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MODIFICATIONS TO THE RF-BEAM CONTROL SYSTEM OF THE PSB IN ORDER TO ACCELERATE ALPHA AND DEUTERON PARTICLES

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1. INTRODUCTION

Recently a study suggested to include the PS Booster into the circuit of ion acceleration, predicting an increase in intensity by a factor 3 (Ref. 1). The way this was indeed achieved is reported in Reference 2. For the users it finally proved to give an increase in luminosity of a factor 10 in the ISR collider.

Most of the more important modifications in the Booster for the alpha and deuteron cycle concerned the RF-Beam Control system, because we had a:

1. capture and acceleration at two different harmonic numbers, within one magnetic cycle (H = 10 from 47 to 200 MeV, and H = 5 from 200 to 1006 MeV);
2. sequence of debunching and rebunching to make the change of harmonic number (at 2508 Gauss);
3. synchronization at the end of the cycle at a frequency quite different from the usual frequency of synchronization;
4. β normalizer that had to be able to consider the change in harmonic number.

In usual proton cycles particles are accelerated in five bunches. Since alphas enter the Booster having half the proton speed, ten bunches will be formed instead of five. This for the same frequency applied to the cavity. These ten bunches will be accelerated up to an intermediate flat top (see Annex 1).

At the beginning of it, the RF voltage is reduced instantaneously which provokes a debunching of the beam. The beam is recaptured towards the end of the intermediate flat top, when the full RF voltage is applied again however with half the frequency it had before. Five bunches will be formed and accelerated to the final flat top where the rings are synchronized and the particles ejected to the PS.

All given parameters in this report concern alpha particles. They are slightly different for deuterons.

2. TIMING (see Annex 2)

Two timings rule the debunching and rebunching process:

1) Debunching: Rift (ready intermediate flat top).
   A timing created by the main power supply and distributed by the general timing. It indicates the beginning of the intermediate flat top.

2) Rebunching: Rift + dt.
   A timing created by the beam control at about 45 ms after Rift.

3. TEN-BUNCH CAPTURE AND ACCELERATION

The phase loop in Annex 3 has been conceived for five-bunch acceleration. This means that the phase relation between the cavity and the phase discriminator (in RF-1) must be the same as the phase relation between the cavity and the phase discriminator (in RF-2) via beam and phase pick-up.

Now we notice in Annex 4 that physically the phase between the cavity and the first phase pick-up is one tenth of a circumference. Electrically the phase distance between two bunches is 360 degrees. With five bunches per circumference this gives 5*360 = 1800 degrees. This means that the electrical phase shift between the cavity and the phase pick-up is 1800/10 = 180 electrical degrees.

In the same way the electrical phase shift between the cavity and the phase pick-up is 360 degrees for ten-bunch acceleration. This means that we introduce an extra 180 degrees' phase shift in the RF-2 chain for the ten-bunch acceleration.

That is why we introduce a device in one of the RF chains which counteracts this unwanted phase shift by shifting the phase again by 180 degrees during the ten-bunch part of the cycle. After having incorporated this device (as is done in Annex 4) we are capable of accelerating ten bunches up to the intermediate flat top.

The acceptance has proved to be more or less equal to the acceptance when we accelerate 5 proton bunches. This even though the debuncher between LINAC-1 and PSB could not be used.

4. DEBUNCHING

In order to debunch the beam, the RF voltage (13 kVp) must drop to 0 Vp. in reality it will only drop to about 600 Vp, the minimum cavity voltage possible, to keep the tuning and the AVC of the cavities closed. To realize this the voltage programme must be modified.

The Voltage Programme generator

The Voltage Programme generator is used to program the RF voltage that must be applied to the cavity as a function of time during the cycle. Starting from a rest voltage at injection, V 0, the voltage must rise adiabatically to a value V_{max}. By delaying the VETO-signal the Voltage Programme will remain at its maximum value up to 10 ms after a beam is debunched or ejected.

As we want to debunch at Rift instantaneously, we cannot use a VETO to reset the Voltage Programme to V 0. Therefore, we have introduced a new, fast reset for the Voltage Programme generator. This input we called B.V.P. (Break Voltage Programme). The figure below explains how this works.

