CALCULATION OF SIGNALLING DELAY TIMES FOR A MODERN ACCESS SYSTEM

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I. INTRODUCTION

For new telephone service providers the relatively most expensive part of their network to built up is the "last mile" between the local exchange and the subscriber. Therefore each possibility of reaching customers without pulling new wires or using wireless systems is of great economic interest for these companies. This is the reason for the boom of so-called "modern access systems" which allows to connect subscribers to their local exchange in an unconventional way like using TV distributing networks. Most of this distributing networks are based upon coaxial cables at least in the subscriber loop. To upgrade this networks, i.e. to implement the "upstream" transmission capacity several system concepts are already common. Usually the system works with a combination of (digital) optical fibre transmission and analogue coaxial system parts so it is called a Hybrid - Fibre - Coax (HFC-) system. Within this HFC-networks the "cablephone systems" allow to connect POTS (Plain Old Telephone Service) and ISDN telephone subscribers to a local exchange.

II. SYSTEM STRUCTURE OF HFC-NETWORKS

HFC-systems are used as network platform for "cablephone" and "cablemodem" systems. These HFC-systems show a large bandwidth in the direction to the subscriber side (47-862 MHz); for the implementation of a "backward" or upstream channel the frequency range between 5 and 33 MHz in some cases up to 70 MHz are used. Figure 1 gives an overview of such a modern access network, which is implemented in parallel to SDH transmission systems. Head ends inside the ring are connected with a so-called Radio and TV receiver station where the analogue signals are fed to the fibre ring (up to 100 km length). Thus the HUB's are supplied. Each HUB itself supplies between 5000 and 10000 subscribers. Between the HUBs and the BONT (broadband optical network termination) optical fibres are usede for transmission too. Within the BONT the signals are e/o resp. e/o converted and then via coaxial cable transmission/received to/from the subscribers. A passive coaxial network is able to supply about 100 subscribers, if amplifiers are used up to 500 subscribers can be connected. Parallel to the fibre ring with the analogue TV signal other optical systems for transmission of digitalized speech and data signals are used among the HEs and HUBs. Connected to this ring are local exchanges and router or gateways to the internet and other data services also server for multimedia services are possible. Inside the HUBs the TV signals and the signals of the interative services are combined. As already mentioned above, the interactive services have the necessity of using an upstream channel for which only a limited bandwidth can be used, so that the channels should be used in an optimized way i.e. you need a dynamic channel allocation (DCA) of telephone channels between active subscribers and the exchange. Besides of the enormous electrical problems to implement interative channels inside a broadband distribution system also questions in the sector of traffic theory may arise which shall be described in the following chapters. For an easy understanding absolute values of an existing system are used.

III. MODELLING OF THE SYSTEM AND THE REQUIREMENTS

DCA takes time before the beginning and after the end of a telephone call. The time after the end of a call is not of relevancy for a subscriber but the call establishing time - that time between "hook-off" and the receiving of the "dial tone" - he is realizing very well and therefore this time is of importance. The system which was investigated has a representative architecture for such type of systems with a central TDM bus for DCA control. To calculate with absolute values we take an example. Figure 2 shows some measured and required values of the regarded example and figure 3 the model for calculation the delay probabilities. Assuming that all delay times in the system - except the TDM bus - are constant or randomly distributed, you are able to reduce the model on to two delay relevant parts in each direction: into one part, which is telephone traffic independent and into another part, the delay of the TDM bus (t_B) which obviously is a funcion of the DCA control traffic caused by the telephone traffic of the subscribers. Let's try to define the load on the TDM bus: the relation between A, the traffic offered to a line, the call rate (l) and the mean occupation time (t_m) is:

$$A = l \cdot tm \quad (3.1)$$

The call rate l for the TDM bus and the telephone traffic is the same the mean occupation times are different, we get:

$$\frac{A_{Tel}}{t_{m,Tel}} = \lambda = \frac{A_B}{t_{mB}}$$

or

$$\frac{A_{Tel}}{A_B} = \frac{t_{m,Tel}}{t_{mB}} = \frac{120\,s}{252\,ms} = 476.2 \qquad (3.2)$$

the load for the bus is:

$$A_B = A_{Tel}\frac{t_{mB}}{t_{m,Tel}} = \frac{268.8\,\text{Erl}}{120\,s}t_{mB} = \frac{2.24}{s}t_{mB} \qquad (3.3)$$

Figure 4 shows the relationship according to equation (3.3) as the line "$A_{B,netto}$ ".

