POINT TO POINT LOSS IN LINK SYSTEMS. MODELS AND CALCULATION METHODS

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ABSTRACT

The switching networks of modern telephone exchanges are often built up as multistage arrays which are controlled by conditional selection. Thereby the strategy is often applied that a certain inlet in stage No. 1 is to be connected with a certain outlet in the last stage. The loss occurring in doing so is called Point to Point Loss or briefly "Point Loss".

In the paper presented here traffic models for the calculation of the Point Loss are defined. Then approximate methods of calculating the Point Loss in three- and four-stage link systems are derived. The results of calculation are compared with results of simulation which were obtained with a full-scale simulation of the systems investigated.

1. INTRODUCTION

The speaking paths of modern telephone arrangements often consist of several selector stages in series, which are controlled by a centralized device in conditional selection: Idle lines between the stages will only be occupied, if they can be switched to an idle outgoing line.

Thereby we often have the case where a certain inlet in stage No. 1 is to be connected with a certain outlet in stage No. S, i.e. with a certain outgoing line. The loss occurring in doing so is called Point to Point Loss or briefly "Point Loss".

2. POSSIBILITIES OF DEFINING THE POINT LOSS

To be able to calculate the Point Loss we first have to make precise the general statement "connexion between a certain inlet and a certain outlet". For that purpose we will develop in this chapter a traffic model, upon which we may base the calculation of the interesting quantity "Point Loss".

The Traffic Model.

When a call arrives at a multiple in the first stage, i.e. when it marks a certain incoming line, out of all the outgoing lines which are idle at this moment or out of all the lines in the route under consideration which are idle at this moment an arbitrary line is chosen at random and marked. Then a connecting path between the two marked points is to be looked for and is to be switched. The probability that the marked free goal cannot be occupied is denoted by B_{NF}.

Calls arriving in the state "all outgoing lines are busy" or "all lines in the route under consideration are busy" cannot be switched and get lost. Such calls only contribute to the total loss B of the system but not to the Point Loss B_{NF}. Therefore, the total loss B comprises both calls which cannot occupy the marked goal being idle and calls which get lost because all outlets of the system are busy. Thus, among the total loss B, the total traffic offered A and the total traffic carried Y holds the equation.

$$Y = A \cdot (1 - B).$$

Now, two different definitions of the Point Loss B_{NF} are possible which are denoted by B_{NF1} and B_{NF2}.

a) Definition of B_{NF1}

The quantity B_{NF1} is defined by the ratio number C_{NF} of calls which could not occupy the idle goal being marked, and the number C_A^* of calls which have arrived in the state "at least one outgoing line is idle". Therefore

$$B_{NF1} = C_{NF}/C_A^* \qquad (1)$$

b) Definition of B_{NF2}

The quantity B_{NF2} is defined by the ratio number C_{NF} of calls which could not occupy the free goal being marked, and the number C_A of calls which have arrived all together. Therefore

$$B_{NF2} = C_{NF}/C_A \qquad (2)$$

The traffic model No. 1 defined herewith will be applied to calculate the Point Loss in the following chapters.

The discussion of the two definitions given here is in chapter 3 in the context of the discussion of the results of the exact calculation.

3. EXACT CALCULATION

As mentioned before we start from the traffic model No. 1 in all the further considerations.

The exact calculation leads to a linear homogeneous system of equations for the probabilities of state. If we can do the numerical solution of the system of equations of state, we will find the Point Loss by linear combinations of certain probabilities of state.

The difficulties and the limits of an exact calculation are well known. Therefore only a small 3-stage link system with preselection (cf. diagram No. 1) has been calculated exactly. In this case the system of equations of state could be set up in a relatively simple way by utilizing properties of symmetry such as an equally distributed traffic offered among the multiples in the first stage and random hunting of the outlets of these multiples.

The value of an exact calculation of such small systems having no practical importance is that on the one hand we can check results obtained by tests with artificial traffic and that on the other hand we can set up statements concerning the course of the curves of loss in principle.

