THE STABLE SYNCHRONIZATION OF SINGLE FREQUENCY NETWORKS USING NEW CONCEPT GPS

Radio and television single frequency digital broadcast networks (SFN - Single Frequency Network) must be synchronized, with time and frequency references (1PPS and 10MHz) common and identical, in all respects, to all transmitters in the network. The easiest and cheapest way to obtain these references is based on the reception of signals coming from the GPS satellite network; however, many of the GPS receivers / synchronizers available are not suitable for this specific application because they can introduce, over time, de-synchronization of the SFN network and network disturbances impacting the viewer. The broadcast SFN application requires the GPS receivers / synchronizers to have special features that can be difficult to implement.

One of the main problems in the implementation of digital broadcasting Single Frequency Networks *(SFN)*, compliant with DVB-T, DVB-T2, ISDB-T and other standards, is the stable synchronization of all transmitters to avoid mutual interference.

Before analyzing the problems, we should quickly review Single Frequency Network operation.

In SFN the distributed Transport Stream must be generated with a very precise bit rate and include certain information *(time-stamp, pointer, etc.)* to synchronize all of the transmitters.

The generated SFN Transport Stream will be transferred to the transmitters in the SFN network via terrestrial or satellite microwave links, fiber-optic or other means, but in ‘transparent’ mode, that is without changing, adding or removing any single bit of the Transport Stream.

The generation or adaptation of the Transport Stream for SFN is done with specific equipment *(MIP inserter, Gateway, Multiplexers, etc.)* according to the chosen broadcast standard; this equipment employs very precise reference time and frequency signals *(pulses at intervals of 1 second - 1PPS - and 10MHz)* that have to be ‘identical’ to the time and frequency signals employed in each transmitter in the SFN network.

In order to ‘start’ SFN transmitters and generate the broadcast signal they must have, in addition to the Transport Stream containing the synchronization information for the SFN, the time and frequency reference signals *(1PPS and 10MHz).* These signals, as mentioned above, will be ‘identical’ to those employed in the generation or adaptation of the Transport Stream and for all the other transmitters in the SFN network.

For ‘identical’, regarding the 1PPS pulse, it means that the 1PPS must be simultaneous everywhere, with a minimum acceptable error, the order of magnitude being hundreds of nanoseconds; so the 1PPS pulse cannot be ‘transmitted’ except in transmission systems with known and constant latency that can be compensated for *(not so easily done via satellite as latency is not constant; in this case, complex dynamic compensation systems must be employed).*

Regarding the 10MHz reference frequency, the meaning of ‘identical’ does not refer to the phase or small instantaneous frequency differences, but to the average frequency that has to be, in the long run, identical.

Practically, if we have 10MHz signals that wander +/-$1 \bullet 10^{-9}$ around 10MHz, but the average value over the long term *(e.g. 24 hours or more)* is 10 MHz with an accuracy of $2 \bullet 10^{-12}$ *(which means a difference of about 2 pulses of the 10MHz clock in a day)*, this will be acceptable.

The instantaneous error *(within certain limits)*, is not particularly important but the problem comes from the accumulated error *(the difference in clock pulses)*. For example: 100 pulses accumulated error from the 10MHz clock, causes a de-synchronization of 10μS that, in the case of a DVB-T 8K SFN network with 1/8 guard interval, amounts to just under 10% of the guard interval duration *(the maximum that may be acceptable)*. As another practical reference, two 10MHz os-

cillators, one with an error of $+5 \bullet 10^{-10}$ and the other with an error of $-5 \bullet 10^{-10}$, in 3 hours accumulates a differential error of 108 clock pulses *(10.8µS)*.
Potentially, once the modulator is synchronized and started in SFN mode, the time signal *(the 1PPS)*, is no longer needed because, if the speed *(the bit rate)* of the Transport Stream to be transmitted is identical to the speed *(bit rate)* required from the modulator *(and it must be because both must have the same 10MHz frequency reference)*, they will continue to be synchronized indefinitely.
In practice, however, the 1PPS pulse must, in the case of SFN transmitters developed and produced by ABE, be continuously supplied to the modulator to keep constantly under control the correct synchronization of the transmission and, if the de-synchronization exceeds 10% of the guard interval, the modulator is automatically reset and starts again with the correct synchronization. Otherwise, the transmission will de-synchronize with reference to the other transmitters in the SFN network, both disturbing and being disturbed.
The easy, accessible and widely used reference for SFN network synchronization is based on the use of GPS receivers *(Global Positioning System - the satellite positioning system operated by the U.S.A.)* that can generate absolutely accurate 1PPS pulses *(with peak errors in the order of magnitude of tens of nanoseconds, but with virtually zero error over the long term),* simultaneously, anywhere in the world.
The GPS service, provided by 24 satellites plus backup, considering the many applications that rely on its use throughout the world, is considered safe and virtually impossible to disable; as confirmation of this, there are currently plans for the maintenance and replacement of satellites and improvement of the system, until at least 2030.
The 1PPS pulses calculated by the GPS receiver using the data received from the GPS satellites, in addition to being the time reference required for the synchronization of the SFN, are also used to discipline the 10MHz oscillator *(usually a high-stability 'oven' type)* that provides the necessary frequency reference.