A bus occupation time of 252 ms thus results in a bus load of 0.56 Erl. Now taking into account that we are only allowed to use 80% of the bus capacity for DCA purposes, the other 20% have to be reserved for other e.g. O&M purposes, our brutto bus load will be 1.25 x 0.56 Erl = 0.7 Erl.

ATel = 80% · 476.2 · AB = 380.9 · AB

or

$$A_B = 1.25\frac{2.24}{s}t_{mB} = \frac{2.8}{s}t_{mB} \qquad (3.4)$$

Withing fig. 4 the relation (3.4) is shown as "$A_{B,brutto}$".

We assume that the O & M traffic has the same traffic characteristic like the DCA traffic caused by the telephone traffic, which is reasonable. The main conclusion of figure 4 is obvious: The shorter the occupation time of the TDM bus, the lower is the load for this bus, because of the required constant telephone load.

IV. DELAY TIME CALCULATION

Figure 3 shows us the way how to get forward in solving our problem of calculation delay time probabilities: we have for each direction to consider the probability density functions for the traffic independent and traffic dependent delays and then, taking into account their statistical independency, you get the probability density function of a cascaded system as the convolution of the single probability density functions (see fig. 5). In a formula expressed:

$$w_{tot}(x) = \int_0^x w_1(x-u)w_2(u)du \qquad (4.1)$$

In our case we have to calculate the convolution of w_D and w_B for each direction separately. Basing on the values of figure 2 and for two assumptions of a per call TDM bus occupation time:
1) TDM bus occupation time is (nearly) constant (= tmB),
2) TDM bus occupation time is negative exponentially distributed (similar to telephone traffic) with the same mean value tmB.
In reality the bus occupation time will likely be between the two values. Nevertheless the calculation shall be done for neg. exp. Distributed traffic as it shows results on the safe side.

The TDM bus is considered as a delay system in which occupations, occuring when all servers are busy, wait until a server becomes free again. The waiting queue may be not limited and the number of servers (trunks") in our TDM bus system shall be N = 1, i.e. the TDM bus can only handle one call per TDM bus occupation.

According to [1], chapter 5.2, we get for the probability distribution of handling calls in a waiting system according to the order of their arrival:

$$P(>t) = P(>0)e^{-\frac{t}{t_m}(N-A)} \quad (4.2)$$

N = number of servers (here N = 1; i.e. 1 bus, 1 call at the same time; for N = 1 we get P(>0) = A_B), so we get out of equ. (4.2):

$$P_B(<t) = 1 - P_B(>t) = 1 - A_B e^{-\frac{t}{t_m}(1-A_B)} \quad (4.3)$$

Out of (4.3) we get by defferentiation

$$w_B(t/t_m) = \frac{dP(<t)}{dt/t_m} = A_B(1-A_B)e^{-\frac{t}{t_m}(1-A_B)} + (1-A_B)\delta(t) \quad (4.4)$$

Figure 6 shows the probability distribution and probability density function versus t/t_m. With such a negative exponent-ially distributed occupation the convolution can be done easily.