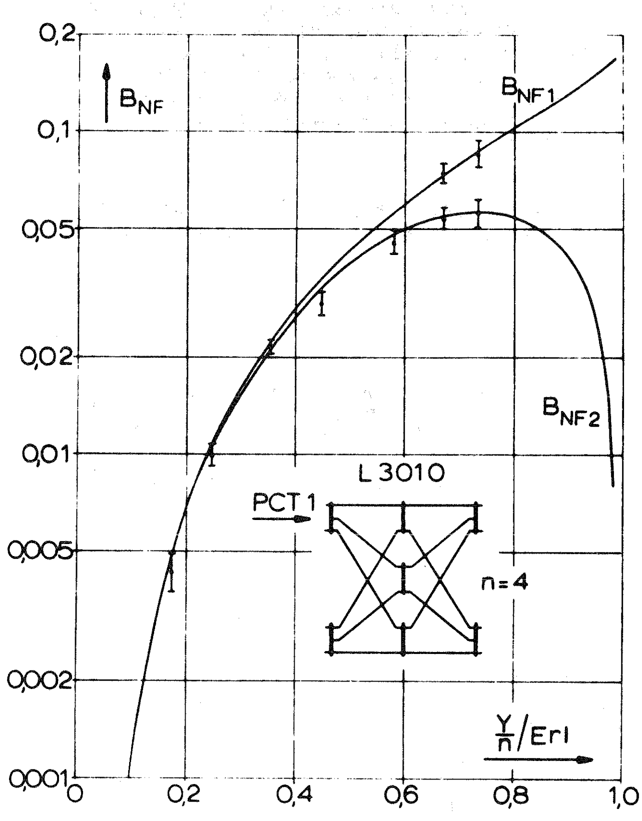

Diagram 1 Exact Calculation of the Point Loss

Because it is known in principle how to set up the equations of state by means of the diagram of states we miss out the derivation.

The course of the curves for B_{NF1} and B_{NF2} is based on the definitions according to the equations (1) and (2). At low loads both curves are practically identical, because the state "all outgoing lines are busy" only occurs with a negligible probability. With a load increasing the curves diverge. The Point Loss defined by B_{NF1} rises in a monotonous way whereas the Point Loss defined by B_{NF2} rises up to a maximum and then falls down to zero when the load is increased.

In link systems with a considerably greater number of outgoing lines of practical interest, the difference between B_{NF1} and B_{NF2} occurs at greater values of the traffic carried and hence may be disregarded within the range of losses ($B_{NF} < 0.05$) considered.

4. APPROXIMATE CALCULATION OF 3- AND 4-STAGE LINK SYSTEMS WITH THE METHOD OF MULTIPLICATION AND SUMMATION OF PROBABILITIES

4.1 Structure and Graph of Connecting Paths

In the figures 1 and 2 the structure of a three- and four-stage link system is shown. When no occupation exists in a system only a certain number of "paths" will be suited to switch a call from the inlet being marked to the outlet being marked. The entirety of these paths which are suited is called the graph of the system considered.

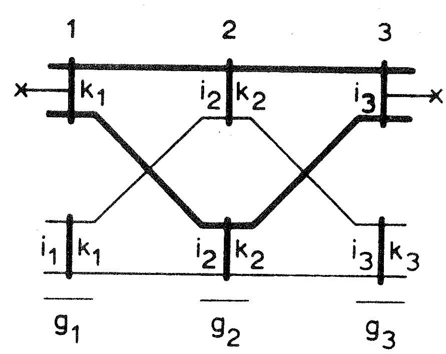

Fig. 1 3-stage link system

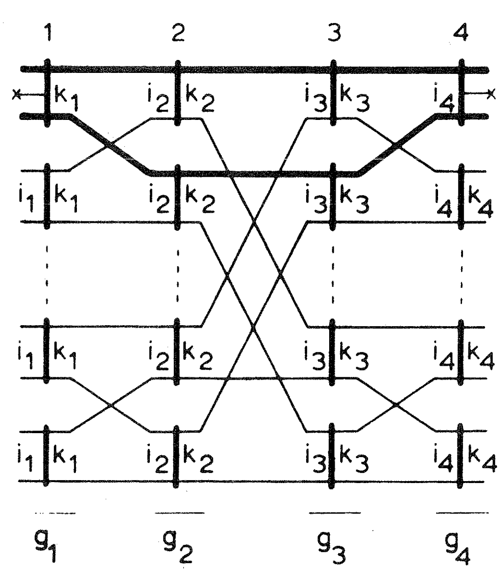

Fig. 2 4-stage link system

The graph lying between the two points marked with * is displayed by heavy lines in the figures 1 and 2.

