Lothar Rohde’s revolutionary “portable” quartz-clock type: CFQ

The General Radio (GR) company built their first commercial frequency standard type “Class C-21-H” somewhere in the nineteen thirties. Its designs showed a more or less similar system philosophy to what we have noted with the quartz-clock apparatus deployed at the PTR.

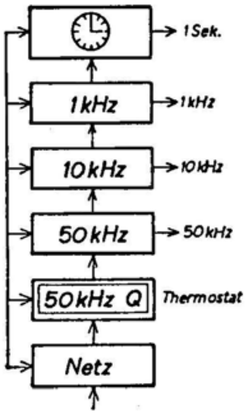


Fig.6: Block diagram of GR's pre-war quartz-clock (Rohde)

GR used a 50 kHz reference oscillator whereas the PTR used a 60 kHz one. (14) Nonetheless, there is strong evidence that they had deployed (optional) a 100 kHz quartz reference as well (type 676-A). Its quartz (bar) mounting was less sophisticated than that of the post war type 1190-A. (see hereafter)

In the late nineteen forties GR built their modified type 1100-A. Its circuit concept still followed their previously described formula though, they had changed to a 100 kHz quartz crystal. A very interesting detail is that, although they used deposited silver electrodes, the quartz crystal was mounted by means of springs. Around the quartz bar was a particular wire cord construction which showed some similarity with that of Giebe and Scheibe’s wire bounding. According to the manual: *The mounting is a spring suspension, holding the quartz bar at the corners only of the long faces, in a manner such as to introduce the least damping. .. The spring tension maintains the mounting conditions essentially constant over long periods. Because of the mode of vibration, there are two nodal regions and supports are placed at each. (Operating instructions for Type 1100 -A Frequency Standards, General Radio, p. 5)*

This support method showed some similarity with that designed by Giebe and Scheibe in the 1920s. An interesting detail is that the quartz bar is not mounted in a vacuum envelope and that very near to its faces (at both ends) there were placed two baffles (so-called ultra sonic reflector plates) to reduce the energy radiated from the ends of the quartz bar. (15) (15a)

In a later chapter we will come back to GR’s particular interest in aspects of the wartime PTR clock designs.

However, a great disadvantage was that both the PTR and the GR quartz-clocks were rather bulky instruments which could hardly be regarded as being “portable”.

Rohde's revolutionary quartz clock design

We have previously learned that PTR, as well as General Radio in the US, built quartz-clocks which employed quartz controlled time bases. These latter circuits were followed by several divider stages to obtain, ultimately, a frequency by which synchronous clock motors could be made to run in a stable (reliable) manner. The frequency most often used was 1000 Hz (the PTR used 333 Hz to drive their clock motors). The clocks which were driven by synchronous motors derived the 1 second time impulses by means of electrical switches. This was the state of the art up until about 1937.

The friends Rohde and Schwarz both got their Ph.D. in 1931 at Jena Technical University and established in 1933 a small design lab in Munich for RF measurement equipment. This company became later very well known as Rohde & Schwarz (R&S). (16) (17)

On 7 July 1937 Rohde applied for a German patent which became classified on 9 May 1940 under DRP Nr. 691 848. (18) He claimed: "a Piezoelectric controlled time standard". Although his name is solely mentioned on this patent application, we may presume that Richard Leonhardt was involved as well.

The associated patent drawing was of a rather cryptic nature and is, on first viewing, not easy to understand. I have made a considerable study of all sorts of patents, but the German patent claims can often be the most puzzling ones.

We will rely mainly on Rohde's explanations in ENT of 1940 (19), this paper was called: "Quarzuhr und Normalfrequenz-Generator", which translates to "Quartz-clock and Standard frequency generator".