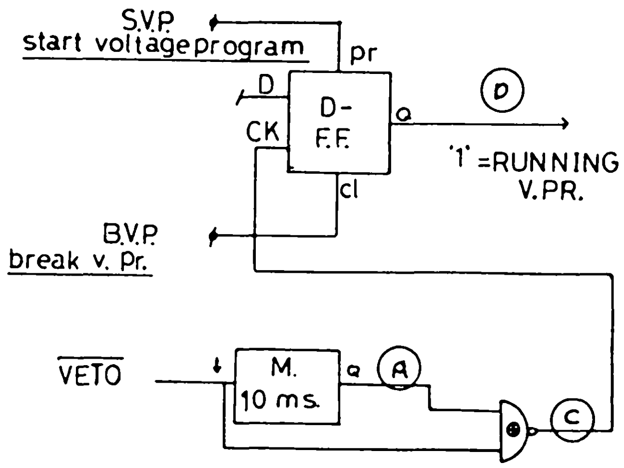


FIG. A

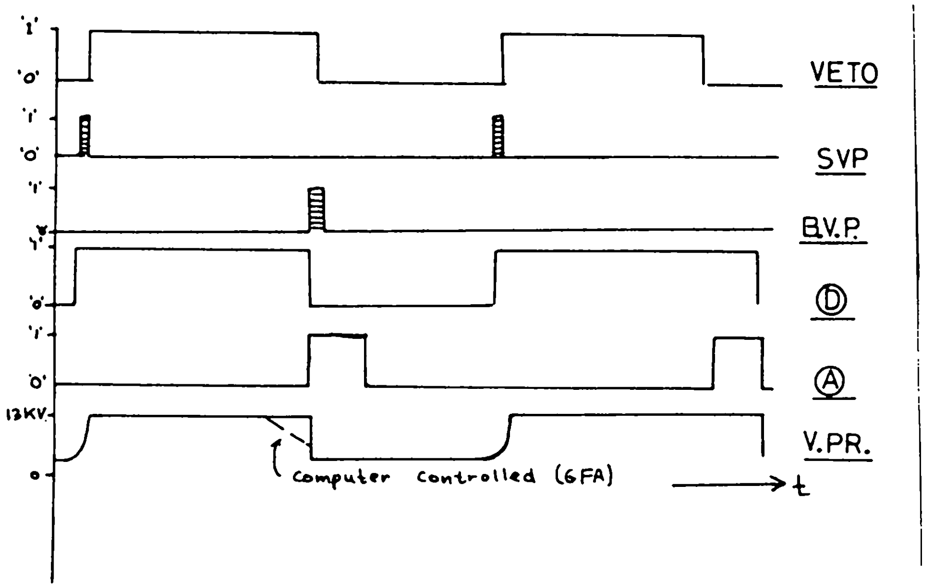


FIG. B

The slow decrease of the Voltage Programme preceding the intermediate flat top is programmed to decrease the dP/P before debunching starts. In that way the particles will be distributed more gently and recapture will be easier.

Resetting the Beam Control

During the intermediate flat top and before the second capture we must reset the Beam Control to its rest state (state we have in between cycles), because for the Beam Control the second capture is implemented as the first one. This is done by provoking a VETO. Since a VETO is provoked automatically when the phase between RF-1 and RF-2 exceeds 90 degrees, we make the change back to 0 degrees in the phase loop at Rift.

5. THE INTERMEDIATE FLAT TOP

A) The V.C.O.

The voltage-controlled oscillator normally takes about 45 ms at the end of a cycle to return to its rest frequency of 3 MHz. As we want the V.C.O. to return to 3 MHz during the intermediate flat top, we have accelerated this process from 45 ms to about 12 ms. This because the intermediate flat top is only about 50 ms long itself. We obtained this acceleration by decreasing a time constant which governs the fall time as shown in the simplified network below.

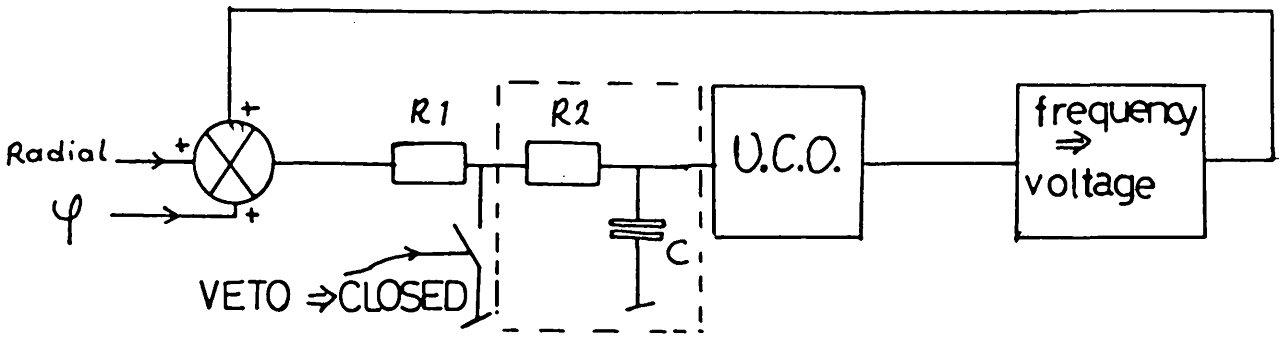


FIG.C.

B) The debunched beam

When the VETO is provoked at Rift, the V.C.O. will return to 3 MHz. During this sweep from 6 to 3 MHz, those frequencies where an integer number of bunches can be formed, will couple with the beam because V 0 is not zero Volts but 600 Volts. To avoid this coupling was a second good reason for decreasing the fall-time constant of the V.C.O. (as explained in Chapter 5.A). Having returned, the beam will couple with the rest frequency of 3 MHz. To avoid this, we apply a supplementary signal to the radial input of the V.C.O. up to the second trapping, to increase the rest frequency by about 100 kHz. Then the beam will not "see" the RF (signal b in Annex 7).

6. RECAPTURE AND ACCELERATION OF FIVE BUNCHES

At recapture we have to be able to tune the retrap frequency to the magnetic field of the intermediate flat top for the best trapping. We could also change the magnetic field of the intermediate flat top to achieve this. But because of little differences between the four rings, we chose to adjust the separate rings' rest frequencies. For this we must apply a correcting signal as well to the radial input of the V.C.O. This signal (a) will also be formed by the circuitry you can find in Annex 7.

There we see three monostable multivibrators (M's). The first one waits for the V.C.O. to return to a frequency slightly above 3 MHz. This to avoid frequencies above 8 MHz. The second M. allows the frequency step to the output. Practically this happens by changing the current in transistor one. Consequently, current will have to go to the 50 Ohms load (the radial input). The third M. allows fine tuning to the output, this by slightly changing the current in transistor one. This modification of the frequency programme (a voltage representing a frequency) is represented in Annex 5.

After having incorporated this device we can capture the beam in five bunches without the loss of too many particles. The loss we do have when we recapture is probably due to an increase in dP/P by a mechanism of coupling of the coasting beam in the machine.

7. SYNCHRONIZATION

Instead of having to synchronize the V.C.O. to an 8.033 MHz reference oscillator, we had to use the very stable oscillator of a network analyzer to provide us with the needed 5.89 MHz, the frequency corresponding to 5924 Gauss of magnetic field.