Figure 7 shows the result of the convolution; for the traffic independent delay the upstream values are used as given above, as they show worse results. The time scale is taken to tm = 252 ms. Equation (4.5) shows the maximum value w1 of the probability density function and for the probability distribution P(>400 ms) we get equation (4.6):

$$w_1 = \frac{t_m}{\Delta t}\int_0^{\frac{\Delta t}{t_m}} \frac{w_0}{t_m} e^{-(1-A_B)\frac{t}{t_m}} dt = \frac{A_B t_m}{\Delta t}\left(1 - e^{-(1-A_B)\frac{\Delta t}{t_m}}\right) \quad (4.5)$$

$$P(>400ms) = \int_{\frac{t_g - t_u}{t_m}}^{\infty} \frac{w_1}{t_m} e^{-(1-A_B)\frac{t}{t_m}} dt = \frac{A_B}{\frac{\Delta t}{t_m}(1-A_B)}\left(1 - e^{(A_B-1)\frac{\Delta t}{t_m}}\right) e^{(A_B-1)\frac{t_g - t_u}{t_m}} \quad (4.6)$$

According to fig.7 it is defined:
t_g = limit for delay , tu = upper limit of traffic independent delay, tl = lower limit of traffic independent delay, t = tu - tl, tm = TDM bus occupation time, AB = bus load, w1 = max. value of probability density function.

Note: AB and tm are used as independent parameters i.e. the relation (equ. 3.4) between AB and tm is ignored (see also figure 4).

IV. CONCLUSION

Summarizing the results, which have been based upon a first system design, it can be shown, that with a bus occupation time of 252 ms there is a probability P(>400 ms) of about 49%. This value is by far out of the specified range. Figure 8 shows the result and gives a comparison of neg. exp. distributed and constant bus occupation times with tm = 252 ms. The three scales for the abscissa shows the various traffic loads AB,brutto, AB,netto and the relevant telephone load ATel. Fig. 8 can also be interpretated , that with a bus occupation time of 252 ms a telephone traffic load of only 9.52 Erl can be handled, to keep the required delay probability P(>400 ms) 5%. The negative exponential dis-tributed bus occupation time always gives worse results than a constant bus occupation. This is obvious and in accordance with all experiences in traffic theory.

If we now combine again our AB and tm according to equation (3.4), in order to guarantee the required ATel = 268.8 Erl the maximum bus cycle time is 114 ms (i.e. AB = 0.32 Erl) the required 5%-level of P(>400 ms) can be fulfilled by the system (see fig. 9); it shows the probability P(>400 ms) as a function of tm and AB, respectively. The analysis of the DCA signalling delays shows that the required system performance cannot be fulfilled for the required telephone load of 268.8 Erl with a TDM bus occupation time of 252 ms. But a possible solution for the problem is already shown in fig. 9: decrease the bus load without decreasing the DCA telephone load by increasing the bus speed! A maximum bus occupation time of 114 ms (basing upon the above mentioned values) guarantees even for a neg. exp. distributed bus occupation time a probability distribution P(>400 ms) 5%.

N	**1 2**	**3 4 5**	**6**
P(>0)	**0.7** **0.19**	**0.04** **0.007** **0.0008**	**0.0001**

Table 1: P(>0) as a function of N; A_B = 0.7 Erl.

Another possibility to increase the effectiveness of the TDM bus is giving up the principle of handling only one call at the same time on the bus. If the protocol would allow to handle two or more calls at the same time, the system can be taken as a system with more than one server. Equation (4.2) shows the influence of the number of servers (N) for the probability of waiting in the case of a neg. exp. distributed bus occupation. The probability distribution of waiting (P(>0))
dramatically decreases; table 1 shows the values up to N = 6 for AB = 0.7 Erl. Already with a value of N = 3 the probability distribution for waiting (P(>0)) is lower than 4%, so it is to expect that after the convolution only 4% of the calls have a delay of more than
tD = tu = 150 ms, which is sufficient to fulfill the requirement! It can be demonstrated that even N = 2 is sufficient.

REFERENCES

[1] SIEMENS AG: 'Telephone Traffic Theory Tables and Charts Part 1' (Siemens, 1970)