4.2 General Derivation

The method denoted by the catchword "Multiplication and Summation of Probabilities" starts from the assumption that the probabilities for x lines to be occupied in a section of the graph are known for each section. Besides this the probability distribution for the whole outgoing group shall be known.

Remark: To state the formulae in a general form we denote the number of stages by S; in the examples given S will be 3 or 4.

The calculation is based upon the graph represented in figure 3.

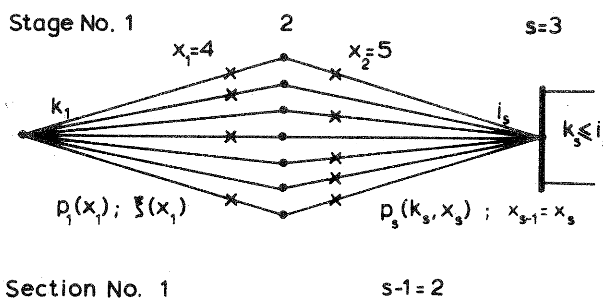

Fig. 3 Graph

I n the first section or in systems with more than three stages (S > 3) r u n n i n g t h r o u g h t o the section No. (S - 2) x_1 arbitrary lines be occupied with the probability $p_1(x_1)$ respectively $\xi(x_1)$. The goal in stage No. S will not be reached, if at least those $(k_1 - x_1) = (i_S - x_1)$ lines are occupied in section No. 2 respectively in section No. (S - 1), which are still idle i n the first or u p t o the (S - 2)-th section. The probability therefore is denoted by $w(k_1 - x_1) = w(i_S - x_1)$.

Provided that all the patterns of occupation of a certain state $\{x_S\}$ occur with an equal probability, we obtain in the well known way

$$w(k_1-x_1) = \sum_{x_S=k_1-x_1}^{k_S} \frac{\binom{x_S}{i_S-x_1}}{\binom{i_S}{i_S-x_1}} \cdot p_S(k_S,x_S) \qquad (3)$$

Additionally we have to take into account that only i d l e outgoing lines get marked, i.e. there must be at least one idle line in the last section of the graph. Besides this we have to take into consideration the influence of the common control, because it is supposed that one out of all idle outgoing lines is marked at random. This means that the probability of having a certain multiple in the last stage as goal is proportional to the number of outlets being idle in it just now. Both demands are taken into account by a weighting function $G(x_S)$ as follows:

$$G(x_S) = \frac{k_S - x_S}{k_S - Y_S} \qquad (4)$$

with

$$Y_S = \sum_{x_S=1}^{k_S} x_S \cdot p_S(k_S,x_S) \qquad (5)$$

Now we obtain from equation (3):

$$w^*(k_1-x_1) = \sum_{x_S=k_1-x_1}^{k_S} G(x_S)\cdot\frac{\binom{x_S}{i_S-x_1}}{\binom{i_S}{i_S-x_1}}\cdot p_S(k_S,x_S) \qquad (6)$$

Finally, if we denote by p(x) the probability distribution of the whole outgoing group, we will obtain for the Point Loss the following equations in the case of Pure Chance Traffic No. 1 (Poisson Input, PCT 1):

$$B_{NF1} = \frac{\sum_{x_1=i_S-k_S}^{i_S} \xi(x_1)\cdot w^*(k_1-x_1)}{1-p(n)} \qquad (7\text{ a})$$

$$B_{NF2} = \sum_{x_1=i_S-k_S}^{i_S} \xi(x_1)\cdot w^*(k_1-x_1) \qquad (7\text{ b})$$

As was already pointed out in chapter 3, the difference between B_{NF1} and B_{NF2} may be disregarded within the range of loss which is of practical interest, because then p(n) will be much smaller than unity.

