material (the index may be absent)	Н	The OC shell and hose of flame-retardant material
5	Number of development	 1 2 3	The nominal outer diameter of OM - 2,7 mm - 3,0 mm - 2,5 mm
6	The central load-bearing element	Д	A dielectric (fiberglass) rod
		М	A metal rope covered by PE PVC
	Type of reinforcing element	A, 2A, 3A, 4, 4A (variants)	High mod aramid yarns that increase the resistance of the cable to stretching
	The type and material of protective covers	1	hose of polyethylene (PE)
		2	hose of flame-retardant PVC plastic
		3	hose of alum polyethylene
		4	shell of polyethylene, steel armor and polyethylene hose
		5	the same, but the shell and hose made of flame-retardant PVC plastic
		6	shell of alum polyethylene, galvanized steel armor and polyethylene hose
		9	shell of alum polyethylene, galvanized steel armor and polyethylene hose
		10	shell of polyethylene, fiberglass plastic armor and polyethylene hose

		11	shell of alum polyethylene, fiberglass armor and polyethylene hose
		12	shell of polyethylene, the armor of the laminated steel with electric chrome covering and a hose from polyethylene
		13	the steel armor, shell and hose of flame-retardant plastic material
	Hose performance (the index may be absent)	П	Simplified construction of the OC hose
7	Construction structure of the OC core	3×4 (variant)	[number of optical modules of OC]×[number of OF in optical module]
		E	Single-mode optical fiber (SOF)
		M	Multi-mode optical fiber (MOF)
8	Designations of reference wavelength	B	λ=850 nm – multimode mode
		A	λ=1300 nm – multimode or single mode
		F	λ=1310 nm – single mode
		H	λ=1550 nm – single mode
	Optical characteristics of fibers		MIAC (maximum individual attenuation coefficient), dispersion (or band) at the corresponding wavelength
	1) Singlemode by G.652 (operate in two frequency windows	0,40F3,5/0.30H19 (variant)	[MIAC (0,40 dB/km), the chromatic dispersion coefficient (not greater than 3,5 ps/(nm·km)) at the reference wavelength F (λ=1310 nm)] / [MIAC (0,30 dB/km), the chromatic

9	λ=1310 nm λ=1550 nm)		dispersion coefficient (not greater than 19 ps/(nm·km)) at the reference wavelength H (λ=1550 nm)]
	2) Singlemode (operate at wavelength λ=1310 nm)	0,7A6,0 (variant)	[MIAC (0,7 dB/km), the chromatic dispersion coefficient (not greater than 6,0 ps/(nm·km)) at the reference wavelength A (λ=1310 nm)]
	3) Multimode by G.651 (operate at wavelength λ=850 nm)	5B250 (variant)	MIAC (5 dB/km), bandwidth (not less than 250 MHz·km) at the reference wavelength (λ=850 nm)
	4) Multimode by G.651 (operate at wavelength λ=1310 nm)	1,0A800 (variant)	MIAC (1,0 dB/km), bandwidth (not less than 800 MHz·km) at the reference wavelength A (λ=1310 nm)
	Total number of OF and RPS wires in cable	12/0	[total number of OF in cable (12 un.)/[number of remote power supply wires in cable]

Input data

1) Distance between network nodes of ring:

Section	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-1
L_{sect}	19	82	94	50	48	112	51	18

2) Parameters of the optical transmitter:

- the transmission level p_{tr}= 8 dBp;
- the emission wavelength of laser λ_0= 1310 nm;
- the width of laser emission line Δλ= 0,18 nm.

3) Parameters of the optical cable in the SDH ring:

- the attenuation coefficient α= 0,38 dB/km;
- the chromatic dispersion σ_{01}= 3,50 ps/(nm*km);
- the factory cable length l_f = 6,4 km.

4) Parameters of the optical receiver:

- optical sensitivity p_{rec}= -31 dBp.

5) STM level in the ring — STM-16 (see subsection 3.1 of a course project)

Solution

1) Calculation of the repeater section length.

a)Limited by fiber attenuation:

$$L_{reg\alpha} = \frac{PB - 2A_{ptc} - A_{res}}{\left(\alpha + \frac{A_{permc}}{l_f}\right)},$$

where PB – power budget ($PB = p_{tr} - p_{rec}$);

$A_{pt\,c}$ - attenuation of the plug-type connection ($A_{pt\,c}$=0,5 dB);

$A_{perm\,c}$ - attenuation of the permanent connection ($A_{perm\,c}$=0,1 dB);

A_{res} - reserve on the attenuation ($A_{res} = 6$ dB).

For current input data we have:

$$PB = 8 - (-31) = 39 \text{ dB};$$

$$L_{reg\alpha} = \frac{39 - 2 \cdot 0{,}5 - 6}{\left(0{,}38 + \frac{0{,}1}{6{,}4}\right)} = 80{,}89 \text{ km}$$

b) Limited by fiber dispersion:

$$L_{reg\sigma} = \frac{0,25}{|D| \cdot \Delta\lambda \cdot B},$$

where D - dispersion coefficient of the optical fiber (s/(nm·km));

- laser emitting line width, nm; $\Delta\lambda$

B - signal bitrate, bit/s.

For current input data we have:

$$L_{reg,\sigma} = \frac{0,25}{3,5 \cdot 10^{-12} \cdot 0,18 \cdot (155,52 \cdot 16) \cdot 10^{6}} = 159,5 \text{ km}$$

The total repeater section length is equal to:

$$L_{reg} = \min\left(L_{reg,\alpha}; L_{reg,\sigma}\right) = \min(80,89;159,5) = 80,89\,\text{km}$$

2) Calculate a length of cable at the sections:

$$L_{cablei} = 1,01 \cdot L_{secti}$$

$$L_{cable1-2} = 1,01 \cdot 19 = 19,19 \text{ km}$$

3) Calculate a quantity of regenerators in the SDH ring by next equation:

$$N_{regi} = ceil\left(\frac{L_{cablei}}{L_{reg}}\right) - 1,$$

Where *ceil(value)* returns the next highest integer value by rounding up *value* if necessary.

For current input data we have:

$$N_{reg1-2} = ceil\left(\frac{19,19}{80,89}\right) - 1 = 0$$

Table 3.3 - Quantity of regenerators in the SDH

Section	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-1
$L_{sect\,i}$	19	82	94	50	48	112	51	18
$L_{cable\,i}$	19,19	82,82	94,94	50,5	48,48	113,12	51,51	18,18
N_{reg}	0	1	1	0	0	1	0	0

4) Describe functions of the terminal multiplexer, add-drop multiplexer, generator and digital cross-connector. Draw corresponding graphical symbols (ГОСТ 21.406-88).

- STM-1: S-1.1 (20 km), L-1.1 (40 km), L-1.2, L-1.3 (80 km);
- STM-4: S-4.1 (20 km), L-4.1 (40 km), L-4.2, L-4.3 (80 km).

I (< 2 km) – interstation interface.

Considering the organization scheme of the SDH ring, we should take into account the building length to construct actual line. For calculation the length of line, it's necessary to find how many pieces are needed to obtain the $L_{sect\ i}$.

It's necessary to take into consideration the building length in order to decrease number of welding.

As $lf = 6,4$ km, the cable length between DNN1 and DNN2 will be:

$$L = 6,4 \cdot 3 = 19,2 \text{ km}$$

$$L_{cable}\text{DNN1} - \text{DNN2} = 6,4 \cdot 3 \cdot 1,01 = 19,392 \text{ km}$$

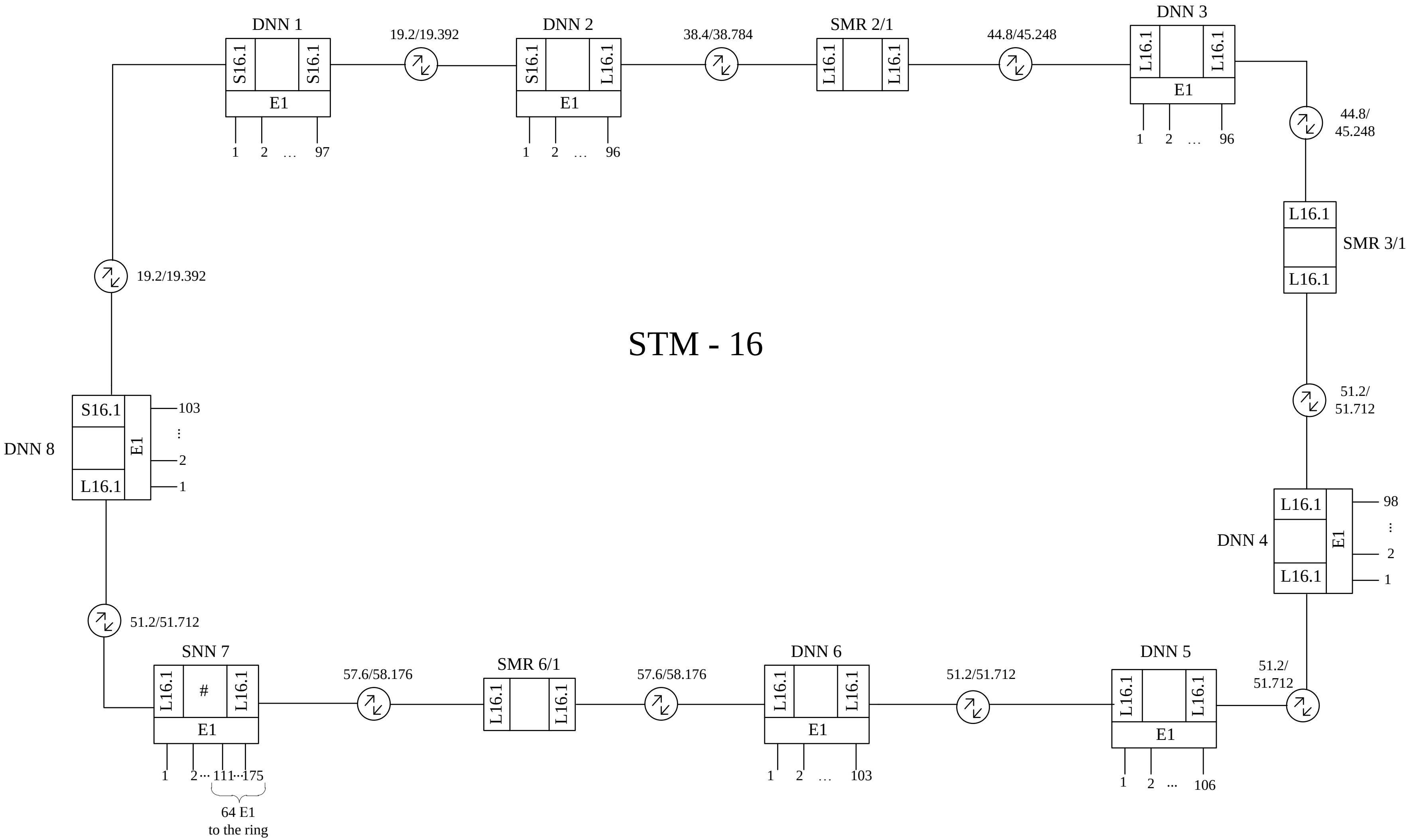


Figure 3.4 – Organization scheme of the SDH ring

Subsection 4 “Radio Relay Systems”

Content

Initial data

Lower boundary of frequency plan: $F1$=2800 MHz

Trunks number: 6+3 (working and reserve) for transmitting and receiving

Spacing between the carriers of the nearest channels: $\Delta f = 4F$

Transmission: fU

Receiving: fL

Digital capacity of trunk: STM-1

LPC of transmitted DBS: RZ

RRTS equipment class: 5

X-11 line length, km: 58

X-12 line length, km: 33

Number of trunk for calculation: 3

Task

- Determine according to the initial data for the analog RRTS with two-frequency plan:

1) upper boundary frequency of frequency plan $F2$;

2) the carrier frequencies of trunks $f_1, f_2 .. f_{n_{tr}}$;

3) Slip frequency f_{sl};

4) medium (central) frequency of the used frequency bandwidth and the corresponding wavelength;

- RRTS frequency plan;

1.1. Parameters of frequency plan;

1.2. Spectral Diagram of frequency plan;

- Terminal radio relay station (TRS);

2.1. Structure chart of TRS;

2.2. Functional scheme for the trunk of TRS transmitter;

2.3. Functional scheme for the trunk of TRS receiver;

- Intermediate radio relay station (IRS);

3.1. Structure chart of IRS;

3.2. Functional scheme for the trunk of IRS.

Introduction

Modern radio-relay systems are multi-trunk systems (многоствольный), which allows increasing economic efficiency of the system using one and the same antenna pylon (антенная опора), technical building, and system of power supply for organization of several barrels. The method of frequency division of a channel is used for building of multibarrelled radio-relay systems, because for transmission of signals of different barrels SHF signals with different frequency bands are used.

While forming the SHF signal in RRS the additional modulation with the help of carrying oscillation of current of intermediate frequency is used.

RRS are divided on local, zonal, main and technological.

Local RRS connect two TEs within a big city, main city with a village or village with village.

Zonal RRS are the line of averaged capacity, they act inside one region.

Main RRS connect paths and transmission channels of different regions (zones), they are the lines of high capacity (thousands of phone channels) and they use under 8 high-frequency radio-barrels.

