A UNIVERSAL ELECTRONIC PHASESHIFTER

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Summary

Future time-sharing operation of the UNILAC for low energy experiments and injection into the Synchrotron SIS requires varying the amplitudes and phases of the accelerating structures' rf from pulse to pulse with a 50 Hz repetition rate. Fast variation of the amplitude is already provided, but the phaseshifting is done so far by coaxial relays and trombones.

The UNILAC consists of accelerating structures with operating frequencies of 27 MHz and 108 MHz, bunchers at 9 and 27 MHz and choppers down to 1.5 MHz. For a new high current injector, structures with frequencies of 13.5 and 54 MHz are also being considered. A new electronic phaseshifter with a range of ± 180° should be usable with minimal changes at all these frequencies.

The selected principle was a digital phase-locked loop circuit. Besides the necessary speed, the realized circuit has several additional advantages. In combination with standard digital frequency-dividers any desired subharmonic frequency of a master frequency up to 160 MHz can be produced phase stable and shiftable in relation to the master frequency in one single device. The circuit can also be used as a phaseshifter and a phaseregulator at the same time.

Phaseshifters at 9, 4.5 and 1.5 MHz have been in operation for one year without problems. A prototype of a 108 MHz phaseshifter is under test.

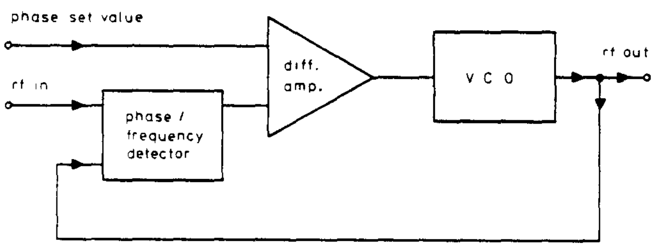


Fig. 1: Principle of operation

Principle of Operation

The basic principle of all existing phaseshifters of the described type is the use of a voltage controlled oscillator, the output of which is phase-locked to an input rf signal by the use of a phase frequency detector and a control amplifier (see Fig. 1).

The variation of the phase of the rf output against the input is provided by a variable offset voltage (or current) to the reference input of the control amplifier.

This simple circuit already allows shifting of the phase of any input frequency in the operating range of the VCO and the phase frequency detector by ± 360° with the used detector. The output amplitude is independent of the shifted phase angle, in contrast to phase shifters using analogue devices like double balanced mixers.

The chosen digital phase frequency detector in ECL technology is able to work up to 80 MHz, while the VCO's can handle up to 160 MHz with an appropriate external oscillator circuit.

Without additional measures, such a simple circuit would have the disadvantage that the output phase is dependent on the actual temperature of the circuit and on the amplitude of the input rf. For example, we measured 1 degree electrical phase shift with each 10° C in a measured range from 10° C to 50° C, which was unacceptably high for our application.

As the phase-locked loop circuit comprises a control amplifier with high amplification factor, the closed loop error is mainly determined by the error of the detector, which cannot be eliminated by the regulation.

Two additional components were introduced into the circuit to reduce these errors:
First, the rf input (and for high frequency applications also the reference) is digitized by a temperature compensated Schmitt-trigger which switches at zero voltage. Consequently, phase jitter due to changed input amplitudes is minimized without additional temperature drifts.

