THE RF SYSTEM OF THE CERN "NEW LINAC"

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Summary

The RF-system of the CERN "New Linac" consists of ten separate amplifier chains of modular construction, with individual fast amplitude and phase regulation systems together with a slow tuning servo. All the servomechanisms act on the low-level part of each chain, without any high-power modulators.

Constructional details of the RF hardware are given and performance figures presented.

Structure of the RF-system

The basic design decision was to assign a separate amplifier chain to each of the ten resonators and to start at an RF-level of 2 Watts. The feedback circuitry can thus be built around high-speed, low power components (such as varactors or PIN-diodes driven by operational amplifiers).

The "semiconductor part" comprising servomechanisms and RF amplifiers up to 400 W is essentially the same in each chain, and only the "tube part" is specifically tailored to the power requirements. Table I gives a summary of the latter.

A common master oscillator generates a quartz-controlled reference signal of 202.56 MHz, which is amplified in a pulsed 300-W-amplifier and distributed via the phase-stable reference-line running along the resonators in the accelerator tunnel. Directional couplers derive the input signals for each of the 8 fundamental-frequency chains with near-to-ideal decoupling. The second-harmonic chains 2 and 10 receive their input signals from doublers in the corresponding 405-MHz chains 1 and 9; this arrangement simplifies the phase setting of the double resonators.

The Anatomy of a Chain

The Feedback Loop

The block diagram is shown on Fig. 2. The RF modulators work below 100 mW but are well shielded. Stray RF from the high power components interfered, however, with the video circuits, causing oscillations. With some additional filtering in these circuits, the problem disappeared.

Cross coupling between the amplitude and the phase loops is small, except in the cavity when this is detuned for beam load compensation. In practice, the cross coupling remains tolerable and the feedback loop is well behaved.

Bandwidth is limited by the phase shifts due to delays in the loop (total length about 50 m for the linac tank loops) and additional phase shifts in the components. We found that we could work with an adequate safety margin at a bandwidth of about 150 kHz.

Another limitation to the bandwidth are resonances of which one is shown in Fig. 3. If this resonance crosses the unity gain line, the loop oscillates at the frequency of the resonance. One cause for resonances are the higher modes in the linac cavities but, in our own case, the next higher mode was more than 1 MHz away and caused no difficulties.

More troublesome are the standing waves between the final amplifier and the cavity, which can be considered a short circuit some 50 kHz from the nominal frequency. This short circuit, transformed by the feeder line, combines with the amplifier load impedance and build up parasitic resonances. The line length can be set between two extremes, 1/4 apart:

<table>
<thead>
<tr>
<th>Chain Designation</th>
<th>Amplifier configuration (Tube type, output power)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 BUNCHER 1</td>
<td>RS 2024 30 KW</td>
</tr>
<tr>
<td>2 BUNCHER 2</td>
<td>RCA 7651 4665</td>
</tr>
<tr>
<td>3 BUNCHER 3</td>
<td>RS 2024 30 KW</td>
</tr>
<tr>
<td>4 TANK I</td>
<td>RS 2024 170 0.5 MW 170 2.5 MW</td>
</tr>
<tr>
<td>5 TANK II</td>
<td>RCA 7651 2024 170 0.5 MW 170 2.5 MW</td>
</tr>
<tr>
<td>6 TANK III</td>
<td>RCA 7651 2024 170 0.5 MW 170 2.5 MW</td>
</tr>
<tr>
<td>7 DEBUNCHER 11</td>
<td>RCA 7651 2024 5 KW 90 KW</td>
</tr>
<tr>
<td>8 DEBUNCHER 12</td>
<td>RCA 7651 2024 5 KW 90 KW</td>
</tr>
<tr>
<td>9 DEBUNCHER 13</td>
<td>RCA 7651 2024 5 KW 90 KW</td>
</tr>
<tr>
<td>10 DEBUNCHER 14</td>
<td>RCA 7651 4665</td>
</tr>
</tbody>
</table>

Table 1: General layout of the RF system
Fig. 2 Block diagram of the Feedback System

(1) 6-bit variable delay line for adjusting loop phase; (2) fast phase modulator with varicaps; (3) fast amplitude modulator with PIN diodes; (4) RF power amplifiers; (5) trombone; (6) cavity; (7) variable delay line for setting the cavity tuning; (8) control of the slow tuning loop; (9) phase detector; (10) 3-way divider; (11) amplitude detector; (12) phase feedback control; (13) amplitude feedback control; (14) trombone for setting cavity phase; (15) frequency doubler;

Signals (A) RF reference; (B) amplitude reference; (C) RF reference for 2nd harmonic cavity (chain 1 or 9); (D) feedback forward signals to improve the transient response when the beam comes in.

In practice, one starts with the safe "maxi-Q" setting and works towards the "mini-Q" until the best compromise is achieved.

In the case of DB 13, which needs high power at the end of a very long cable, the safest solution was to include a circulator in the feeder line.