Also the distribution of this reference signal to different users had to be taken care of. The layout changed as follows:

SYNCHRONIZATION

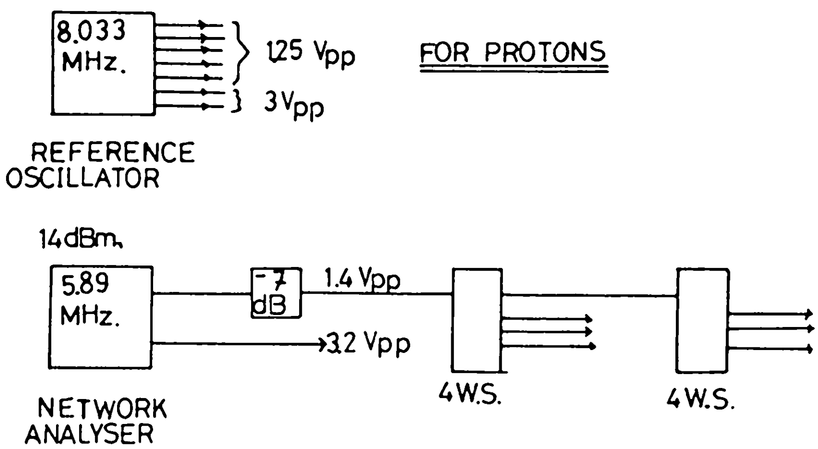


FIG. D

8. MODIFICATION OF THE β NORMALIZER FOR BEAM INTENSITY MEASUREMENT

The β normalizer calculates Np = 5*I/(q*F-rf), which is a simplification of the formula Np = Nb*I/(q*F-rf).

With: Np = Number of particles

Nb = Number of bunches

I = measured beam current

Q = charge of particle

F-rf = radio frequency applied to the gap.

(NB.: Considering a constant number of bunches during the whole cycle, changes of particles only means changing a scale factor for Np.)

This simplification only considers 5-bunch acceleration. Since for alpha and deuteron acceleration we have to deal with 10 bunches a part of the cycle, the normalized number of particles will be wrong for that part of the cycle. That is half of what it should be. So we have to multiply the Np signal by a factor 2 during this part of the cycle.

For this we implement a conditional amplifier as shown in Annex 6. As you can see we take away the times 2 amplification at Rift, i.e. at debunching.

During the intermediate flat top the RF will be moving from 6 MHz to 3 MHz. If we consider the formula we notice that we get again wrong values for Np. Therefore, at Rift, we switch to an external oscillator of 3 MHz. We use this oscillator during the whole intermediate flat top. We see easily by comparing the formula before and after Rift that no change will be noticed in the Np signal.

At Rift = > amplif. 2, freq. 6 MHz, Np = 2*5*I/(q*6 MHz). On the intermediate flat top: = > aplif. 1, freq. 3 MHz, Np = 5*I/(q*3 MHz).

9. RESULTS AND DIFFICULTIES ENCOUNTERED

Most of the findings described in this report were done in tests with parasite proton cycles. We simulated the ion cycle by a proton cycle that had a debunching and rebunching. We started with 5 bunches the first half of the cycle, we debunched, and we recaptured 3 bunches (debunching at 5 MHz, rebunching at 3 MHz). The problem we have when we rebunch with

3 bunches is that the phase difference between cavity and first phase pick-up is 108 degrees and not 360 degrees as is the case for 10-bunch capture and acceleration. Consequently for 3-bunch capture we can only use one phase pick-up. The major problem, how to rebunch, could nevertheless be studied as if we were dealing with alpha particles.

A major problem during the alpha setting up was the coupling between injection frequency and retrap frequency. When we changed the injection frequency we had to re-adjust the retrap frequency (see below). We could have prevented this by making a switching between the injection and retrap steering signals. Of course, we would have had to steer the injection frequency input instead of the radial input.

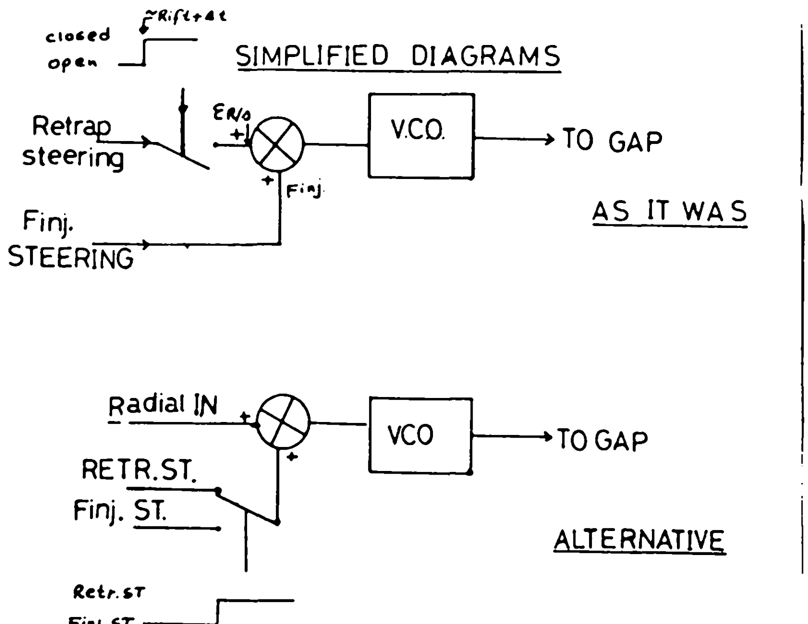


FIG.E.

As we have seen before (Chapter 6) we had to take into consideration that the rings were different. We only could adjust the magnetic field to the retrap frequency for one ring.

The result for a whole ion cycle is visualized in the different photographs you find in Annex 8. As you can see the efficiencies were excellent.