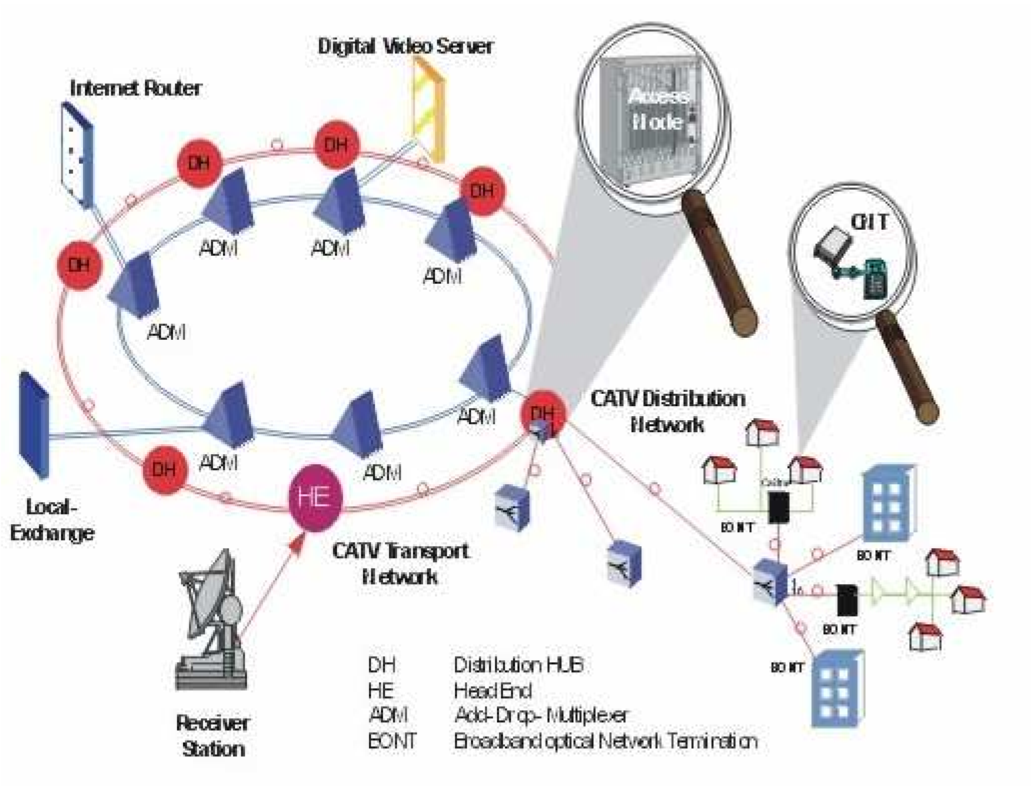

Figure 1 : HFC-Network

tel. traffic per TDM-bus 268.8 Erl
tel. traffic characteristic neg. ex. distrib.
mean tel. occupation time tm,Tel= 120 s
number of tel. channels 16 ·30 = 480
mean value of TDM-bus occ. time per call tmB=252 ms
delays rand. distributed (up) 76...150 ms
delays rand. distributed (down) 98...108 ms
call origin distribution (up/down) 50% / 50%

max. allowed call establ. delay (95%) <=400 ms

Figure 2 : System Data (Example)