Technological RRS are used for organization of technological communication in exploitation of pipelines, gas pipeline, electro-transmission lines, and railway transport.

Modern RRS work in different frequencies from 0,1 to 15 GHz.

RRSs are divided on digital and analog by the way of processing of the information. Analog RRS are used for transmission multi-channel telephone messages and TV signals together with signals of audio signals in analog form. Digital RRS are used for transmission of telephone messages in digital form, signals of data with high speeds and also TV signals and video-telephone signals

RRS by functions are divided on Nodal RRS (NRS), Terminal RRS (TRS), and Intermediate RRS (IRS).

On NRS transmitted information is retransmitted with ability of adding and extracting of information to users.

On TRS transmitted information is inputted and extracted and distribution of information to users is provided. (TX)

On IRS transmitted signals are retranslated on intermediate frequency.

Solution

4.1 Classification of line-of-sight RRTS

Table 4.1 – RRTS classes

Class №	Modulation type	Δf_m
1	FM-2	$2\ \Delta f_s$
2	QAM-4	Δf_s
3	PM-8	$\frac{2}{3}\Delta f_s$
4	QAM-16	$\frac{\Delta f_s}{2}$
5	QAM-64	$\frac{\Delta f_s}{3}$
6	QAM-256	$\frac{\Delta f_s}{4}$

Frequency plan of RRTS-5

4.2 Parameters of frequency plan

Modern radio-relay systems are multi-trunk systems, which allows increasing economic efficiency of the system using one and the same antenna pylon, technical building, and system of power supply for organization of several barrels. The method of frequency division of a channel is used for building of multi barreled radio-relay systems, because for transmission of signals of different barrels SHF signals with different frequency bands are used.

B = 155,52 Mbit/s = 0,15552 Gbit/s

For RZ code: $\Delta f_s = 2 f_{cl} = 2 \cdot 0{,}15552 = 0{,}311$ GHz

As the equipment class is RRTS-5 so the modulation type is QAM-64 for which:

$$\Delta f_m = \frac{\Delta f_s}{3} = \frac{0{,}311}{3} = 0{,}104\,\text{GHz}$$

Choose the $2F$ so that $2F > \Delta f_m$ from next row: 1; 2; 3,5; 4; 5; 7; 10; 14; 20; 28; 40; 56 MHz or if $\Delta f_m > 56$ MHz, then:

$$2F = 28\left[\frac{104}{28}\right] = \text{MHz} \rightarrow 0{,}112\,\text{GHz}$$

F = 56 MHz = 0,056 GHz

Upper boundary of frequency plan is calculated by the following formula:

$$F_2 = F_1 + 2F\left(n_{tr} - 1\right) \cdot 2 + 2F + \Delta f,\ \text{GHz},$$

Where F_2 – is upper limited frequency band; F_1 – is lower limited frequency band; $2F$ – is the interval between carriers of neighboring trunks; Δf – is the separation between carriers of adjacent trunks with the opposite transmission directions; n_{tr} – is the number of trunks.

The carrier frequencies of lower boundary frequency plan are calculated by the formulas:

$$f_{l1} = F1 + F\text{, GHz}$$

$$f_{l2} = F1 + 3F\text{, GHz}$$

$$f_{l3} = F1 + 5F\text{, GHz}$$

$$f_{l4} = F1 + 7F\text{, GHz}$$

$$f_{l5} = F1 + 9F\text{, GHz}$$

$$f_{l6} = F1 + 11F\text{, GHz,}$$

$$f_{l7} = F1 + 13F\text{, GHz,}$$

Where $f_{c1}, f_{c2}, f_{c3}, f_{c4}, f_{c5}, f_{c6}$ – are the carrier frequencies of trunks in the lower boundary frequency plan.

The carrier frequencies of upper boundary frequency plan are calculated by the formula:

$$f_{iu} = f_{il} + 2F\left(n_{tr} - 1\right) + \Delta f$$

The slip frequency (the interval between carriers of lower and upper group of one trunk in the RRTS frequency plan):

$$f_{sl} = 2F \cdot \left(n_{tr} - 1\right) + \Delta f\text{, GHz,}$$

Where f_{sl} – slip frequency.

Central frequency of the used frequency bandwidth is calculated by the formula:

$$f_0 = \frac{F1 + F2}{2}, \text{GHz},$$

Where f_0 – is middle frequency of bandwidth.

The corresponding wavelength is:

$$\lambda = \frac{30}{f_0}, \text{sm},$$

Where λ – is the wavelength, that corresponds to the middle frequency of bandwidth.

Let’s perform the calculation using formulas below:

$$F_2 = 2{,}8 + 2 \cdot 0{,}056 \cdot (9-1) \cdot 2 + 2 \cdot 0{,}056 + 4 \cdot 0{,}056 = 4{,}928 \text{GHz}$$

$$f_{l1} = 2{,}8 + 0{,}056 = 2{,}856 \text{GHz}$$

$$f_{l2} = 2{,}8 + 3 \cdot 0{,}056 = 2{,}968 \text{GHz}$$

$$f_{l3} = 2{,}8 + 5 \cdot 0{,}056 = 3{,}08 \text{GHz}$$

$$f_{l4} = 2{,}8 + 7 \cdot 0{,}056 = 3{,}192 \text{GHz}$$

$$f_{l5} = 2{,}8 + 9 \cdot 0{,}056 = 3{,}304 \text{GHz}$$

$$f_{l6} = 2{,}8 + 11 \cdot 0{,}056 = 3{,}416 \text{GHz}$$

$$f_{l7} = 2{,}8 + 13 \cdot 0{,}056 = 3{,}528 \text{ GHz}$$

$$f_{l8} = 2{,}8 + 15 \cdot 0{,}056 = 3{,}64 \text{ GHz}$$

$$f_{l9} = 2{,}8 + 17 \cdot 0{,}056 = 3{,}752 \text{ GHz}$$

$$f_{u1} = 2{,}856 + 2 \cdot 0{,}056(9-1) + 0{,}224 = 3{,}976 \text{GHz}$$

$$f_{u2} = 2{,}968 + 2 \cdot 0{,}056(9-1) + 0{,}224 = 4{,}088 \text{GHz}$$

$$f_{u3} = 3{,}08 + 2 \cdot 0{,}056(9-1) + 0{,}224 = 4{,}2 \text{GHz}$$

$$f_{u4} = 3{,}192 + 2 \cdot 0{,}056(9-1) + 0{,}224 = 4{,}312 \text{GHz}$$

$$f_{u5} = 3{,}304 + 2 \cdot 0{,}056(9-1) + 0{,}224 = 4{,}424 \text{GHz}$$

$$f_{u6} = 3{,}416 + 2 \cdot 0{,}056(9-1) + 0{,}224 = 4{,}536 \text{GHz}$$

$$f_{u7} = 3{,}528 + 2 \cdot 0{,}056(9-1) + 0{,}224 = 4{,}648 \text{GHz}$$

$$f_{u8} = 3{,}64 + 2 \cdot 0{,}056(9-1) + 0{,}224 = 4{,}76 \text{GHz}$$

$$f_{u9} = 3{,}752 + 2 \cdot 0{,}056(9-1) + 0{,}224 = 4{,}872 \text{GHz}$$

$$f_{sl} = 2F(ntr-1) + \Delta F = 2 \cdot 0{,}056 \cdot (9-1) + 0{,}244 = 1{,}12 \text{GHz}$$

$$f_0 = \frac{2{,}800 + 4{,}928}{2} = 3{,}864 \text{GHz}$$

$$\lambda = \frac{3 \cdot 10^8}{3{,}864 \cdot 10^9} = 0{,}0776\,\mathrm{m}$$

4.3. Spectral diagram of frequency plan

The spectral diagram of frequency plan is shown of Fig. 4.1

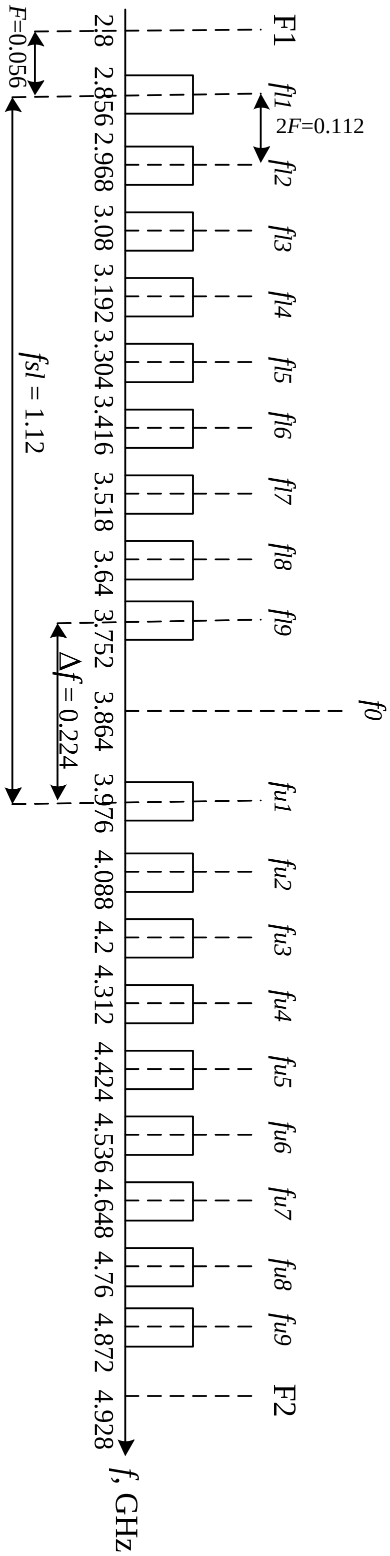


Fig. 4.1 – Spectral diagram of frequency plan

The dual frequency conversion of operating frequencies for one high-frequency trunk is used at duplex communications through radio relay links. The high-frequency trunk – is the chain of radio relay stations, and on each of them one set of the same type high-frequency signatures and separation band pass filters are installed. In case of dual-frequency distribution of operating frequencies, at each intermediate station transmitters operate on one frequency, and receivers – on other.

The transmitter has no interfering effect on the receiver, as transmission and reception of radio signals is performed on different radio frequencies. Frequency separation is performed by separation band pass filters. The frequency changing is performed at intermediate station in order to eliminate communication between the transmitter and receiver, which operate in different directions.

In multi-channel RRL with dual frequency conversion of operating frequencies, transmission and receiving frequencies of each trunk differ by the same value.

4.4 Terminal radio relay station (TRS)

Structure chart of TRS:

$$f_{\text{int}} = 10\Delta f_s$$

$$f_{\text{int}} = 10 \cdot 0{,}311 = 3{,}11 \text{ GHz}$$

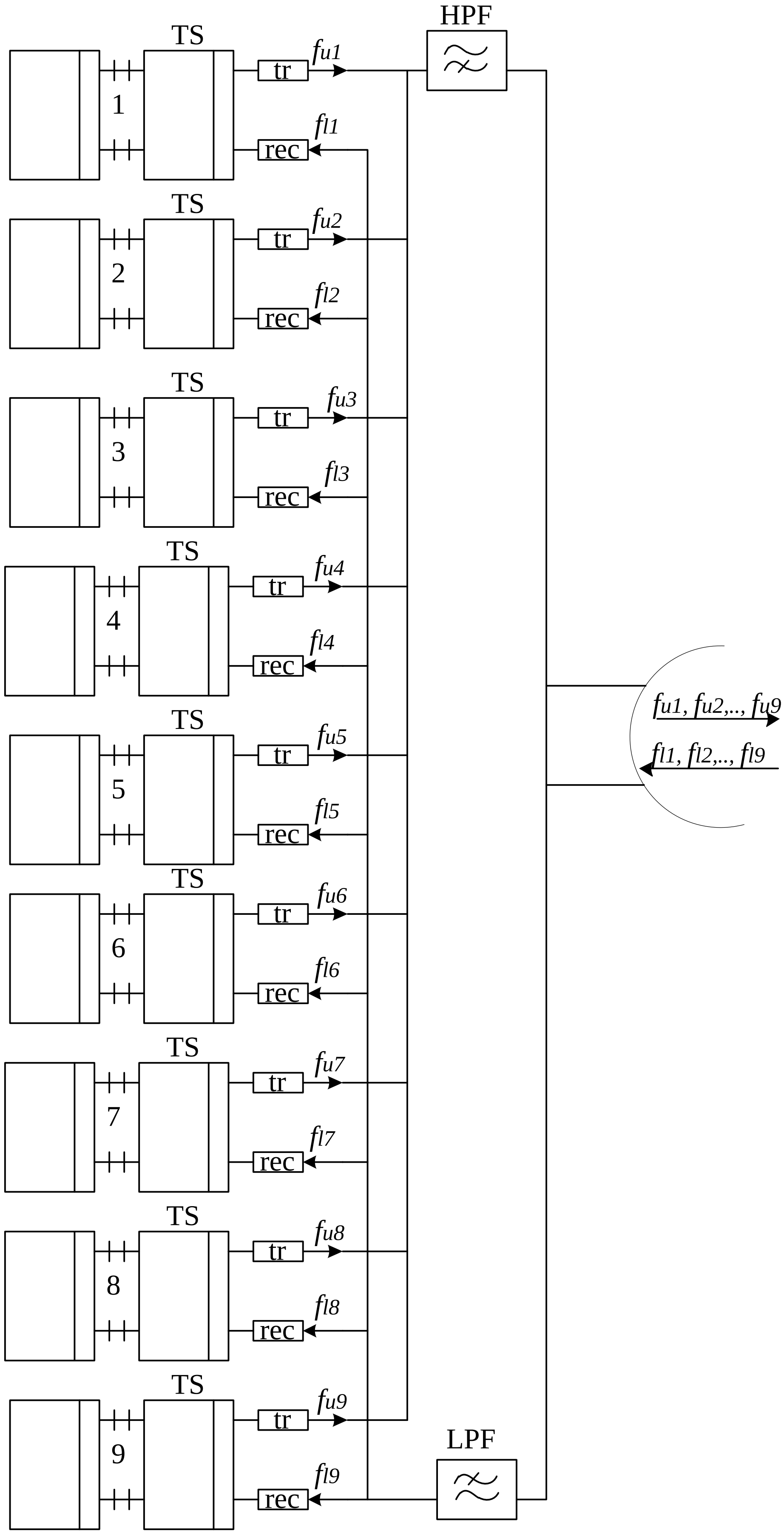


Fig.4.2a – Structure chart of TRS

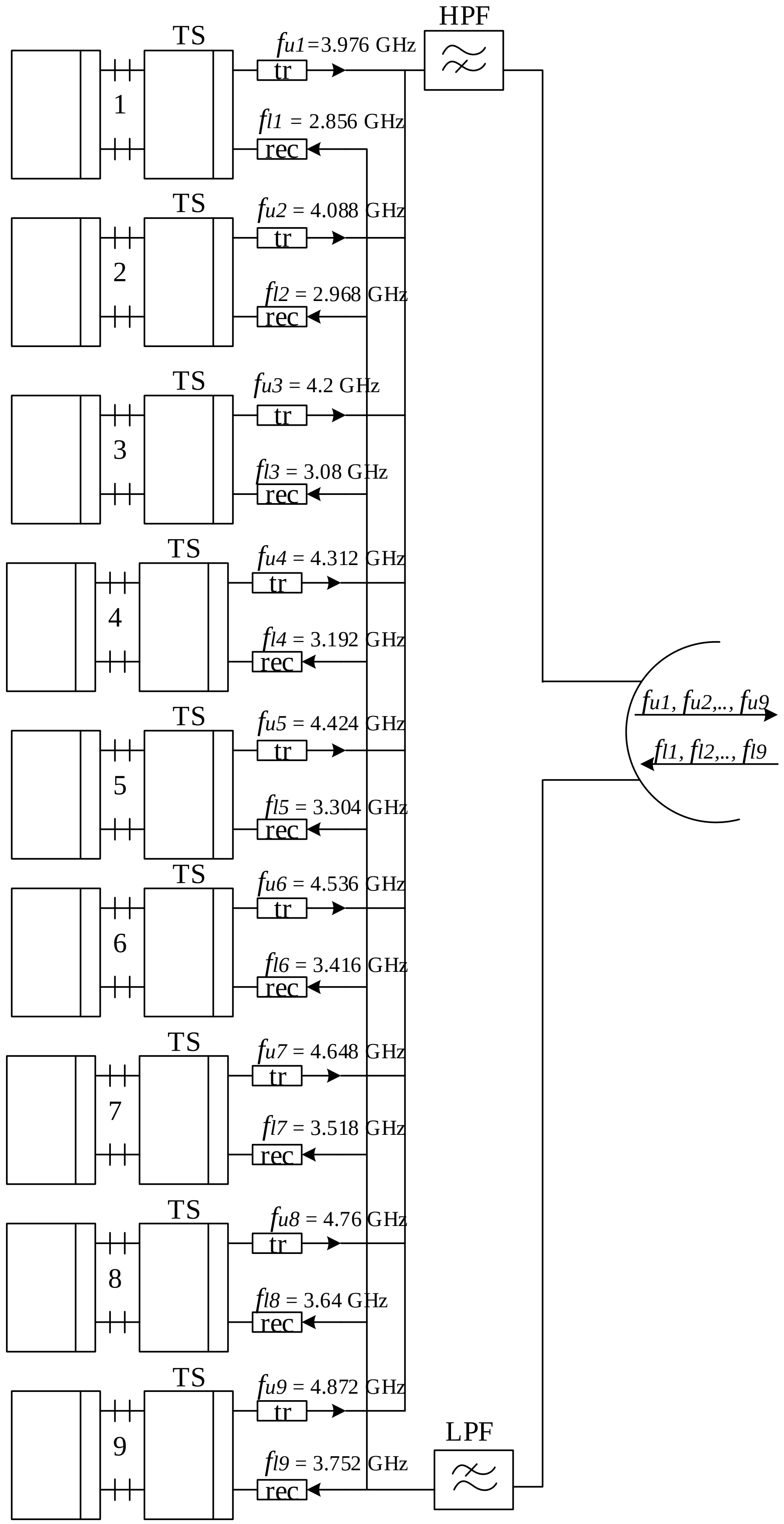


Fig.4.2b – Structure chart of TRS

The following designations are represented on Fig. 4.2:

- TS – transmitting set

- HPF, LPF – separation filters

The signal is amplified and corrected in transmitting set. The separation filter excludes the effect of the transmission path to receive path.

Functional scheme of transmitter

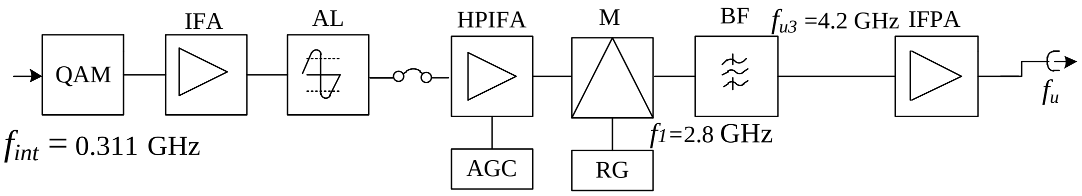


Fig. 4.3 – The functional scheme of transmitter

IFA - intermediate frequency amplifier;

AL - amplitude limiter;

HPIFA - high power IFA;

RG - reference generator;

BF - band-pass filter;

PA - power amplifier;

AGC - automatic gain controller

QAM – quadrature amplitude modulator

As a modulated signal the harmonic oscillations with frequencies f_c = 35 MHz, 70 MHz, 108 MHz, 140 MHz are used. They are called intermediate frequencies. Through the quadrature amplitude modulator the signal is transferred to the intermediate frequency range. An intermediate frequency amplifier calculates the main amplification. The amplitude limiter eliminates residual amplitude deviation, introduced by intermediate frequency amplifier. Then the signal enters high power IFA which provides the desired signal power. After, here is a mixer: modulator and band-pass filter that form a single sideband. Reference generator – a heterodyne channel, which forms a carrier frequency. A mixer transfers the signal into SHF range, that is amplified and transmitted into antenna-feeder path. The intermediate frequency range allows to construct an amplifier with high linearity of amplitude characteristic, small band pass flatness (regularity of frequency response) and obtain high amplification that can not be obtained in the SHF range. Besides, intermediate frequency usage allows to unify the part of equipment.

Functional scheme of receiver

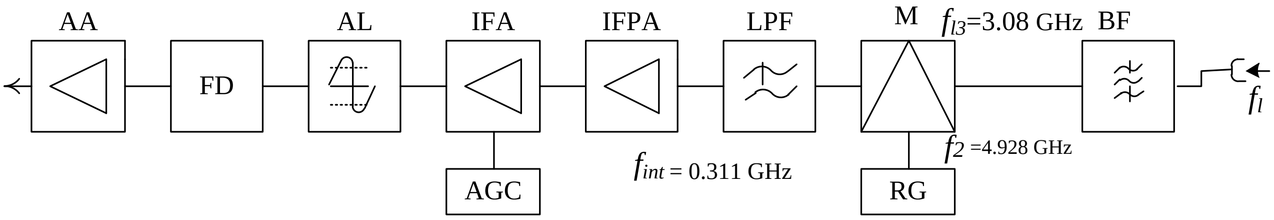


Fig. 4.4 – The functional scheme of receiver

AA - auxiliary amplifier;

FD - frequency demodulator;

AL - amplitude limiter;

IFA - intermediate frequency amplifier;

LPF - low pass filter;

BF - band-pass filter;

IFPA - intermediate frequency power amplifier.

The band-pass filter at the input of reception path eliminates the influence of neighboring trunks. Frequency converter (modulator and filter) transfers a signal to intermediate frequency range. There are intermediate frequency power amplifier (performed by low-noise amplifier) and intermediate frequency amplifier. The intermediate frequency amplifier in a feedback circuit performs an automatic gain control as a method of fading control. The amplitude limiter eliminates residual amplitude deviation. The profound limitation is used. Frequency demodulator demodulates the signal. And after this the signal enters an auxiliary amplifier.

Intermediate radio relay station (IRS)