As to the calculation or assumption of the probabilities $p_i(x_i)$, there exist different possibilities similar to the calculation of route blocking in link systems /21/.

Remark: If we assign the weight function $G(x_S)$ (equ. (6)) the value unity for all values x_S and extend the summation in the case of $i_S = k_S$ up to $(k_S - 1)$ instead of k_S, equation (7 b) with equation (6) will yield the following relation:

$$B^*_{NF2} = \sum_{x_1=0}^{i_S} \xi(x_1)\cdot w^*(k_1-x_1) - p_S(k_S,k_S) \qquad (8)$$

The Point Loss B^*_{NF2} according to equation (8) is very similar to /15/ and /16/.

4.3 Numerical Evaluation

4.3.1 Functional Dependence and Statistical Independence

As is well known the probability distributions $p_i(x_i)$ on the different sections of the graph are dependent on each other functionally.

This means for example (cf. fig. 3) that the probability for x_1 lines being occupied in the first section is a function of the probability for x_2 lines being occupied in the last section and vice versa. The consideration of this functional dependence of the probability distributions leads to iterative methods for the calculation of the $p_i(x_i)$. In the paper presented here we calculate these probabilities by means of the iterative procedure according to /16/. Then we obtain the probability $\xi(x_1)$ starting from the probabilities $p_i(x_i)$, $i = 1, 2, \ldots, S - 2$, by means of the algorithm according to /15/. Now the Point Loss B_{NF} may be calculated with the equations (7 a,b).

Remark: The functional dependence between the probability distributions $p_i(x_i)$ could only be taken into consideration in the case $i_S = k_S$, i.e. if there was no concentration in the last stage, because the iterative procedure in /16/ is only planned for this case.

However, to avoid a too complicated process of calculation, in the above cited iterative procedure as well as in the equations (7 a,b), a further simplifying approximate assumption is introduced, namely the assumption of the statistical independence of the states of occupation in the different sections of the graph.

4.3.2 Functional and Statistical Independence

If on the contrary to section 4.3.1 the functional independence of the probability distributions of the different sections of the graph is assumed, we will have to prescribe probability distributions of well known types. That means, for the evaluation of the equations (7 a,b) the distributions $p_i(x_i)$ are to be prescribed, e.g. Erlang-distribution, Bernoulli-distribution and so forth. Apart from the weighting function G the calculation method is in this case identical to the principle of JACOBAEUS /1/.

Remarks:

1.) If we presume independent Bernoulli distributions on each section of the graph and if we assign to the weighting function $G(x_S)$ in equation (6) the value of unity for all values of x_S, we will get in the case of $i_S = k_S$ the same results as according to the method by C.Y. LEE /4/. If we denote by $Y_i (i = 1, 2, \ldots, S - 1)$ the traffic carried on the different sections of the graph, we will obtain:

$$B_{LEE} = \left(1 - \prod_{i=1}^{S-1}\left(1 - \frac{Y_i}{k_1}\right)\right)^{k_1} \qquad (9)$$

It must be pointed out, however, that the method of C.Y. LEE will yield such simple and clear relations only if it is applied to graphs with a series-parellel structure as considered in the paper presented here. Applied to more complicated structures - such as meshed graphs - the method of C.Y. LEE will be very unwieldy and in most cases not applicable.

2.) To determine the Point Loss defined according to C.Y. LEE in such complex structures, GRANTGES and SINOWITZ /14/ developed the simulation method NEASIM. The characteristic feature of this simulation method is that not the whole link system and the real traffic are simulated but the graph with independent Bernoulli-distributions on each section upon which the calculation method is based. This means, with NEASIM not the whole link system is simulated but the calculation method by C.Y. LEE. Therefore the results of simulation with NEASIM naturally correspond to the numerical results by C.Y. LEE. This has to be pointed out strongly, because the results of simulation with NEASIM are often used in practice for the comparison with and for the estimation of approximate calculation methods. However, the significance of such results of simulation cannot be expected to be greater than the accuracy of the calculation method by C.Y. LEE.

