The Philips Digital Temperature-Compensated Quartz Oscillator

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Introduction

The quartz oscillator is generally known as a high-quality oscillator with high Q-factor and stable frequency characteristics.

However, for many applications the frequency stability in the temperature range is insufficient and the effect of the quartz temperature has to be reduced.

With the aid of analog networks stabilities up to ±1 ppm in the -20/+70°C temperature range can be realized. With analog techniques a further reduction of the temperature effects is possible only on the basis of the so-called "oven oscillators" which, however, have a very long build-up period associated with a very high current consumption (up to 300 mA).

For some years now a new technology has been developed, where compensation of the quartz oscillator is accomplished by application of the latest digital electronics. For instance, it permits stabilities of ±0.3 ppm to be realized in the -40/+80°C temperature range. It is to be observed in this respect that the current consumption is hardly any higher than with analog compensated quartz oscillators and is a factor 10 lower compared with oven oscillators!

With the modern SMD technology the dimensioning can be such that the DTCXO has an overall height of max. 8 mm.

For some years now Philips has been making a DTCXO on an industrial basis and is now working on further optimization of the digital technology, so that in future it will be possible to produce very small digitally compensated quartz oscillators in regular quantities.

The advantage of digital compensation.

Normally, a non-compensated quartz oscillator has a temperature behaviour as shown in Figure 1. (so called AT section).

The best frequency stabilities in the -40/+85°C temperature range are ±12 ppm. Consequently, an improvement to ±0.3 ppm in the same range requires a further reduction by a factor of 12/0.3 = 40. Such a reduction can be achieved only on the basis of modern digital electronics.
This circuit offers the possibility of determining 512 temperature measurement points in the -40/+80°C temperature range. This means that for almost each 0.25°C a related compensation voltage can be fixed for the main oscillator.

With the D/A converter 256 direct voltage levels are available. This number is directly related to the reduction that can be achieved through the quartz crystal used in the main oscillator.

Pre-programming.

In an automated production process each DTCXO is pre-measured in an air-conditioned cabinet in the required temperature range. During this operation at 512 temperature points the direct voltages together with the related addresses inquired by the main oscillator are stored in a computer. From here the PROMs are programmed automatically for each different main oscillator. Thus, each DTCXO receives a specific PROM of its own.

Further characteristics incorporated

Both the main oscillator and the measuring oscillator are equipped with glass quartz crystals. Thus, the DTCXO is provided with extremely high long-term stabilities (ageing).

Moreover, an additional connection offers the possibility of adjustment of the DTCXO.

Also, techniques have been developed for elimination of any hysteresis effects.

A highest possible proportion of SMD components enable the product to be produced with a small overall height. (fig 7)

The layout of the p.c. board was optimized for its HF characteristics through a CAD/CAM design.

The case is sealed hermetically by resistance welding in a nitrogen atmosphere with a dew point below -46°C.

At the request of the customer the output can be realized in TTL, LP Schottky, CMOS or HCMOS technology.

Fig. 6 shows a typical curve characteristic $f = (f) T$ of the digitally compensated oscillator.

Future developments

Further integration of the various functions will enable a further reduction of the DTCXO dimensions.

The latest IC techniques, like Bi-MOS for example, will enable a combination of analog and digital electronics to be used.

Mass production of TCXO's in very small cases will then be possible, together with a further drastic reduction of the current consumption.
The main oscillator

A varicap diode has been inserted into the circuit, permitting the frequency to be controlled by voltage variation (fig. 2).

As can be seen from fig. 1, with different temperatures different voltages are required at the varicap diode to reduce the frequency deviation relative to the zero line to zero. For this a voltage curve as a function of the change in temperature for a constant frequency can be derived (fig. 3).

Each main oscillator has its own specific voltage curve, which is determined in a preliminary measurement. In the digital TCXO this pre-determined voltage curve is digitally stored, so that at a certain temperature the voltage determined in the preliminary measurement equals the voltage at the varicap diode. Thus, at each temperature the frequency deviation is minimized by suitable voltage control at the varicap diode.

Temperature measurement and storage

The storage structure is shown in fig. 4. The measuring oscillator is a quartz oscillator too and is operated by a Y-section quartz crystal.

With a Y-section quartz crystal, the frequency deviation is very high and linearly dependent on the temperature. Thus, the Y-section oscillator is the suitable temperature sensor with a high resolution of max. 0.001°C.

The temperature measurement oscillator and the main oscillator (AT-section) are mounted next to each other on the p.c. board. This ensures that the frequency delivered by the measurement oscillator fairly represents the temperature at the main oscillator. This frequency is referred to as a measuring frequency (Fy). Because this measuring frequency is to serve as temperature address, it is necessary to convert this frequency into a binary number through a divider.

This divider requires a reference frequency. The main oscillator frequency (Fx) is used for this purpose because of its high stability in comparison with the measuring frequency. This has the great advantage that an A/D converter is not needed.

The counter output is a 9-bit binary number that is used for PROM addressing. Each digital output has its related digital output, which is fed to the 8-bit D/A converter. This D/A converter supplies the required direct voltage for the varicap diode of the main oscillator, by which the frequency is brought to nominal value.

The PROM is programmed in the factory during the pre-measurement process already.