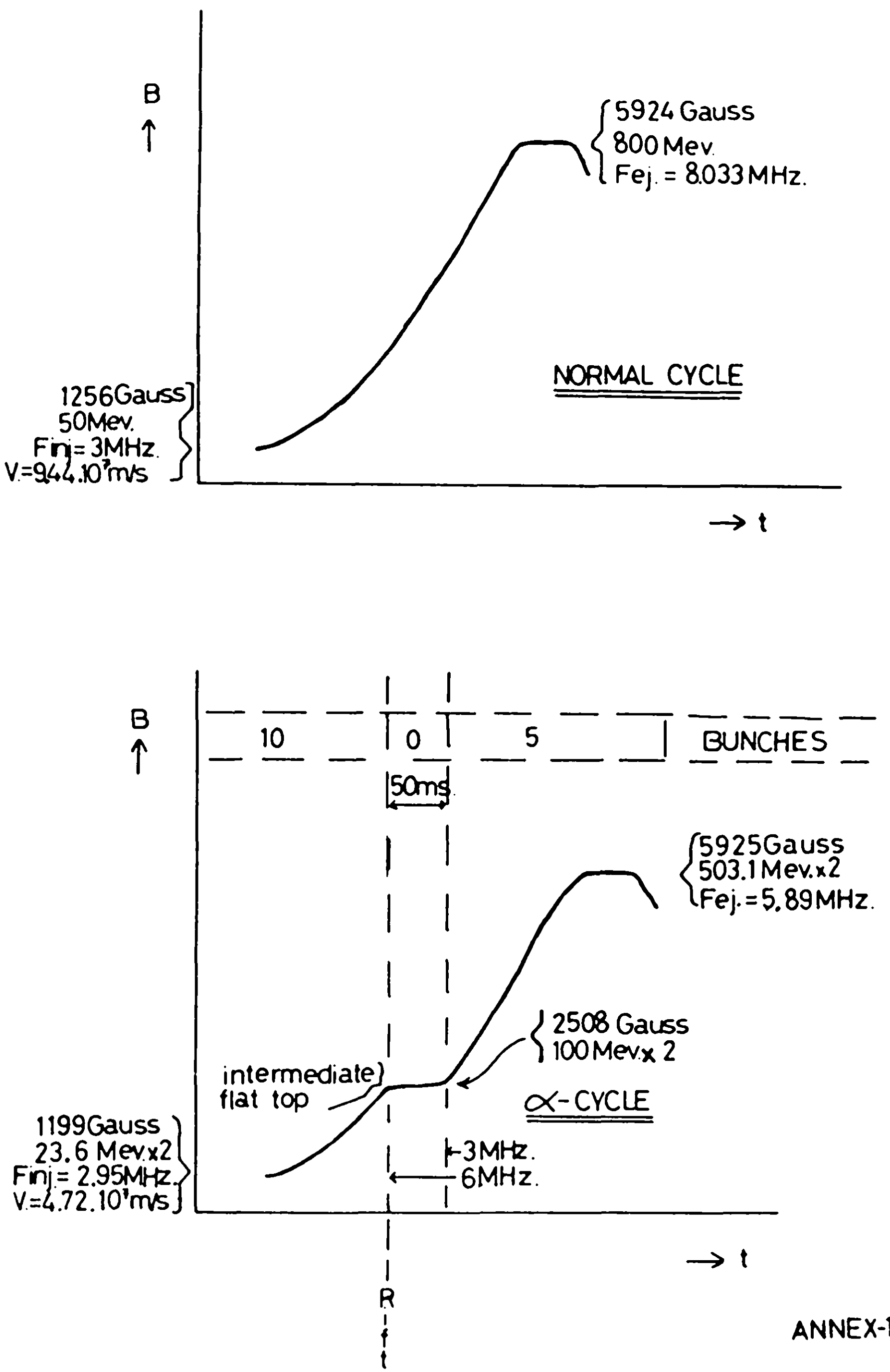
10. ACKNOWLEDGEMENTS

We would like to thank K. Schindl for finalizing basic parameters as well for setting up the special proton parasite cycle. We would like to thank G. Gelato for his advice and support (especially concerning the β normalizer). The authors also wish to thank R. Gailloud and J.D. Schnell for their respective help concerning the main power supply and the general timing, as well as the PSB operators for the many parasite cycles to be set up and modified.