4.4 Examples

To check the accuracy and the utility of the method of "Multiplication and Summation of Probabilities" for the calculation of the Point Loss, we calculate 3- and 4-stage systems in this section and compare the numerical results with the results of the simulation. When simulating, the w h o l e link system and the running off of the traffic according to model No. 1 were realized (full-scale simulation). The confidence limits have been calculated for a significance level of o.o5. The diagrams inclusive of the explanations of the curves are made up at the end of the paper.

Discussion of the curves

a) Diagrams No. 2 and No. 3

The Point Loss having been calculated according to the equations (7 a,b), t a k i n g into account both the functional dependence of the probability distributions a n d the influence of the common control (cf. curve 1, diagram 2) corresponds very well within the whole range of loss to the simulation results.

If we calculate the Point Loss according to the same equations but w i t h o u t taking into consideration the functional dependence, we will obtain results which are still sufficiently accurate (cf. curve 3, diagram 2; curve 1, diagram 3).

When starting from the equations (8) and (9) the Point Loss doesn't correspond to reality.

b) Diagrams No. 4 and No. 5

The Point Loss having been calculated according to the equations (7 a,b) t a k i n g into account both the functional dependence of the probability distributions a n d the influence of the common control (cf. curve 1, diagram 4), lies within the whole range of loss considered above the simulation results. The divergences are so considerable - relatively between 6o % and 17o % - that in any case we can only call the method a rough estimation. Even if the statistical dependence is taken into account partially according to /19, 2o/ (curve 3, diagram 4), we will have no significant improvement. To achieve an essential improvement of the accuracy, the statistical dependence has to be taken into consideration more accurately.

If we calculate the Point Loss according to the same equations but w i t h o u t taking into account the functional dependence, we will obtain the curves No. 4 (diagram 4) and No. 1 (diagram 5) respectively with the improvement according to /19, 2o/ the curves No. 6 (diagram 4) and No. 3 (diagram 5). The accuracy is not satisfactory.

When starting from the equations (8) and (9) the Point Loss doesn't correspond to reality.

5. APPROXIMATE CALCULATION OF 3- AND 4-STAGE LINK SYSTEM WITH THE METHOD OF THE AVERAGE AVAILABILITY

5.1 General Derivation

In this chapter we will calculate the Point Loss according to model No. 1 for 3- and 4-stage link systems (cf. fig. 1 and 2), when the calculation starts from the method of the "Combined Inlet and Route Blocking" (CIRB) by A. LOTZE /12/. Thereby it is essentially the considerations occurring with the calculation of the route blocking by means of the average availability which will be applied.

5.1.1 Average Availability in 3-Stage Systems

Figure 4 shows the graph suitable for a connexion between the two marked points of the 3-stage link-system according to figure 1. If on the average Y_2 of i_3 lines in the second

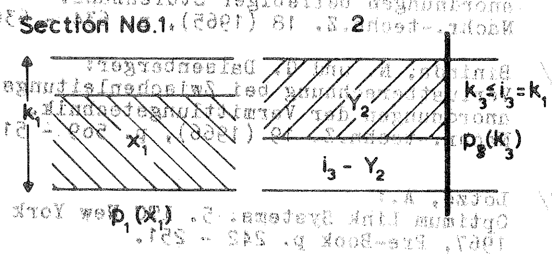

Fig. 4 Graph of a 3-stage system

section are occupied, through the remaining $(i_3 - Y_2)$ lines being idle on the average, $(i_3 - Y_2)$ lines in the first section will be "visible". That means, the average number k_m of lines in the first section, which can be hunted from the considered idle outlet of the system, is:

$$k_m = i_3 - Y_2 \tag{10}$$

5.1.2 Average Availability in 4-Stage Systems

Figure 5 represents the graph suitable for a connexion between the two marked points of the 4-stage link system according to figure 2.