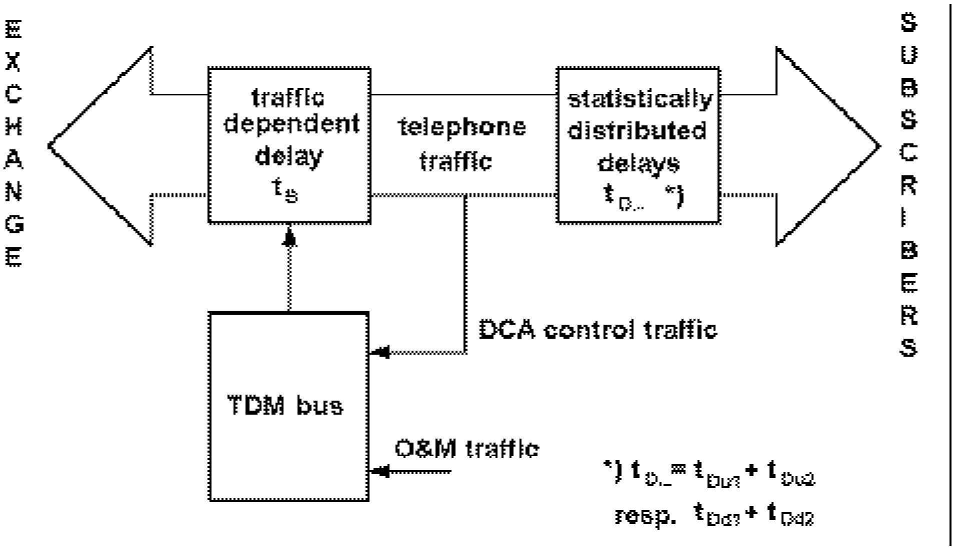

Figure 3 : Traffic dependent and traffic independent delays

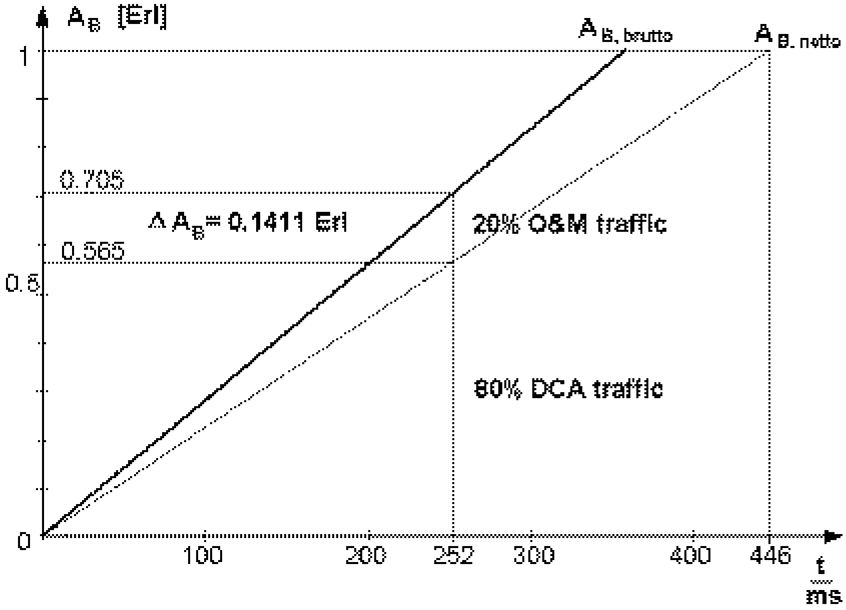

Figure 4 : Bus traffic A_B versus bus occupation time; A_{Tel} = 268.8 Erl

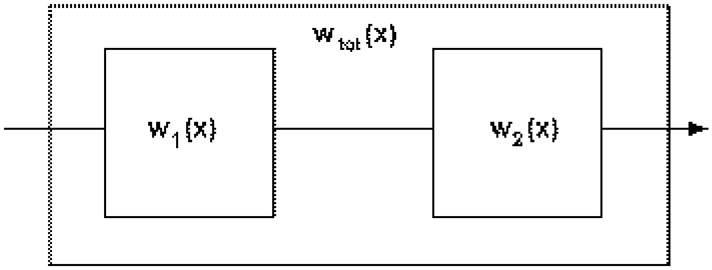