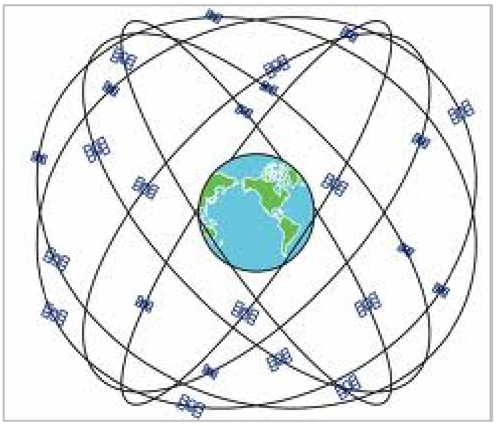

Fig.1 GPS satellite constellation

Not all available equipment that include GPS receivers and 10MHz disciplined 'oven' type oscillators are usable as time and frequency references for the synchronization of SFN networks; most are not and can easily cause de-synchronizations in the network. Problems, in fact, are many; we will now examine the main ones.

ACCUMULATED ERROR

As described above, the 10MHz reference frequency disciplined from GPS, in the long-term, should not accumulate errors and thus avoiding de-synchronization of SFN networks; instantaneous frequency precision *(which can also be in the order of magnitude of $1 \bullet 10^{-9}$ or worse)* is not as important as the long-term average. In fact, even a very low frequency error, but continuing steadily over time, leads in the long run, to de-synchronization.
ABE Elettronica has developed its intellectual property algorithm called 'ZERO CUMULATED ERROR' that solves the problem by ensuring virtually zero errors in the very long term.

MINIMUM NUMBER OF RECEIVED SATELLITES

To generate the precise 1PPS pulses, GPS receivers need to receive and process data from a minimum of 4 satellites. The GPS system ensures the constant reception, anywhere in the world, in an open sky, of a minimum of 4 satellites *(recently also 5)*. However the receiving antennas are often installed in places that are not completely open to the sky, in the presence of buildings, towers, mountains, etc. In these cases, and although sometimes they can receive many more satellites *(such as 7 or 8)*, reception of 4 satellites is not guaranteed. In other cases there may be

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conditions where, due to electromagnetic or other local interference the receivable satellites are only those with the stronger signals and, may be, less than the minimum of 4.

ABE Elettronica has solved this problem in its product, by having the ability to generate precise 1PPS pulses and thus discipline the 10MHz 'oven' oscillators, even when receiving a single GPS satellite. Each GPS satellite continuously transmits, together with the timing information, the data from which the receivers can precisely calculate the orbital position of the satellite. To precisely synchronize the 1PPS pulses, the receiver also needs to know its position and, to calculate it precisely, the reception of a minimum of 4 satellites is required. However, since the application type is for fixed installations, the ABE GPS receiver initially performs, at the time of installation, an accurate survey of its position *(which normally lasts about half an hour, averaging the position of 2,000 valid data acquisitions)*, and then stores it so as to be able to generate accurate timing information even when receiving a single satellite.

Fig. 2 GPS Satellite

GPS RECEIVING ANTENNA TYPES AND THEIR INSTALLATION PROBLEMS

Since the GPS signal is extremely weak, the receiving antennas employed should preferably be active *(i.e. pre-amplified)* otherwise the losses in the cable, which often has a length of several meters or tens of meters, could make the received signal *(at a frequency of about 1,575MHz)* too low, thus preventing the receiver from operating reliably. Considering the noise figure of the receivers and antennas, a good rule might be to use antennas whose gain is at least 6dB higher than the loss of the cable.

