# Optical and Transport Networks

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**Last and first name:** *(capital letters)*

*(signature)*

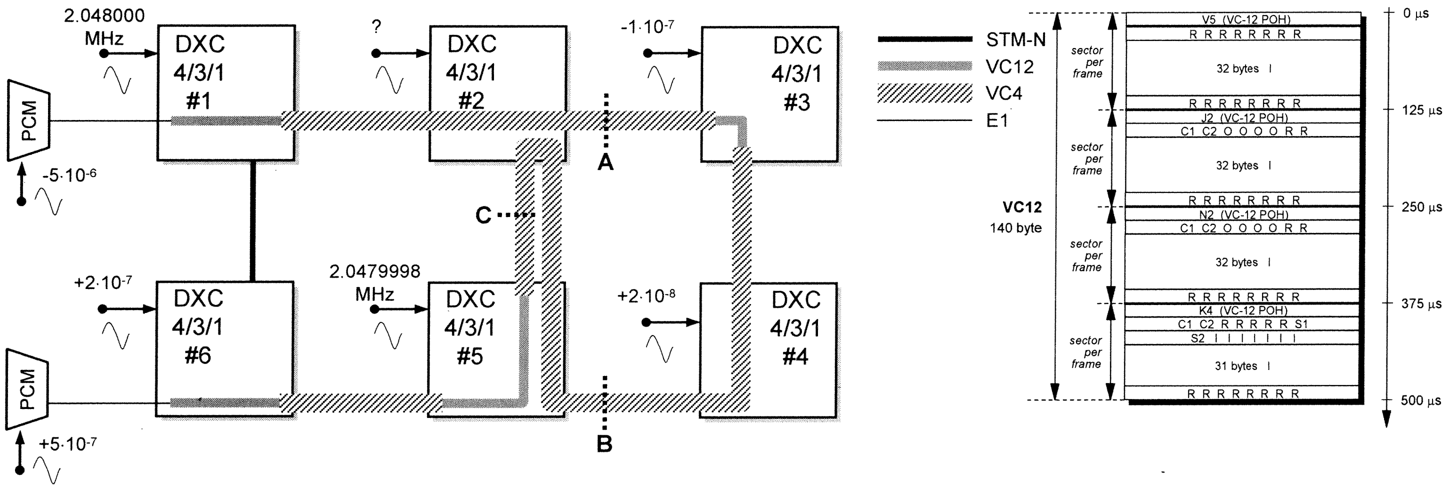
**Matriculation number:**

***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 path 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).




a) Compute the justification ratio $\rho$ (as fraction of justification opportunity bits occupied by dummy bits) in the VC12 terminated at the desynchronizer of the E1 interface of DXC #6.

b) Compute every how many seconds AU4 pointer justifications do happen at interface C (i.e., the inter-justification period), in the direction from DXC #5 to DXC #2, specifying also their sign (POS/NEG).

c) Compute every how many seconds TU12 pointer justifications do happen at interface A (i.e., the inter-justification period), in the direction from DXC #3 to DXC #2, specifying also their sign (POS/NEG).

d) Compute every how many seconds TU12 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).

a) $2{,}048\ \text{Mb/s}\,(1-5\cdot10^{-6}) = (1025-2\rho)\cdot 2000$ bit/s

$\Rightarrow \rho = 0{,}50256$

b) NO AU4 JUST

c) In the p.p. TU12 in #3: $\Delta f = f_{VC12}\,(+2\cdot10^{-7} - (-10^{-7})) = +0{,}672$ bit/s

1 just TU12 every 8 bit / 0,672 bit/s = 11,9 sec (NEG)

d) In the TU12 p.p. in #3: $\Delta f = f_{VC12}\cdot 10^{-7} = +\,0{,}224$ bit/s

1 just TU12 every 8 bit/0,224 bit/s = 35,71 sec (NEG)