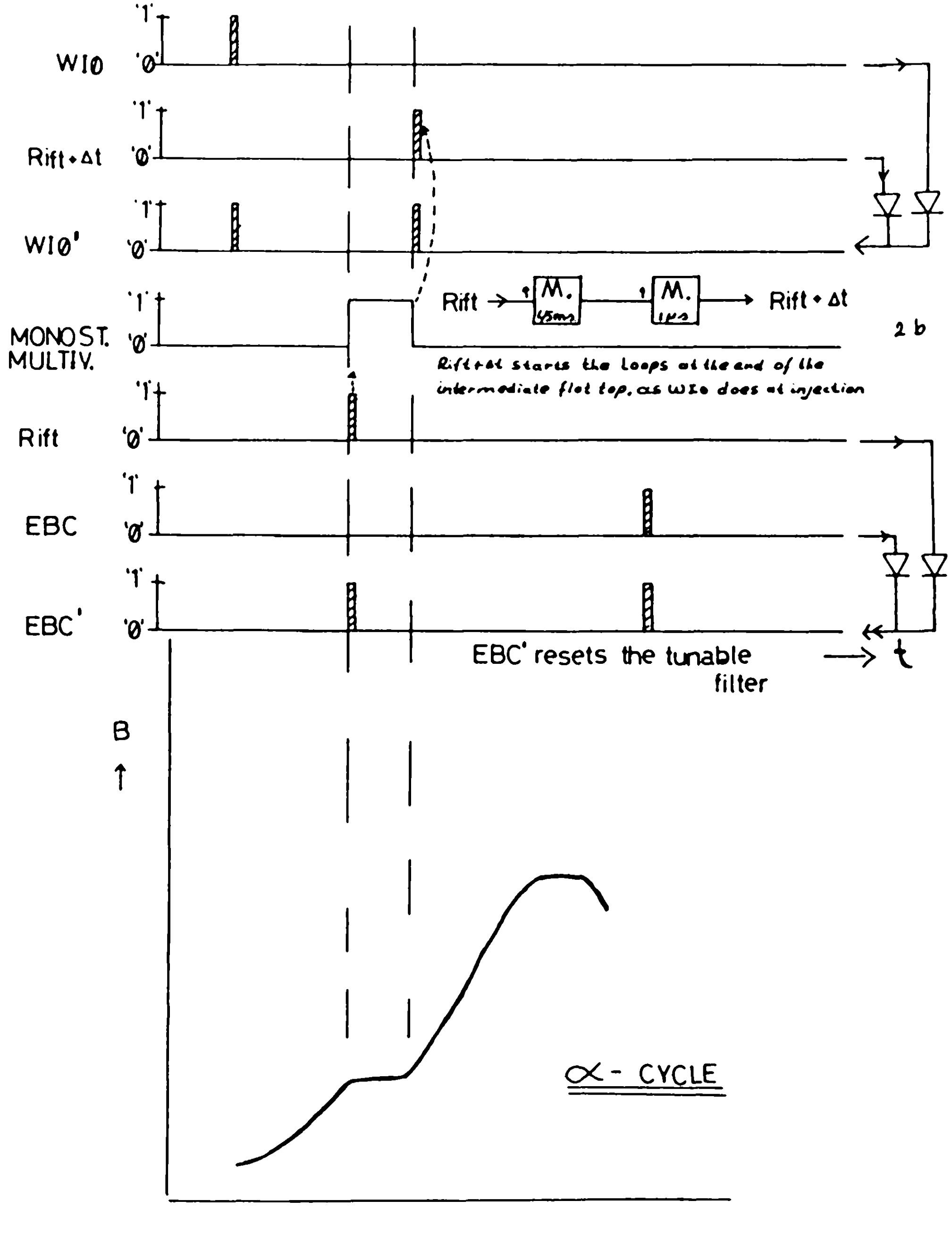
11. REFERENCES

1) K. Schindl, PS/BR Note 81-10.

2) J. Fopma et al., PS/BR Note 83-2.



