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by

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Introduction

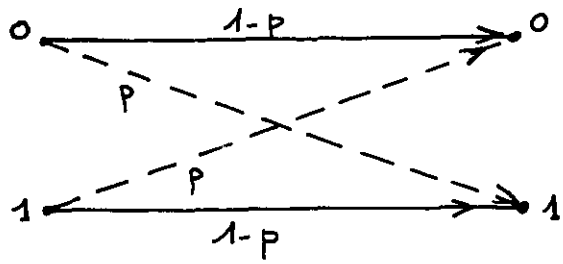
Starting with Viterbi's idea, we shall perform a simulation of the decoding algorithm. Our aim is not to deal with some theoretical aspect of this algorithm, but on the contrary, to give the performances obtained from a computer simulation.

We want to evaluate P_B the bit error probability, as a function of the length of the path register for several values of the channel error probability.

I DECODING ALGORITHM

We invite our readers to consider Viterbi's and Formey's papers [1,2.] as the theoretical background of our work. We shall only point out the main ideas we used to perform our simulation.

1. Minimum distance decoder for Binary Symetric Channel (B.S.C.)

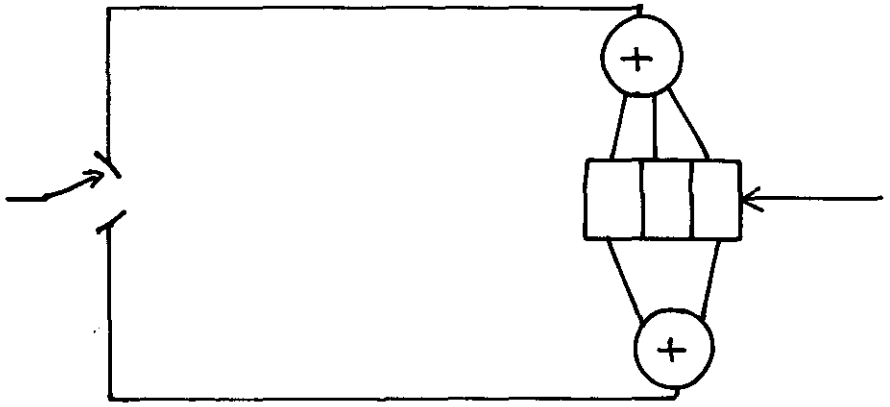


If we assume that the input sequence are equally probable, the appropriate decoder which minimizes the event error probability is the one that examines the received sequence and chooses the data sequence which is closest to the received sequence in the sense of Hamming distance.

2. Convolutional Encoder.

It is time now to introduce the convolutional encoder that we consider. It is composed of K stage, shift register, and n modulo 2 adders.

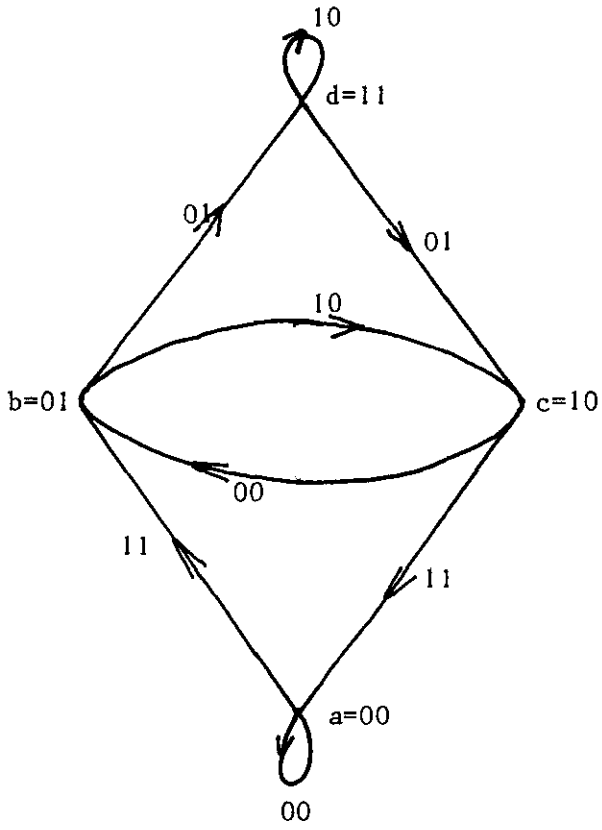
Let us take Viterbi's exemple:



We can see then, that for one data bit we obtain in this case 2 code

bits, Hence then transmission rate will be R = ½.

As it was demonstrated in Viterbi's paper the structure of the algorithm becomes repetitive after two data intervals and we can obtain the following state diagram.



To label the states we may use the last two data bits, while the present data bits determines the transition.

3. Decoding Algorithm.

We now review the several steps of the decoding algorithm:

1. for each state preserve one surviving path and its distance from the received sequence if the distance or metrics of two imerging paths are equal we may simply flip a coin to choose one of them;

2. at any one time we have to memorize the survivor for each state plus the state metrics ans thus one needs two registers for each state;

3. the new survivors and state metrics can be obtained recursively using

the old state metrics and the previous survivors;

4. we have also to introduce some useful modifications. It is necessery to truncate survivors to some manageable length. In other words the algorithm must come to a definite decision on nodes up to time k-1 at time k. We shall call L the path register length.

II DECODING PROGRAM

To help the comprehension of our readers we have drawn a flow-chart which we think will be very usefull to follow the way of programming that we used.
In this section we shall explain the programming of each of the blocks which compose our program running on a PDP 11-20.

B L O C K I

- Declaration of the 6 registers needed.
- Loading of the stack pointer.
- Reservation of the memory locations.
- Declaration of some system adresses used for extended arithmetic unit.

Theses adresses are AC, MQ, SC, SR.

All symbols used haven the following meaning.

PAO : old path for the A state.
PBO : old path for the B state.
PCO : old path for the C state.
PDO : old path for the D state.
PAN : new path for the A state.
PBN : new path for the B state.
PCN : new path for the C state.
MAO : old metric for the A state.
MBN : old metric for the B state.
MCN : old metric for the C state.
MDN : old metric for the D state.
PDN : new path for the D state.

MAN : new metric for the A state.
MBN : new metric for the B state.
MCN : new metric for the C state.
MDN : new metric for the D state.
TEL 1 : counter of one decoded.
TEL 2 : counter of one transmitted.
CD 1 : first binary digit transmitted.
CD 2 : second binary digit transmitted.
DOO : Hamming distance between the transmitted digit and OO.
D 11 : Hamming distance between transmitted digits and 11.
D 10 : Hamming distance between transmitted digits and 10.
L : path register length minus 1.
P : shift counter of B in correspondance with p.
error channel probability.
LG : dummy word to enter L.
PG : dummy word to enter P.
BUF : double word containing Xo in PRG
GETA : double word containing Xo in FLIP
TOUR : word for output editing.
COUNTR: counter of number of cycles.
number of transmitted digits = 2 x COUNTR.

B L O C K 2

Soubroutines PRG and FLIP

These two soubroutines are both Pseudo - Random - Generator PRG, is used to generate. O's and 1's, where 1's appear with probability p. Indeed, if we consider a zero sequence in the input line, the channel will transform some of these O's into 1's and the probability of a 1 at the channel output is p.

FLIP is used to flip a coin when you need to decide between two paths of equal weight in the decoding algorithm.

For both these soubroutines we use a pseudo random generator described in 3.4 In fact we choose the multiplicative congruental method defined by

$Xi+1 = Axi \mod m$

with: Xo relatively prime to m

$A = +3$ or $+5 \mod 8$

in respect with these value the maximum period length would be $2^{31-2}=2^{29}$
as mentioned in [5] we shall start with
Xi: double word
Xo: initial value of Xi = 070707 - 070707
A : will be defined thus as to facilitate the compution Let us take $A = 2^{15}+3$

The product A by Xo will be obtain such:
first: Shift Xo 15 positions to the left
second : Shift Xo 1 position to the left and add the result to first
third : Add Xo to second.

In this way we get a random sequence of number Xi.All these numbers belong to the interval $[1,2^{31}-1]$ Hence, to obtain a binary sequence with $Pr[1] = p$.
We compare the Xi's with the number B, where B satisfies $\frac{B}{2^{31}-1} = p$.

For computing facilities we introduce a corresponding parameter P.,
which gives the number of left - shifts for a "1" in the right most position.

The correspondence with p is given in TABLE 1.
Now we can decide:
If $Xi > B$; we transmit a "0".
If $Xi \leq B$; we transmit a "1".

B L O C K 3

Input parameters L and P

As mentioned previously, we want to check the influence of the path register length L on P_B.

We shall choose L between 2 and 15 in octal 17 (8).