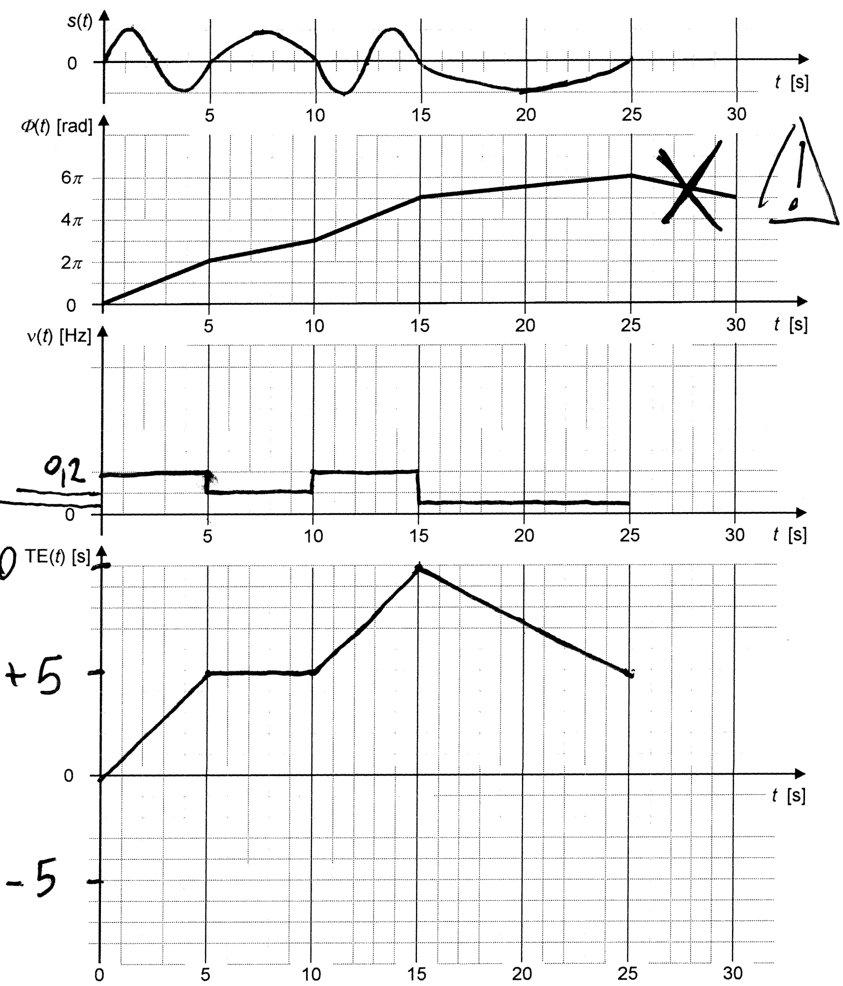
## Problem 2

a) Let $s(t)$ be a pseudo-sinusoidal timing signal with nominal frequency $\nu_0 = 0.1$ Hz and *Total Phase* $\Phi(t)$ 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 instantaneous frequency $\nu(t)$;
- the *Time Error* TE($t$) with respect to an ideal timing signal with frequency $\nu_0$, starting from TE(0)=0, with the convention that positive TE denotes time advance.



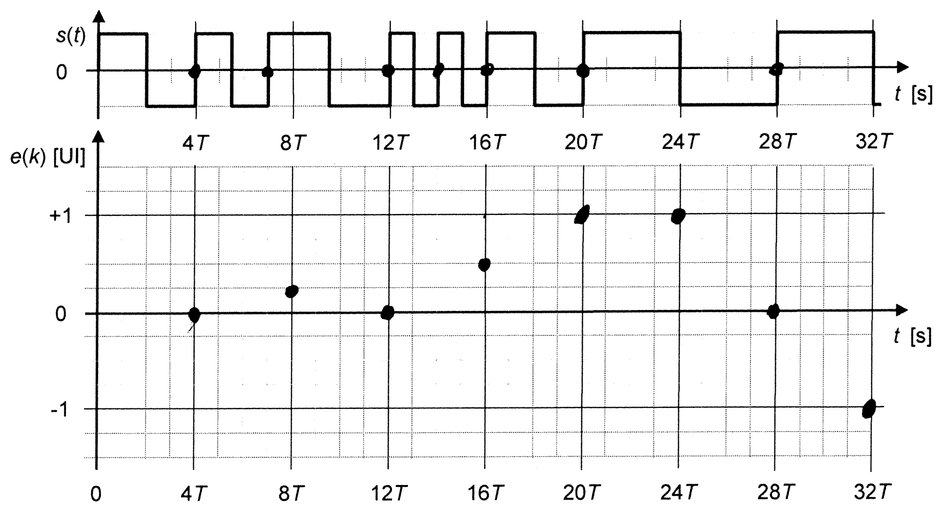

$$T(t) = \frac{\Phi(t)}{2\pi\nu_0}$$

$$T_0 = \frac{1}{\nu_0} = 10 \text{ sec}$$

b) Let $s(t)$ be the square timing signal $s(t)$ plotted in figure and with nominal frequency $\nu_0 = 1/(4T)$ Hz.

