Study Collection

The design of a tone generator

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The reader of these regular contributions by the Study Collection of EWI [1] will expect an article explaining the functioning of a piece of equipment from the early days of electricity. Well, the explanation will come later but first the authors would like to ask you to try to design a tone generator according to the following specification:

Designing a tone generator

We would like to have a tone generator for testing audio equipment, loudspeakers, tone control filters and similar equipment. The generator should produce sinusoidal waves from 30 Hz to 16 kHz, have a practically flat output level in this frequency range and have a distortion of less than 0.4%. The output should be delivered into loads of 1000, 500, 250 and 50 Ohms and have a maximum level of 200 mW. At the expense of a slightly greater distortion, the output can be further increased to 1 W such as to drive a loudspeaker directly. The instrument should not be a top-class ultra-precise tone generator, but an easily transportable piece of equipment designed to work in various situations. One particular requirement is that our generator should be able to range through all the output frequencies with only one turn of a dial. A second dial should be used to shift the frequency shown on the first dial with an offset from 0 .. 1000 Hz.

And by the way, we are situated around the year 1940, so the technology should be analog and use vacuum tubes. So, we will be quiet for some time while you, the reader, should try to design such a generator according to the above specifications.

Hoping you have succeeded, we will start the discussion now. By the way, this article is an adapted version of the description of the Philips GM 2307 tone generator by L. Blok [2]. This generator is part of the inventory of tone generators of the Study Collection. The generator intrigued us because of the front panel cathode ray indicator, a device we know as a tuning indicator in radio receivers from the fifties of the previous century of which we have many examples in our collection. We decided to revive this generator and succeeded in getting the generator into a working state again. This article will describe the result of our investigations.

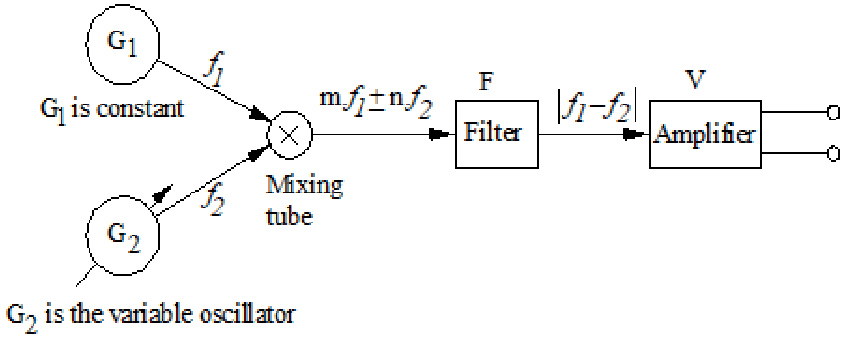

Figure 1. Heterodyning principle as used in the tone generator.

The requirement to range through all the frequencies with only one turn of a dial will rule out conventional tone generators based upon Wien bridges and so on. Also, adjustable L-C-oscillators are ruled out because of the high values of L and C needed for the audio range, so we will have to look for another mechanism.

The heterodyning principle

Heterodyning is a signal processing technique that creates new frequencies by combining or mixing two frequencies. Heterodyning, for example, is used to shift one frequency range into another, new one. The two frequencies are combined in a nonlinear (multiplying)

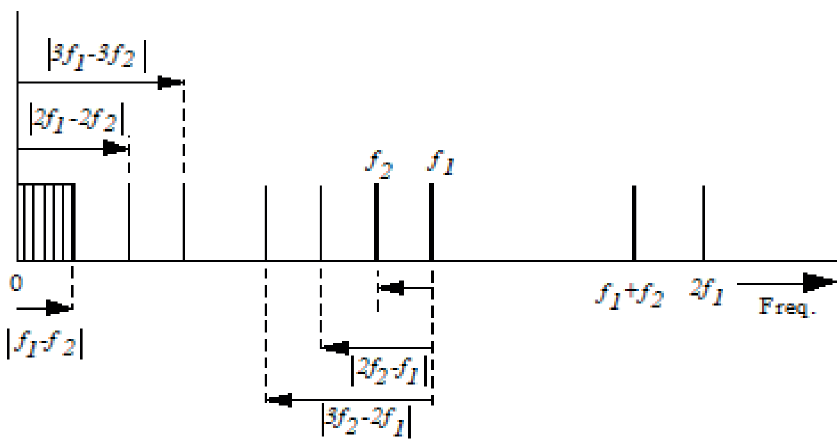

Figure 2. The frequency spectrum resulting from the mixing process

Figure 5. *Heterodyning principle as used in the tone generator.*

electronic device such as a special vacuum tube, usually called a mixer. Suppose we have two signals $x_1(t) = \sin(2\pi f_1 t)$ and $x_2(t) = \sin(2\pi f_2 t)$, and the nonlinear device performs a pure multiplication. Then, the output signal xr(t) is found to be

$$x_r(t) = x_1(t) \cdot x_2(t)$$
$$x_r(t) = \{cos[2\pi(f_1\text{-}f_2)t] - cos[2\pi(f_1+f_2)t]\}$$