For P let us give the conversion table for input.

p error channel probability	2^{-8}	2^{-7}	2^{-6}	2^{-5}	2^{-4}	2^{-3}	2^{-2}	2^{-1}
P parameter in decimal	23	24	25	26	27	28	29	30
P parameter in octal	27	30	31	32	33	34	35	36

TABLE 1: correspondance table $p^{-n} \rightarrow P$

All datas which are entered with the téletype are in ASC I I code.

The input sequence will then be:

first : type the left most digit

second : use a mask to transform this digit from ASC I I code to octal code

third : shift the input digit 3 positions to the left

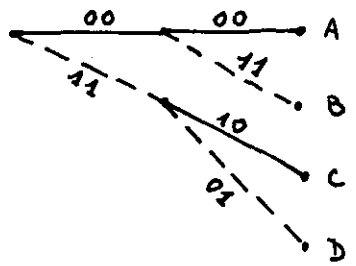
fourth : type the second digit

fifth : use a mask as in second

B L O C K 4

Initialisation

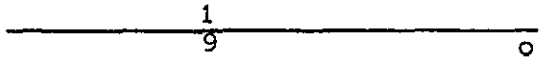
1. All the registers, except R6, are set to o
2. All path registers are set to o
3. The metrics are initialized as follow: (see fig. 2).



4. Set TEL 1 and TEL 2 equal to o, counters of respectively the number of 1's decoded and the number of 1's transmitted.
5. Initialize the counter that keep the track of the number of data bits transmitted.
   To upper bound this counter you have only to consider the simulation time which can be very large; exemple: 2 hours for 2^{31} cycles.
   In fact we choose 2^{16} and 2^{20}.
6. BUF and GETA represent Xo for PRG and FLIP.

B L O C K 5

The maximum length of the path register is 16, i.e. one word. The actual path register length L is obtain with a 1 in the L th position of the path register mask; R2.



Here L = 10

B L O C K 6

To generate the received sequence, assuming the all zero code sequence being transmitted, we use PRG twice each data interval and put the two resulting received digits in CD 1 and CD 2 respectively.

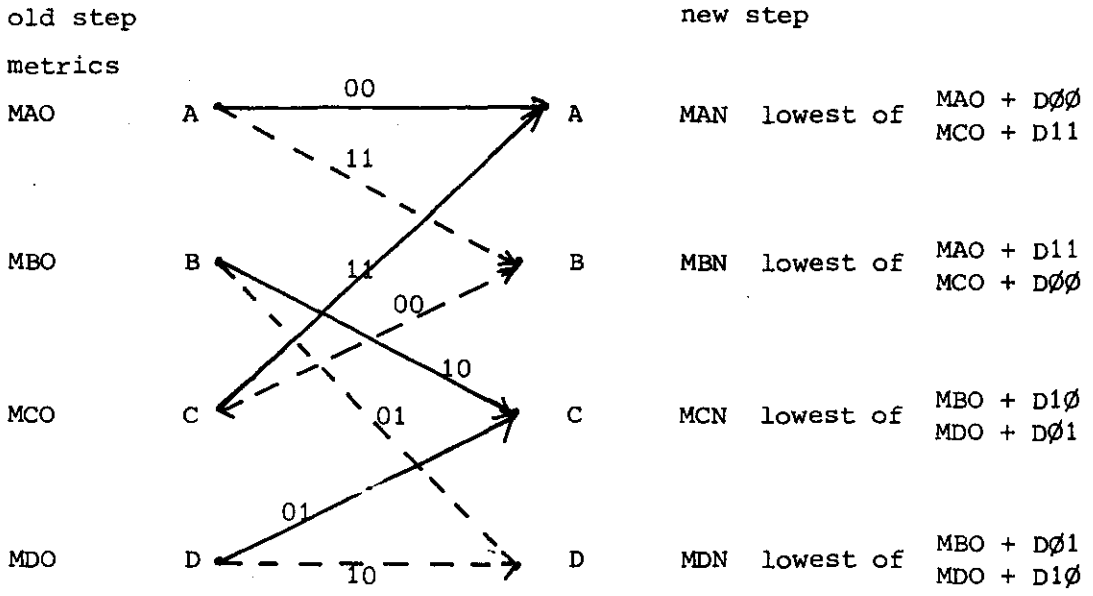
B L O C K 7

Now we are able to compute the Hamming distance between received digits (CD 1, CD 2) and all possible pairs of binary digits of the treillis diagra,.

Then we get : DØØ D11, DØ1, D1Ø

B L O C K 8

In each node, two paths are merging. To choose one of them we have compute their associated metric.



The continuous lines correspond to an information digit O.
The dotted lines correspond to an information digit 1.
For each node, then we follow this algorithm.

first : compute the two metrics associated to the merging path
second : choose the lowest, or if they are equal call FLIP to determine the survivor
third : shift the survivors one position to the left and add a O for the nodes B and D

After this step you get four new paths, one for each node, and you can then considered this new path as the old one for the next step.

B L O C K 9-10

Majority dicision method

Among the four survivors paths we have to choose one a simple method consist

of counting the number of times we meet O or 1 in the L^{th} position of the different survivors. To isolate this bit we can make a bit comparaison between R 2 and each survivor and add the results together.

- Magority decision on O
if the sum is O,1,2 we decide that the data bit was a O
if ths sum is 3,4 we decide that the data bit was a 1

- Magority decision on 1

if the sum is O,1 we decide that the data bit was a O.
if the sum is 2, 3, 4 we decide that the data bit was a 1.
The block 9 is not adbosutely needed, we let it to reinitialize the metrics.

B L O C K 9 bis (Instead of Blocks 9 and 10)

Decide according to survivor with lowest metric

By comparing, it is easy to find the lowest metrics survivor. Then we obtain one survivor.
After comparaison with R 2 we are able to decide if the L^{th} bit of this survivor will be a O or a 1.
According to the result, we increment, or not, counter TEL 1.

P_B is given as the radio of TEL 1 and data bit counter.

B L O C K 11

Output of the results

For each we have to output TEL 1 and TEL 2 then output sequence will be:
first: with a mask isolate the 3 right most digits
second: move these digits to R4
third : add 1 in the 4^{th} and 5^{th} position of R4 Thus, we have now, an ASCI I character

fourth : print it on teletype
fifth : shift TEL 1 three position to the right to transmit the next character and go to first

However, we have to remark that TEL 1 and TEL 2 apprear on the teletype with upper character being the rightmost.

Exemple:

If you read on the teletype 4531 (8)
make the conversion 1354 (8)

B L O C K 12

Incrementation

This program can run itself and we have included a self incrementation for L and P till they reach their maximum values 15 for L;
30 for P.

III RESULTS

We obtain two sets of results for a numer of information digit first 2^{16} and second 2^{20}.
We can expect better results for 2^{31}-1 data digits, but in this case the complete experience would spend 2 hours x 70 = 140 hours!

The first set of results are for the majority decision method.
The latter results are for the method establishing the best survivor.

These results are mentioned both in table and in plot diagram to show the influence of the path register length on P_B.
P is then given as a parameter.

SET I

Results : $P_B\ 10^{-3}$ with magority decision on 1

nota results for magority decision on O and on 1 are closed.

number of cycles 2^{16}

absolute error of p = 2×10^{-5}

L \ P	2^{-7}	2^{-6}	2^{-5}	2^{-4}	2^{-3}
3	27.4	55	69.5	204	369
4	20.1	40.8	82.5	167	337
5	8.9	18.9	42.8	106	281
6	4.8	11.7	28.1	76.6	250
7	0.68	3.04	11.5	48	222
8	0.38	1.97	7.9	36.1	202
9	0.2	1.16	5	26.7	183
10	0.04	0.71	3.1	17.9	170
11	0	0.42	1.8	14.9	159
12	0	0.32	1.25	11.8.	153
13	0	0.29	0.88	9.55	145
14	0	0.2	0.7	7.95	141
15	0	0.12	0.53	6.7	138

