

Optical and Transport Networks

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II Exam 2020-21 – 17 February 2021

Last and first name:

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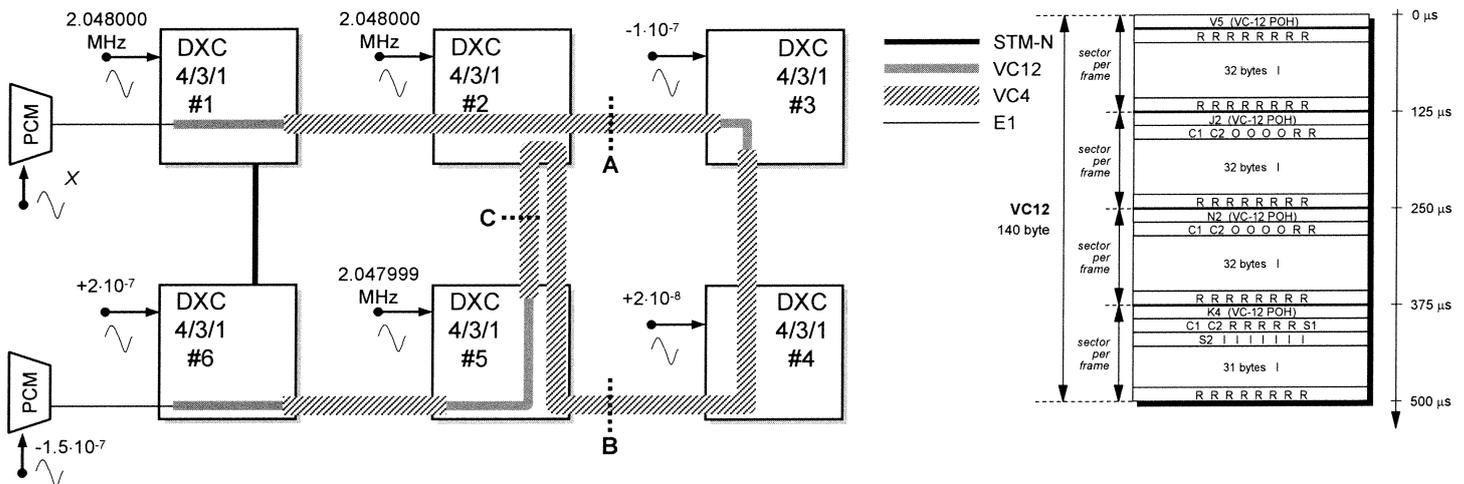
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NB: In any exercise, any answer not justified adequately, even with few words, will not be considered.

Problem 1

Consider the network of DXC 4/3/1 elements in figure below, where all links are bidirectional. Links between DXCs are STM-4 ($f_0 = 622.080$ Mbit/s). Each Network Element (NE) is synchronized by an external reference, of which either the fractional frequency deviation from the nominal value $f_0 = 2.048$ MHz or directly the absolute frequency is given. For your convenience, the asynchronous mapping scheme of E1 into VC12 is also given.

Two PCM multiplexers, synchronized by autonomous references, are connected by a bidirectional E1 link ($f_0 = 2.048$ MHz), which follows the path indicated with the black thin line in figure. The E1 circuit is transported (asynchronous mapping) via the VC12 path indicated with the grey line in figure (1-2-3-4-5-2-5-6). The VC12 is transported in its turn via VC4 paths indicated with wider grey lines in figure (1-2-3, 3-4-5-2-5, 5-6).



- The justification ratio ρ (as fraction of justification opportunity bits occupied by dummy bits) in the VC12 terminated at the desynchronizer of the E1 interface of DXC #6 has value $\rho = 0.51$. What is the fractional frequency deviation from the nominal value $\Delta f/f_0 = X$ of the carried E1?
- Compute every how many seconds AU4 pointer justifications do happen at interface C (i.e., the inter-justification period), in the direction from DXC #2 to DXC #5, specifying also their sign (POS/NEG).
- Compute every how many seconds ^{AU4} pointer justifications do happen at interface A (i.e., the inter-justification period), in the direction from DXC #2 to DXC #3, specifying also their sign (POS/NEG).
- Compute every how many seconds TU12 pointer justifications do happen at interface B (i.e., the inter-justification period), in the direction from DXC #5 to DXC #4, specifying also their sign (POS/NEG).