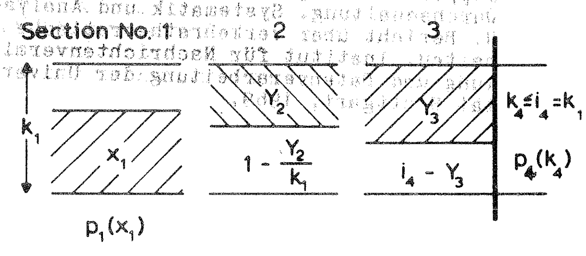

Fig. 5 Graph of a 4-stage system

If on the average Y_3 of i_4 lines in the third section are occupied, through the remaining $(i_4 - Y_3)$ lines being idle on the average and through the lines in the second section being idle with the probability $(1 - Y_2/k_1)$, on the average $(i_4 - Y_3) \cdot (1 - Y_2/k_1)$ lines in the first section will be "visible". Therefore the mean number k_m of lines in the first section which can be hunted from the considered idle outlet of the system or in other words the mean number k_m of paths idle behind the first section up to the goal in the last stage is

$$k_m = (i_4 - Y_3) \cdot (1 - Y_2/k_1) \tag{11}$$

Instead of the average availability k_m according to equation (11) we can use with reference to an investigation by DAISENBERGER /19, 2o/ a modified availability k_m^* taking approximately into account the statistical dependence in consecutive sections of the system:

$$k_m^* = (i_4 - Y_3)\cdot\left(1 - \frac{Y_2}{k_1}\right)\cdot\frac{1}{1 - \frac{Y_3}{i_4 t_3}} \tag{12}$$

5.1.3 Point Loss B_{NF}

A call arriving in the considered multiple in the first stage will not be able to occupy an idle line in section 2, if in the first section at least those k_m "visible" lines are occupied. In the case of Pure Chance Traffic No. 1 (PCT 1) we presume an Erlang-distribution on the k_1 lines of the first section. According to the MPJ-formula /1o/ we obtain for the probability $w(k_m)$ that at least certain k_m lines are occupied in the first section:

$$w(k_m) = \frac{E_{k_1}(A_o)}{E_{k_1 - k_m}(A_o)} \tag{13}$$

with

$$Y_1 = A_o \cdot (1 - E_{k_1}(A_o)) \tag{14}$$

If k_m is not an integer number we will to have interpolate.

Remark: On the contrary to the equations (7 a,b) we do not apply a weighting function to take into account the influence of the common control in this case, because the calculation starts from average values and hence such a function does not appear to be justified.

To determine the Point Loss we have to take into consideration additionally that in the goal under consideration there must be at least one idle outlet. If we denote the probability that in the goal all k_s outlets will be occupied by $p_s(k_s)$ and if we assume the states of occupation corresponding to the probabilities $w(k_m)$ ans $p_s(k_s)$ to be statistically independent, we will get for the Point Loss:

$$B_{NF1} = \frac{w(k_m)\cdot(1 - p_s(k_s))}{1 - p(n)} \tag{15 a}$$

$$B_{NF2} = w(k_m)\cdot(1 - p_s(k_s)) \tag{15 b}$$

As already mentioned (cf. the equations (7 a,b)) p(n) is the probability that all outgoing lines are occupied. Since within the range of losses considered $p(n) \ll 1$, the difference between B_{NF1} and B_{NF2} can be disregarded.

5.2 Examples

To check the accuracy of the method derived in section 5.1, we calculate in this section the Point Loss for some 3- and 4-stage systems and compare the results with tests made with artificial traffic. The diagrams including the explanation of the curves are made up at the end of the paper.

We can state generally that the method of the "Average Availability" yields results sufficiently close to reality for 3- and 4-stage link systems (cf. curve 6, diagram 2; curve 4, diagram 3; curves 7 and 8, diagram 4; curves 5 and 6 diagram 5).