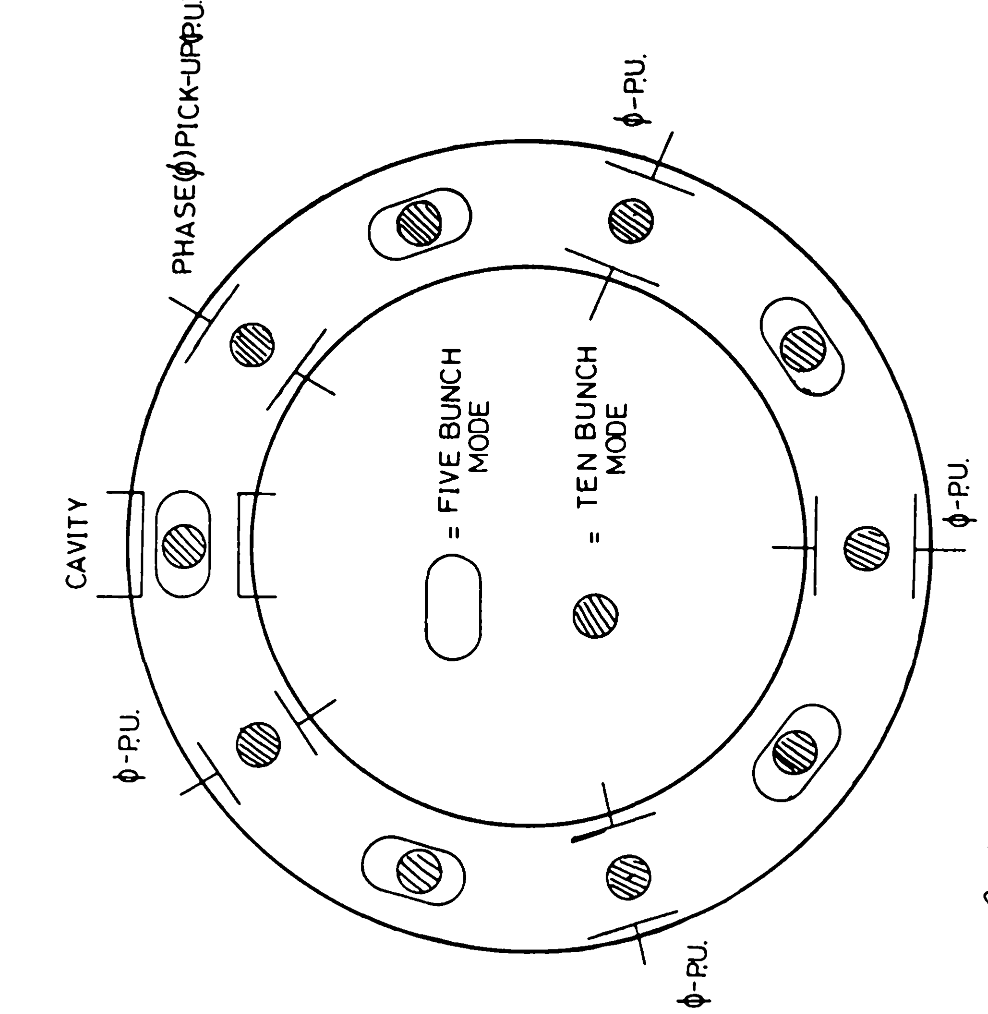
ANNEX-1



MAIN TIMING IMPULSES FOR DE- AND REBUNCHING

ANNEX 2

WHY 180° PHASE SHIFT FOR 10 BUNCH-ACCELERATION



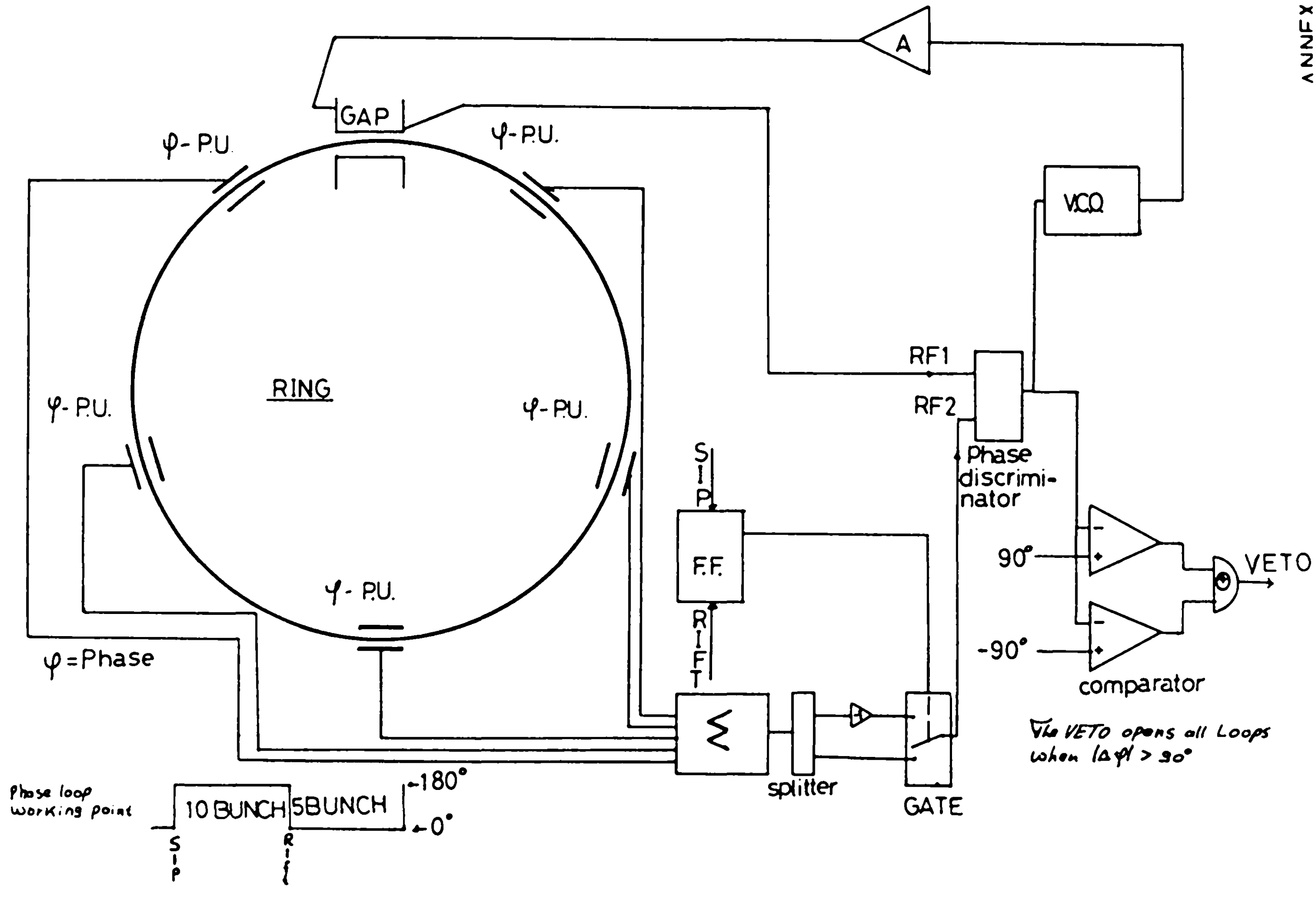
Proof:
5 Bunches ⇒ Electrical circumference = 5 x 360° = 1800°