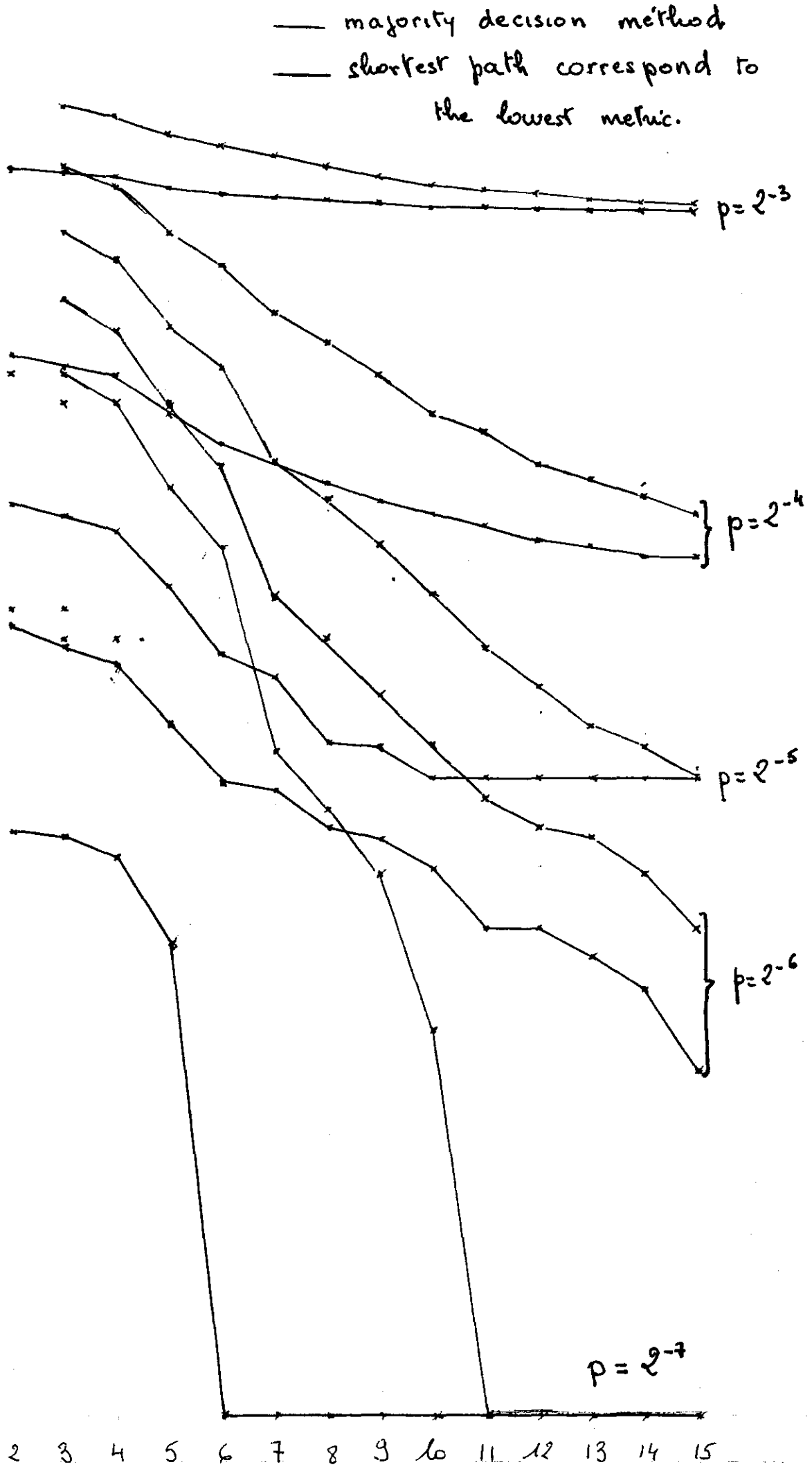
SET II - a

Results: P_B $^{10-3}$ with Deciding according to survivor with lowest metric

Number of cycles 2^{46}

Absolute error on p = 2×10^{-5}

L \ P	2^{-7}	2^{-6}	2^{-5}	2^{-4}	2^{-3}
2	0.308	2.29	7.55	32.6	209
3	0.29	1.83	6.7	28.5	194.5
4	0.244	1.57	5.7	26.2	184
5	0.107	0.885	3.17	17.85	166.5
6	0	0.504	1.74	13.6	155
7		0.457	1.37	11.4	149.5
8		0.32	0.73	9.12	144.5
9		0.29	0.7	7.63	139
10		0.214	0.518	6.8	135.5
11		0.122	0.518	5.93	134
12		0.122	0.518	5.22	131.5
13		0.099	0.518	4.92	130.5
14		0.066	0.518	4.53	130
15		0.03	0.518	4.5	128.5


—— majority decision method
—— shortest path correspond to the lowest metric.
$p = 2^{-3}$
$p = 2^{-4}$
$p = 2^{-5}$
$p = 2^{-6}$
$p = 2^{-7}$
L → 2 3 4 5 6 7 8 9 10 11 12 13 14 15

SET II-b

Results $P_B 10^{-3}$ with deciding according to survivor with lowest metric

Number of cycle 2^{20}

absolute error on p 5.10^{-5}

L \ P	2^{-7}	2^{-6}	2^{-5}
2	0.248	1.98	6.85
3	0.312	1.63	6.04
4	0.22	1.32	5.3
5	0.133	0.68	2.94
6	0	0.3	1.7
7	0	0.26	1.34
8	0.01	0.20	0.82
9		0.17	0.73
10		0.11	0.56
11		0.07	0.55
12		0.07	0.55
13		0.05	0.53
14		0.03	0.52
15		0.01	0.54

IV How to use these programs

The people who wish to run themself these programs can make it very easily:

first: choose one of the three paper punch tapes corresponding to each set.
These programs are written in P.A.L. (Assembleur Language of the PDP 11) and must be run on PDP 11-20 with additional arithmetric element for working with double lenght word;

second: start the program a first time with address 2000 and a second time with address 2420. The program is waiting for parameters L and P;

third : type from teletype the choosen values of L and P. Thus the program would run;

output: you will received 70 couples of datas, each corresponding to a complete cycle. The first value divided by the number if cycle will be P_B.
The second divided by 2 times the number of cycle will be P.