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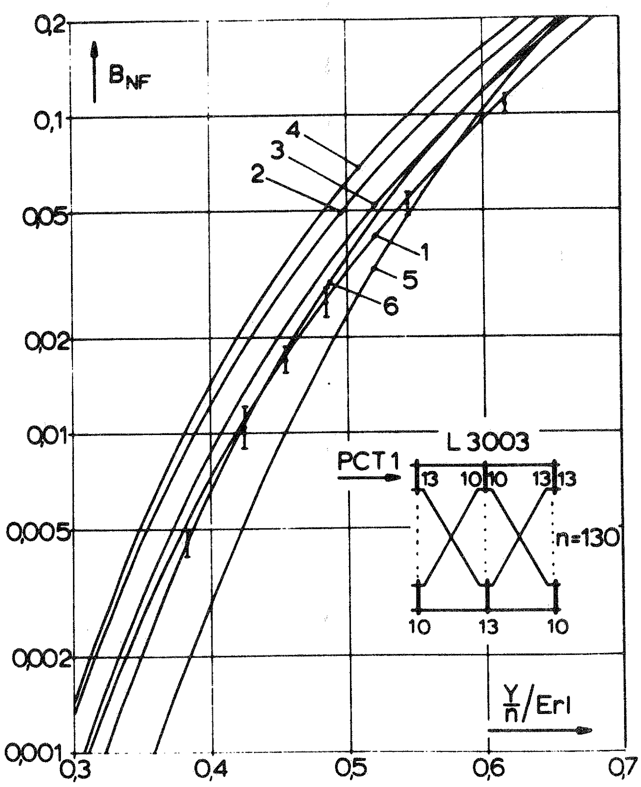