It should also be considered that in transmitting stations, where GPS receivers and synchronization equipment are located, usually there can be problems with radio frequency electromagnetic fields that might cause 'blocking' or saturation of the GPS antenna preamplifiers and receiver front ends; it is therefore appropriate that the gain of the antennas is not too high and that the GPS antennas are equipped with a pre-selector filter inserted between the antenna receiving element and the pre-amplifier. Obviously this filter makes the noise figure characteristic of the pre-amplified antenna slightly worse *(typically 1 dB)*, but avoids or greatly reduces the possibility of blocking. However care should be taken in the choice of the antenna as there are 'filtered' antennas with the pre-selector filter placed after the first pre-amplifier. To help avoid the potential for blocking, this type of configuration *(which does have a slightly better noise figure)* is not recommended.

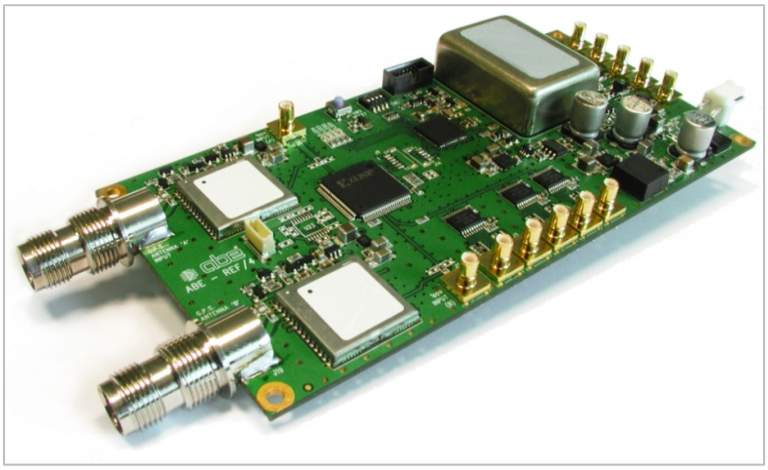

Fig. 3 The GPS synchronizer board equipped with 2 receivers and the oven oscillator

A major problem can occur when strong radio emissions from the transmitting station have harmonics that fall in the GPS reception frequency range. In this case it is recommended a careful positioning of the GPS receiving antenna in a place shielded from the transmitting antennas, even if this results in a lower number of receivable GPS satellites. ABE receivers, as mentioned above, also work well with the reception of a single satellite. However, it is also possible to use GPS receivers equipped with dual radios *(and thus dual antenna inputs)*, and placing the two antennas in different locations, seeing different parts of the open sky, whilst also being shielded from the transmitting antennas.

COLD START

Many GPS synchronization devices require a long warm-up period *(often several hours)* to stabilize before being put into operation. This is because premature introduction to the network could lead to de-synchronization of the SFN transmitters because the time and frequency signals are not yet sufficiently precise.

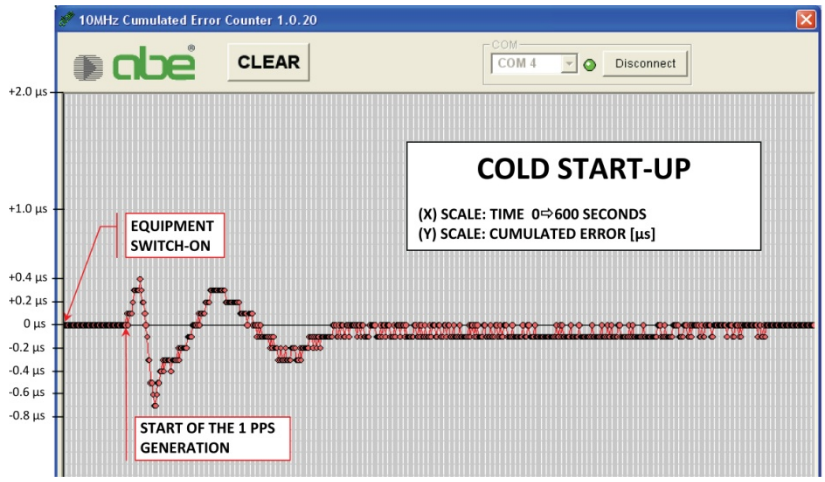

Fig. 4 Graphic of ABE GPS1000 performance vs. time and frequency reference instrument certified by the metrological institute Galileo Ferraris (national standard)

ABE Elettronica has developed an algorithm of its intellectual property called 'FAST COLD START-UP' which allows quick cold start times of the equipment (typically one minute) without creating de-synchronization problems.