Amplifier

The 400 MHz power amplifiers are commercial units using the RCA tetrodes 7651 and 4665. These are the only amplifiers that were bought ready-made. The others have been developed at CERN.

The transistor amplifiers are 4-stage linear amplifiers with a wide dynamic range. The final stages consist of 4-module units each delivering 100W. Thanks to the low duty cycle the transistors operate without cooling fins.

Three other amplifiers were developed. One started as a grounded cathode stage for 40 kW output from 300 W of drive. The Siemens RS 2024 CL was selected as the best tube for the job. By tuning out the cathode inductance and using screen-grid inductor neutralization, the design goal was achieved. A production model suffered from a parasitic oscillation at 2.3 GHz which took some time to cure. Although one amplifier of this type was used operationally for about a year, on the grounds of increased simplicity and higher output power, this configuration was aborted to a grounded-grid, grounded-screen design. With this change, only 36 kW from a drive of 400 W was obtained.

To ensure an ample reserve of power as drive for the high power stages, an additional amplifier known as the "pre-driver" was designed and built. Using more drive power, the RS 2024 was driven up to an output power of 100 kW. A particular feature of the RS 2024 stage is the re-entrant plate cavity with...
integral "POLYFLON" plate blocker; this is a Teflon cylinder with electroformed copper on both sides, making a distributed capacitance with high dielectric strength. The plate supply is 14 kV obtained from a capacitor bank. The "pre-driver" also uses an RCA 7651 in a grounded-grid, grounded-screen circuit. An output power of 8 kW from a drive power of 400 W has been achieved. The plate supply is 5 kV derived from a capacitor bank. Both amplifiers use identical screen-grid supplies; these are 1 kV, 1 A units with built-in protection against overcurrent. Fast acting protection is provided for both amplifiers by means of ignitron crowbars triggered by plate overcurrent pulses.

8 identical 2.5 MW amplifiers are used in the final and drive stages of all tank chains. They are equipped with the triode TH 170, a water cooled version of the well-proven vapour-cooled triode TH 470. It was found that this type is the most economical solution for this low-duty-cycle machine; the amplifier can however as well accept the triode TH 116, the water cooled equivalent of the TH 516, to deliver > 50% more power.

The amplifier is a re-development of the original CERN Linac amplifiers; modifications include larger resonator diameters (up to the very limit of the first circumferential mode), improved RFI shielding, different tube cooling, completely redesigned input circuit, easily adjustable output coupling loop, grid neutralization. The latter cured instabilities at the leading edge of the pulse that were initially attributed to tank-multipactoring due to very similar symptoms. As in the earlier version, the amplifier is two floors in height. The upper part extends into the equipment gallery with a removable cover that is part of the output resonator; from here a tube may be changed in about 20 minutes. The lower part is based in a service tunnel and comprises the infrastructure such as blowers, filament transformer, drive mechanisms, etc., as well as RF-input and output ports imbedded in their respective resonators. A thyristor-controlled filament supply and associated electronics with an analogue multiplier keeps the filament power constant despite mains fluctuations and resistance drop of the thoriated tungsten cathode; in addition, it provides smooth turn-on and turn-off during a 3 minute ramp.

HV-Modulator and Charging Supply
Each of the three tank-chains is equipped with a 40 kW plate supply, consisting of an LC pulse-forming network (PFN), an ignitron as high-power switch, a pulse transformer to provide voltage step-up and ground separation, and a crowbar system with ignitron and resistive termination.

All the two (Tank I) or three (Tank II, Tank III) amplifiers of a chain are connected in parallel to their respective pulse transformer. The modulator is designed for a pulse length of up to 1.1 μsec (Proton-operation); therefore, many special features of the circuit such as the resetting of the pulse-transformer core by the capacitor charging current or the mere size of the transformer or the capaci-
Performance
This is best described by a selection of photos taken for tank 3, whilst operating with a beam current of 100 mA, i.e. 2/3 of the maximum value.

The amplitude shows a transient of 1.3%. This has negligible effect for the accelerators downstream. To improve the transient response of the feedback loops, feedforward signals can be supplied when the beam comes in. This facility is not used at present as the system works satisfactorily without it.

The second photo shows the control signals operating on the loops. During operation it is of course essential that enough power is available during the beam time. Also, due to the fact that the phase modulator has only a limited range of 80°, one has to make sure that the loop delay is properly adjusted (by item 1 in Fig. 2). Note the large amount of correction required due to the heavy beam loading of 100 mA. This can also be seen on the next photo.

Concluding Remarks
The described system gives adequate performance over the full range of beam current up to 150 mA, without any resetting of parameters; if this were applied (e.g. for feedforward, adjustment of tank loops and tank tuning for minimum reflection, etc.), there would be potential for improvement at the expense of a more complicated operation.

The system was not designed with low cost as primary goal. However, we feel that the low expenditure of 3.5 Mfr. (including all temporary labour) deserves mentioning.

Reference:
E. Boltezar & al.: "The new CERN 50 MeV Linac"
Invited paper, this conference.