or, in terms of the spectral components

$$X_r(f)=1/2\ (f_1\text{-}f_2)+1/2\ (f_1+f_2)$$

From this equation, it becomes immediately obvious that we may generate a low frequency
$f_0 = (f_1 - f_2)$ by multiplying two relatively high frequencies f_1 and f_2 and suppressing the high-frequency component $f = (f_1 + f_2)$ by means of a low pass filter. Usually, the nonlinearity involved deviates from being purely multiplicative, which is the case in almost all nonlinear devices, such as the vacuum tube in the instrument described here. In this case, the output signal will also comprise components with multiples of f_1, f_2, as well as $(f_1 - f_2)$ and $(f_1 + f_2)$, or in general: $m.\ f_1 \pm n.f_2$ (m, n = 0, 1, 2, …..). However, the basic principle is maintained, since all generated components apart from the desired component $f_0 = (f_1 - f_2)$ have frequencies far beyond f_0. It should be noted that, based on the choices for f_1 and f_2, the value of $(f_1 - f_2)$ might become negative. In this case we need to write $|f_1 - f_2|$.

A variable low frequency can now be arrived at by generating one fixed and one variable frequency. Hence, in a variable low frequency signal generator we employ one fixed and one variable frequency generator, respectively G1 and G2. The principle of such a generator is depicted in fig. 1. Both generated signals are fed into the mixer and the desired signal is obtained by means of a low pass filter (F) and amplified by V.

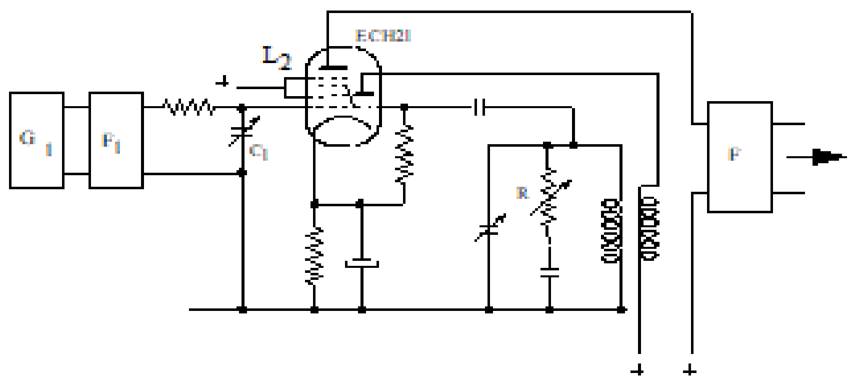

Figure 3. *Diagram of the mixing stage and the G2 oscillator for f2.*

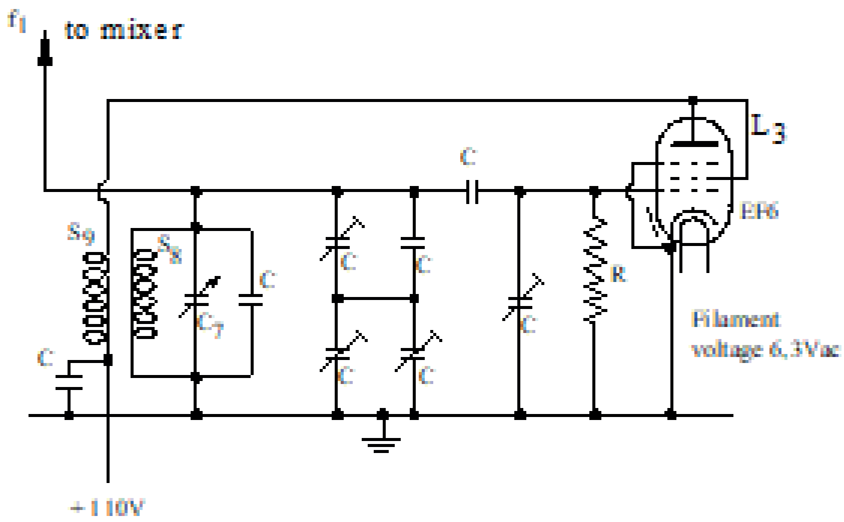

Figure 4. *Diagram of the tunable oscillator G1 for f1.*

From the spectral representation of the output signal of the mixer (fig. 2), it may be clear that high values f_1 and f_2 will allow for easy removal of the generated yet undesired high-frequency components. However, it should be noted that a small deviation (in terms of percentage) from the set values of f1 and f2 will result in large absolute frequency deviations, resulting in the same large deviations of the desired frequency f0. This imposes high demands on the stability of both generators.
In the case at issue, f1 is chosen to be 100 kHz and f2 is variable between 85 kHz and 100 kHz. To enable the functionality required by the second dial, (i.e. allowing for calibration with respect to the scale of the variable oscillator) the frequency f1 is not constant: it is allowed to be varied between 100 kHz and 101 kHz. More information on the heterodyning process is available from [3].