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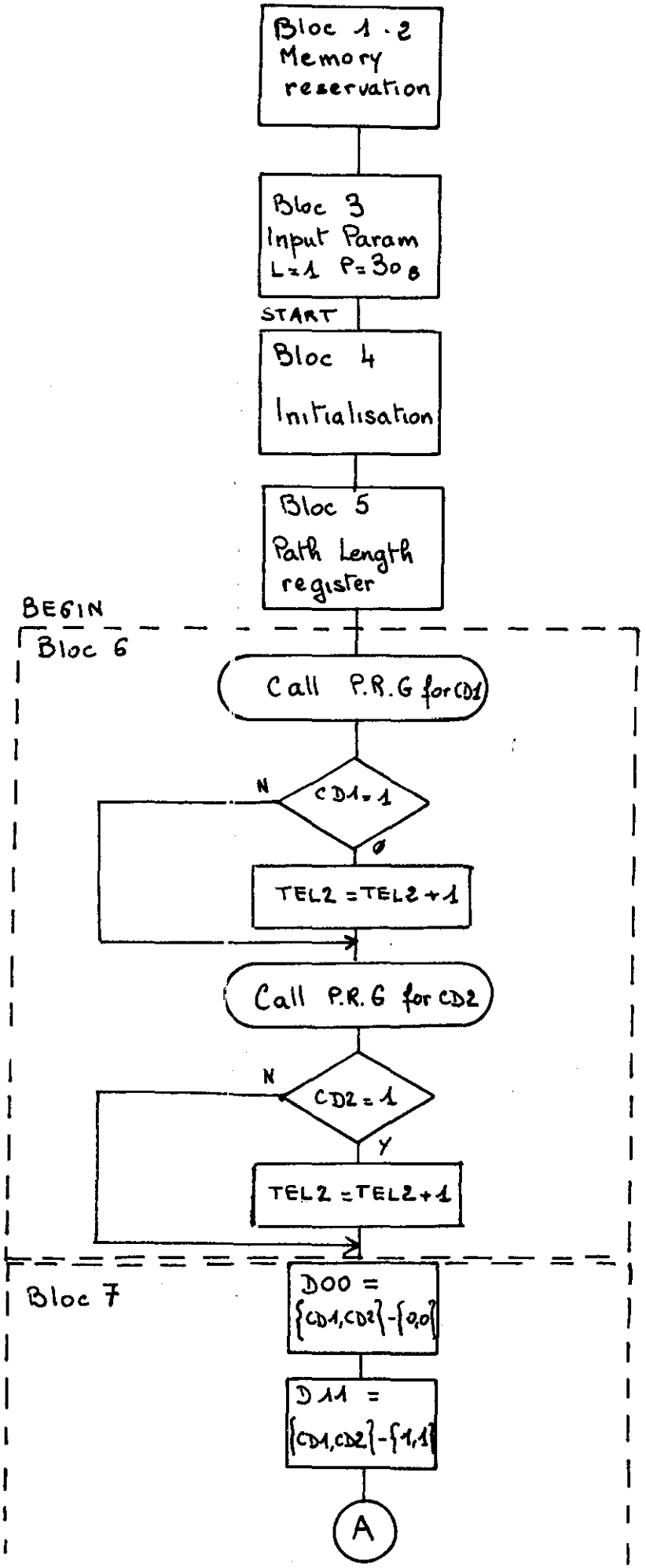
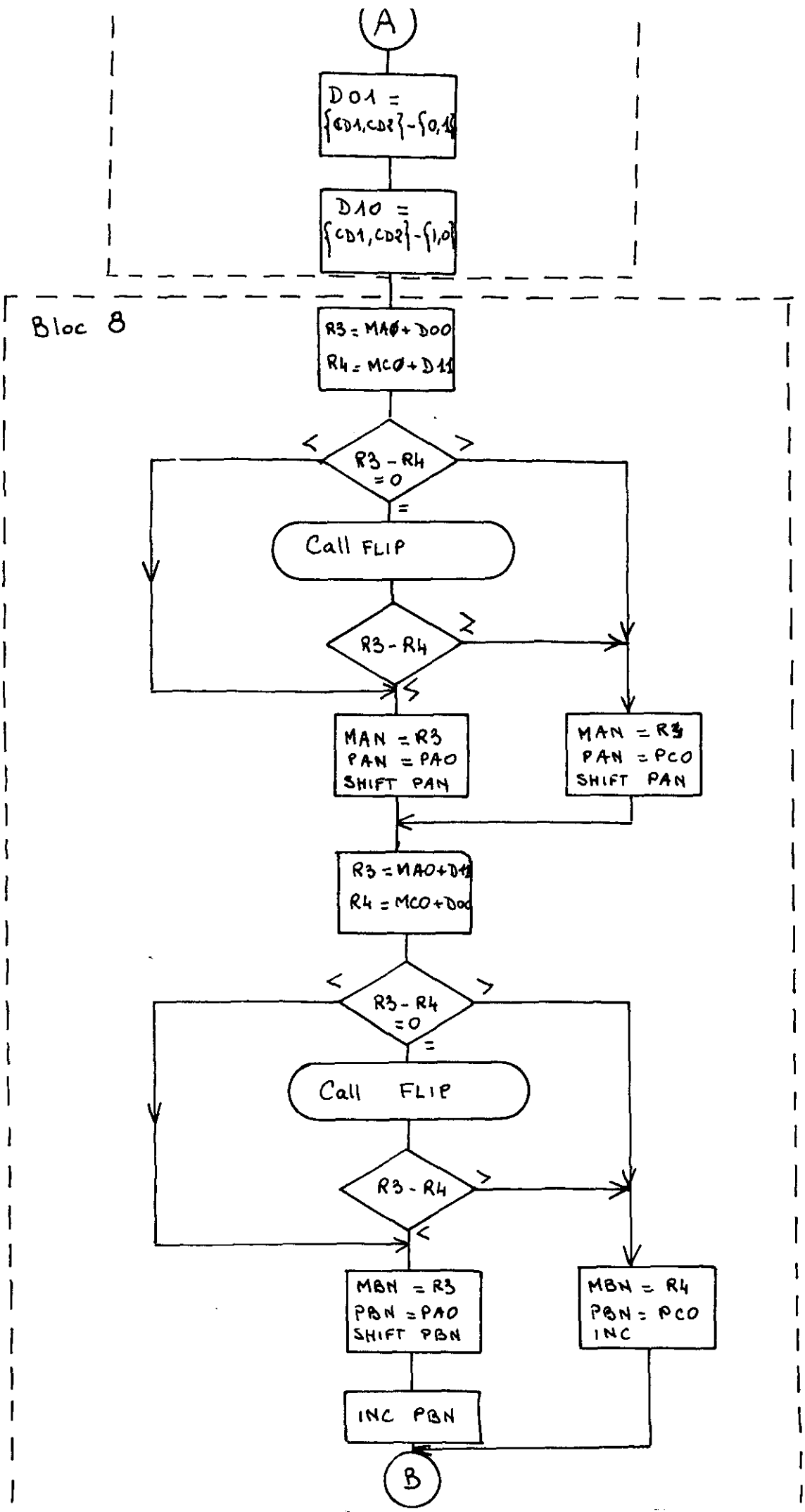