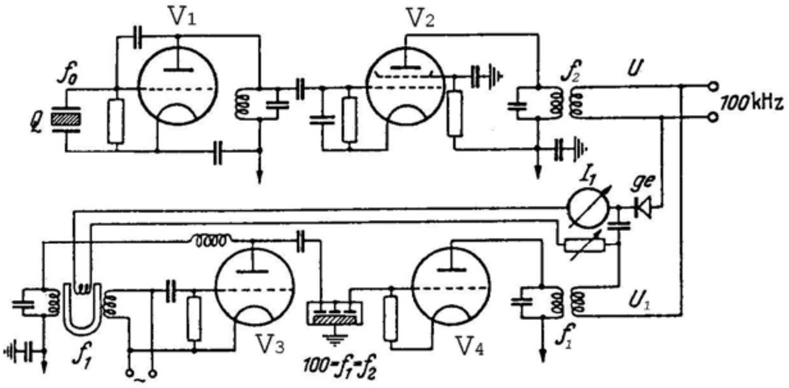


Fig.7: Rohde's way to control the freq. of the tuning fork

The quartz oscillator valve V_1 is, in this circuit, followed by a buffer stage, which valve was omitted in the modified version. Its signal was fed onto the RF transformer which was tuned on the quartz frequency f_2 at 100 kHz. A tuning fork oscillator of conventional design was tuned at a frequency of 1000 Hz; its output signal, at V_3, wasn't of a sinusoidal nature but contains considerable harmonics of which the 100 th was selected by means of a narrow quartz band-filter (flexural type). Its signal was, after amplification, being fed onto V_4 and then to the transformer tuned at f_1. Both signals will interfere by means of vector summation when linked together. We call the output signal of the tuning fork U_1 and the output of the quartz oscillator U_2, which will result in the modulus u.

$$u = U_1 \ \cos(\omega t + \varphi) + U_2 \cos \omega t \qquad (1)$$

Practically, we can assume (which was estimated to be valid for this circuit) $U_1 = U_2 = U$ We may consider:

$$u = 2\ U \cos(\varphi/2) \cos(\omega t + \varphi/2) \qquad (2)$$

It is evident that when $\varphi = \pi$ the resulting $u = 0$, and that for $\varphi = 2\ \pi$ the resulting output is at its maximum. For the regions where (argument) $0 < \varphi < \pi$ we get instability and no phase locking will occur. In practice the angle φ will vary for only about 10 %, which results in a phase shift error of $\approx 5 \times 10^{-7}$. This can, according to Rohde, be neglected with respect to the 100 kHz reference frequency.

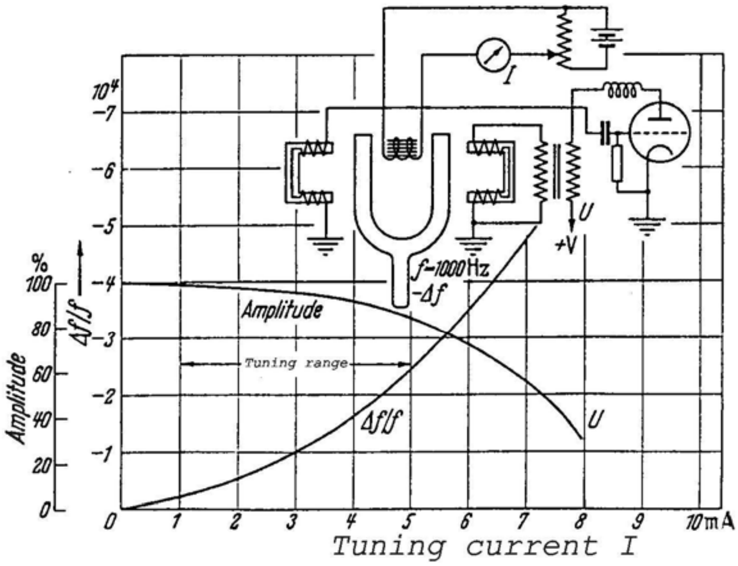


Fig.8: The parameters of the tuning fork control

The response curve of the tuning current versus the detuning $\Delta f / f$ of the tuning fork is shown in figure 8, which was obtained by means of an electro-magnet placed between the two fork legs. Increasing its magnetic flux slows the fork oscillations and in consequence decreases its output frequency. Of course, the inverse will occur when the magnetic flux is being reduced. It is evident that when the frequency is being decreased this also will lower the Q factor of the vibrating tuning fork. If we estimate that the bandwidth of a tuning fork is 0.1 Hz at 1000 Hz, then the Q will be 10,000. A damping of the Q factor of the tuning fork, due to its magnetic loading, obviously decreases its output voltage. The voltage swing of the tuning fork oscillator (output) can be estimated for a maximum of about 15 % (which didn't caused any technical problems).