Structure scheme of IRS-1

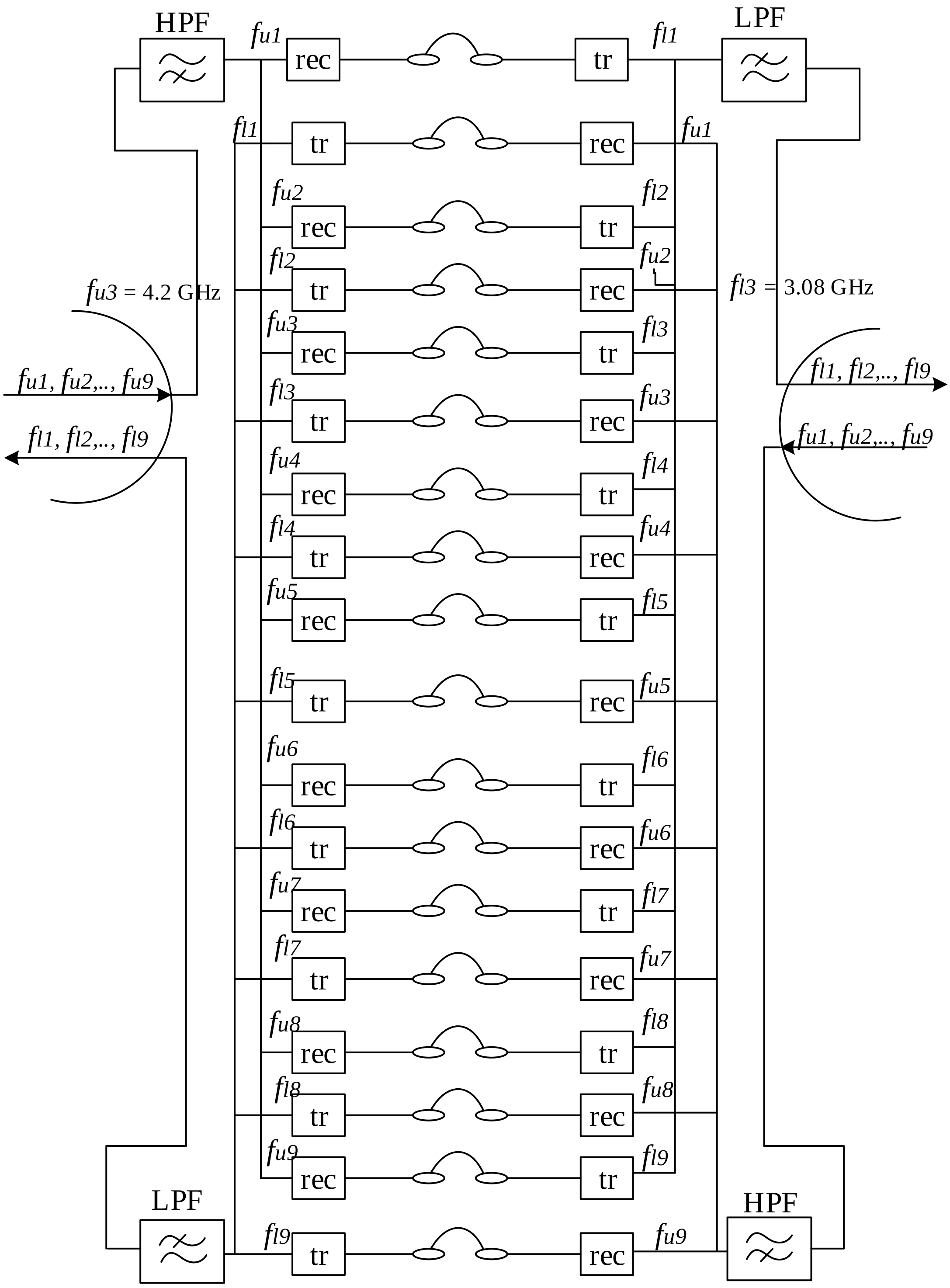


Fig. 4.5a – Structure scheme of IRS-1

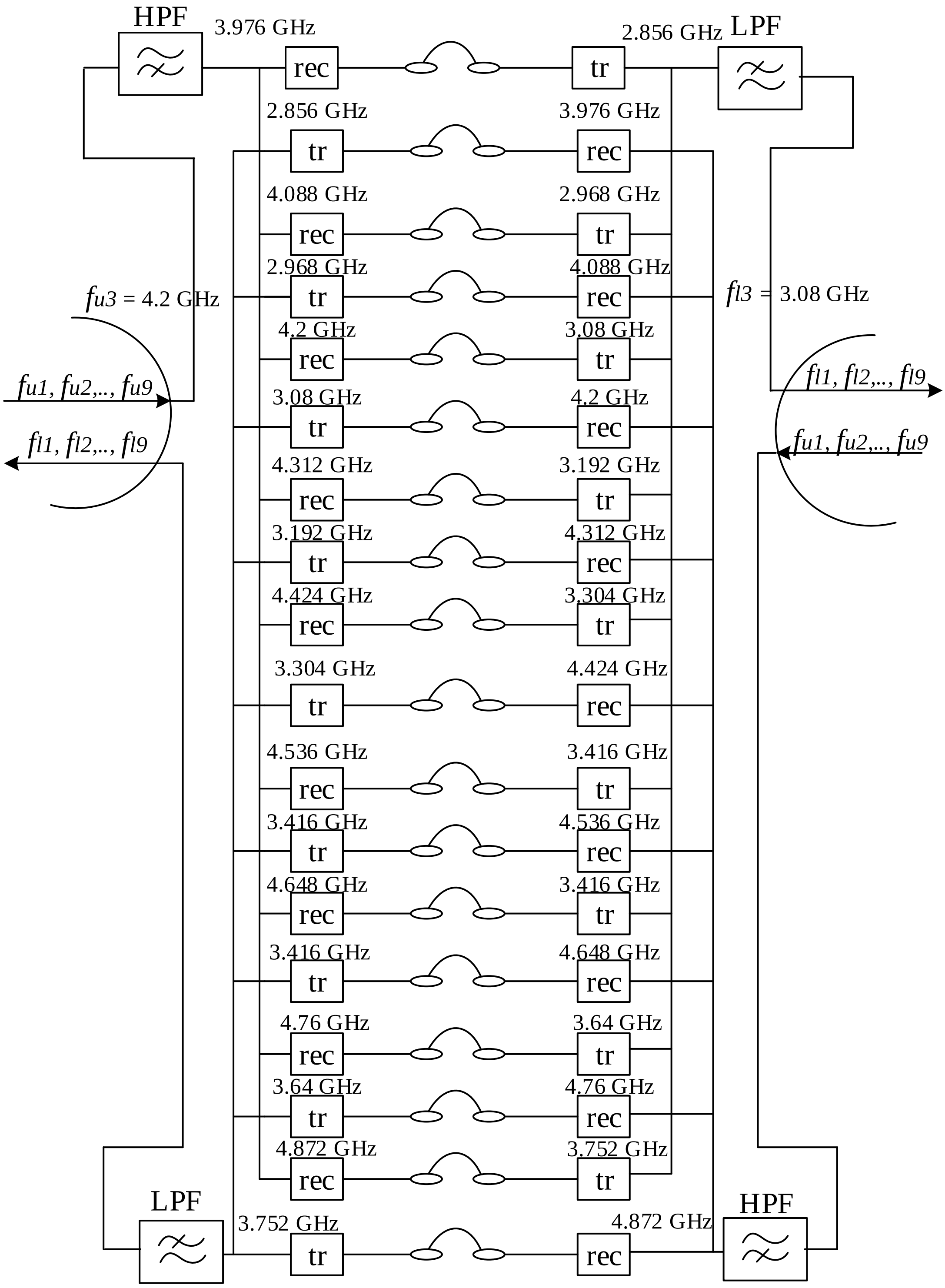


Fig. 4.5b – Structure scheme of IRS-1

The following designations are represented on Fig. 4.5:

LPF - law pass filter;

HPF - high pass filter;

Tr – transmitter;

Rec - receiver

Functional scheme of IRS1

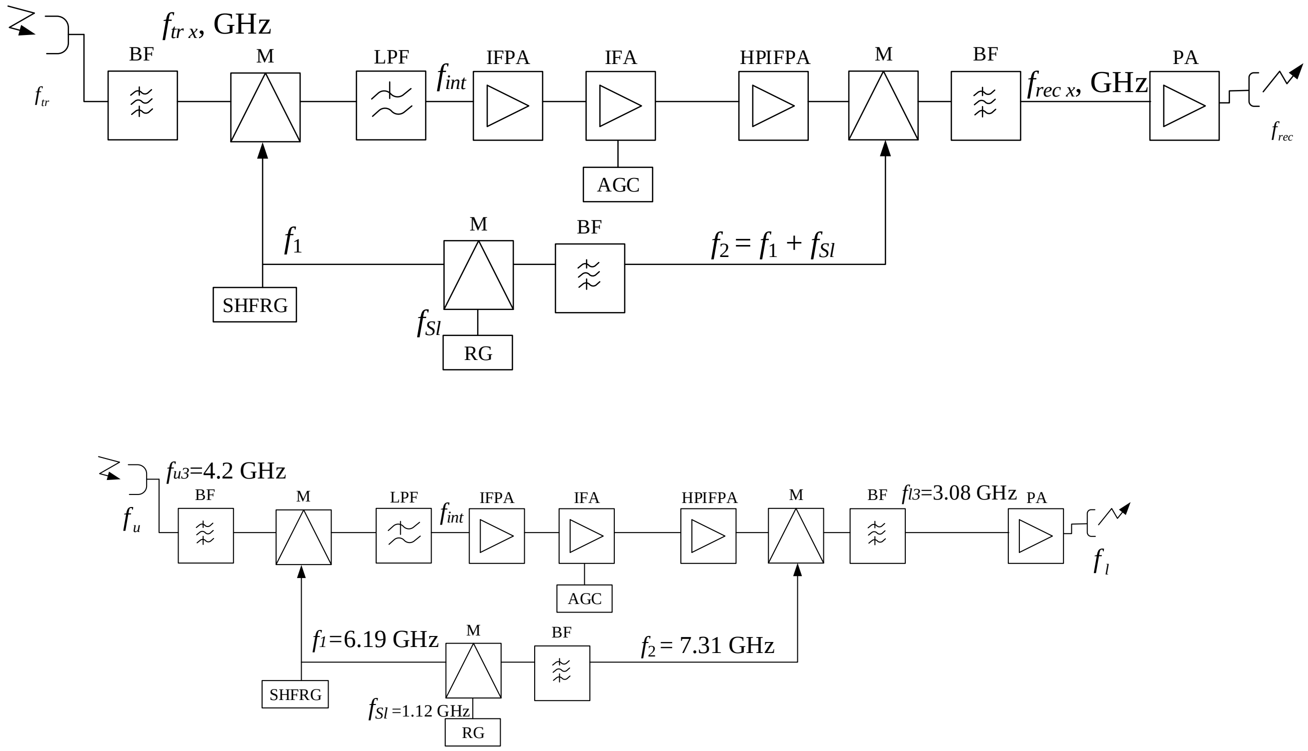


Fig. 4.6 – The functional scheme of IRS1

SHFRG-super high frequency generator.

IFA-intermediate frequency amplifier;

HPIFA-high power IFA;

RG-reference generator;

BF-band-pass filter;

PA-power amplifier;

AGC-automatic gain controller.

Radio repeaters are installed at intermediate stations between transmitting and receiving antennas in order to compensate the SHF signals' attenuation during their transmission in the free air.

The 1st variant when $f1 < freceived$:

$$f_1 = freceived - f\ \mathrm{int}$$

$$f_2 = f_{transmitted} - f_{int} = \begin{cases} \mathrm{f}_1 + \mathrm{f}_{sl} (\text{if } f_u = f_{transmitted}) \\ \mathrm{f}_1 - \mathrm{f}_{sl} (\text{if } f_l = f_{transmitted}) \end{cases}$$

1st stage: Lower Sideband is extracted.

2nd stage: Upper Sideband is extracted.

The 2nd variant when $f1 > freceived$:

$$f_1 = freceived + f\ \mathrm{int}$$

$$\mathrm{f}_2 = f_{transmitted} + \mathrm{f}_{int} = \begin{cases} \mathrm{f}_1 + \mathrm{f}_{sl} (\text{if } f_u = f_{transmitted}) \\ \mathrm{f}_1 - \mathrm{f}_{sl} (\text{if } f_l = f_{transmitted}) \end{cases}$$

1st and 2nd stages: Lower Sideband is extracted.

Lower sideband is extracted.

As by the 1st variant (when $f1 < freceived$) we obtain negative frequencies, then we use the 2nd variant.

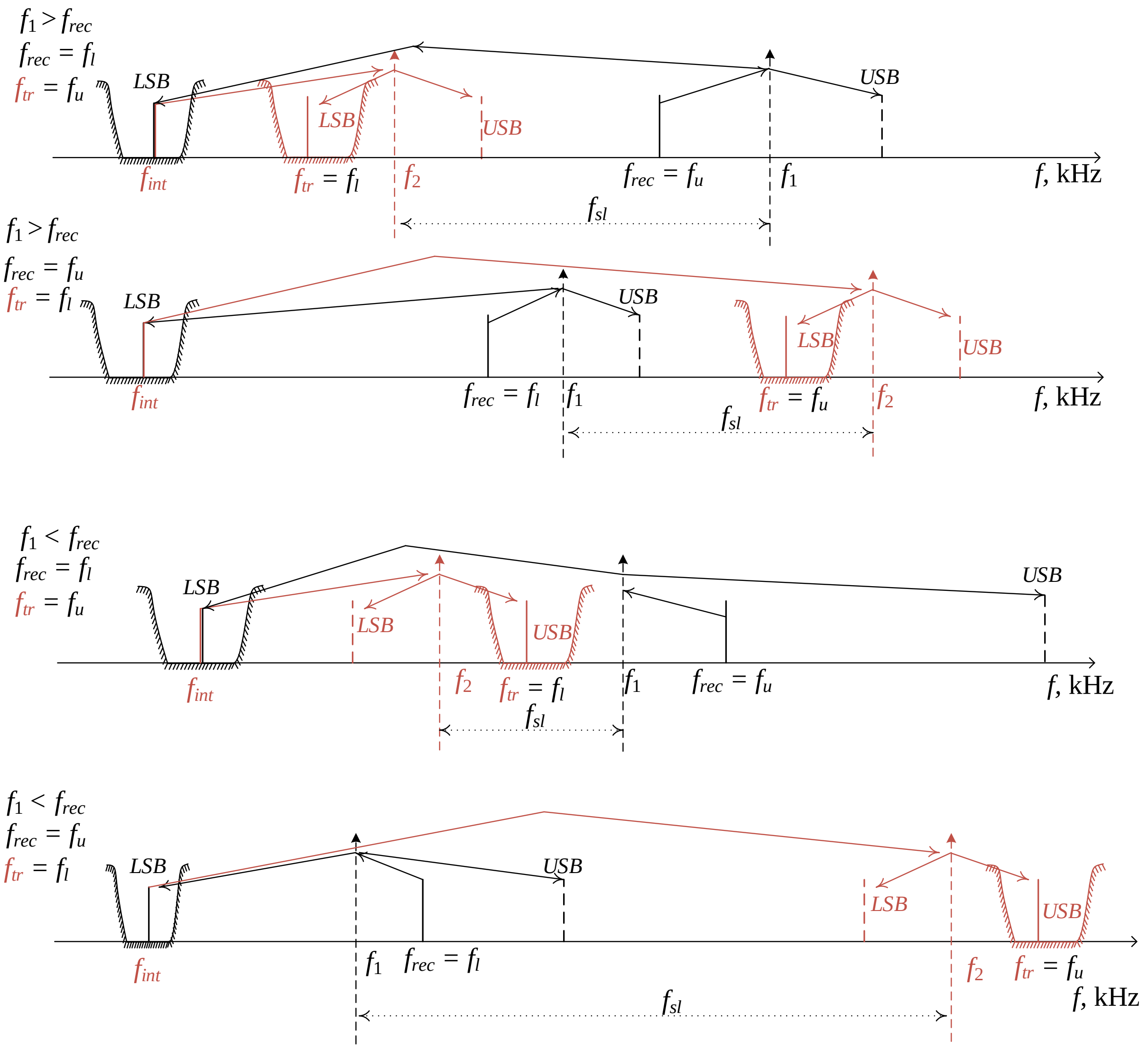
The 2nd variant when $f1 > freceived$:

$$f_1 = freceived + f\ \mathrm{int}$$

$$f_2 = f_{transmitted} + f_{int} \Rightarrow f1 + fsl$$

$$f_1 = 3{,}08 + 3{,}11 = 6{,}19 \text{ GHz}$$

$$f2 = 3{,}08 + 1{,}12 + 3{,}11 = 7{,}31 \text{ GHz}$$



4.5. RRTS line characteristics

The sections length for the 3.864 GHz frequency l_2 = 55 km.

$$l = l_2 \frac{2}{F_0}$$

The number of IRS on section X – 11:

$$N_{IRS\ X-11} = \left[\frac{L_{X-11}}{l}\right] - 1$$

The number of IRS on section 11 – 12:

$$N_{IRS\ 11-12} = \left[\frac{L_{11-12}}{l}\right] - 1$$

The transmission line of RRTS:

$$l = 55 \cdot \frac{2}{3,864} = 28,5\,\text{km}$$

The number of IRS on section X – 11:

$$N_{IRS\ X-11} = \left[\frac{58}{28.5}\right] - 1 = 2$$

The number of IRS on section 11 – 12:

$$N_{IRS\,11-12} = \left[\frac{33}{28.5}\right] - 1 = 1$$

The transmission line of RRTS:

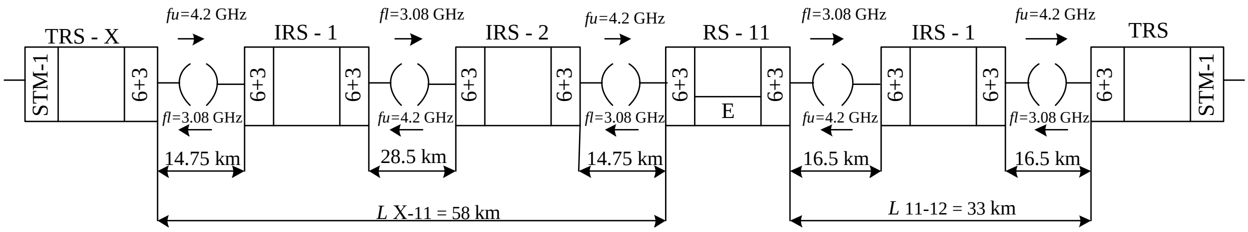


Fig. 4.7 – The transmission line of RRTS

As for X-11 the shortened section length without shifting is:

$$lsh = 58 - 28,5 - 28,5 = 1\text{ km}$$

Which is less than half of regeneration section length:

$$l = \frac{28,5}{2} = 14,25\text{ km}$$

We should shift regenerator and use two sections with lengths:

$$l = \frac{1 + 28,5}{2} = 14,75\text{ km}$$

The same for 11-12 – the shortened section length without shifting is:

$$lsh = 33 - 28,5 = 4,5\text{ km}$$

Which is less than half of regeneration section length:

$$l = \frac{28,5}{2} = 14,25\text{ km}$$

That's why we should shift regenerator and use two sections:

$$l = \frac{4,5 + 28,5}{2} = 16,5 \text{ km}$$

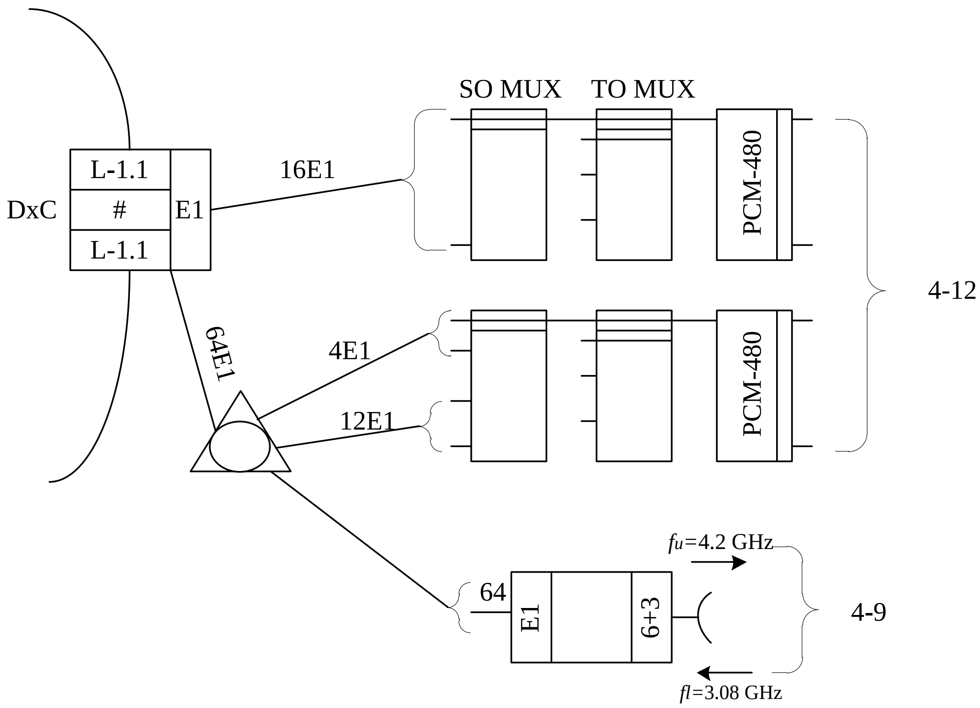


Fig. 4.8 – Connection organization scheme for **PCM-480**

New content of the 5th section

1.Multiservice network using DWDM DTS
   1.1.Choice of multiplexing equipment type
   1.2.The multiplex plan structure for DWDM DTS
   1.3The organization scheme of communication network using SDH and DWDM technologies
   1.4.The quality parameters of optical channels
   1.5. Efficiency of DWDM technology usage

Directions for performing the 5th subsection

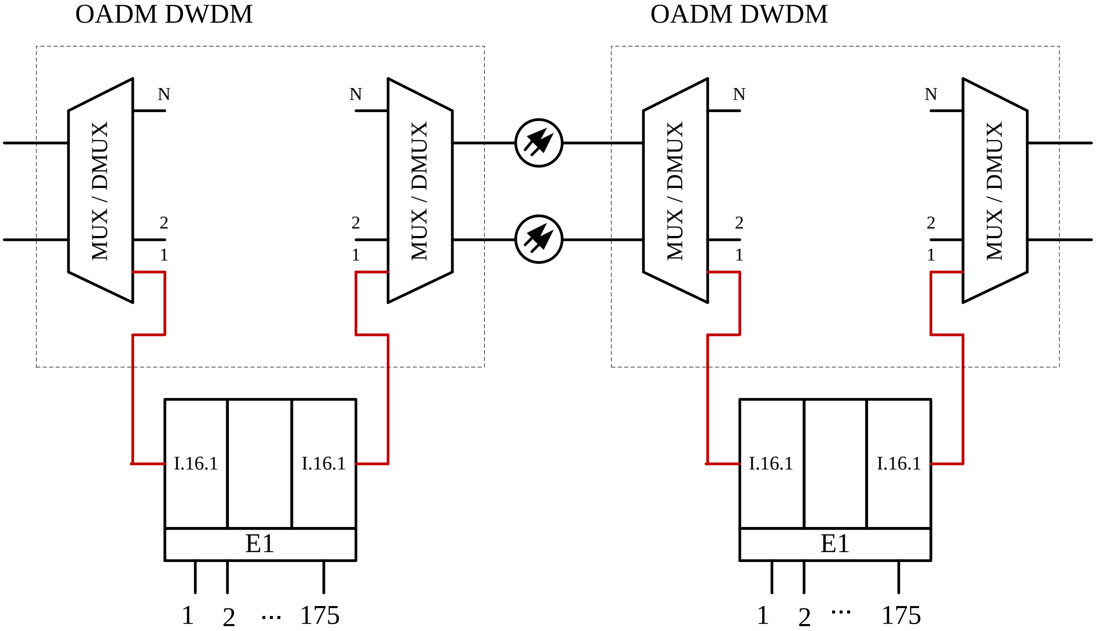
Directions for performing the 5.1 subsection

The multiplex plan structure for DWDM DTS

Input data for performance:

1) *Number of OF extracted for SDH network operating (2OF/4OF)*

SHD interface for DWDM with using of two optical fibers



In this case one duplex optical channel (OCh) is assigned for SDH network.

$$N_{OChSDH} = \frac{N_{fibers}}{2} \qquad (5.3)$$

$$N_{OChSDH} = \frac{2}{2} = 1$$

Transfer of Ethernet traffic in WDM ring arranged on a star topology (between SNN and each DNN). Total should be allocated to 1×OCh for each connection SNN-DNN. General view of the multiplex plan is shown in fig. 5.2.

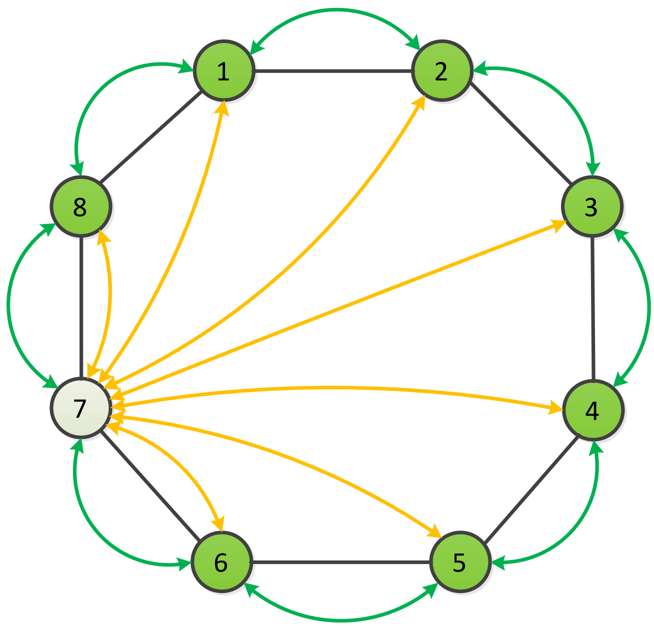


Table 5.3 –The matrix of DWDM node – to – node.

NN	1	2	3	4	5	6	7	8
1	-	1					+1	
2		-	1				+1	
3			-	1			+1	
4				-	1		+1	
5					-	1	+1	
6						-	1+1	
7							-	1+1
8								-

The DWDM multiplex plan structure (SDH with using of 2 OF)

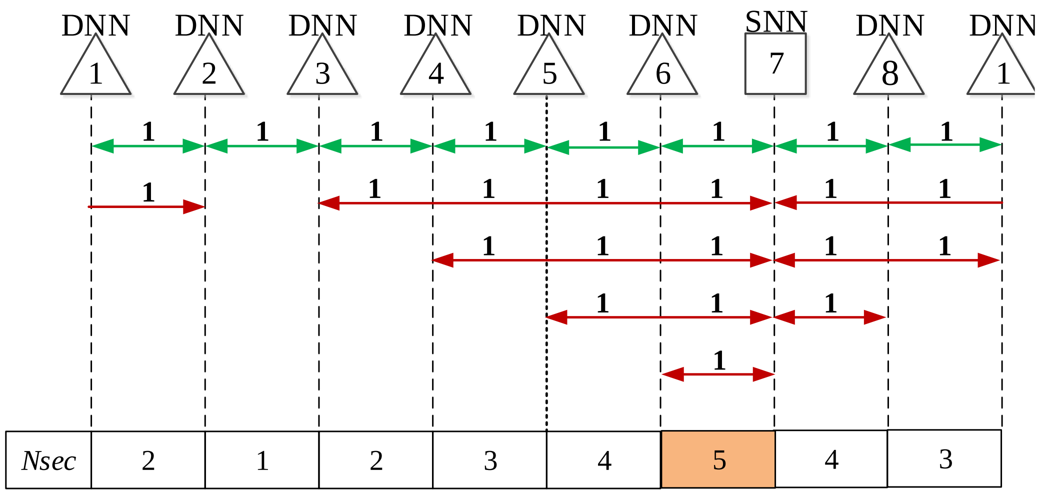
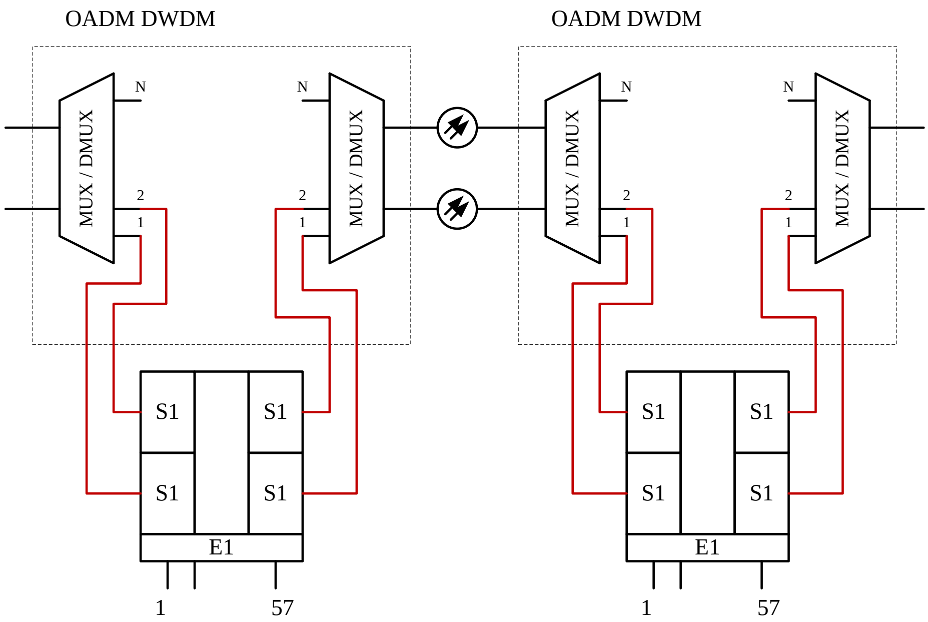


Fig. 5.2 – DWDM multiplex plan

The maximal load on DWDM section is 5 OCh.

SHD interface for DWDM with using of four optical fibres



Two duplex optical channels (OCh) are assigned for SDH network.