Diagram 2

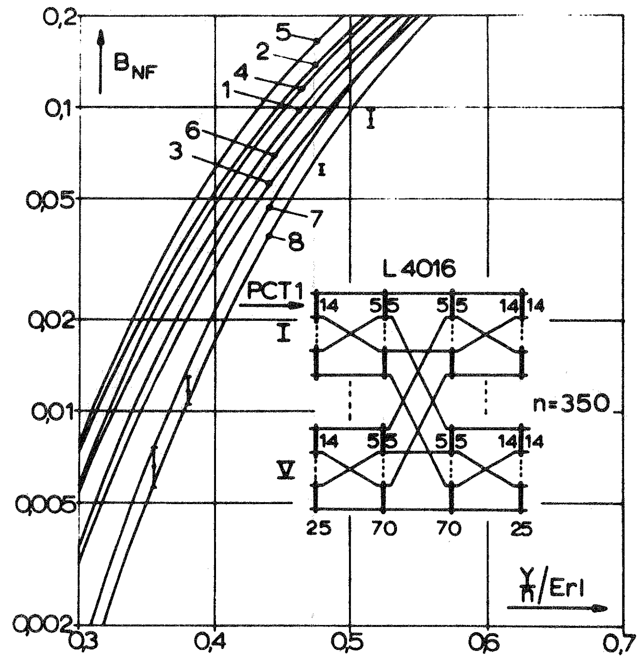

Diagram 4

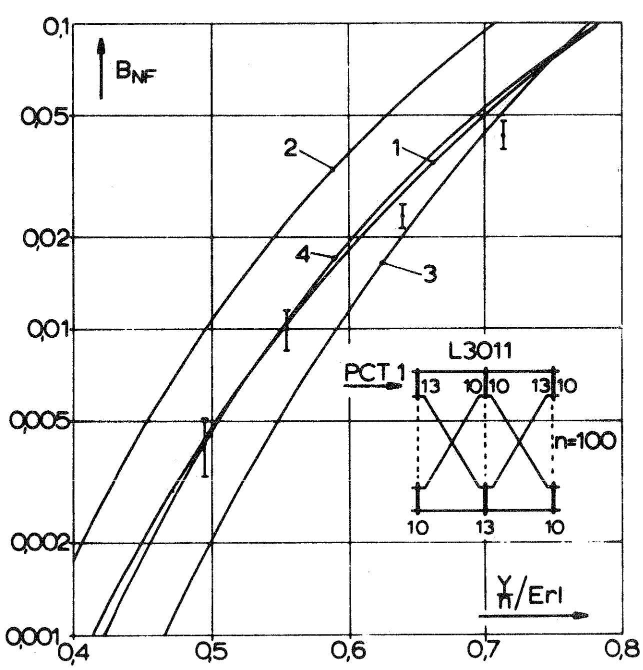

Diagram 3

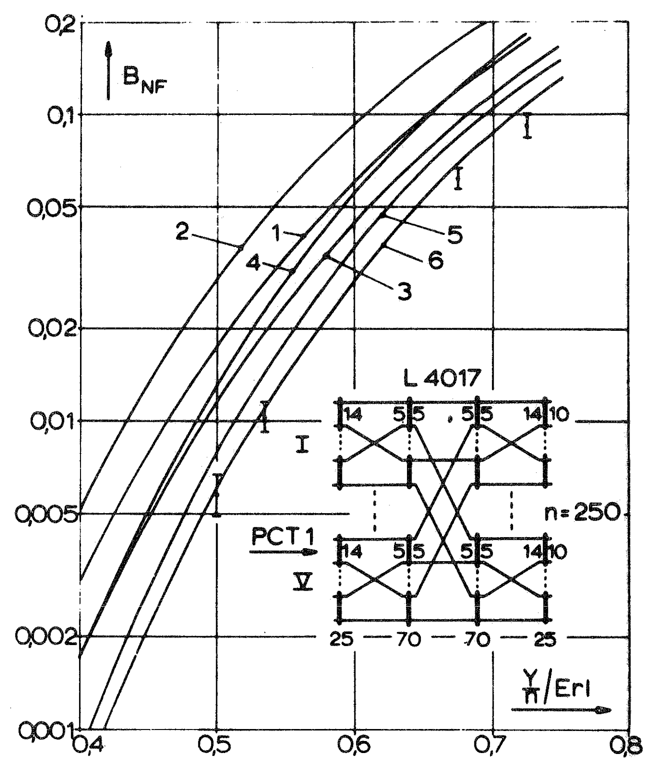

Diagram 5

Diagram	Curve	Explanations	Equations
2	1	Functional dependence; statistical independence	(4) - (7 a,b)
	2	Such as curve 1; influence of the common control not taken into account	(8)
	3	Functional and statistical independence; Erlang-distributions on each section	(4) - (7 a,b)
	4	Such as curve 3; influence of the common control not taken into account	(8)
	5	Functional and statistical independence; Bernoulli-distributions on each section; method of C.Y. LEE /4/	(9)
	6	Average Availability	(1o), (13) - (15 a,b)
3	1	Functional and statistical independence; Erlang-distributions on each section	(4) - (7 a,b)
	2	Such as curve 1; influence of the common control and concentration in the last stage not taken into account	(8)
	3	Functional and statistical independence; Bernoulli-distributions on each section; method of C.Y. LEE /4/	(9)
	4	Average Availability	(1o), (13) - (15 a,b)
4	1	Functional dependence; statistical independence	(4) - (7 a,b)
	2	Such as curve 1; influence of the common control not taken into account	(8)
	3	Such as curve 1; correction according to DAISENBERGER /19, 2o/	(4) - (7 a,b)
	4	Functional and statistical independence	(4) - (7 a,b)
	5	Such as curve 4; influence of the common control not taken into account	(8)
	6	Such as curve 4; correction according to DAISENBERGER /19, 2o/	(4) - (7 a,b)
	7	Average Availability k_m	(11), (13) - (15 a,b)
	8	Modified Average Availability k_m^*	(12) - (15 a,b)
5	1	Functional and statistical independence; Erlang-distributions on each section	(4) - (7 a,b)
	2	Such as curve 1; influence of the common control and concentration in the last stage not taken into account	(8)
	3	Such as curve 1; correction according to DAISENBERGER /19, 2o/	(4) - (7 a,b)
	4	Functional and statistical independence; Bernoulli-distributions on each section; method of C.Y. LEE /4/	(9)
	5	Average Availability k_m	(11), (13) - (15 a,b)
	6)	Modified Average Availability k_m^*	(12) - (15 a,b)