OPERATION DURING PERIODS OF ABSENCE OF GPS SIGNAL (HOLDOVER) AND ERROR CORRECTION

If the GPS signal, for whatever reason fails, the equipment must maintain the generation of the time and frequency signals *('Holdover' condition)* having, as reference, no longer the received GPS signal, but the 10MHz reference 'oven' oscillator present inside the equipment. This oscillator, despite its good stability performance, will lead to a slow de-synchronization of the SFN network.

For example, suppose you have an oscillator with an aging characteristic of $5 \cdot 10^{-10}$ per day, and assuming that the aging has a linear function versus time, during 8 hours of Holdover it will accumulate an error of about 2.4µs *(corresponding to 24 clock pulses @ 10MHz)*. If the 2.4µs error is considered acceptable, under the same conditions mentioned above, the error accumulated in 24 hours becomes 21.6µs: most probably unacceptable. The GPS synchronization equipment should have an alarm and automatic shut-down *(at least for the 1PPS pulse)* after a programmed holdover time that is adjusted according to the SFN network settings *(duration of the guard interval)* and the characteristics of the oven oscillator used *(aging)*.

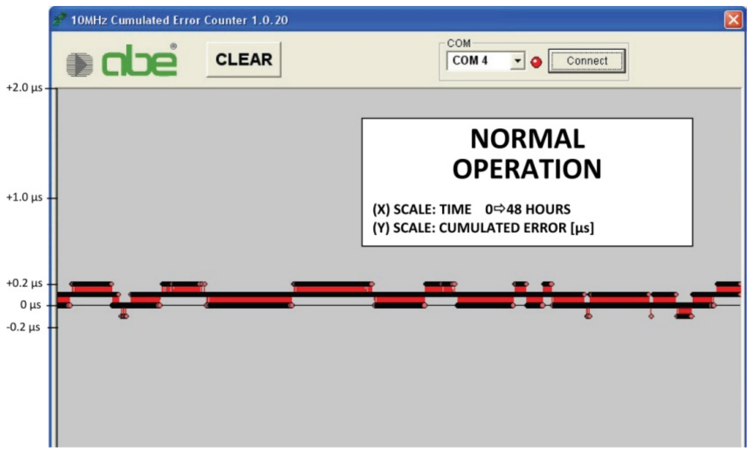

Fig. 5 Graphic of ABE GPS1000 performance vs. time and frequency reference instrument certified by the metrological institute Galileo Ferraris (national standard)

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When the GPS signal returns, most of the GPS synchronization equipment available re-start to correct and align the 10MHz oscillator, but the SFN modulator will remain de-synchronized with an error equal to the timing difference accumulated during the holdover period. It might be true that a lack of GPS signal for several hours is quite rare; but it can also be true that, adding many shorter periods of GPS down-time, it is possible to accumulate de-synchronization values that are unacceptable.

ABE has developed an algorithm of its intellectual property called 'HOLDOVER ERROR RECOVERY' that solves the problem by slowly compensating the error accumulated during the holdover periods, so re-synchronizing SFN modulators. It is also possible to determine the maximum recoverable error: in this case, if the detected error, at the end of the holdover period, exceeds this value, the ABE equipment switches-off the 1PPS timing signal for a short period of time, so forcing the re-start of the associated SFN modulators. The algorithm works correctly even when the compensation for an holdover error has not yet been fully made when a new holdover condition starts.