Figure 5 : Probability density functions for two cascaded delay systems

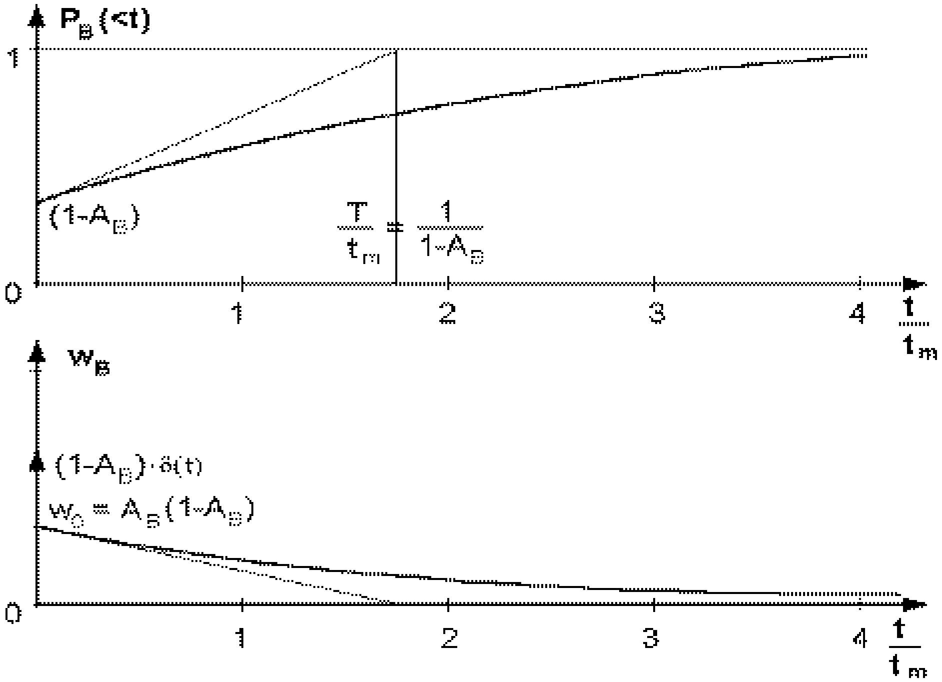

Figure 6 : Graphs for $P_B(<t)$ and $w_B(t)$ (neg. exp. bus occupation time)

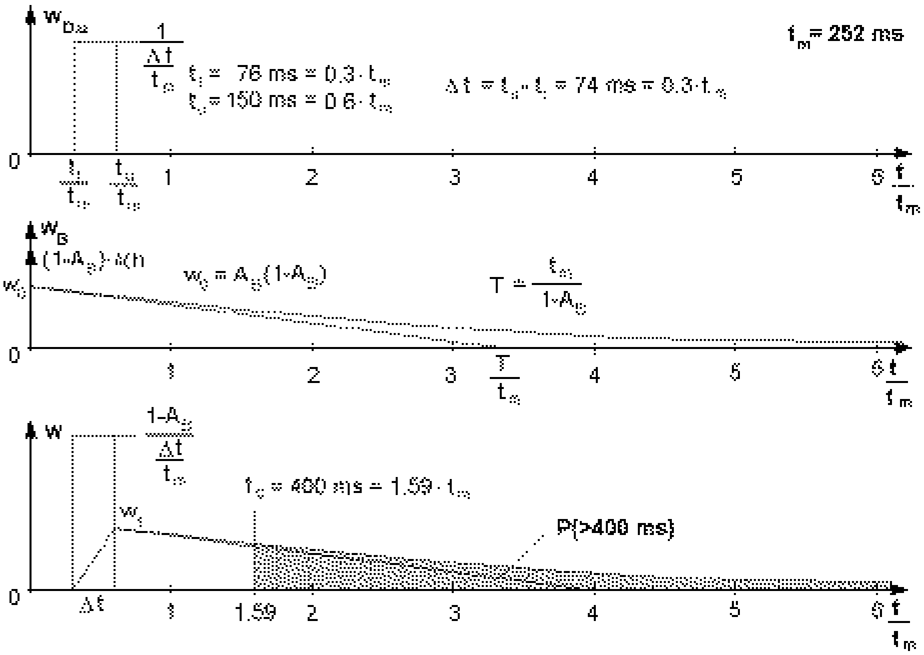

Figure 7 : Graphical convolution, neg.exp. distrib. bus occ. time, $A_B = 0.7$ Erl