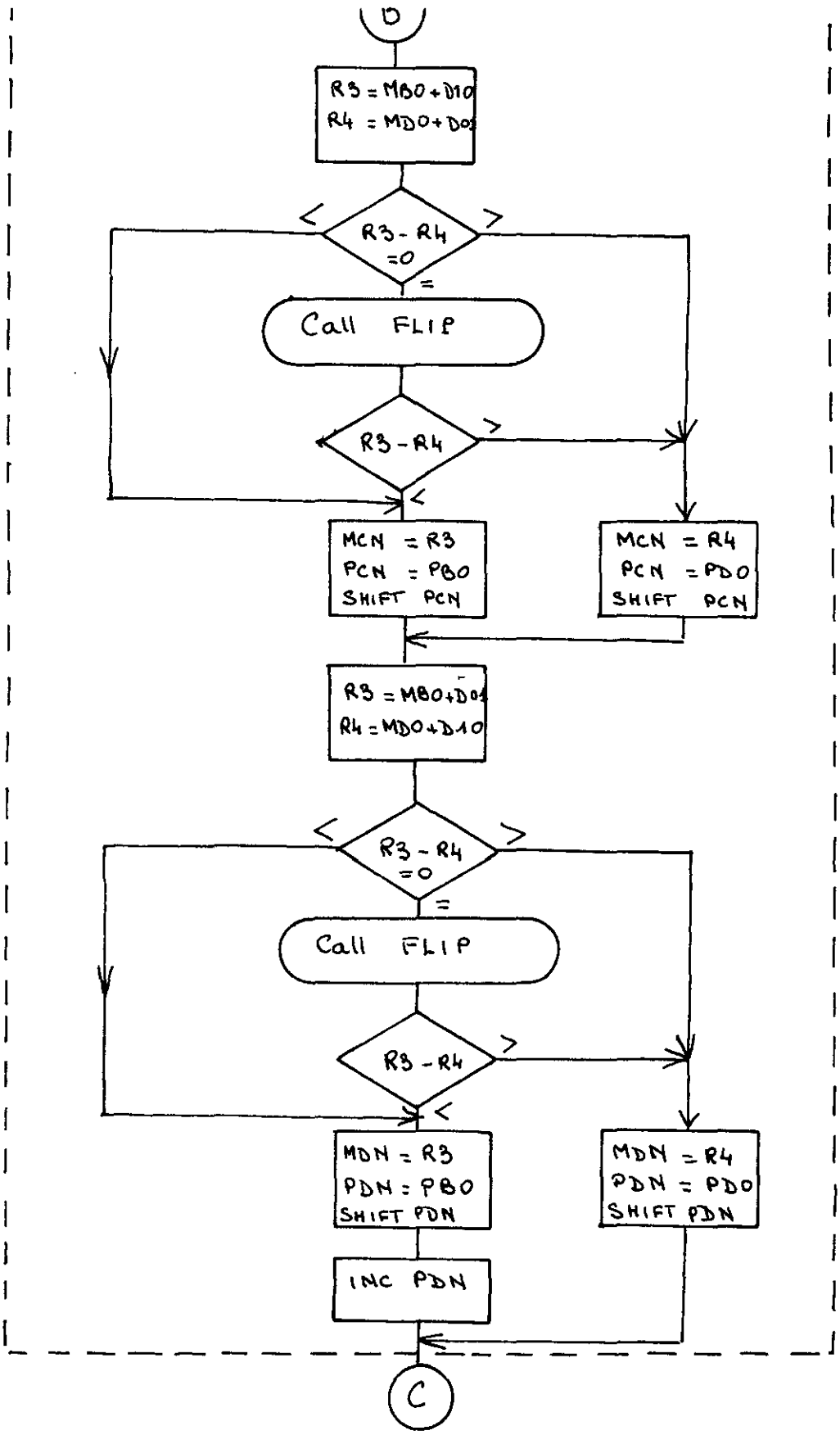
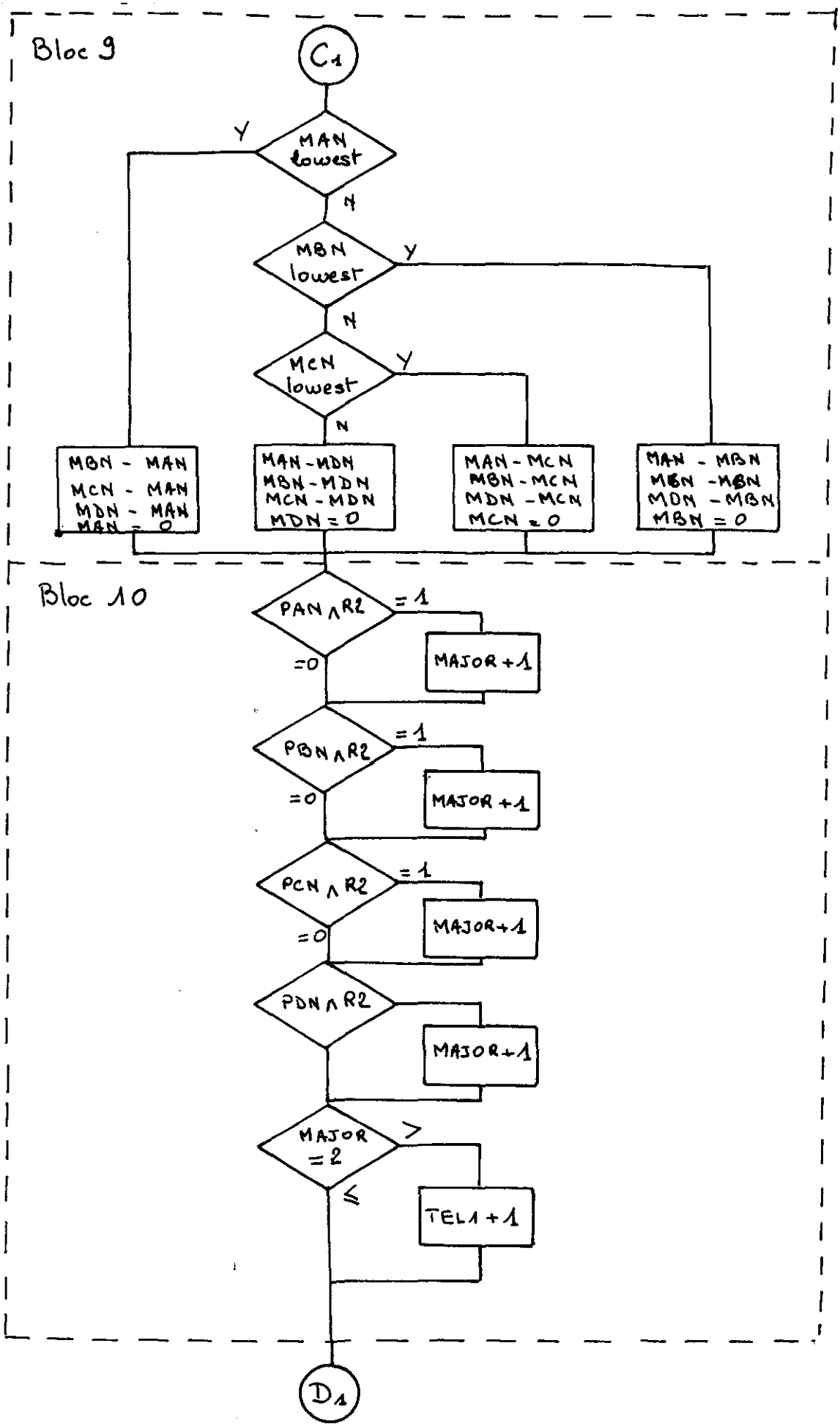
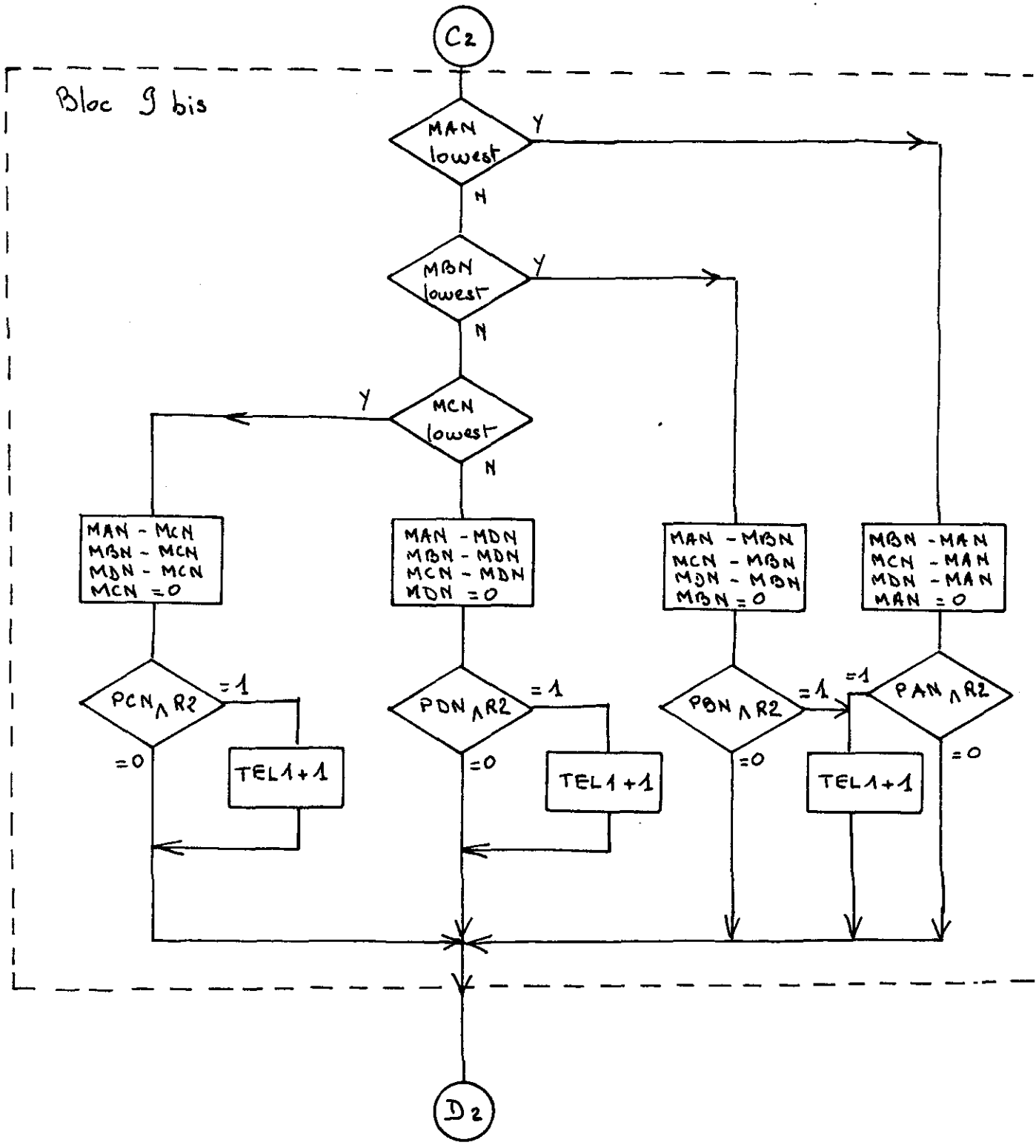
FLOW CHART