Details of the diagrams

Figure 3 shows the details of the oscillator G2 and the mixing stage. The triode part forms the oscillator G2, the hexode part performs the mixing function. The frequency of the oscillator is determined by a regular LC-circuit using a rotating capacitor with air as isolation. The signal from G1 is coupled to the first grid of the hexode and the signal from G2 is coupled to the fourth grid of the hexode. The anode current of the hexode is the product of the two frequencies f1 and f2. The filter F1 removes the harmonics produced by G1, while at the same time preventing a reaction of G1 on the signal from G2. The capacitor C1 serves to regulate the distortion and the output level of the generator. Resistor R serves to adjust the zero point correction of the frequency scales and will be described below.
Figure 4 shows the oscillator G1, producing the frequency f1. The frequency is determined by an LC-circuit; the variable capacitor C7 regulates the frequency being between 100 kHz and 101 kHz.

The zero point correction

In order to make the calibration of the frequency scales agree with the frequencies actually obtained (in spite of any frequency variations from fluctuations in the temperature of the housing,) another small capacitor with an adjustable resistor R in series is connected in parallel with the rotating capacitor of the oscillator G2 (see fig. 3). By varying R, the small capacitor is made to contribute more to the total capacitance,

and in this way the frequency of G2 is slightly affected. When the two rotating capacitors are set at the zero position of the frequency scales, f2 can be made exactly equal to f1 by means of this fine regulation and therefore f0 = 0 Hz. The equality of f1 and f2 can be ascertained by means of a cathode ray indicator in L1; a circuit derived from a tuning indicator in a radio receiver. More details on this tube can be found in [6].

The output amplifier

The output amplifier will not be described here in detail. It is constructed as a regular output stage of a radio receiver from that era. The pentode part of L1 is used as a preamplifier and the power pentode (L4) drives the output transformer. Negative feedback is used to reduce distortion in this amplifier. More details may be found in the full diagram reproduced in [4].

Figure 5 shows the front view of the GM 2307, the two frequency scales, from 0 to 1000Hz and from 0 to 15.000 Hz and the dials of the rotating capacitors. Above in the middle we find the cathode ray indicator.

In Figure 6 the rear view of the generator shows that the heat-producing elements (the power supply and the power amplifier) have been placed at the top level. In order to reduce the temperature sensitivity of the generators G1 and G2, the two oscillators have been placed at the bottom level.

Figure 7 shows the cathode ray indicator. With both frequency dials placed in the zero position, the resistor R (see Figure 3) will be varied until the observed beat frequency equals zero and the display will be stable. The green bands of the indicator will fluctuate according to the 'beat frequency' of the oscillators f1 and f2. When | f1 – f2 | = 0, the green bands will be steady.

Conclusion

We have discussed the design of a remarkable tone generator, the Philips GM 2307. We started the discussion with a question to the reader: How would you design such a tone generator from the specifications given? We want to end this article with another question:

Could such a design be implemented with either transistors, an analog IC, or through digital technology? Or could we arrive at the desired specifications by applying a completely different approach using contemporary methods and technology?

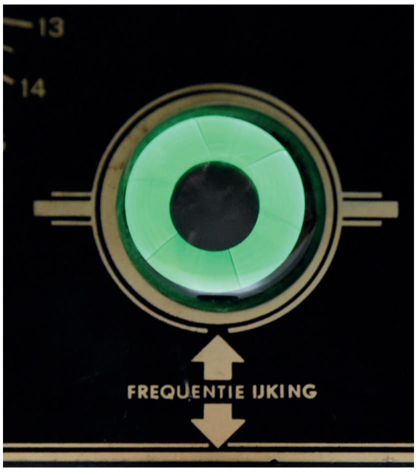

Figure 7. *The cathode ray indicator.*

[1] Study Collection EWI, TU Delft. https://studieverzameling.ewi.tudelft.nl/

[2] L. Blok, A Tone Generator; in Philips Technical Review, Volume 5, No 9, 1940 http://www.extra.research.philips.com/hera/people/aarts/_Philips%20Bound%20Archive/PTechReview/PTechReview-05-1940-263.pdf

[3] More information on the heterodyning principle may be found in: https://en.wikipedia.org/wiki/Heterodyne

[4] Full details and diagrams of the GM 2307 are given in: https://www.pa3esy.nl/Philips/meetinstrumenten/html/gm2307A/pdf/GM2307_1.pdf

[5] The vacuum tubes used in the tone generator GM 2307 are:

L1 = EFM1	Pentode + cathode ray indicator	LF-amplifier and indicator
L2 = ECH3	Triode + Hexode	Oscillator and mixer
L3 = EF6	Pentode	Fixed frequency oscillator
L4 = EL3	Pentode	Power output stage
L5 = EZ2	Double diode	Rectification for power supply
L6 = 150A1	Neon stabilisation tube	Power stabilisation

[7] Information about the EFM1 tuning indicator may be found here: https://www.radiomuseum.org/tubes/tube_efm1.html