a) $2,048 \text{ Mb/s} (1+X) = (1025-2\rho) \cdot 2000 \text{ b/s} \Rightarrow X = -1,95 \cdot 10^{-5}$

b) In the AU4 p.p. in #2: $\Delta f = f_{VC4} [-10^{-7} - 0] = -15,0336 \text{ bit/s}$
 1 just AU4 every $24 \text{ bit} / 15,0336 \text{ bit/s} = 1,5964 \text{ (POS)}$

c) In the AU4 p.p. in #2: $\Delta f = 0 \Rightarrow$ NO AU4 JUST

d) In the TU12 p.p. in #5: $\Delta f = f_{VC12} \left[2 \cdot 10^{-7} - \left(\frac{2,047999}{2,048} - 1 \right) \right] = 1,542 \text{ bit/s}$
 1 TU12 just every $8 \text{ bit} / 1,542 \text{ bit/s} = 5,19 \text{ sec (NEG)}$

Problem 2

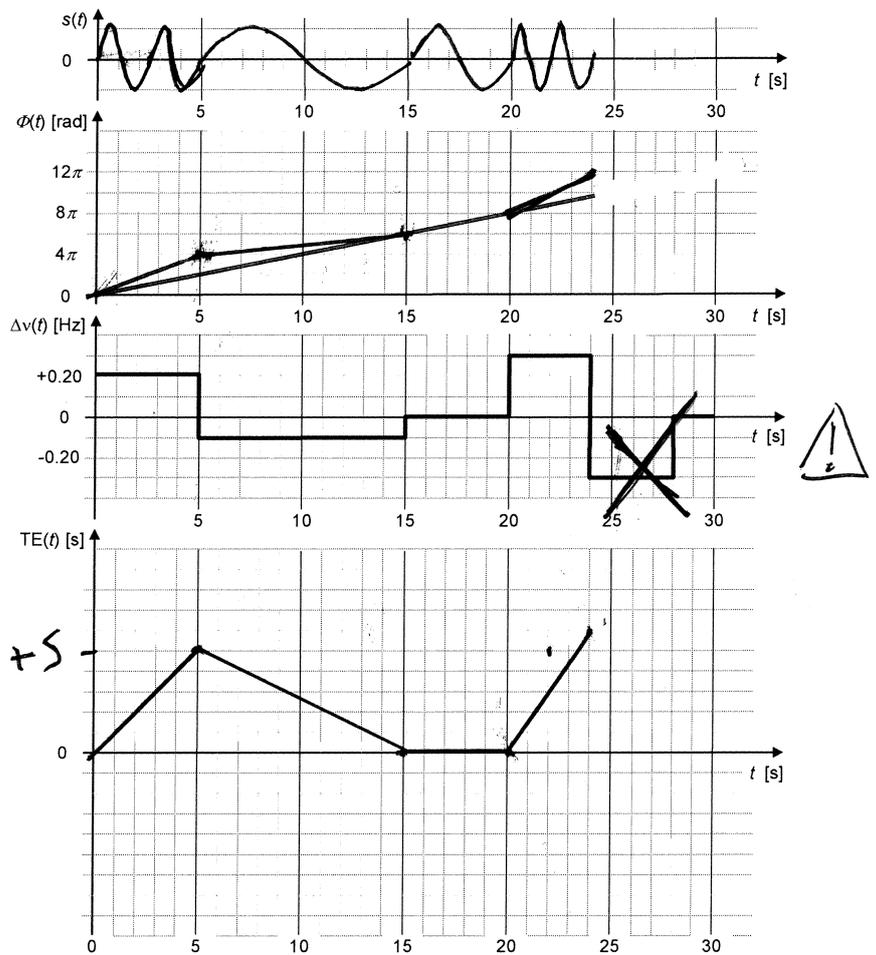
- a) Let $s(t)$ be a pseudo-sinusoidal timing signal with nominal frequency $\nu_0 = 0.2$ Hz and *instantaneous frequency error* $\Delta\nu(t) = \nu(t) - \nu_0$ as plotted in figure.