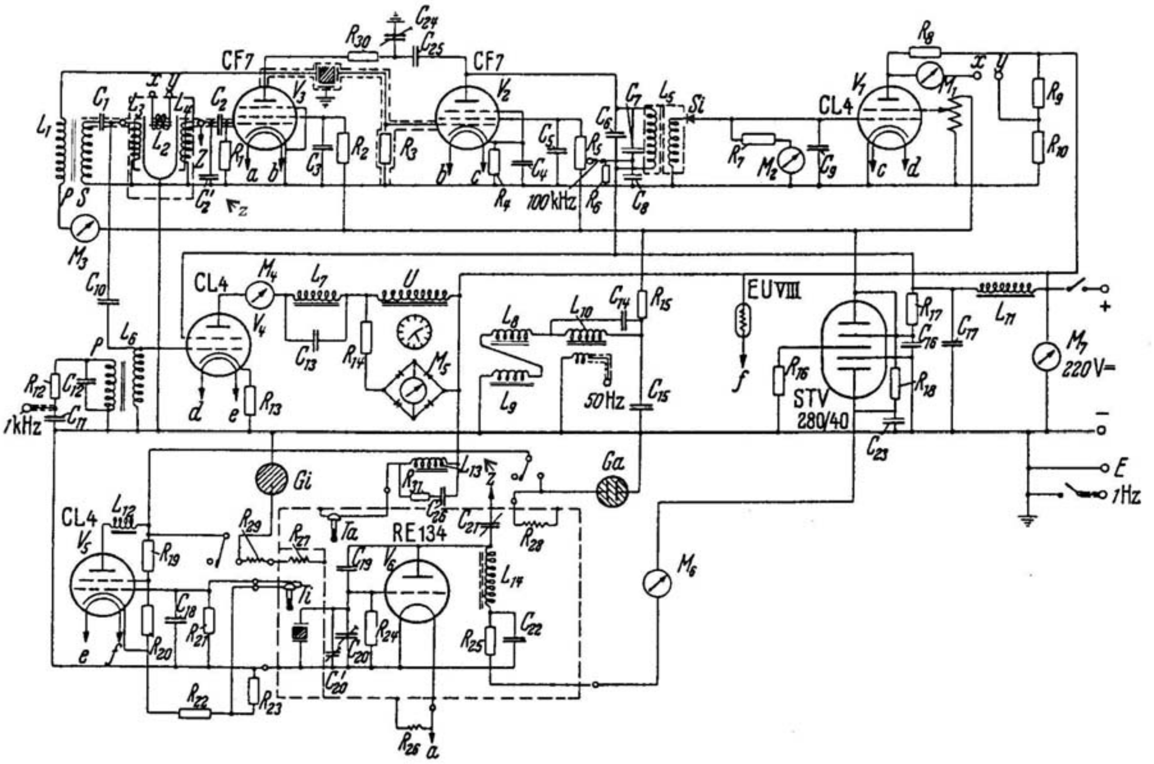


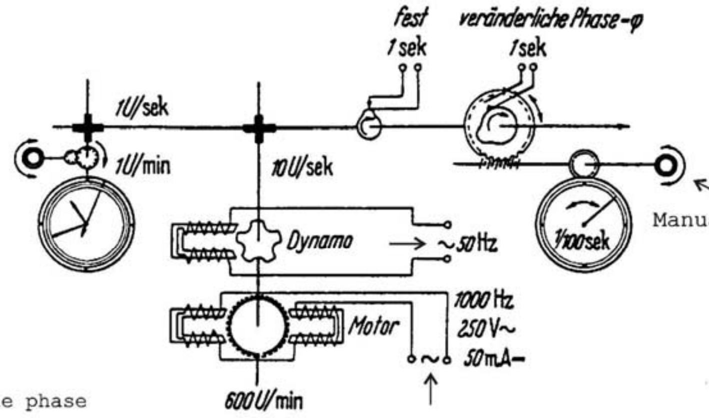
Fig.9: Simplified diagram of the quartz-clock type CFQ (R&S)

Shown here is a, slightly simplified, electrical circuit diagram of the famous Rohde and Schwarz quartz-clock type CFQ. The tuning fork oscillator valve is V_3. The 100 kHz quartz reference oscillator valve is V_6. If we keep figure 7 in mind, then it is obvious that the output of the tuning fork signal and that of the 100 kHz quartz reference oscillator have to add their mutual signals by means of vector summation (modulus).

The output signal of V_6 is fed, via line *'Z'*, onto the grid circuit of the tuning fork oscillator valve V_3, which circuit was especially designed to generate harmonics of high order. The later oscillator valve acts, by this means, as an additive mixing circuit as well. Its output at the anode contains a wide signal spectrum of which the 100 kHz region is selected by means of a narrow band quartz-filter QF (the modulus of the 1 kHz x 100 and the 100 kHz reference signal, notice equation 1 and 2). The great advantage of this circuit is that when the signal is following the same signal path (delay) then their mutual phase deviations are (all) kept equal.

