Portable calibration of GSM base station clocks

Summary

This application note illustrates how Pendulums counter/calibrators CNT-85 and CNT-85R, can be used for accurate and portable frequency calibration of GSM base station clocks.

Unlike older analog communication system, the GSM specifies a very stable system clock in the base stations. The maximum tolerated deviation in the base station system clock = $5x10^{-8}$ (as defined by GSM 05.10)

This puts a tough **accuracy** requirement on the frequency calibrating device, it must be capable to measure frequency with an uncertainty that is several times better. And above all, the frequency calibrator must be truly **portable**. You must be able to transport it to the base station site, and be up and running a short time after power-on.

Why traditional counters can't do it

Traditional counters using AT-cut crystal oscillators could not be transported to a different location, without a *continuous battery backup*. This is because traditional AT-cut crystals suffer from significant *frequency retrace* (the frequency after a power interruption is not the same as before) and a very long warm-up time (24h or more to arrive close enough at the final frequency value after a power-up). Furthermore, the aging properties of AT-cut crystals are such that very frequent re-calibrations are needed, even if the crystal is continuously powered. The oscillators need to be calibrated every second week or so.

And frequency reference receivers (e.g. GSM-disciplined oscillators) are no options either. The time it takes to arrive at specified frequency accuracy - after a transportation to a new location - is too long (several hours or more)

New state-of-the-art oven crystal oscillators

The option 40 in Pendulum's frequency counter CNT-85 is a very-high-stability OCXO (Oven Controlled X-tal Oscillator). It is designed around the more advanced SC-cut crystal oscillator, having virtually no frequency retrace, and a very short warm-up period. In just 10 minutes the frequency is within $5x10^{-9}$ from the final value. There is no longer a need for battery supply during transportation.

This oven oscillator has an aging per year of 2x10, and need to be calibrated and adjusted approx. two to three times a year, to have a reasonable margin to the GSM requirements.

Rubidium oscillators

Pendulum's frequency counter/calibrator CNT-85R includes a Rubidium timebase oscillator.

The extremely low aging of the Rubidium timebase of $1x10^{-9}$ in 10 years ensures that the Rubidium timebase need *no adjustment at all during a 10 year period* and still will have a margin of 50 times to the GSM requirements. A performance check every second year is recommended, but no time consuming adjustment procedure will be needed.

The warm-up of the Rubidium oscillator version (CNT-85R) is even faster; just about 5 minutes to reach $1x10^{-9}$.

The CNT-85R offers safe, easy and low cost operation, due to:

- Low calibration cost, due to long intervals and no adjustment need
- Less downtime for calibration
- Less sensitive for environmental influences (like shock, vibration, bumps etc.)
- Very wide margin (50 times) to GSM requirements, also after 10 years without adjustment

Frequency counter models for GSM calibration

To be suited for frequency calibrations on digital communication systems, there are certain requirements.

very-high stability timebase oscillators (Rubidium or ultra-stable OCXO with max. $2x10^{-8}$/year)

fast warm-up (max. 10 minutes)

very-high resolution (10 digits/s)

transportable

easy to use (smart Auto-functions)

All these requirements are fulfilled with Pendulum's *CNT-85* (incl.. option 40) or *CNT-85R*. The model to choose is dependent on desired TUR (Test Uncertainty Ratio), acceptable re-calibration intervals and purchase budget.

Selecting the right timebase oscillator

The table below shows the selection parameters for a suitable time base option to the CNT-85 frequency counter.

Uncertainty factor	CNT-85 incl. opt. 40 (OCXO)	CNT-85R (Rubidium)
Initial (calibration) uncertainty *u(i)*	$5x10^{-9}$	$5x10^{-11}$
Aging *u(a)* per:		
1 month	$3x10^{-9}$	$5x10^{-11}$
3 month	$8x10^{-9}$ typ.	$1x10^{-10}$ typ.
6 month	$1.5x10^{-8}$ typ.	$1.5x10^{-10}$ typ.
12 month	$2x10^{-8}$	$2x10^{-10}$
10 year	n.s.	$1x10^{-9}$
Temperature *u(t)*:		
20...26 °C	$4x10^{-10}$ typ.	$2x10^{-11}$ typ.
0...50 °C	$2.5x10^{-9}$	$3x10^{-10}$

As can be seen in the table, a yearly calibration of the option 40 OCXO, gives a 2:1 TUR ($2.5x10^{-8}$ compared to required $5x10^{-8}$). This is normally not sufficient according to normal metrology practice, so a calibration should be made at least twice a year.