Highlight and explain any mistake you may notice in the figure.

Where possible, plot on the graphs at right:

- the timing signal $s(t)$;
- the *Total Phase* $\Phi(t)$ of $s(t)$ and of the ideal timing signal with frequency ν_0 , both starting from $\Phi(0) = 0$;
- the *Time Error* $TE(t)$ with respect to the ideal timing signal with frequency ν_0 , starting from $TE(0)=0$, with the convention that positive TE denotes time advance. Specify values on the Y axis.

$$T_0 = \frac{1}{\nu_0} = 5 \text{ } \mu\text{s}$$



- b) What is the *jitter* of a digital signal? Provide its definition and explain why it may cause bit errors on reception.

- c) What is the main cause of *packet jitter* in packet-switched transport networks? Explain in what cases it is an important performance index and what problems may cause if not controlled.

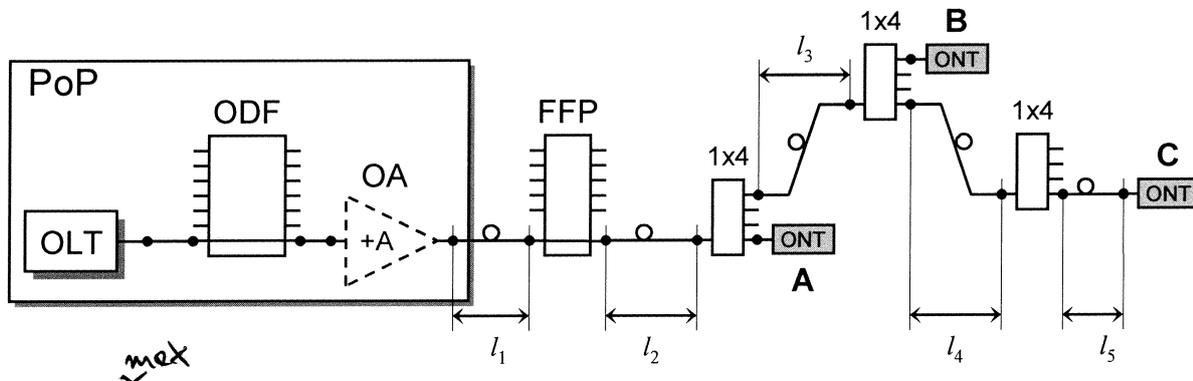
Problem 3

Consider to design a Passive Optical Network reaching up to 512 users at variable distances from the Optical Line Termination (OLT) via a number of 1x8 splitters, with an asymmetric tree topology according to the scheme in figure.

The line from the OLT is cross-connected via an Optical Distribution Frame (ODF) to the PON. An Optical Amplifier (OA), if needed, may be added after the ODF at the Point-of-Presence (PoP). After a first single feeder fibre segment with length l_1 , another ODF (Fibre Flexibility Point, FFP) cross-connects to the PON. The fibre segments between the FFP and the following splitters have length l_2, l_3, l_4, l_5 , respectively. The length of other segments of fibres connecting network elements is negligible. The Optical Network Terminations (ONT) can be connected at the output of any splitter at the three stages (A, B, C).

Assume the following data for the PON elements:

- fibre with attenuation $\alpha = 0.2$ dB/km;
- $l_1 = 2$ km, $l_2 = 2$ km, $l_3 = 1$ km, $l_4 = 1$ km, $l_5 = 1$ km;
- OLT transmission power $P_{TX} = +3$ dBm;
- splitter insertion loss $\alpha_s = 1$ dB;
- power loss by each couple of optical connectors $\alpha_c = 0.5$ dB (connections marked with dots in figure);
- sensitivity of ONT receivers $P_{RX} > -33$ dBm, with at least 6 dB of safety margin to be guaranteed;
- optional OA gain $+A$ [dB] (excluding the additional attenuation $2\alpha_c$ introduced by its two couples of connectors);