The resulting signal is, after amplification in V_2, fed onto the tuned circuit of L_5. Its signal output is, after rectification in diode S_i, fed onto the dc amplifier V_1. The output signal, at the terminals *x* and *y*, is linked onto the (de)tuning control coil L_2 (between the tuning fork legs).

The 1000 Hz signal for the synchronous clock motor was amplified by V_4. The filter circuit L_7 and C_{13} was (presumably) tuned at the second, or eventually third, harmonics of the original fork frequency. The principle diagram of the synchronous clock module is shown in figure 10.



Manual fine adustments

U= rounds
sek=seconds
fest=fixed
veränderl.= adjustable phase

Fig.10: The principle of the synchronous clock module

The synchronous clock motor employed 100 poles which consequently resulted in 10 rounds per second which corresponds with 600 rpm (the rotor was damped by means of the, adjustable, flow of mercury). The drawing is self explanatory.

The quartz resonators which were used by R&S for their early quartz-clock designs were of (more or less) similar design to the ones which were used by the PTR (both employed longitudinal quartz bar resonators). The quartz bars were similarly fixed by a silk wire cord (later artificial silk) (see fig. 4a-b). (20) This information was confirmed, in a fax message, by Mooser, one of the former employees of R&S. He stated that the early quartz (clock) references were manufactured by the firm Loewe and that the quartz bar was fixed in the envelope by means of two special knots. This demanded very special skills (work of art) to ensure that the wire cord didn't change its configuration during long term operation. Unfortunately, after Loewe's specialist had died there was no one left who was capable to continue this skilful job. As a result they modified the crystal resonator type and used CT cut quartz resonators. (21)

However, in contrast to the fundamental mode operation used by PTR, the R&S quartz-clock crystals were excited at the second harmonic frequency.

The Temperature coefficient was at 39° C (which was the working temperature) about $1 \cdot 10^{-7}$ K^{-1}, the crystals were kept in a nitrogen filled glass envelope at a pressure of about
0.1 mm Hg.

The reference quartz at 100 kHz and its oscillator valve V_8, including the tuning fork oscillator were placed inside the inner, thermostatically controlled, cabinet and kept at 39° C within 0.01° C.

Quite remarkable was the fact that the oscillator valve used a relatively low emission current of only about 800 µA. Normally this can "poison" the cathode - grid area of a thermionic valve. Due to this annoying phenomenon, they employed a directly heated valve (RE 134) which proved to be a good choice. It could run continuously for many years without replacement! (As long as the filament voltage had been properly adjusted!)

During the war years R&S modified their CFQ clocks slightly and replaced the CF 7s valves by four, so-called, "metal encased valves" type EF 12.

According to information which was passed on to me by Gerd Langloh, during a meeting in the R&S head quarters in December 1999, they produced a total of 107 CFQ clock instruments.

R&S quartz-clock type CFQ serial number 106 (by courtesy of Rohde & Schwarz)

The advantages of using a tuning fork as frequency divider device can perhaps best be explained by quoting from the conclusions which were expressed in the Allied report which was published in the late 1940s. (22)

... A point of considerable interest is the comparative freedom from stoppage of the Rohde and Schwarz equipment. This probably constitutes the only evidence so far available concerning the long time reliability of the type of dividing circuit used and the results suggest that this and other time discrimination methods of division described recently by F.C. Williams and T. Kilburn should be considered for the possible application to quartz clock equipments. In the United Kingdom the frequency division is usually effected by the multivibrator type of circuit and this has on the whole been found satisfactory, unbroken periods of over a year having been obtained. The Rohde and Schwarz method using a tuning fork as an intermediate oscillator has one considerable advantage however. Owing to the inertia of the system, control of the tuning fork by the quartz oscillator can be maintained in spite of transient impulses which might be induced in the circuit by, for example, a momentary breaking of the circuit; whereas with electronic division such transient would almost certainly disturb the phase relationship between the quartz oscillator and the dividing circuits. On the other hand there is some "hunting" of the tuning fork frequency and consequently some loss in the precision of the time impulses. This can be overcome by the use of a special circuit arrangements by which the tuning fork impulses serves as a "gate" for the appropriate impulses from the standard itself. .... It is noteworthy that all the quartz oscillators used as time standards in Germany were made by a commercial firm. In the United Kingdom, on the other hand, oscillators of the necessary precision have so far been made only in Government laboratories. (Such as by the GPO at Dollis Hill, AOB).