10 Bunches ⇒ Electrical circumference = 10 x 360° = 3600°

Physical distance cavity → Phase pick-up = 1/10 of a circumference

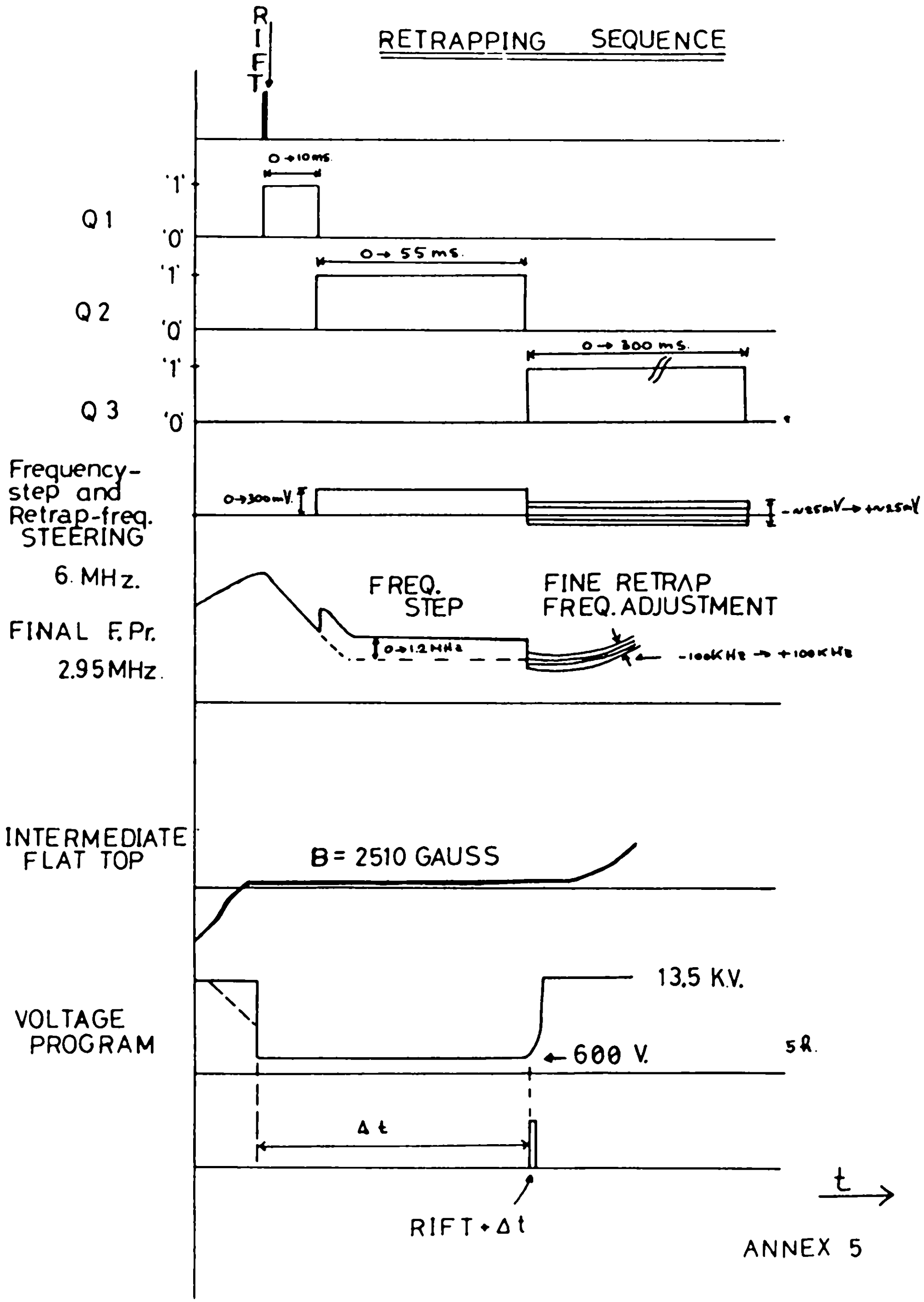
This means for 5 Bunches : 1800°/10 = 180°
This means for 10 Bunches : 3600°/10 = 360°
} ⇒ *extra phaseshift 10 Bunch-mode = 180°*