For the CNT-85R the margin is 200:1 after the first year, which is reduced to 50:1 after 10 years.

Calibration requirements for GSM base stations.

The accuracy requirements for GSM Base Stations (BS) are formulated by the ETSI organization, (European Telecommunications Standards Institute) in the GSM 05.10 recommendation "Radio subsystem synchronization" as follows:

5. BS requirements for synchronization.

5.1 The BS shall use a single frequency source of absolute accuracy better than 0.05 ppm for both RF frequency generation and clocking the time base. The same source shall be used for all carriers at the BS.

The base station system clock is typically a 13 MHz high precision oscillator, that sometimes is synchronized to the Central Office master clock system.

Also in a centrally synchronized system, the base stations own master clock must be able to maintain network synchronization if the central clock synchronization should fail.

Modern frequency counters are ideal tools to verify the compliance, providing that the timebase of the counter is accurate enough. For this purpose, only the best available SC-cut oven controlled crystal oscillators or Rubidium oscillators will do.

Is timebase uncertainty calculation enough?

The overall uncertainty of the frequency measurement is the combined uncertainty of the timebase according to the previous table plus the following:

1. Counter resolution uncertainty
2. Counter trigger uncertainty due to noise
3. Counter internal delay uncertainty

For all three uncertainty factors, the common denominator is that the uncertainty is reduced by increased measuring time. With e.g. a measuring time of 1s, both the resolution and the systematic delay uncertainty are only $2.5x10^{-10}$, which is totally negligible with respect to the GSM requirements.

The uncertainty due to noise could normally also be neglected for the normal frequency (13 MHz) used and a measuring times of 1s or more. This is especially true for the GSM master clock signal, which must be free from noise to ensure a proper operation The contribution from internal counter noise on a clean 13 MHz sine wave of 1 Vrms, measured during 1s, is less than 10^{-11}.

The conclusion is: For measuring times of 1 s or more, it is the timebase uncertainty that is *THE* uncertainty parameter, that will determine the counter's usefulness for GSM base station calibration. Thanks to the very-high resolution and noise-free design of the CNT-85 and CNT-85R, the resolution and trigger uncertainties can be neglected.

Required counter time base uncertainty:

1. Maximum allowed GSM base station clock deviation according to ETSI:

0.05 ppm ($5x10^{-8}$)

2. It is common metrology practice to have a margin of at least 3-5 between the measurand and the measurement equipment. This means that the frequency counter uncertainty should be at least:

$5 x10^{-8}/3...5 = 1...1.5 x10^{-8}$

From the previous table, we find the CNT-85 including option 40 OCXO, can reach this uncertainty, at the cost of short calibration intervals. But the CNT-85R maintains a very wide margin, practically "for ever".

Traditional (AT-cut) x-tal oscillators could not fully meet the requirements. Users had to minimize aging by frequent calibration The initial uncertainty due to calibration and retracing, could only be reduced by continuous operation via built in batteries. This way, it was theoretically possible to reach a total uncertainty of a few parts in 10^{-8} by calibration every 10th day.

Rubidium time bases

A Rubidium time base oscillator behaves in many aspects quite differently from x-tal oscillators:

The frequency is determined by intrinsic atomic properties, which results in very low sensitivity to temperature, shock and other environmental influences. This means *safe operation*, no matter what happens in the counter's environment. Furthermore the atomic properties are basically time invariant, resulting in excellent long term aging properties.

In spite of a higher purchasing price, the CNT-85R will in the long run give an over all low cost of ownership, due to very long calibration intervals.