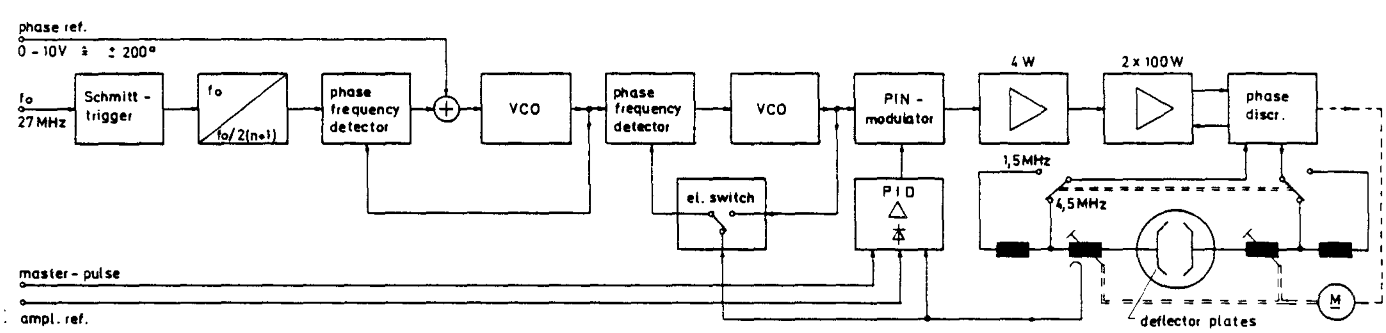


Fig. 2: Application as frequency down/converter, phaseshifter and phase-regulator

Second, the phase detector chip has temperature control by means of a heat sink on top of the chip to keep its operating temperature constant.

The main advantages of the described phase-shifters as well as further solved problems are demonstrated in the following two examples.

For an extension of the experimental possibilities at the UNILAC, a resonant rf-chopper with the operating frequencies of 1.5 MHz and 4.5 MHz was built with the ability to kick 2 of 3 or 8 of 9 micro-bunches out of the beam. The normal bunch separation of 37 ns can be increased to 110 ns or 330 ns by this device.[1]

The 1.5 MHz and 4.5 MHz of the rf-chopper have to be phase stable against the 27 MHz rf. Fig. 2 shows the signal conditioning block diagram of the rf installation of the chopper.

First the UNILAC 27 MHz reference frequency is digitized by an above mentioned Schmitt-trigger. The following programmable divider

($f_{out} = f_{in} / 2(n+1)$, n=1,2,3 ...)

produces the desired 4.5 MHz or 1.5 MHz (n= 2 or 8).

This rectangular wave, phase stable to the 27 MHz, is connected to one of the two inputs of the phase frequency detector. The output signal of this detector controls the VCO, which delivers a sinusoidal output signal near the desired frequency. The feedback of this signal to the second input of the phase frequency detector closes the "phase-locked-loop" circuit and synchronizes the output of the VCO with the digital input frequency (and hence to the 27 MHz).

One can see that by adding a divider in the forward input of the phase frequency detector, one can produce a subharmonic frequency. Locating this divider in the feedback input would allow to multiply the input frequency (which we did not use so far).

By adding a dc voltage to the input of the VCO, the phase of its output can be shifted by ± 360°. In this application, however, the range was limited to ± 200°.

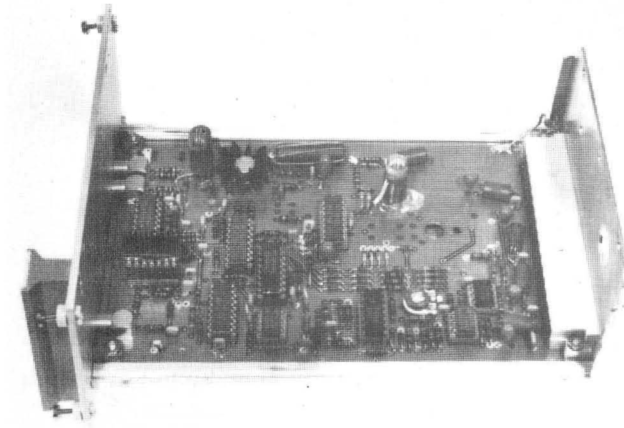
The same circuit, with some modifications, is also used for the phase regulation. As the phase of the deflecting voltage should be regulated directly, an additional problem appears. For thermal reasons, the chopper is not driven cw, but with the normal 5 ms UNILAC macropulses. During the 15 ms pauses between the macropulses, the feedback of the phaselock, which comes from an inductive pickup, receives no signal from the resonator. This would lead to a large frequency shift of the VCO. Once out of its limited bandwidth, the resonator could never be filled again and the VCO would never be able to lock. Therefore this input of the phase frequency detector is switched during the pauses from the resonator voltage to the output of the VCO, which locks this again to the input frequency.