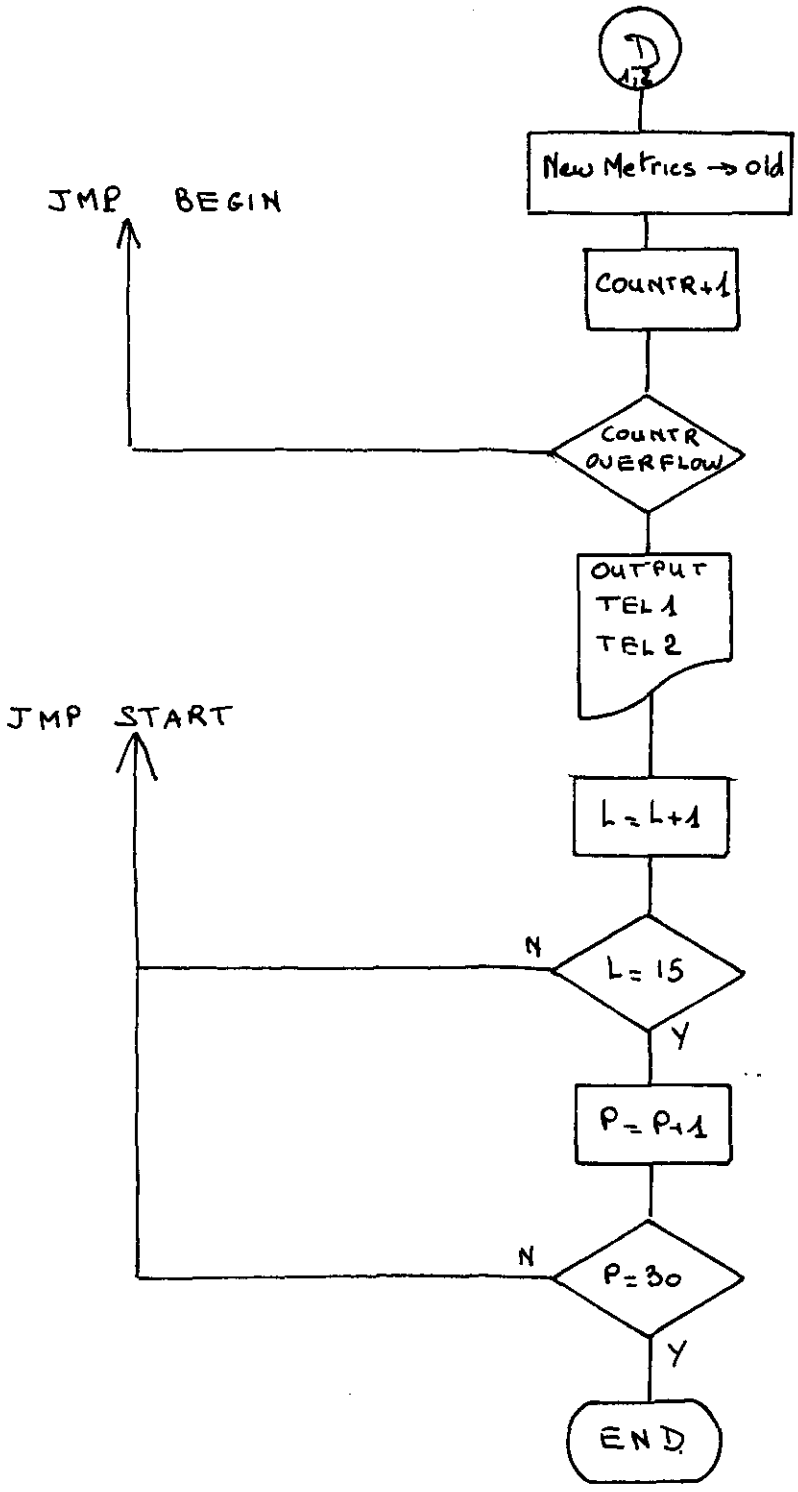

Bloc 1 . 2
Memory
reservation
Bloc 3
Input Param
L=1 P=30 8
START
Bloc 4
Initialisation
Bloc 5
Path Length
register
BEGIN
Bloc 6
Call P.R.G for CD1
N
CD1 = 1
0
TEL2 = TEL2 + 1
Call P.R.G for CD2
N
CD2 = 1
Y
TEL2 = TEL2 + 1
Bloc 7
D00 =
{CD1, CD2} - {0,0}
D11 =
{CD1, CD2} - {1,1}
A


A
D01 = {CD1, CD2} - {0,1}
D10 = {CD1, CD2} - {1,0}
Bloc 8
R3 = MA0 + D00
R4 = MC0 + D11
R3 - R4 = 0
<
=
>
Call FLIP
R3 - R4
>
<
MAN = R3
PAN = PA0
SHIFT PAN
MAN = R3
PAN = PC0
SHIFT PAN
R3 = MA0 + D11
R4 = MC0 + D00
R3 - R4 = 0
<
=
>
Call FLIP
R3 - R4
>
<
MBN = R3
PBN = PA0
SHIFT PBN
MBN = R4
PBN = PC0
INC
INC PBN
B


D
R3 = MB0 + D10
R4 = MD0 + D0
R3 - R4 =0
<
>
=
Call FLIP
R3 - R4
>
<
MCN = R3
PCN = PB0
SHIFT PCN
MCN = R4
PCN = PD0
SHIFT PCN
R3 = MB0+D0
R4 = MD0+D10
R3 - R4 =0
<
>
=
Call FLIP
R3 - R4
>
<
MDN = R3
PDN = PB0
SHIFT PDN
MDN = R4
PDN = PD0
SHIFT PDN
INC PDN
C


Bloc 9
C1
MAN lowest
Y
N
MBN lowest
Y
N
MCN lowest
Y
N
MBN - MAN
MCN - MAN
MDN - MAN
MAN = 0
MAN - MDN
MBN - MDN
MCN - MDN
MDN = 0
MAN - MCN
MBN - MCN
MDN - MCN
MCN = 0
MAN - MBN
MBN - MBN
MDN - MBN
MBN = 0
Bloc 10
PAN ∧ R2
= 1
=0
MAJOR + 1
PBN ∧ R2
= 1
=0
MAJOR + 1
PCN ∧ R2
= 1
=0
MAJOR + 1
PDN ∧ R2
MAJOR + 1
MAJOR = 2
>
≤
TEL1 + 1
D1


C2
Bloc 9 bis
MAN lowest
Y
N
MBN lowest
Y
N
MCN lowest
Y
N
MAN - MCN
MBN - MCN
MDN - MCN
MCN = 0
MAN - MDN
MBN - MDN
MCN - MDN
MDN = 0
MAN - MBN
MCN - MBN
MDN - MBN
MBN = 0
MBN - MAN
MCN - MAN
MDN - MAN
MAN = 0
PCN ∧ R2
=1
=0
TEL1+1
PDN ∧ R2
=1
=0
TEL1+1
PBN ∧ R2
=1
=0
TEL1+1
PAN ∧ R2
=1
=0
D2


D
New Metrics → old
JMP BEGIN
COUNTR+1
COUNTR OVERFLOW
OUTPUT
TEL 1
TEL 2
JMP START
L = L+1
N
L = 15
Y
P = P+1
N
P = 30
Y
END

```
          002000  .=2000
          000000  R0=%0
          000001          R1=%1
          000002          R2=%2
          000003          R3=%3
          000004          R4=%4
          000005          R5=%5
          000006  SP=%6
          177560          TKS=177560
          177562          TKB=177562
          177564          TPS=177564
          177566          TPB=177566
 002000   012706  MOV   #2000,SP
002000
 002004   000000  PA0:      .WORD 0
 002006   000000  PB0:      .WORD 0
 002010   000000  PC0:      .WORD 0
 002012   000000  PD0:      .WORD 0
 002014   000000  PAN:      .WORD 0
 002016   000000  PBN:      .WORD 0
 002020   000000  PCN:      .WORD 0
 002022   000000  PDN:      .WORD 0
 002024   000000  MA0:      .WORD 0
 002026   000000  MB0:      .WORD 0
 002030   000000  MC0:      .WORD 0
 002032   000000  MD0:      .WORD 0
 002034   000000  MAN:      .WORD 0
 002036   000000  MBN:      .WORD 0
 002040   000000  MCN:      .WORD 0
 002042   000000  MDN:      .WORD 0
 002044   000000  TEL1:     .WORD 0,0
 002046   000000
 002050   000000  TEL2:     .WORD 0,0
 002052   000000
 002054   000000  CD1:      .WORD 0
 002056   000000  CD2:      .WORD 0
 002060   000000  D00:      .WORD 0
 002062   000000  D11:      .WORD 0
 002064   000000  D01:      .WORD 0
 002066   000000  D10:      .WORD 0
 002070   000000  L:        .WORD 0
 002072   000000  P:        .WORD 0
 002074   000000  LG:.WORD 0
 002076   000000  PE:.WORD 0
 002100   000000  BUF:      .WORD 0,0
 002102   000000
 002104   000000  GETA:     .WORD 0,0
 002106   000000
 002110   000000  COUNTR:   .WORD 0,0
 002112   000000
 002114   000000  TOUR:.WORD 0
          177302          AC=177302
          177304          MQ=177304
          177310          SC=177310
          177311          SR=177311
```

Bloc 1

```
                177316          ASH=177316
 002116 000000 TAMP:    .WORD 0,0
 002120 000000
 002122 000000 DUMY:.WORD 0,0
 002124 000000
 002126 012501 PRG:MOV  (R5)+,R1
 002130 013503 MOV  @(R5)+,R3
 002132 012700 MOV  #AC,R0
177302
 002136 016110 MOV  2(R1),(R0)
000002
 002142 011160 MOV  (R1),2(R0)
000002
 002146 012767 MOV  #15.,ASH
000017
175142
 002154 016067 MOV  2(R0),TAMP
000002
177734
 002162 011067 MOV  (R0),TAMP+2
177732
 002166 016110 MOV  2(R1),(R0)
000002
 002172 011160 MOV  (R1),2(R0)
000002
 002176 012767 MOV  #1,ASH
000001
175112
 002204 066067 ADD  2(R0),TAMP
000002
177704
 002212 005567 ADC  TAMP+2
177702
 002216 061067 ADD  (R0),TAMP+2
177676
 002222 066711 ADD  TAMP,(R1)
177670
 002226 005561 ADC  2(R1)
000002
 002232 066761 ADD  TAMP+2,2(R1)
177662
000002
 002240 042761 BIC  #100000,2(R1)
100000
000002
 002246 005060 CLR  2(R0)
000002
 002252 005260 INC  2(R0)
000002
 002256 005010 CLR  (R0)
 002260 010367 MOV  R3,ASH
175032
 002264 021061 CMP  (R0),2(R1)
000002
 002270 000205 RTS  R5
 002272 012501 FLIP:MOV  (R5)+,R1
```

bloc 2 . P.R.G

```
 002300 011160 MOV  (R1),2(R0)
000002
 002304 016110 MOV  2(R1),(R0)
000002
 002310 012767 MOV  #15.,ASH
000017
175000
 002316 016067 MOV  2(R0),DUMY
000002
177576
 002324 011067 MOV  (R0),DUMY+2
177574
 002330 011160 MOV  (R1),2(R0)
000002
 002334 016110 MOV  2(R1),(R0)
000002
 002340 012767 MOV  #1,ASH
000001
174750
 002346 066067 ADD  2(R0),DUMY
000002
177546
 002354 005567 ADC  DUMY+2
177544
 002360 061067 ADD  (R0),DUMY+2
177540
 002364 066711 ADD  DUMY,(R1)
177532
 002370 005561 ADC  2(R1)
000002
 002374 066761 ADD  DUMY+2,2(R1)
177524
000002
 002402 042761 BIC  #100000,2(R1)
100000
000002
 002410 022761 CMP  #40000,2(R1)
040000
000002
 002416 000205 RTS  R5
 002420 005267 INC TKS
175134
 002424 105767 KLA0:TSTB  TKS
175130
 002430 100375 BPL  KLA0
 002432 016767 MOV  TKB,LG
175124
177434
 002440 042767 BIC  #177760,LG
177760
177426
 002446 016767 MOV  LG,L
177422
177414
```