- What is its average frequency over the interval $(0, 32T)$?

$$\bar{\nu} = \frac{7{,}5 \text{ cycles}}{32T}$$




- Plot on the graph the jitter values $e[k]$ measured in [UI], at significant instants $t_k = k(4T)$ of the ideal timing signal with frequency $\nu_0$, starting from the initial point $e[0] = 0$, with the convention that positive jitter denotes time advance.

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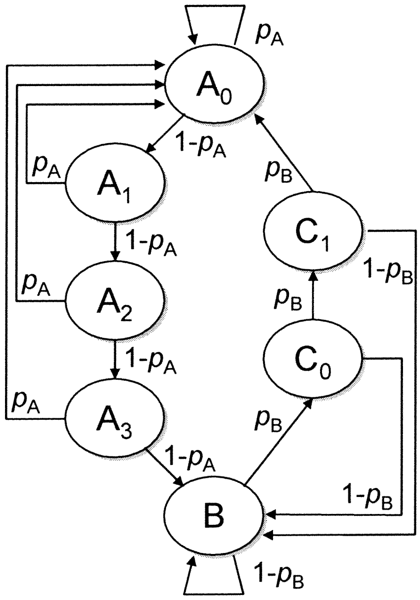
## Problem 3

Consider the frame alignment algorithm represented by the diagram below ($A_0$ state: system aligned in service; B state: alignment lost). The frame aligner operates on a test E2 framed signal at input (nominal frequency $f_0$ = 8.448 Mbit/s, frame length $L_m$ = 848 bit), with random content everywhere in all frames except the alignment word (10 bits during both hunting and maintenance). The test signal is affected by random transmission errors, uncorrelated and with rate $\varepsilon$.




a) Let the system be aligned and in service ($A_0$ state). What is the maximum value of the line bit error rate $\varepsilon$, in order to have the probability of *forced loss of alignment* within 4 frame periods less than $10^{-10}$?

b) Let the system be out of alignment (B state). What is the minimum length [bits] of the alignment word, required to have the probability of *fake alignment* less than $10^{-10}$ with random unframed test signal?

a) $P_A = (1-\varepsilon)^{10}$ $\quad (1-P_A)^4 < 10^{-10}$ $\quad (10\varepsilon)^4 < 10^{-10}$ $\quad \varepsilon < 10^{-14/4} = 3.16\cdot 10^{-4}$

b) $P_B = \frac{1}{2^b}$ $\quad P_B^3 < 10^{-10}$ $\quad 2^{-3b} < 10^{-10} \to b > \frac{10}{3\log 2} \to b \geq 12$

**Problem 4**

**1)** Consider an STM-16 signal transmitted over an optical fibre with refractive index $n = 1.5$ and length $L = 200$ km. Knowing that the coefficient of variation of the refractive index vs. temperature of the fibre is $\partial n/\partial\theta = +5\cdot10^{-6}$/K, calculate the peak-to-peak amplitude (expressed in [UI]) of the wander caused by 20°C diurnal excursion of fibre temperature.

**2)** What is the efficiency of payload utilization in the transport of 100 Mb/s Ethernet over SDH via VC-4 and via VCAT VC-12?

**3)** What is the *jitter* of a digital signal? Provide its definition and explain why it may cause bit errors. What is the *jitter tolerance* of a network interface? How is it defined, and how would you measure it?

1) $\tau = \frac{Ln}{c} \rightarrow \Delta\tau = \frac{L}{c}\Delta n \qquad \Delta n = +10^{-4} \qquad 1\ UI = 0{,}4\ ns$

$\Delta\tau = \frac{200\ Km}{3\cdot10^5\ Km/s}\cdot10^{-4} = 66{,}7\ ns = 166{,}7\ UI$

2) $C_{C4} = 155.520\ Mb/s\ \frac{260}{270} = 149.760\ Mb/s$

$C_{C12} = \frac{34\ byte}{125\mu s} = 2{,}176\ Mb/s$

VC-4 : $\eta = 66{,}8\%$

VC-12-46v : $99{,}9\%$