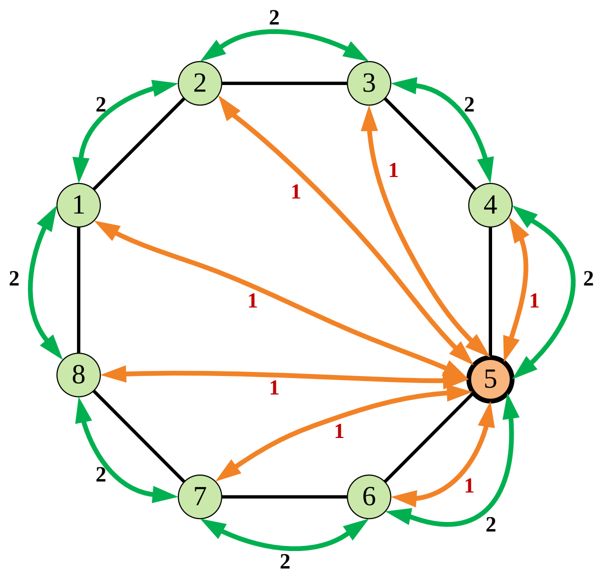


Table 1 - The matrix of DWDM node-to-node load (2^{nd} variant)

NN	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	-	2			+1			2
2		-	2		+1			
3			-	2	+1			
4				-	2+1			
5					-	2+1	+1	+1
6						-	2	
7							-	2
8								-

WDM multiplex plan contains main and reserve paths of optical channels. Since

the optical channel is duplex, it is the equivalent of two optical fibers (2 OF = 1 OCh). Therefore for SDH rings operating we need to extract:

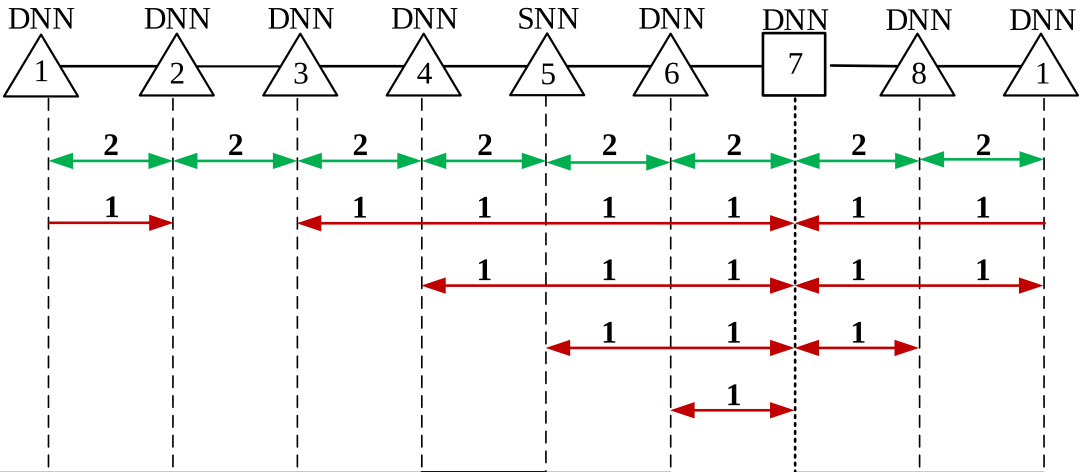
$$N_{\text{OCh SDH}} = \frac{N_{\text{fibers}}}{2}; \qquad (4.3)$$

$$N_{\text{OCh SDH}} = \frac{4}{2} = 2.$$

Two duplex optical channels (OCh) are assigned for SDH network.

Transfer of Ethernet traffic in WDM ring is organized by star topology (between SNN and every DNN). Altogether 1 OCh should be taken for each SNN-DNN connection. The general view of multiplex plan structure is shown lower.

The DWDM multiplex plan structure (SDH with using of 4 OF)



N_{sec}	3	2	3	4	5	6	5	2

The maximal load on DWDM section is 6 OCh.

Directions for performing the 5.2 subsection

The organization scheme of communication network using SDH and DWDM technologies

Example for the protection circuit with using of 2 OF

5.2 The organization scheme of communication network using SDH and DWDM technologies

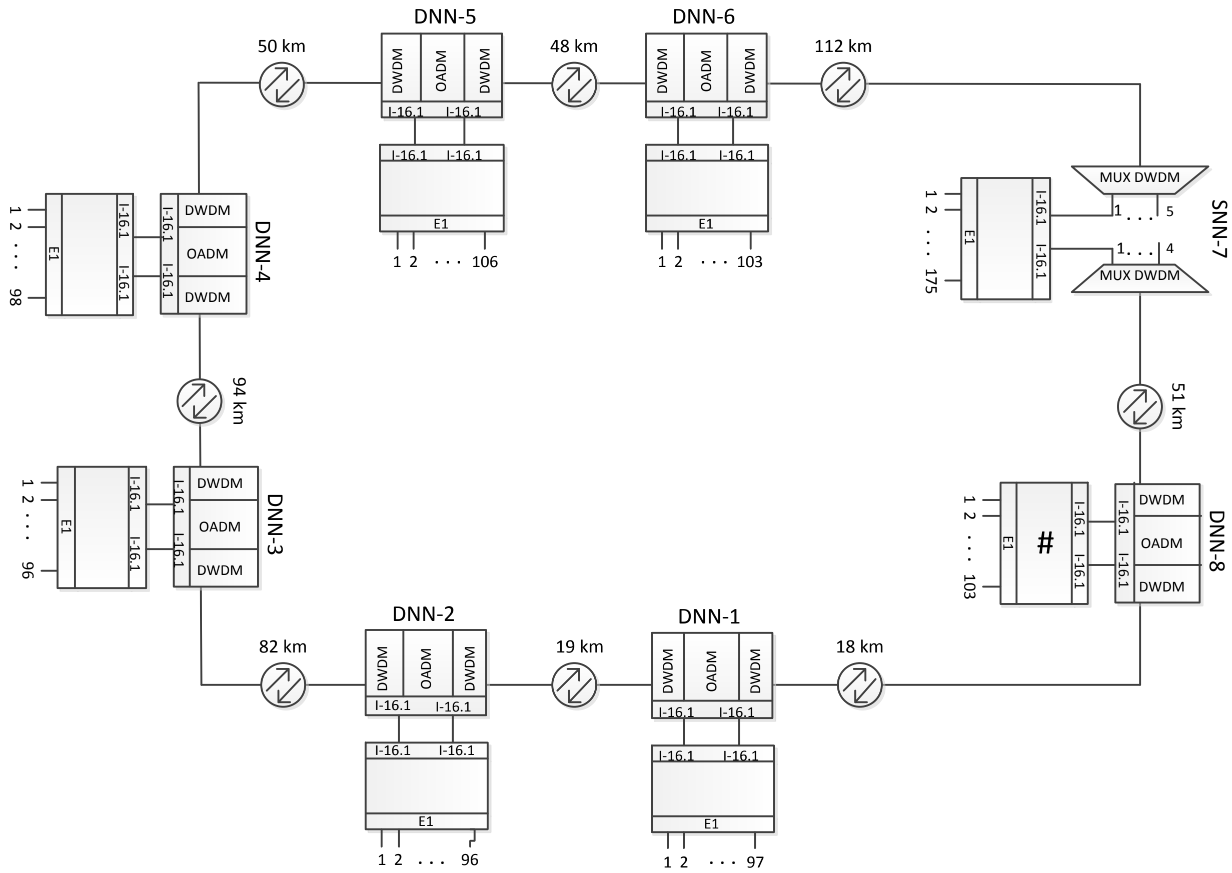
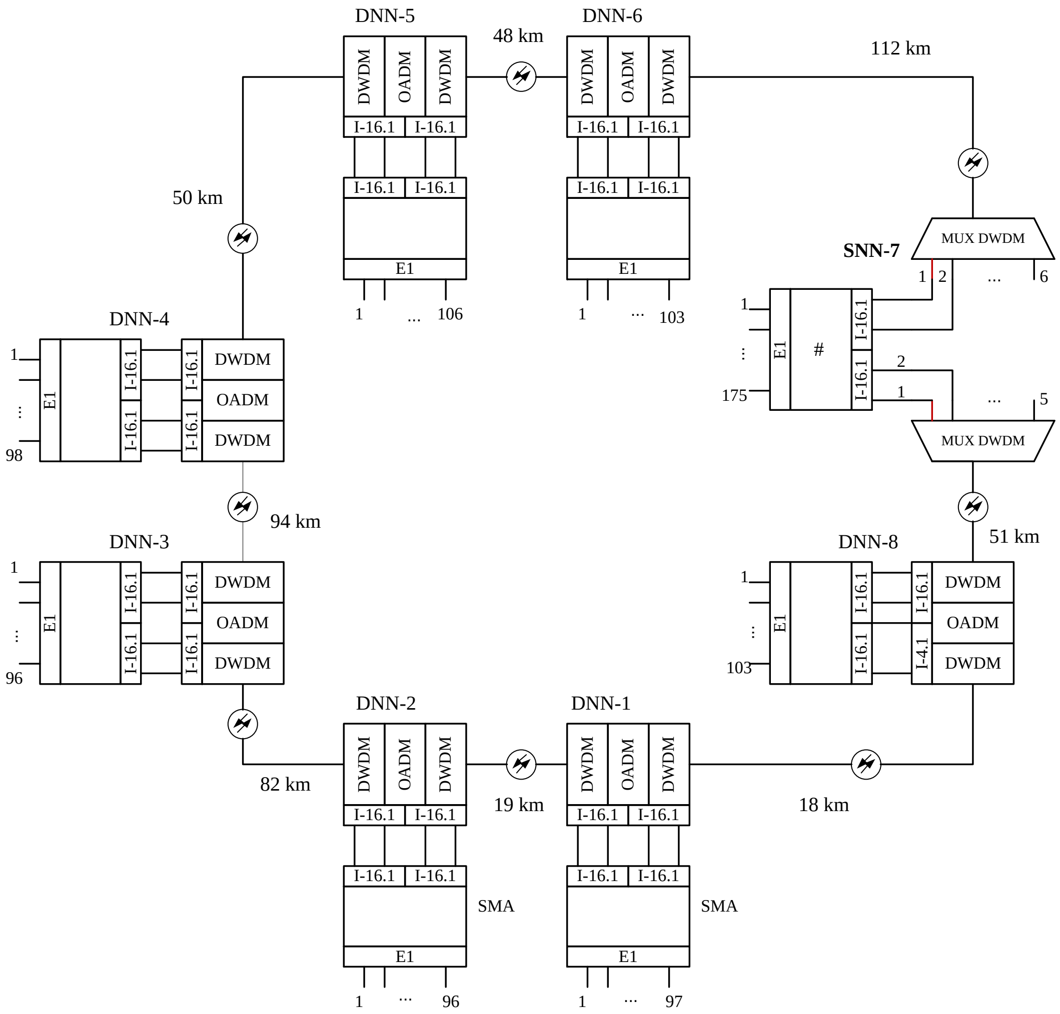


Figure 5.3 – Scheme of ring communication organization using SDH and DWDM

Example for the protection circuit with using of 4 OF for STM-4



Example for the protection circuit with using of 4 OF for STM-4

5.3 Choice of multiplexing equipment type

Input data for performance

1) STM transmission rate of SDH DTS B_{STM-N} (it's been chosen in the 3.1 subsection);

$$B_{stm} = 155{,}52 \cdot 16 = 2448{,}32 \text{ Mbps} \approx 2{,}5 \text{ Gbps}$$

2) The Internet channels transmission rate – it's given in input data:

$$B_{eth} = 2 \text{ Gbps}$$

3) Quantity of fibers in the SDH Ring $N_{fibers} = 2$;

4) $N_{SNN} = 7$;

5) The coder RS (239,255) is used in DWDM transponders;

6) Parameters of the optical transmitter:

- the transmission level $p_{out} = p_{tr} = +5$ dBp;

7) Parameters of the optical cable in the ring:

- the attenuation coefficient $\alpha = 0{,}2$ dB/km;

8) Distance between network nodes of ring:

Section	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-1
L_{sect}	19	82	94	50	48	112	51	18

9) p_{in}= -10 dBp

Solution

5.1 Choice of multiplexing equipment type

Selected type of DWDM system must provide the transfer of two types of traffic: SDH and Ethernet. Ethernet technology uses a linear code 8B10B (which increases the linear speed of 1,25 times). We define the maximum transmission rate of the optical channel as a maximum of two given:

$$B_{OCh} = \max\{\mathrm{B_{STM}}; \mathrm{B_{Eth}}\}$$

$$B_{OCh} = \max\{2{,}5\ \text{Mbps}; 1{,}25{\cdot}2\ \text{Gbps}\} = 2{,}5\,\text{Mbps} = 2{,}5\,\text{Gbps} \tag{5.1}$$

$$B_{OCh} = \max\{\mathrm{B_{STM}}; \mathrm{B_{Eth}}\}$$

In WDM systems using modulation of intensity, therefore, the signal spectrum is similar to the case of AM modulation, containing spectral lobes. We will focus on the need of transfer four spectral lobes (B_{OCh} width each) in the optical channel. Also note the presence of a transponder code FEC (forward error correction) encoder with the code RS (239,255), which leads to an increase in the transmission rate of the modulated signal by 7%.