ANNEX 2

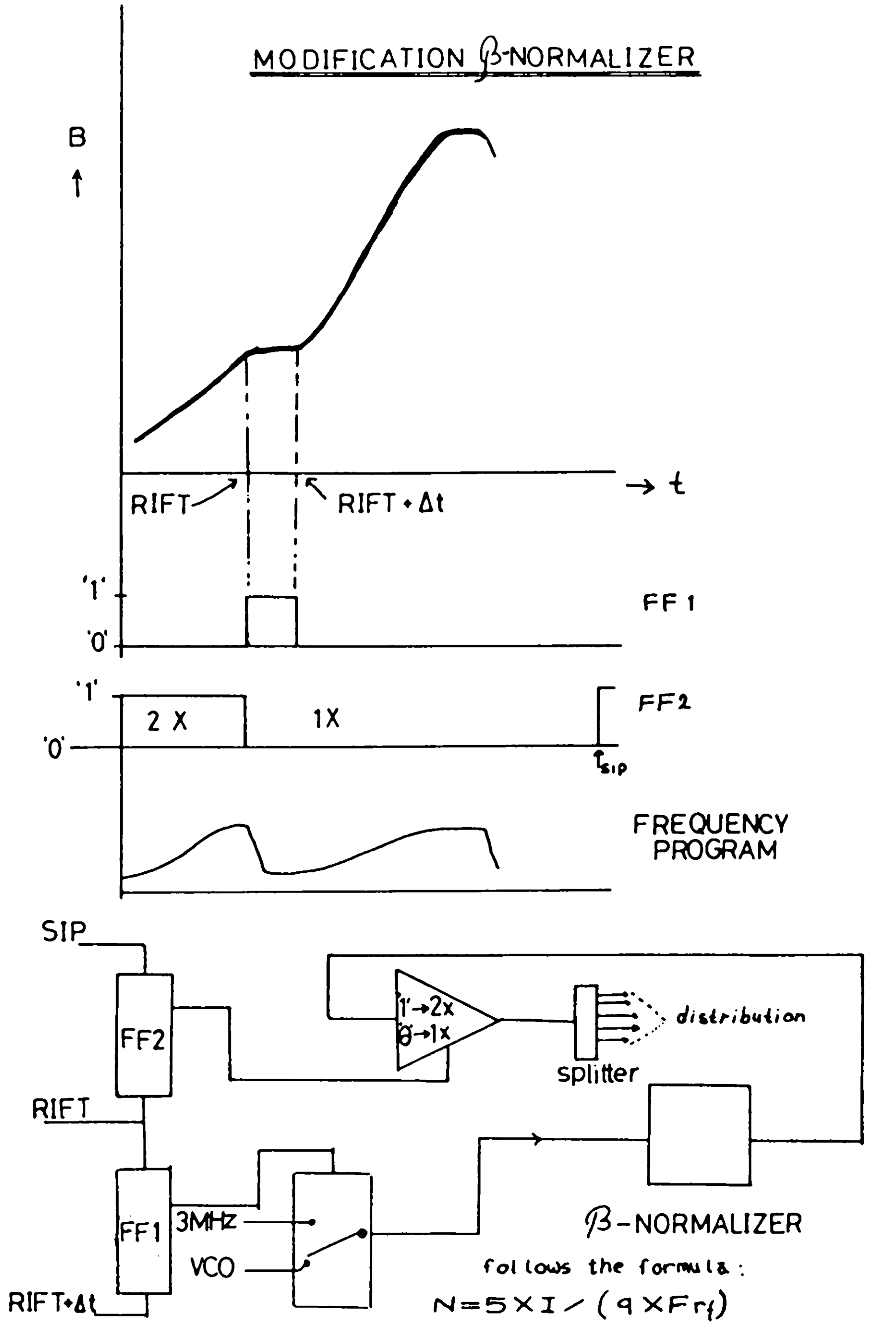
SIMPLIFIED PHASE LOOP



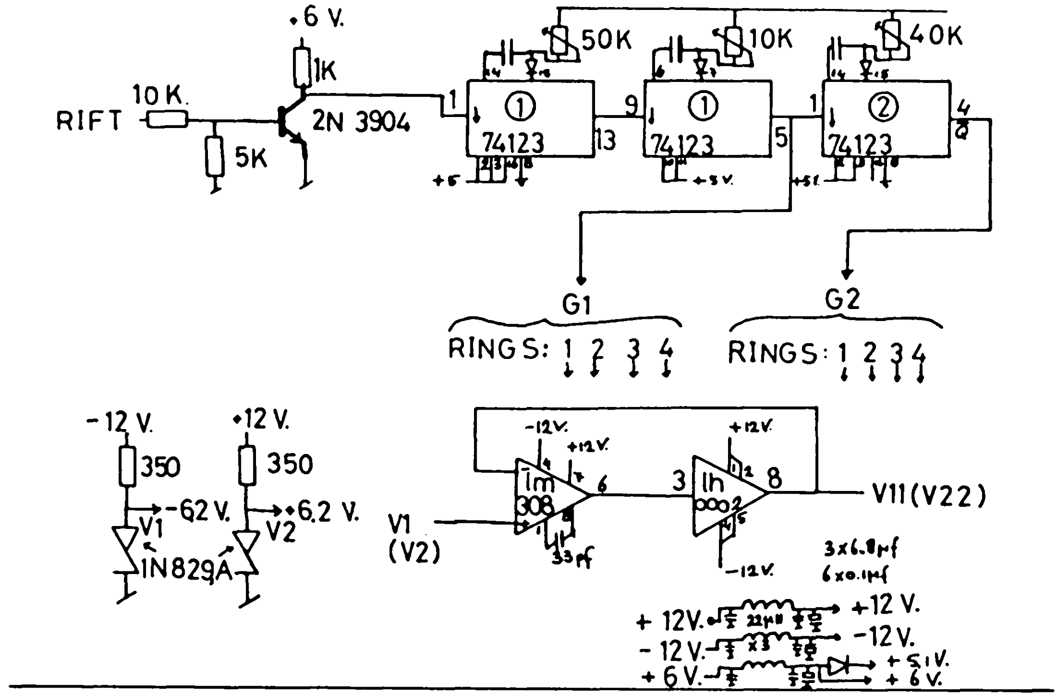
ANNEX 3



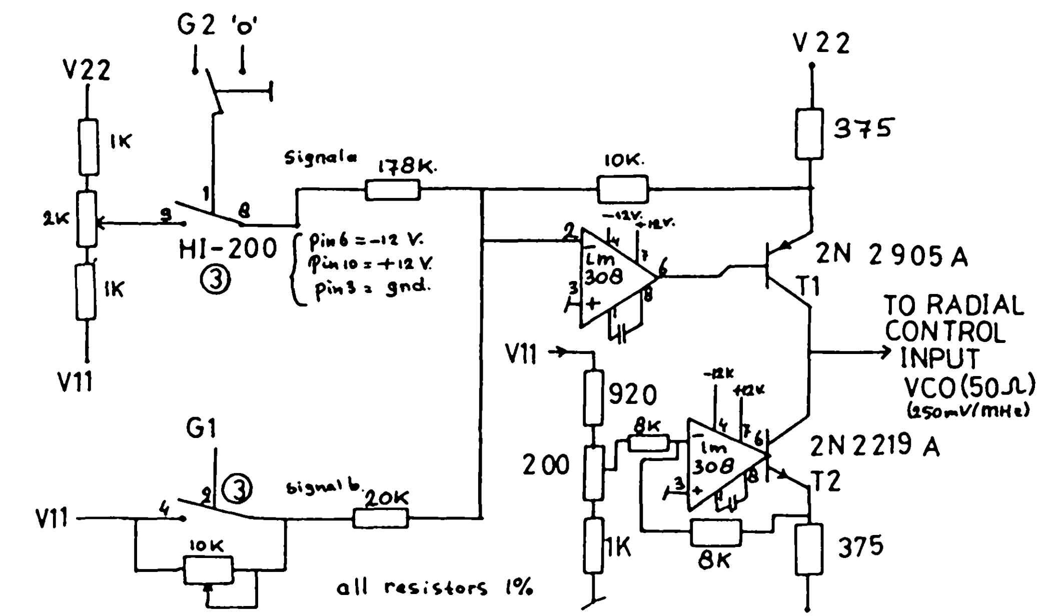
ANNEX 5



ANNEX 6

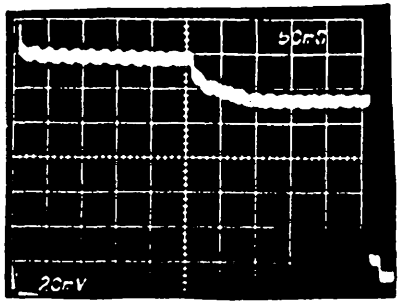


FOUR TIMES,ONE TIME PER RING.



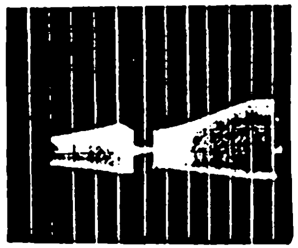
ALPHA-DEUTERON RETRAP CONTROL

ANNEX 7.



50 ms/div.

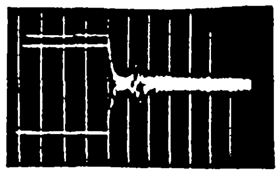
Signal from β-normaliser representing the number of accelerated protons



50 ms/div.

Wideband signal (1): The whole cycle

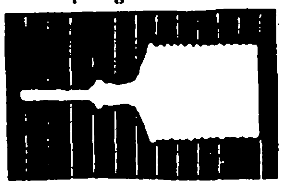
coupling



0.5 ms/div.

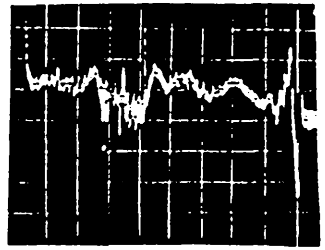
Wideband signal (2): The de-bunching of the beam

coupling



0.5 ms/div.

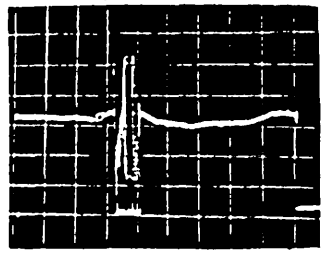
Wideband signal (3): The re-bunching of the beam



50 ms/div.

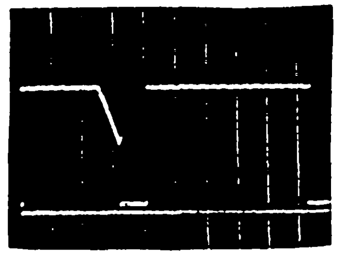
The radial position during the cycle (.4 mm/div.)

Interval of no-bunch beam



50 ms/div.

Phase between pick-up and cavity (50°/div.)



50 ms/div.

The voltage program as it was applied to the cavity (3.3 kV/div.)

RESULTS ANNEX 8

Light ions MODIFICATIONS BEAM CONTROL