- Evaluate the *Differential Path Loss* [dB] between ONTs as in figure.
- Evaluate the power P_{RX} [W] received by the farthest ONT in position C without OA.
- Evaluate the OA gain $+A$ [dB] (excluding the additional attenuation $2\alpha_c$ introduced by its two couples of connectors), which is necessary (if it is necessary) in order to meet the receiver sensitivity of ONT in position C guaranteeing the 6-dB safety margin.

$$a) DPL_{A/C} = P_{RX/A} - P_{RX/C} = \alpha(l_3 + l_4 + l_5) + 5\alpha_c + 2(\alpha_s + g) = [dB]$$

$$= 23.1 \text{ dB}$$

$$b) P_{RX/C} = P_{TX} - 12\alpha_c - 3(\alpha_s + g) - \alpha(\sum_1^5 l_i) = -34.4 \text{ dBm} = 0.363 \mu W$$

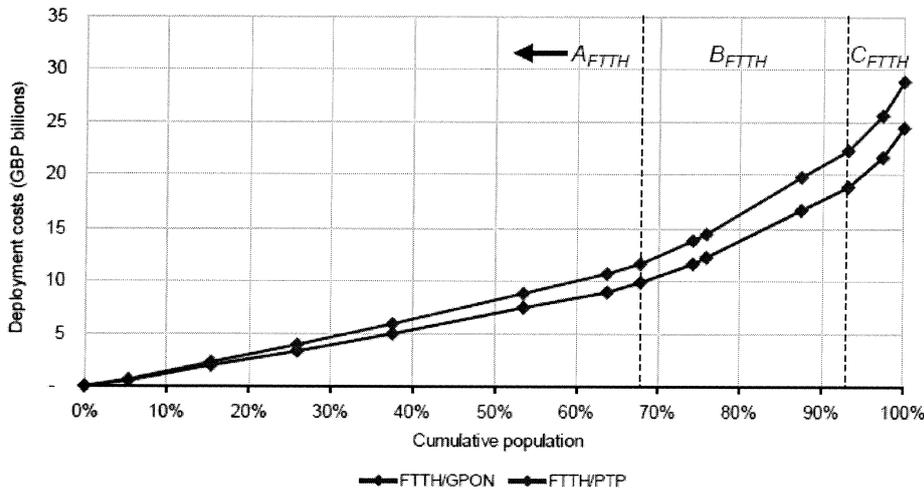
$$c) P_{TX} + A - 14\alpha_c - 3(\alpha_s + g) - \alpha(\sum_1^5 l_i) \geq -27 \text{ dBm}$$

$$A \geq 9.4 \text{ dB}$$

Problem 4

1) Explain and discuss the graph below, in particular:

- what is the slope?
- why the slope is increasing moving to right?
- plot this graph, as you expect it could be in Bolivia (10M inhabitants, of which about 5M in the three major urban areas of La Paz, Santa Cruz and Cochabamba), and explain your considerations.



2) Let $s(t)$ be a non-ideal timing signal generated by a clock with initial instantaneous frequency $\nu(0) = \nu_0$ and coefficient of linear frequency drift $D = 10^{-9}/\text{month}$.

- Should the frequency drift remain linear with coefficient D indefinitely, after how many years the clock instantaneous frequency $\nu(t)$ would be increased by 1 ppm?
- Evaluate the *Time Error* $TE(t)$ measured by this clock at $t = 1$ year with respect to an ideal timing signal with constant frequency ν_0 and same phase at $t = 0$.

$$\nu(t) = \nu_0 + Dt \nu_0 \quad Dt = 10^{-6} \rightarrow t = \frac{10^{-6}}{10^{-9}/\text{month}} = 10^3 \text{ months} = 83,3 \text{ y}$$

$$\Phi(t) = 2\pi \int_0^t \nu(t) dt =$$

$$T(t) = \frac{\Phi(t)}{2\pi\nu_0} = t + \frac{D}{2}t^2 \quad TE(t) = T(t) - t = \frac{D}{2}t^2$$

For $t = 1 \text{ year} : TE(t) = 191,8 \text{ ns}$ (1 month = 30 days, 1 year = 365 days)