Frequency band of one optical channel is:

$$\Delta f_{signal} = \frac{4 \cdot 255}{239} B_{OCh} \approx 4{,}2678 \cdot B_{OCh} \tag{5.2}$$

$$\Delta f_{signal} = 4{,}2678 \cdot 2{,}5 = 10{,}6695\,\text{GHz}$$

Let's choose from the standard interval series between the carrier frequencies $\Delta f_{OCh} = \{12{,}5; 25; 50; 100\,\text{GHz}\}$ the minimal one according to the Δf_{signal} so that $\Delta f_{OCh} \geq \Delta f_{signal}$ (in this case according to table 5.1 choose $\Delta f_{OCh} = 12{,}5\,\text{GHz}$).

Table 5.1 – WDM types

WDM type (ITU recommendation)	Inter channel interval Δf_{OCh}, GHz	The *n-th* channel central frequency, THz
DWDM (G.694.1)	100	193,1 + *n*· 0.1
	50	193,1 + *n*· 0.05
	25	193,1 + *n*· 0.025
	12,5	193,1 + *n*· 0.0125

Optical erbium doped fiber amplifier (EDFA) allows to amplify the signal within the C band (1530 nm – 1565 nm). Therefore carrier frequencies of optical channels (in THz) will be chosen within this specified band, where n – the optical channel's quantity ($n \geq 1$).

Let's fill the 5.2 table with the carrier frequencies according to the calculated optical channel's number in the maximum loaded section N_{OCh} in the 5.2 subsection.

$$f_{c1} = 193{,}1 + 1 \cdot 0{,}0125 = 193{,}1125 \text{ THz}$$

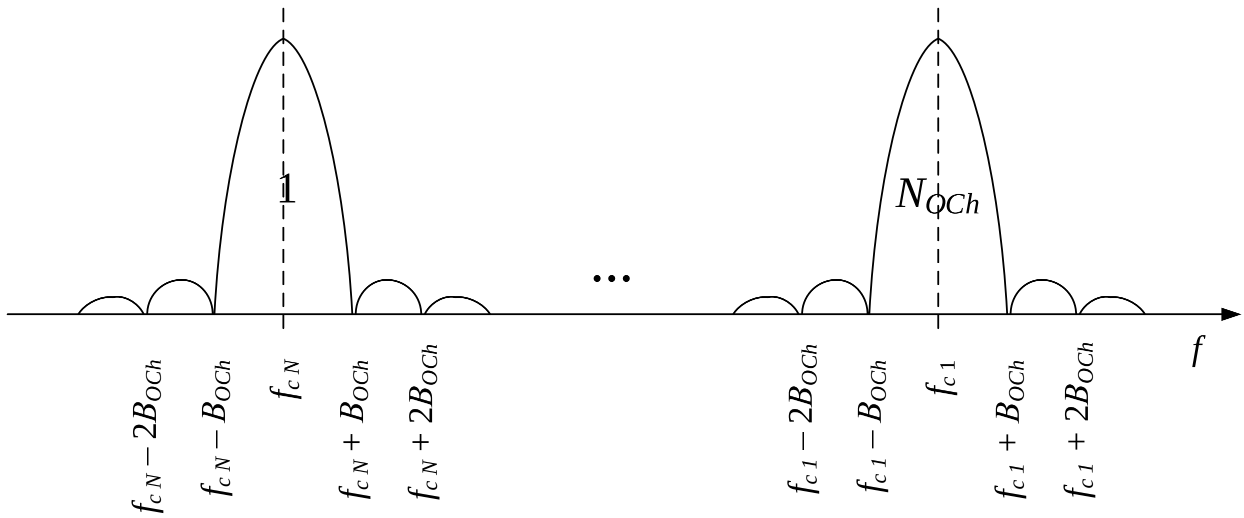
$$f_{c2} = 193{,}1 + 2 \cdot 0{,}0125 = 193{,}1250 \text{ THz}$$
$$f_{c3} = 193{,}1 + 3 \cdot 0{,}0125 = 193{,}1375 \text{ THz}$$
$$f_{c4} = 193{,}1 + 4 \cdot 0{,}0125 = 193{,}1500 \text{ THz}$$
$$f_{c5} = 193{,}1 + 5 \cdot 0{,}0125 = 193{,}1625 \text{ THz}$$

The results of calculations for this and other channels are shown in Table 5.2.

Table 5.2- Carrier frequency DWDM for Δf_{OCh} =12,5 GHz.

N	1	2	3	4	5
$f_{c(n)}$, THz	193,1125	193,125	193,1375	193,15	193,1625

Let's adduce the system's spectrum for the section with the maximal number of OCh.



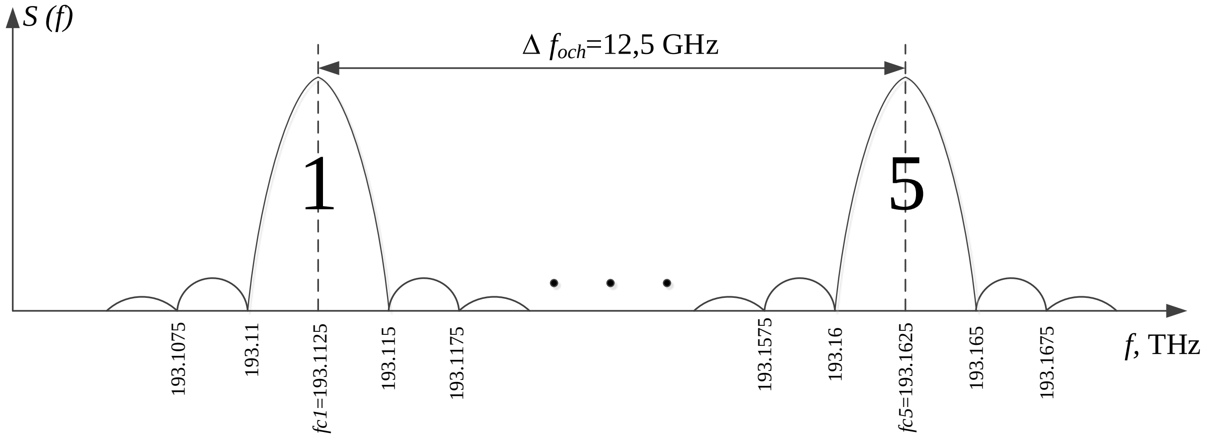


Figure 5.1 - Spectrum WDM system with $N_{OCh} = 5$ and $\Delta f_{OCh} = 12{,}5\,\text{GHz}$

Directions for performing the 5.4 subsection

Input data for performance:

1) DWDM multiplex plan;
2) Distance between NNs (see directions for the 1st section);
3) Rate of the Internet channel $B_{OC} = 10\,\text{Gbps}$ (from the ID);
4) Attenuation coefficient of the cable α= 0,38 dB/km.

Solution

OCh is chosen from the multiplex plan (OCh that passes through the highest number of transit nodes). Suppose there are two optical EDFA amplifiers in each node: preamplifier and booster. Optical channel between the 3st and the 7thnodes contains the highest number of transit nodes.

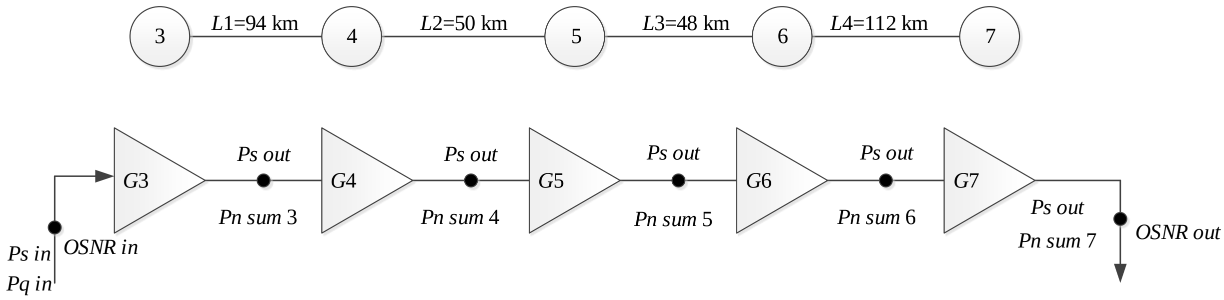


Figure 5.4 – Structure scheme of optical channel SNN-7 – DNN-3

Let's take optical signal's power at the input of amplifier in DNN-1 as p_{in} = -10 dBp (P_{in} = 0,1 mW) and optical signal's power at the outputs of amplifiers G1- G5 as p_{out} = +8 dBp. There is optical signal and quantum noise power at the input of amplifier:

$$P_{q\,n} = h \cdot v \cdot \Delta v_0 \ , \tag{5.4}$$

where h – Planck's constant ($h = 6{,}626 \cdot 10^{-34}$ J·s);

ν – central wave length of optical radiation ($\nu \approx 2{,}29 \cdot 10^{14}$ Hz for λ=1310 nm, or $\nu \approx 1{,}935 \cdot 10^{14}$ Hz for λ=1550 nm);
$\Delta \nu_{\text{o}}$ – bandwidth of optical filter of DWDM demultiplexer ($\Delta \nu_{\text{o}} \approx \Delta f_{\text{OCh}}$).

$$P_{qn} = 6{,}626 \cdot 10^{-34} \cdot 2{,}29 \cdot 10^{14} \cdot 12{,}5 \cdot 10^{9} = 1{,}897 \cdot 10^{-9} \text{ W}$$

If there is no signal, on the optical amplifier's input there is noise of amplified spontaneous emission (ASE) with power:

$$P_{\text{ase}} = 2 n_{sp} (G-1) \cdot h \cdot \nu \cdot \Delta \nu_{\text{o}}, \tag{5.5}$$

where n_{sp} - coefficient of spontaneous emission ($n_{\text{sp}} \approx 1.4$);

G – gain factor of EDFA.

$$G_1 = \frac{1}{10^{-0{,}1\left(P_{s\,out} - P_{s\,in}\right)}} \tag{5.6}$$

.

$$G_i = \frac{1}{10^{-0,1 \cdot \alpha L_{(i-1)}}}, 2 \le i \le N_{EDFA} \qquad (5.7)$$

where L_i - the i^{th} optical amplifiers in gain section

N_{EDFA} - quantity of optical amplifiers in considering section (N_{EDFA} = 5).

$$G_1 = \frac{1}{10^{-0,1(8+10)}} = 63,096 = 18 \text{ (dB)}$$
$$G_2 = \frac{1}{10^{-0,1 \cdot 0,38 \cdot 94}} = 3733 = 35,72 \text{ (dB)}$$
$$G_3 = \frac{1}{10^{-0,1 \cdot 0,38 \cdot 50}} = 79,433 = 19 \text{ (dB)}$$
$$G_4 = \frac{1}{10^{-0,1 \cdot 0,38 \cdot 48}} = 66,681 = 18,24 \text{ (dB)}$$
$$G_5 = \frac{1}{10^{-0,1 \cdot 0,38 \cdot 112}} = 1,803 \cdot 10^4 = 42,56 \text{ (dB)}$$

Now let's calculate ASE noise power corresponding to (5.5):

$$P_{ase1} = 2 \cdot 1,4 \cdot (63,096 - 1) \cdot 6,626 \cdot 10^{-34} \cdot 2,29 \cdot 10^{14} \cdot 12,5 \cdot 10^9 = 3,298 \cdot 10^{-7} \text{ W}$$
$$P_{ase2} = 2 \cdot 1,4 \cdot (3733 - 1) \cdot 6,626 \cdot 10^{-34} \cdot 2,29 \cdot 10^{14} \cdot 12,5 \cdot 10^9 = 1,982 \cdot 10^{-5} \text{ W}$$
$$P_{ase3} = 2 \cdot 1,4 \cdot (79,433 - 1) \cdot 6,626 \cdot 10^{-34} \cdot 2,29 \cdot 10^{14} \cdot 12,5 \cdot 10^9 = 4,166 \cdot 10^{-7} \text{ W}$$
$$P_{ase4} = 2 \cdot 1,4 \cdot (66,681 - 1) \cdot 6,626 \cdot 10^{-34} \cdot 2,29 \cdot 10^{14} \cdot 12,5 \cdot 10^9 = 3,488 \cdot 10^{-7} \text{ W}$$

$$P_{ase5} = 2 \cdot 1,4 \cdot (1,803 \cdot 10^4 - 1) \cdot 6,626 \cdot 10^{-34} \cdot 2,29 \cdot 10^{14} \cdot 12,5 \cdot 10^9 = 9,575 \cdot 10^{-5} \text{ W}$$

There is ASE noise accumulation in the linear path with several amplifiers. The noise power at the output of the n^{th} amplifier equals to:

$$P_{n\,sum\,n} = P_{q\,n} + \sum_{i=1}^{n} P_{ase\,i} \qquad (5.8)$$

Let's determine the total noise power at the outputs of each of 5 amplifiers from our example by using this expression:

$$P_{nsum1} = 1{,}897 \cdot 10^{-9} + 3{,}298 \cdot 10^{-7} = 3{,}317 \cdot 10^{-7}\ \text{W}$$

$$P_{nsum2} = 1{,}897 \cdot 10^{-9} + 3{,}298 \cdot 10^{-7} + 1{,}982 \cdot 10^{-5} = 2{,}015 \cdot 10^{-5}\ \text{W}$$

$$P_{nsum3} = 1{,}897 \cdot 10^{-9} + 3{,}298 \cdot 10^{-7} + 1{,}982 \cdot 10^{-5} + 4{,}166 \cdot 10^{-7} = 2{,}057 \cdot 10^{-5}\ \text{W}$$

$$P_{nsum4} = 1{,}897 \cdot 10^{-9} + 3{,}298 \cdot 10^{-7} + 1{,}982 \cdot 10^{-5} + 4{,}166 \cdot 10^{-7} + 3{,}488 \cdot 10^{-7} = 2{,}092 \cdot 10^{-5}$$

$$P_{nsum5} = 1{,}897 \cdot 10^{-9} + 3{,}298 \cdot 10^{-7} + 1{,}982 \cdot 10^{-5} + 4{,}166 \cdot 10^{-7} + 3{,}488 \cdot 10^{-7} + 9{,}575 \cdot 10^{-5}$$

The transmission quality of optical signal is determined by the optical signal/noise ratio at the input of photo receiving unit:

$$OSNR_n = \frac{P_\text{s}}{P_{\text{n}\ n}} = \frac{P_\text{s out}}{P_{\text{n sum}\ n}}; \qquad (5.9)$$

where P_s and $P_{n\ n}$ – signal and noise power, which corresponds to the optical i^{th} section.