In the next stage the phase-regulated rf is pulsed by a PIN modulator and a PID controller. Finally a multistage amplifier drives the resonant circuit in series.

To make the same phaseshifter usable at 1.5 MHz as well as at 4.5 MHz needs only a change of the inductances of the VCO's oscillators. This is provided by a short circuit of one part of the inductances by relay contacts which are driven parallel to the input of the programmable counter and the vacuum relay of the main resonance circuit.

Absolutely no tuning or mechanical changes are necessary for the "one button" frequency change.

Picture 1 shows the actual device.

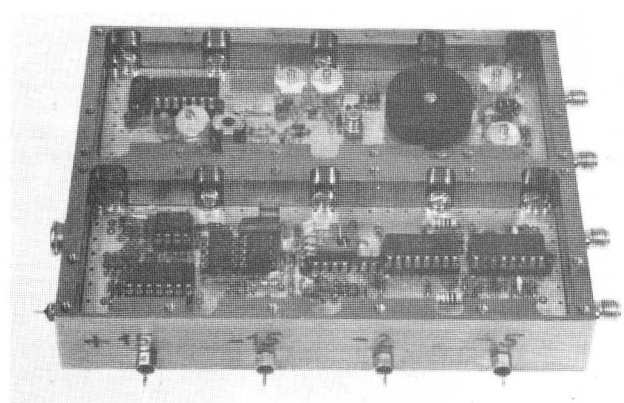


Picture 1

In a second application, a phase shifter should operate at 108 MHz input and output frequency. As the available phase frequency detectors are not able to work at this frequency, the rf input as well as the reference were divided by two, as it can be seen in Fig. 3. Before the division, which is done for both signals in the same chip, the signals pass the normal pulse forming network, which is realized in a symmetric manner for input and reference (in a single chip to minimize temperature failures). Both 54 MHz converted signals are now fed into the phase frequency detector which controls a VCO with 108 MHz output. This 108 MHz signal is then amplified and an attenuated part of the output signal is fed back as reference.

By the division of the input frequency by a factor of two, the range of the possible phase shift of the 108 MHz is raised to ± 720°.

The feedback of the reference is not done in the circuit itself, but over connectors and a cable to keep the phaseshifter more universal. By this, also a power amplifier or even a cavity load can be integrated in the phase-locked loop. Picture 2 shows the actual phaseshifter.