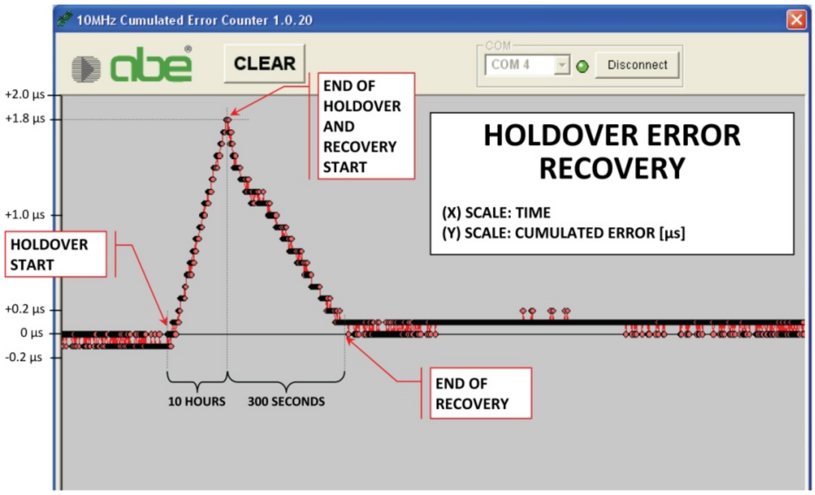

Fig. 6 Graphic of ABE GPS1000 performance vs. time and frequency reference instrument certified by the metrological institute Galileo Ferraris (national standard)

An extreme test of this feature has been made, successfully, with lack of GPS signal for more than 90% of the time, with each period of absence of the GPS signal not exceeding the maximum time set for holdover *(usually in the order of magnitude of 8 hours - but could be significantly higher)*, followed by periods of GPS signal reception sufficient to allow the accumulated error recovery *(usually in the order of a few tens of minutes)*.

OTHER USEFUL FEATURES

There are many additional features that can make GPS synchronization equipment more suitable for broadcasting SFN networks applications.

For example, to increase the accuracy of the timing signal *(1PPS)*, the GPS receiver manufactured by ABE can compensate for the receiving cable length.

ABE Elettronica can also equip the GPS receiver / oven board *(which can be provided as a stand-alone ABE product, embedded in ABE transmitters or as an OEM board)* with a dual-radio, significantly increasing the reliability of the system, both in case of failure, and for greater certainty

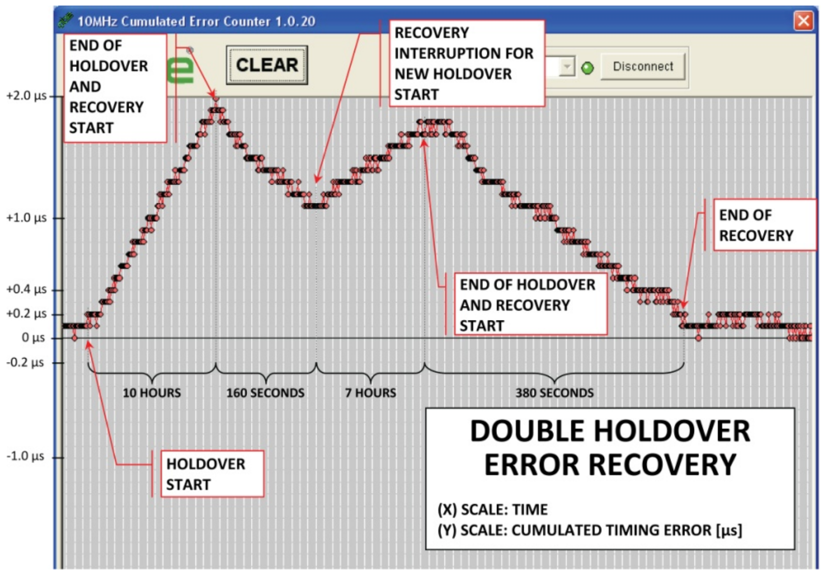

Fig. 7 Graphic of ABE GPS1000 performance vs. time and frequency reference instrument certified by the metrological institute Galileo Ferraris (national standard)

of receiving GPS signals, having two receivers and two antennas.
And again, for reasons of high-availability, the equipment can have the possibility be supplied equipped with dual redundant oven oscillator, dual power supply, etc.
Finally, with regard to the 10MHz oven oscillator it is important that it has a good inherent frequency stability *(i.e. with minimum variation from aging and/or temperature, when not disciplined by the GPS)* since it influences maximum holdover time. Other oscillator parameters are not particularly important: for example, the harmonics and phase noise since the 10MHz reference frequency is normally used in modulators & transmitters for phase locking *(PLL)* of an internal oscillator *(re-clocking)*. Therefore, it is much more important to have a good specification for short term stability *(Allan deviation - 1s).*

Fig. 8 The ABE GPS1000 receiver - synchronizer with 2 pre-amplified antennas

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