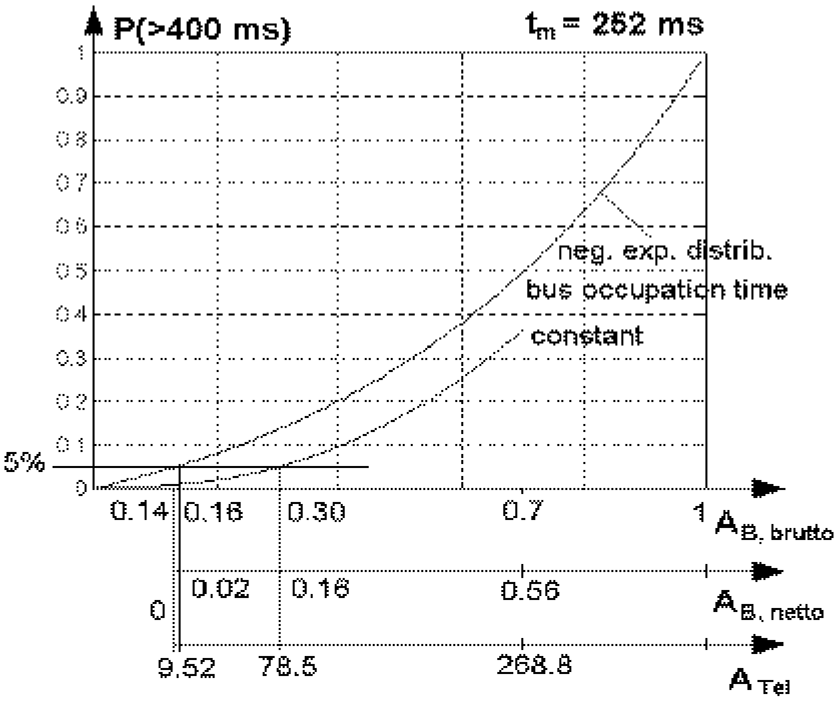

Figure 8: P(>400 ms) versus A_B with t_m = 252 ms

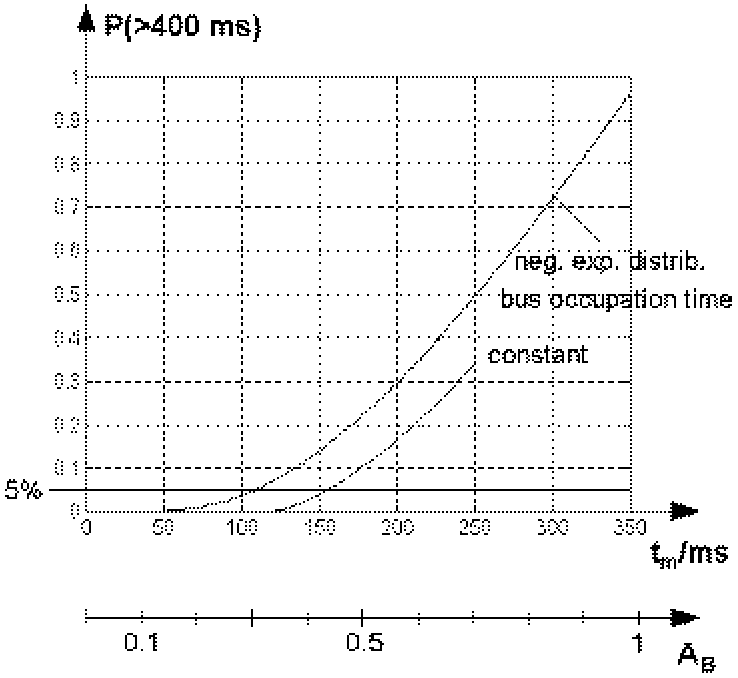

Figure 9: P(>400 ms) as a function of t_m resp. A_B for required A_{Tel} = 268.8 Erl.

Brief Biography

Prof. Doster was born in 1946 in Stuttgart, Germany. In 1972 he graduated at the University of Stuttgart in Communication Technology and Data Processing. He joined then the development division of ALCATEL-SEL in Stuttgart where he worked within projects of various fields of transmission systems e.g. data multiplexing, remote control units and optical transmission systems. Finally he took over responsibility for the technical sales support of the line transmission division. In 1991 he changed as a Professor to the Technical University of Applied Sciences in Esslingen, Germany. Since the year 1995 he is the dean of the Department of Information Technology.
Since 1968 he is member of VDE, in April 1997 he was elected into council of the regional group of Wuerttemberg. Between 1981 and 1992 he was member of "working group 03" (data

communication) within study committee 35 of CIGRE.

[1] This paper was presented at the CSDSP'98 (Communication Systems and Digital Signal Processing 1998) at Sheffield, UK.