Bloc 2

FLIP

← Starting address

Blue 3

```
 002454 006367 ASL   L
177410
 002460 006367 ASL   L
177404
 002464 006367 ASL   L
177400
 002470 005267 INC   TKS
175064
 002474 105767 KLA1: TSTB TKS
175060
 002500 100375 BPL   KLA1
 002502 016767 MOV   TKB,LG
175054
177364
 002510 042767 BIC   #177760,LG
177760
177356
 002516 066767 ADD   LG,L
177352
177344
 002524 005267 INC   TKS
175030
 002530 105767 LUS0: TSTB TKS
175024
 002534 100375 BPL   LUS0
 002536 016767 MOV   TKB,PE
175020
177332
 002544 042767 BIC   #177760,PE
177760
177324
 002552 016767 MOV   PE,P
177320
177312
 002560 006367 ASL   P
177306
 002564 006367 ASL   P
177302
 002570 006367 ASL   P
177276
 002574 005267 INC   TKS
174760
 002600 105767 LUS1: TSTB TKS
174754
 002604 100375 BPL   LUS1
 002606 016767 MOV   TKB,PE
174750
177262
 002614 042767 BIC   #177760,PE
177760
177254
 002622 066767 ADD   PE,P
177250
177242
 002630 005001 START:  CLR   R1
 002632 005002         CLR   R2
```

Bloc 3

```
 002634 005003          CLR   R3
 002636 005004          CLR   R4
 002640 005005          CLR   R5
 002642 005067           CLR   PAO
177136
 002646 005067          CLR   PBO
177134
 002652 005067          CLR   PCO
177132
 002656 005067          CLR   PDO
177130
 002662 005067          CLR   PAN
177126
 002666 005067          CLR   PBN
177124
 002672 005067          CLR   PCN
177122
 002676 005067          CLR   PDN
177120
 002702 012767          MOV   #2,MBJ
000002
177116
 002710 012767          MOV   #3,MCJ
000003
177112
 002716 012767          MOV   #3,MDJ
000003
177106
 002724 005067          CLR   MAO
177074
 002730 005067          CLR   TEL1
177110
 002734 005067          CLR   TEL2
177110
 002740 005067 CLR   COUNTR
177144
 002744 012767 MOV   #077600,COUNTR+2
077600
177140
 002752 012767 MOV   #177777,BUF
177777
177120
 002760 012767 MOV   #177777,BUF+2
177777
177114
 002766 012767 MOV   #177777,GETA
177777
177110
 002774 012767 MOV   #177777,GETA+2
177777
177104
 003002 016703 MOV   L,R3
177062
 003006 005202          INC   R2
 003010 006302 BOUCLE: ASL   R2
```

Bloc 4

```
 003012 005367          DEC   L
177052
 003016 001374          BNE   BUCLE
 003020 010367 MOV   R3,L
177044
 003024 004567 BEGIN:   JSR   R5,PRG
177076

 003030 002100          .WORD BUF
 003032 002072          .WORD  P
 003034 100003          BPL   EEN
 003036 005067          CLR   CD1
177012
 003042 000410          BR   TWEE
 003044 012767 EEN:     MOV   #1,CD1
000001
177002
 003052 062767 ADD   #1,TEL2
000001
176770
 003060 005567 ADC   TEL2+2
176766
 003064 004567 TWEE:    JSR R5,PRG
177036
 003070 002100          .WORD  BUF
 003072 002072          .WORD P
 003074 100003          BPL   ONE
 003076 005067          CLR   CD2
176754
 003102 000410          BR   TWO
 003104 012767 ONE:     MOV   #1,CD2
000001
176744
 003112 062767 ADD   #1,TEL2
000001
176730
 003120 005567 ADC   TEL2+2
176726
 003124 016703 TWO:     MOV   CD1,R3
176724

 003130 066703          ADD   CD2,R3
176722
 003134 010367          MOV   R3,D00
176720
 003140 012703          MOV   #2,R3
000002
 003144 166703          SUB   CD1,R3
176704
 003150 166703          SUB   CD2,R3
176702
 003154 010367          MOV   R3,D11
176702
 003160 012703          MOV   #1,R3
000001
 003164 066703          ADD   CD1,R3
176664
```

Bloc 5

Bloc 6

```
 003170 166703           SUB   CD2,R3
176662
 003174 010367           MOV   R3,D01
176664
 003200 012703           MOV   #1,R3
000001
 003204 166703           SUB   CD1,R3
176644
 003210 066703           ADD   CD2,R3
176642
 003214 010367           MOV   R3,D10
176646
 003220 016703           MOV   MAO,R3
176600
 003224 066703           ADD   D00,R3
176630
 003230 016704           MOV   MCO,R4
176574
 003234 066704           ADD   D11,R4
176622
 003240 020304           CMP   R3,R4
 003242 001406           BEQ   GELA
 003244 100011           BPL   A
 003246 010367 ATOG:     MOV   R3,MAN
176562

 003252 006367           ASL   PAN
176536
 003256 000413           BR    B
 003260 004567 GELA:     JSR   R5,FLIP
177006

 003264 002104           .WORD GETA
 003266 100367           BPL   ATOG
 003270 010467 A:         MOV   R4,MAN
176540
 003274 016767           MOV   PCO,PAN
176510
176512
 003302 006367 ASL   PAN
176506
 003306 016703 B:MOV   MAO,R3
176512
 003312 066703 ADD   D11,R3
176544
 003316 016704       MOV   MCO,R4
176506
 003322 066704           ADD   D00,R4
176532
 003326 020304           CMP   R3,R4
 003330 001413           BEQ   GELC
 003332 100016           BPL   C
 003334 010367 CTOG:     MOV   R3,MBN
176476
 003340 016767         MOV   PAO,PBN
176440
176450
```

Bloc. 7

Bloc 8

```
 003346 006367          ASL   PBN
176444
 003352 005267          INC   PBN
176440
 003356 000415          BR    D
 003360 004567 GELC:    JSR   R5,FLIP
176706
 003364 002104          .WORD GETA
 003366 100362          BPL   CTDG
 003370 010467 C:       MOV   R4,MBN
176442
 003374 016767          MOV   PCD,PBN
176410
176414
 003402 006367          ASL   PBN
176410

 003406 005267          INC   PBN
176404
 003412 016703 D:       MOV   MBD,R3
176410
 003416 066703          ADD   D10,R3
176444
 003422 016704          MOV   MDD,R4
176404
 003426 066704          ADD   D01,R4
176432
 003432 020304          CMP   R3,R4
 003434 001411          BEQ   GEGE
 003436 100014          BPL   E
 003440 010367 ETDG:    MOV R3,MCN
176374
 003444 016767          MOV   PBD,PCN
176336
176346
 003452 006367          ASL   PCN
176342
 003456 000413          BR    F
 003460 004567 GEGE:    JSR   R5,FLIP
176606
 003464 002104          .WORD GETA
 003466 100364          BPL   ETDG
 003470 010467 E:       MOV   R4,MCN
176344
 003474 016767          MOV   PDD,PCN
176312
176316
 003502 006367          ASL   PCN
176312
 003506 016703 F:       MOV   MBD,R3
176314
 003512 066703          ADD   D01,R3
176346
 003516 016704          MOV   MDD,R4
176310
 003522 066704          ADD   D10,R4
176340
```

