Feasibility of DCF 77 or NTP-Time Servers to Control Carrier Frequencies of Base Stations

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***Abstract*—We studied how to control the frequencies of those simple crystals used in typical telecommunication transmitter. According to the common standards, the uncertainty of carrier frequency should be less than 0.3 ppm. That of simple XO is only 100 ppm.**

Two approaches have been studied here. The first one is the German transmitter DCF 77. The second one is the utilization of the NTP-time servers.

We studied phase distribution and calculated Allan variances, both for raw data and cleaned data. Three-standard-deviation-criterion was applied to detect outliers. The results point out, that usually DFC 77 enables sufficient phase locking in a couple of seconds. The main problem is the atmospheric noise during thunderstorms in the late summer seasons.

The NTP-time servers suffer from 100 µs level time jumps. Typically the 10 min integration time is needed to achieve the 0.3 ppm accuracy. Therefore, some kind of temperature compensation of those XOs is needed to fulfill the requirements.

I. INTRODUCTION

Local oscillator relative frequency stability of 0.1 ppm is adequate for most of the applications. This stability level can be attained by numerous ways. Because telecommunication applications are numerous and their prices are typically low the cost of reference oscillator must also be low. This leads to the use of basic crystal oscillators (XO), which need nearly continuous control. GPS-controlled oscillators are by far too expensive and their antenna installations can be problematic. Therefore, one has to take one step back or look around for new commercial solutions.

Although many standard time and frequency transmitters have been turned off, the German DCF 77-transmitter is still functioning. Another new possibility is to take advantage of NTP-time servers.

DCF 77 is a long wave time signal and standard frequency radio station. Its primary and backup transmitters are located in Mainflingen. It is operated by T-Systems Media Broadcast on behalf of the Physicalisch Technischen Bundesanstalt (PTB).

NTP time servers offer a simple and cheap way to keep computer clocks in time. The official specification of the Network Time Protocol is RFC1305.

A freeware program "ntpd" (later daemon), developed by professor Mills, takes care of computer timing. This program selects automatically the best NTP time servers from a fixed group and controls the time of the computer clock in an "optimal" way.

II. DCF 77 SIGNAL STRENGTH AND PROPAGATION MODES

PTB is responsible for the accuracy of both carrier frequency (77.5 kHz, $df/f < 1\cdot10^{-12}$) and the time code (AM) of DCF 77 transmitter.

At frequencies below 150 kHz, two dominating propagation modes exist. The most stable propagation mode is the ground wave. This mode follows air/ground interface assuming that the dielectric constant of ground is essentially higher than that of air. Because water mainly determines permittivity, the range of ground wave can be 2000 km over see but 1000 km over standard ground.

If the distance from the transmitter is more than 500 km, the most important propagation mode is reflection from the ionosphere. The reflection occurs from the so called D-layer (height 50…70 km). In Finland, 1-hop and 2-hop models have to be considered. The path delay of the one-hop model is around 100 µs longer than that of the ground wave. The two-hop waves arrive about 300 µs late.

The height of the D-layer depends on solar activity. On daytime the elevation is low and on night time it is higher. This height variation produces systematic phase variation, which is more than 12.9 µs cycle length. Then interference behaviour is detected during sunrise and sunset. Those two or even three wave components may amplify or weaken each other.

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On daytime the field strength is 10 dB - 15 dB lower than on night time due to higher absorption in D-layer.

A typical night time field strength in Southern Finland is more than100 µV/m, but in Lapland it is only around 30 µV/m. However, active DCF 77 receivers are sited on Utsjoki Kevo station. In central Europe, stable ground wave propagation mode dominates. Naturally ionosphere wave exists, too, and causes interference problems at ranges above 500 km. Because typical field strength (ref. PTB home page) is above 1 mV/m, antenna placing is easier than e.g. in Finland.

III. PC-CLOCK NTP STRATUM 2 STABILITY

Typical timing errors are less than 1 ms in a well defined fast subnet. This is equivalent to $< 3 \cdot 10^{-7}$ relative frequency error during one hour integrating time.

If one wants to keep the frequency error as small as possible, the daemon program is not the best choice. The reason is that computer time must be continuous and uninterrupted. Time jumps in any direction are not convenient because application programs rely on the clock.

Time and frequency stability of a typical PC-clock is determined by two things. The first one is the quality of the crystal oscillator (XO), which is often poor. The second one is connected to the time keeping program, daemon.

The initial frequency accuracy of a typical computer XO is ± 100 ppm. In addition, the temperature coefficient of the crystal is substantial, around ± 1 ppm/ºC. Because the temperature may vary quite rapidly, e.g. 10 ºC per hour in normal room without air conditioning, ± 10 ppm frequency changes can be expected.

IV. EXPERIMENTAL OBSERVATIONS ON DCF 77 FREQUENCY STABILITY

We studied the frequency stability of our DCF 77 receiver 200 sequential days in 1992, for 350 days in 1995 and around 100 days in 2006. These data contain both good and bad days. These results show that a frequency stability with df/f standard deviation (SD) of $1 \cdot 10^{-8}$ can be obtained with 2-hour averaging.