Let's perform calculations:

$$P_{sout} = 10^{-3} \cdot 10^{0{,}1 \cdot 8} = 6{,}31 \cdot 10^{-3}\ \text{W};$$

$$OSNR_{in} = \frac{P_{sin}}{P_{qn}};$$

$$OSNR_{in} = \frac{1 \cdot 10^{-4}}{1{,}897 \cdot 10^{-9}} = 5{,}271 \cdot 10^{4}\ \text{W};$$

$$OSNR_1 = \frac{6{,}31 \cdot 10^{-3}}{3{,}317 \cdot 10^{-7}} = 1{,}904 \cdot 10^{4}\ \text{W};$$

$$OSNR_2 = \frac{6{,}31 \cdot 10^{-3}}{2{,}015 \cdot 10^{-5}} = 313{,}151\ \text{W};$$

$$OSNR_3 = \frac{6{,}31 \cdot 10^{-3}}{2{,}057 \cdot 10^{-5}} = 306{,}757\ \text{W};$$

$$OSNR_4 = \frac{6{,}31 \cdot 10^{-3}}{2{,}092 \cdot 10^{-5}} = 301{,}625\ \text{W};$$

$$OSNR_5 = \frac{6{,}31 \cdot 10^{-3}}{1{,}167 \cdot 10^{-4}} = 54{,}07\ \text{W};$$

$$OSNR_{out} = OSNR_5 = 54{,}07\ \text{W}.$$

In order to determine the error probability for detected signal let's calculate its Q-factor:

$$Q = \sqrt{\frac{OSNR_{out} \cdot \Delta\nu_0}{\Delta\nu_e}} \qquad (5.10)$$

.

where $\Delta\nu_0$ and $\Delta\nu_e$ - bandwidth of optical filter of DWDM demultiplexer and electrical filter of photo receive module ($\Delta\nu_e = 0,7 \cdot B_{Och}$);

$\Delta\nu_e = 0,7 \cdot 2,5 \cdot 10^9$;

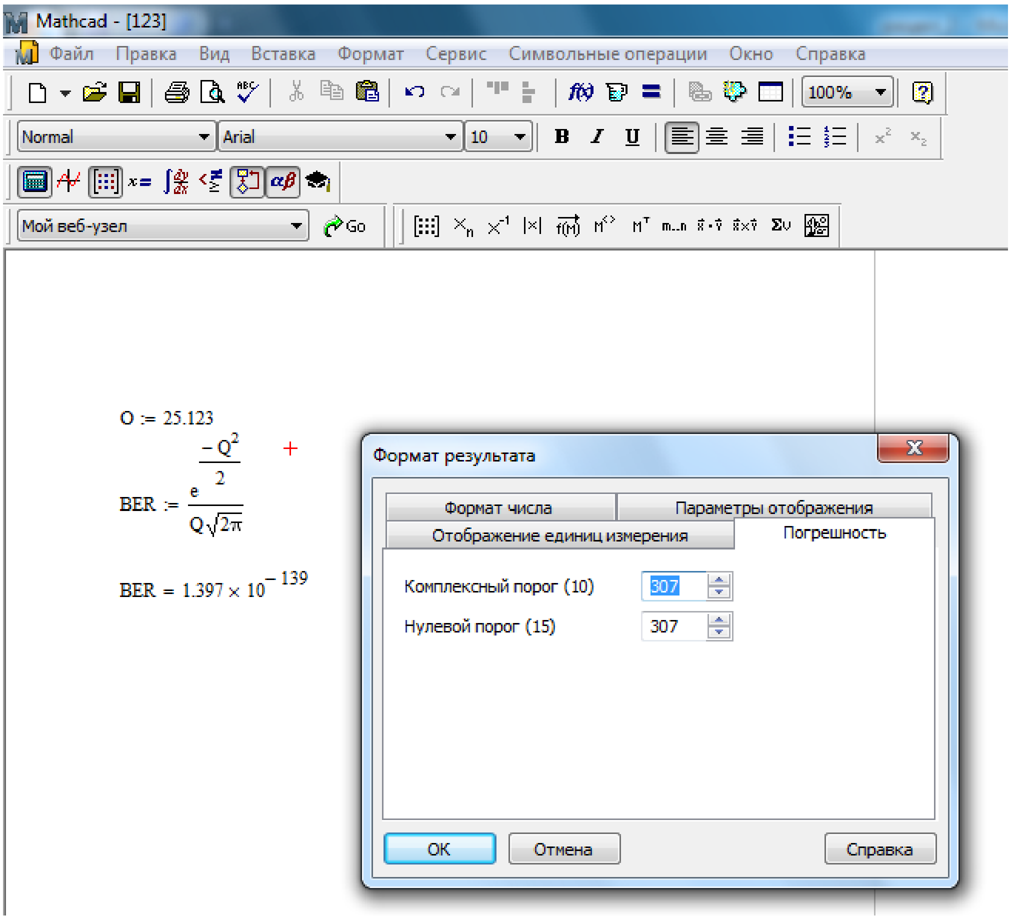
$$Q = \sqrt{\frac{54,07 \cdot 12,5 \cdot 10^9}{0,7 \cdot 2,5 \cdot 10^9}} = 19,652$$

Let's determine the BER value from Q-factor:

$$BER \approx \frac{e^{-\frac{Q^2}{2}}}{Q\sqrt{2\pi}}. \qquad (5.11)$$

$$BER \approx \frac{e^{-\frac{19,652^2}{2}}}{19,652\sqrt{2\pi}} = 2,786 \cdot 10^{-86}$$

It's required to perform the calculations by this formula in the MathLab or in the MathCad (don't forget to change the zero limit of the result to the 307th power – see picture below).



If the result is represented in view $BER = 10^{-C}$, than error probability power can be calculated by using the next formula

$$C = -\lg(BER) \tag{5.12}$$

$$C = -\lg\left(2,786 \cdot 10^{-86}\right) = 85,555$$

$$BER = 10^{-85,555}$$

This dependence characteristic is shown on the figure 5.5. In case if Q>37, the error probability is not possible to calculate over the (5.11) formula. In this case write the conclusion about the channels' satisfying the requirements ($BER_{OCh} < 10^{-15}$).

All calculations results fill into the table 5.2.

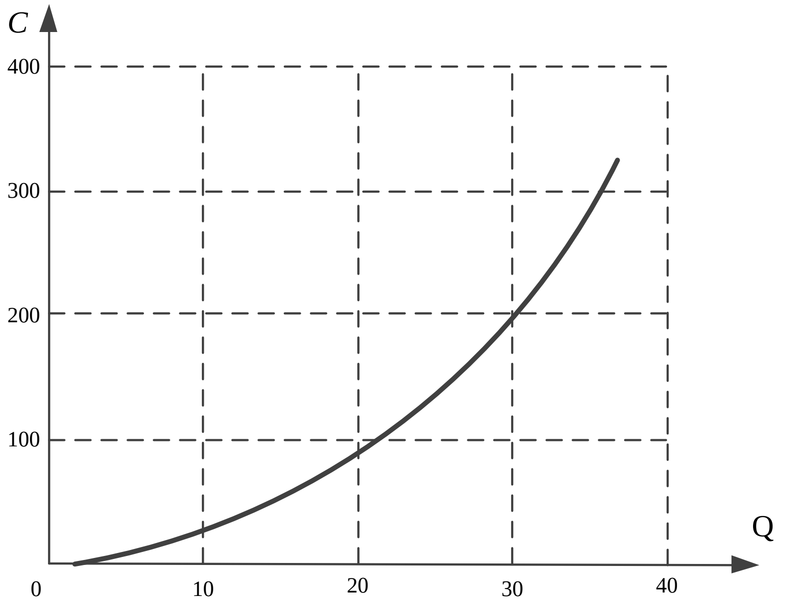


Fig. 5.5 — Q-factor dependence on BER power

Table 5.2 – quality parameters of the DNN1 – SNN5 optical channel

Line trunk point of OTL WDM	Amplifier 1		Amplifier 2		Amplifier 3		Amplifier 4		Amplifier 5	
	input	output	input	output	input	output	input	output	input	output
p_S, dBm	-10	+8	+8 -35,72	+8	+8 -19	+8	+8 -18,24	+8	+8 -42,56	+8
$p_{n\ sum}$, dBm	-57,22	-34,793	- 34,793 -35,72	-16,957	- 16,957 -19	-16,868	- 16,868 -18,24	-16,794	- 16,794 -42,56	-9,329
G, dB	18		35,72		19		18,24		42,56	
$osnr$, dB	47,22	42,8	42,8	24,958	24,958	24,87	24,87	24,795	24,795	17,33
Q										19,652

Directions for performing the 5.5 subsection

Efficiency of DWDM technology usage

Input data for performance:

1) STM-16 is used in the SDH ring (B_{SDH}=2,5 Gb/s) and the maximum loaded section transmits N_{E1}=235 E1 according to the multiplex plan structure;
2) the maximum loaded section in DWDM system transmits N_{OCh} = 5 OC with the channel's rate B_{OCh} =2,5 Gb/s.

Solution.

Ratio between the total informational rate of all DWDM channels $B_{\Sigma DWDM}$ and informational rate of SDH system B_{SDH} is meant by the efficiency of DWDM technology usage η:

$$\eta = \frac{B_{\Sigma DWDM}}{B_{SDH}}. \tag{1}$$

At first let's determine the efficiency of DWDM technology usage for the calculated in advance load in SDH and DWDM network:

$$\eta_1 = \frac{B_{OCh} \times N_{OCh}}{B_{STM-16} \times N_{E1}}; \tag{2}$$

$$\eta_1 = \frac{2,5 \cdot 5}{2,048 \cdot 10^{-3} \cdot 235} = 25,972$$

DWDM system provides up to 32 channels with the Δf_{OCh} = 12,5 GHz spacing. In case with a different spacing the channels quantity is changing in following proportion:

$$N_{OCh\,\max} = 32 \times \frac{10}{B_{OCh}}; \tag{3}$$

$$N_{OCh\,\max} = 32 \times \frac{10}{2,5} = 128$$

Let`s determine the efficiency of DWDM technology usage in case with the full capacity usage of SDH and DWDM network:

$$\eta_2 = \frac{B_{OCh} \times N_{OCh\,\max}}{B_{STM-16} \times N_{E1\max}}; \tag{4}$$

$$\eta_2 = \frac{2,5 \times 128}{(2,048 \cdot 10^{-3}) \times 1008} = 155,01$$

Conclusion

Specify the purpose of the coursework and sketch its main fundamentals. Tabulate the results of the calculation from the 1st and the 2nd subsections.

№	Parameter	Value
1	STM level in SDH ring	*STM-N*
2	Regeneration section length using SDH - by dispersion .... - by attenuation .... - nominal	
3	SDH protection method	
4	Interval between the DWDM carrier frequencies	
5	Optical channels quantity in the maximum loaded DWDM section	
6	Efficiency of DWDM technology usage: - η_1 .... - η_2	

In this course project we have designed the segment of multiservice telecommunication network with radially-ring architecture. In order to transmit data, it is necessary to use PDH, SDH and DWDM technologies. In the ring topology we have 12 nodes. The switched network node is 7.

After preparing the course project I compare two ways of construction of a ring:

1) by means of SDH and DTS;
2) sharing of SDH and DWDM DTS

In the first case, it is possible to organize transmission of 458 E1 digital streams. For this I choose STM-16 for transmission with the speed 2488,32 Mbps. When I built organization scheme of the SDH ring I use regenerators on the necessary sections, because the length between nodes is greater than the calculated regeneration section.

At the second case, the maximal bitrate of transmission is SDH bitate and it is equal 2.5 Gbps. DWDM gives possibility to transmit data and voice, using an optical fiber, with greater speed, it is more cheaper and also it provides low insertion of losses.

Also I have studied the radio relay systems. I have built and studied principles of work of structure chart of terminal radio relay station (TRS), functional scheme of transmitter, functional scheme of receiver, structure chart and functional scheme of (intermediate radio relay station) IRS.

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