Bloc 8

```
 003526 020304          CMP   R3,R4
 003530 001413          BEQ   GELG
 003532 100416          BPL   G
 003534 013367 GTJG:    MOV   R3,MDN
176302
 003540 016767          MOV   PBJ,PDN
176242
176254
 003546 006367          ASL   PDN
176250
 003552 005267          INC   PDN
176244
 003556 000412          BR    H
 003560 004567 GELG:    JSR R5,FLIP
176506
 003564 002104          .WORD GETA
 003566 100362          BPL   GTJG
 003570 010467 G:        MOV   R4,MDN
176246
 003574 006367          ASL   PDN
176222

 003600 005267          INC   PDN
176216
 003604 016767 H:        MOV   PAN,PAJ
176204
176172
 003612 016767          MOV   PBN,PBJ
176200
176166
 003620 016767          MOV   PCN,PCJ
176174
176162
 003626 016767          MOV   PDN,PDJ
176170
176156
```

Bloc 8

```
 003634 026767          CMP   MAN,MBN
176174
176174
 003642 001403          BEQ   GBA
 003644 100410          BMI   ALI
 003646 000167          JMP   VAB
000154
 003652 004567 GBA:     JSR   R5,FLIP
176414
 003656 002104          .WORD GETA
 003660 100002          BPL   ALI
 003662 000167          JMP   VAB
000140

 003666 026767 ALI:      CMP   MAN,MCN
176142
176144
```

Bloc 9 bis

```
 003674 001403            BEQ  GCA

 003676 100410            BMI  AL2
 003700 000167            JMP  VAC
000262
 003704 004567 GCA:       JSR  R5,FLIP
176362
 003710 002104            .WORD GETA
 003712 100002            BPL  AL2
 003714 000167            JMP  VAC
000246
 003720 026767 AL2:       CMP  MAN,MDN
176110
176114
 003726 001403            BEQ  GDA
 003730 100410            BMI  AL3
 003732 000167 JMP  VAD
000336
 003736 004567 GDA:       JSR  R5,FLIP
176330
 003742 002104            .WORD GETA
 003744 100002            BPL  AL3
 003746 000167            JMP  VAD
000322

 003752 166767 AL3:       SUB  MAN,MBN
176056
176056
 003760 166767            SUB      MAN,MCN
176050
176052
 003766 166767            SUB  MAN,MDN
176042
176046
 003774 005067            CLR  MAN
176034
 004000 016703            MOV  PAN,R3
176010
 004004 030203            BIT  R2,R3
 004006 001556            BEQ  KLAAR
 004010 062767 ADD  #1,TEL1
000001
176026
 004016 005567 ADC  TEL1+2
176024
 004022 000167            JMP  KLAAR
000316
 004026 026767 VAB:       CMP  MBN,MCN
176004
176004
 004034 001403            BEQ  GCB
 004036 100410            BMI  JL3
 004040 000167            JMP  VAC
000122
 004044 004567 GCB:JSR  R5,FLIP
176222
```

Bloc 9bis

> OLA

```
 004050 002104          .WORD GETA
 004052 100002          BPL   OL1
 004054 000167          JMP   VAC
000106
 004060 026767 OL1:           CMP   MBN,MDN
175752
175754
 004066 001403          BEQ   GDB
 004070 100410          BMI   OL2
 004072 000167 JMP   VAD
000176
 004076 004567 GDB:     JSR   R5,FLIP
176170
 004102 002104          .WORD  GETA
 004104 100002          BPL   OL2
 004106 000167          JMP   VAD
000162
 004112 166767 OL2:     SUB   MBN,MAN
175720
175714

 004120 166767          SUB   MBN,MCN
175712
175712
 004126 166767          SUB   MBN,MDN
175704
175706
 004134 005067          CLR   MBN
175676
 004140 016703          MOV   PBN,R3
175652
 004144 030203          BIT   R2,R3
 004146 001476          BEQ   KLAAR
 004150 062767 ADD   #1,TEL1
000001
175666
 004156 005567 ADC   TEL1+2
175664
 004162 000167          JMP   KLAAR
000156
 004166 026767 VAC:           CMP   MCN,MDN
175646
175646
 004174 001403          BEQ   GDC
 004176 100410          BMI   EL1
 004200 000167          JMP   VAD
000070
 004204 004567 GDC:           JSR   R5,FLIP
176062
 004210 002104          .WORD GETA
 004212 100002          BPL   EL1
 004214 000167          JMP   VAD
000054
 004220 166767 EL1:           SUB   MCN,MAN
175614
175606
```

Bloc 9 bis

```
 004226 166767          SUB   MCN,MBN
175606
175602
 004234 166767          SUB   MCN,MDN
175600
175600
 004242 005067          CLR   MCN
175572
 004246 016703          MOV   PCN,R3
175546
 004252 030203          BIT   R2,R3
 004254 001433          BEQ   KLAAR
 004256 062767 ADD   #1,TEL1
000001
175560
 004264 005567 ADC   TEL1+2
175556
 004270 000167          JMP KLAAR
000050
 004274 166767 VAD:           SUB   MDN,MAN
175542
175532
 004302 166767          SUB   MDN,MBN
175534
175526
 004310 166767          SUB   MDN,MCN
175526
175522
 004316 005067          CLR   MDN
175520
 004322 016703          MOV   PDN,R3
175474
 004326 030203          BIT   R2,R3
 004330 001405          BEQ   KLAAR
 004332 062767 ADD   #1,TEL1
000001
175504
 004340 005567 ADC   TEL1+2
175502
 004344 016767 KLAAR:      MOV   MAN,MA)
175464
175452
 004352 016767          MOV   MBN,MB)
175460
175446
 004360 016767          MOV   MCN,MC)
175454
175442
 004366 016767          MOV   MDN,MD)
175450
175436
 004374 062767 ADD   #1,COUNTR
000001
175506
 004402 005567          ADC   COUNTR+2
175504
```

Bloc 9 bis

```
 004406 102402          BVS   OUT
 004410 000167          JMP   BEGIN
176410
 004414 022767 OUT:CMP   #0,TOUR
000000
175472
 004422 001406 BEQ   CAR
 004424 022767 CMP   #2,TOUR
000002
175462
 004432 001016 BNE   GOON
 004434 005067 CLR   TOUR
175454
 004440 105767 CAR:TSTB  TPS
173120
 004444 100375 BPL   CAR
 004446 012767 MOV   #15,TPB
000015
173112
 004454 105767 LF:TSTB   TPS
173104
 004460 100375 BPL   LF
 004462 012767 MOV   #12,TPB
000012
173076
 004470 005267 GOON:INC  TOUR
175420
 004474 012700 MOV   #AC,R0
177302
 004500 016760 MOV   TEL1,2(R0)
175340
000002
 004506 016710 MOV   TEL1+2,(R0)
175334
 004512 012703 MOV   #11.,R3
000013
 004516 016004 LOOP1:MOV  2(R0),R4
000002
 004522 042704 BIC   #177770,R4
177770
 004526 062704 ADD   #60,R4
000060
 004532 105767 EDIT1:TSTB TPS
173026
 004536 100375 BPL   EDIT1
 004540 010467 MOV   R4,TPB
173022
 004544 012767 MOV   #-3,ASH
177775
172544
 004552 005303 DEC   R3
 004554 001360 BNE   LOOP1
 004556 012703          MOV   #08.,R3
000010
 004562 105767 IMP3:        TSTB  TPS
172776
```

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```
 004566 100375          BPL   IMP3
 004570 012767          MOV   #40,TPB
000040
172770
 004576 005303          DEC   R3
 004600 001370          BNE   IMP3
 004602 012700 MOV   #AC,R0
177302
 004606 016760 MOV   TEL2,2(R0)
175236
000002
 004614 016710 MOV   TEL2+2,(R0)
175232
 004620 012703 MOV   #11.,R3
000013
 004624 016004 LOOP2:MOV   2(R0),R4
000002
 004630 042704 BIC   #177770,R4
177770
 004634 062704 ADD   #60,R4
000060
 004640 105767 EDIT2:TSTB  TPS
172720
 004644 100375 BPL   EDIT2
 004646 010467 MOV   R4,TPB
172714
 004652 012767 MOV   #-3,ASH
177775
172436
 004660 005303 DEC   R3
 004662 001360 BNE   LOOP2
 004664 012703 MOV   #2,R3
000002
 004670 105767 SPACE:TSTB  TPS
172670
 004674 100375 BPL   SPACE
 004676 012767 MOV   #40,TPB
000040
172662
 004704 005303 DEC   R3
 004706 001370 BNE   SPACE
 004710 005267          INC   L
175154
 004714 022767          CMP   #15.,L
000017
175146
 004722 001402 BEQ   COUNT1
 004724 000167 JMP   START
175700
 004730 005067 COUNT1:CLR L
175134
 004734 012767 MOV   #1,L
000001
175126
 004742 005267 INC   P
175124
```

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```
                                30.
  004746 022767 CMP   #29.,P
000035
175116
  004754 001402 BEQ   COUNT2
  004756 000167 JMP   START
175646
  004762 000000 COUNT2:HALT
         000001 .END
```

Bloc 12.

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THE NETHERLANDS
DEPARTMENT OF ELECTRICAL ENGINEERING

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