Picture 2

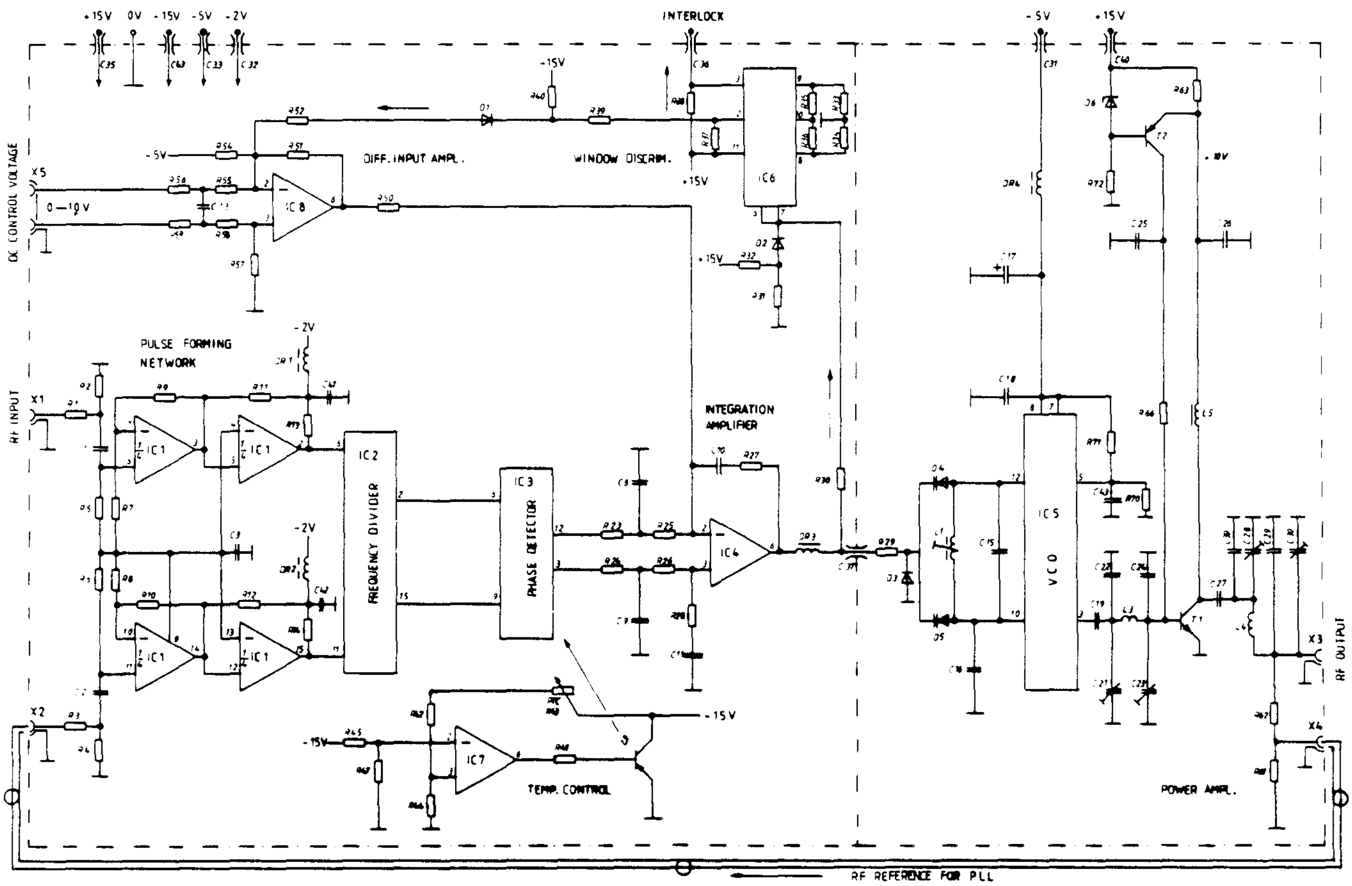


Fig. 3: A phaseshifter for 108 MHz

It consists of two cabinets. One is used for the low level digital circuitry and the other for the rf and the amplified output, to avoid coupling.

One problem still remained. When the power supply of the whole circuitry was switched off and on or the input rf disconnected and reconnected, it sometimes occured that the circuit did not lock but oscillated at one end of the possible frequency range, depending on the actual dc control voltage.

In this case, however, the output voltage of the amplifier IC4, which determines the working point of the tuning diodes, is far away from the normal voltage, which is constant at a selectable value (by L1) as long as no new phase shift is done.

We installed a window discriminator which gives an error signal if the working point leaves its normal value. This error signal is added to the dc control voltage, simulating its stable range. Therefore the circuit locks again and as soon as this is done, the error signal is no longer present and the normal control voltage determines the output phase again.

Reference

[1]W. Gutowski, G. Hutter, "1.5 MHz/4.5 MHz RF-Chopper for the Unilac", GSI-scientific report 1983, p. 303.