Another problem is that signal may fade away during sunrise or sunset, causing XO to lose phase lock after which clock phase starts to drift. When the carrier comes back, it may take nearly half a day to correct the clock phase back to the nominal value.

One second data is not routinely collected in our laboratory. We have collected it during working hours only. A typical length of this data is 2-3 hours, one point per second.

Thunderstorms during summer seem to cause problems lasting for several hours. This problem can be solved by using a receiver with excellent pulse rejection characteristics. One has to realize that disturbing pulses must be cut out in the front end of the receiver, before band pass filter.

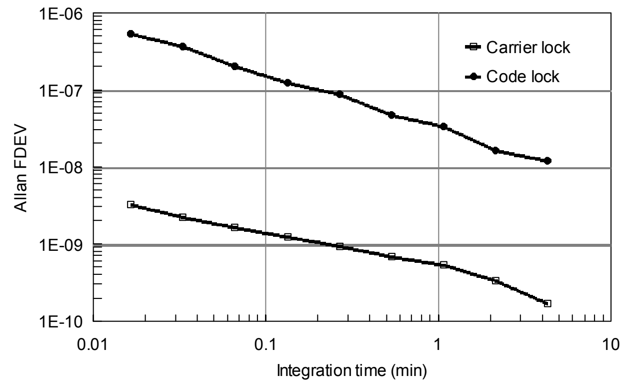

Figure 1. DCF 77 Frequency stability, carrier and time code locks

V. STUDIED NTP SERVERS AND CONNECTIONS

MIKES has four stratum 1 NTP servers: ntp2.mikes.fi and ntp4.mikes.fi are in a subnet connected to the internet with a connection provided by ELISA, and ntp1.mikes.funet.fi and ntp2.mikes.funet.fi are connected to the internet with a connection via FUNET provided by CSC – Scientific Computing Ltd, Finland. These servers are independently controlled on stratum 0 level by our atomic clocks (ntp2.mikes.fi and ntp1.mikes.funet.fi) or by GPS receivers (ntp4.mikes.fi and ntp2.mikes.funet.fi).

The above mentioned GPS-time servers monitor each other and the atomic clock servers. In addition, we monitor our servers with a common PC hardware at stratum 2 level in Espoo, Soukka using a SDSL (~ 1.2 Mbit/s both directions) connections (distance about 12 km).

A. Time server NTP1 monitored directly inside MIKES building

We monitor time of our NTP time servers directly. Thus the errors caused by switches and routers are eliminated. The data show that the server time jumps forth and back in 100 ns steps. This time step corresponds to 10 MHz reference frequency. We can attain 0.1 ppm accuracy just in 1 second. After 10 minutes integration, relative error is about $1 \cdot 10^{-11}$.

B. ELISA /FUNET ntp-ghost.ntp1.mikes.funet.fi.delay

The daemon program collects several data files called ".delay", ".offset", ".loops" and ".dispersion" at 65 s intervals. The basic information is delay data. It its simply two way delay divided by two. Thus the error of local clock is mainly eliminated. In this case a relatively short part of internet is in use. ntp1.mikes.funet.fi monitors itself via ELISA / FUNET. The delay distribution is smooth, SD is only 0,089 ms (see Fig. 2). Data does not need any cleanup.

Allan FDEV shows that it is possible to attain 0.1 ppm (SD) uncertainty after 10 minutes integration.

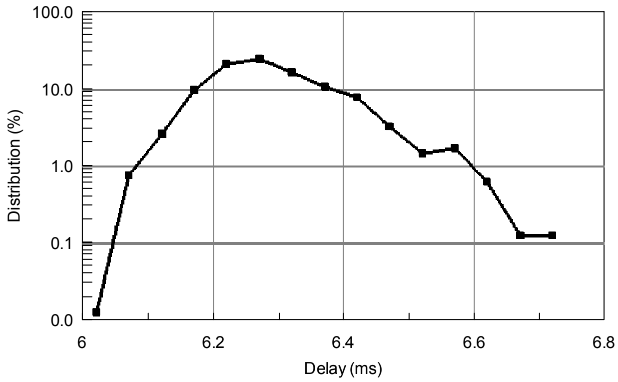

Figure 2. Delay distribution when surveillance server monitors ntp1.mikes.funet.fi via ELISA/FUNET

VI. CONCLUSIONS

DCF 77 standard frequency and time transmitter seems to provide 98 % of time better than 0.1 ppm frequency stability in Finland, nearly 2000 km from transmitter site. The problems occur practically every day during sunrise and sunset. Carrier loss due to interference may last 10 minutes. Local thunderstorms seem to cause problems lasting for several hours. To reduce lightning pulse disturbances, pulses must be cut out in antenna circuit before any band pass filtering. To cover the remaining 2 % of bad data, a two channel receiver (DCF 77 + MSF 60 kHz) may help.

All studied examples of NTP time stability show that at least 10 min. integration time is needed to attain 0.1 ppm frequency uncertainty. One problem is that PC-time is updated at long intervals (typically 1-3 min). Therefore, standard XO is not recommended if temperature varies 0.1 ºC in above mentioned integration times, 10 to 30 minutes. Basic XO must be replaced by temperature compensated crystal oscillator (TCXO).

ACKNOWLEDGMENT

Nokia Technology Ltd has supported this study.