Considerations on using the time information from the GPS signal for achieving modern master clock/clock installations

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ABSTRACT

The paper presents (considerations on using the time information from the GPS signal for achieving modern master clock) the results of researches undertaken in the domain of realizing Installation Master Clock with GPS Signal for Zonal Nets .
From the functional point of view the installation is made of the following main blocks: GPS antenna – for receiving the signal on the 1575 MHz frequency; Module for GPS signal processing which , provides the signal control for secondary digital clocks , shows the GPS signal quality by led (stabile reception status) ,is connected to the computer by a serial interface in order to send the time information , displays the universal time information (hours, minutes, seconds) respectively (day, month)

<u>The general presentation of the GPS system and of the time information from the GPS signal</u>

GPS is a positioning in space system by the help of the satellites, made by the USA Defense Department (DOD) and is made mainly by 3 sectors.

<u>The spatial sector</u> – is including 24 satellites (21 operational and 3 active reserve) positioned on orbits at 20.200 km high with a revolution period of 12 hours (speed 13,9 km/s). The satellites constellation is placed on 6 plane equidistant orbits, inclined approx. 55^0 to the equator.
In reality there are 29 operational satellites that may replace any moment of a satellite that overpasses the foreseen functioning duration (approx. 7 years).
The orbital placement will allow direct visibility between 6 and 10 satellites from any position on the globe.
Each satellite has very high precision atomic watches (based on cesium and rubidium), radio emitter transmitting on the fundamental frequency L of 10,23 MHz two frequencies L_1 şi L_2 by multiplication with 154 respectively 12.
L_1 = 1574,42 MHz (19 cm)
L_2 = 1227,60 MHz (24 cm)
The sinusoidal porting frequency is modulated in binary code (C/A codes) containing the time and position information (Broadcast Message) including 1023 elements with a period of 1 ms.
GPS data transmitting is made according the CDMA (Code Division Multiple Aces) each satellite having a C/A principle own code that may be identified by the receiver.
L_1 frequency is designated to the civilian users and the L_2 for military and governmental purposes.

The control sector is composed from 5 control satellites spread on the globe, one central in Colorado Springs USA coordinating the whole system and other 4 in Hawai, Ascension, Garcia, Kwajalaen.
They have the role receiving continuously the signals from all the satellites, to calculate the "ephemeredes" (satellites position and speed), to verify the satellites clocks and to resend (correct) these data for each satellites (inclusive the courses modification).

The users sector is including the GPS receptors receiving the signals from satellites, decodes data and calculates the navigation equation solution named PVT (position, speed and time).
The main purpose to create GPS is determining with precision the object position (fix or mobile) mainly to determinate the spatial coordinates x, y, z, z is its altitude and indirectly the geographic parameters (latitude, longitude, high) by the triangular method.

The importance of the time signal precision for the position determination
Are necessary 4 satellites to determinate the x, y, z coordinate included in the following equation system
$(x_i - x) + (y_i - y)^2 + (z_i - z)^2 = (R_i - c*b)^2$
Where:
x_i , y_i , z - i satellite coordinate
$R_i = c*Dt_i$ c is the light speed
Dt_i - the signal propagation time between the I satellite and the receptor
b – is the time measurement error
Thus to the light speed 300.000 km/s and a time error of 1 nano second (10^{-9}) is obtained a positioning imprecision of 300 meters, showing the necessity of measuring the time with a very high precision using the atomic clocks included in satellites.
The users sector has extended including the following fields:

- Terrestrial, aerial, naval navigation mainly telecommunication and radio navigation;
- Data acquisition for exploring the oil and gas resources;
- GPS receptors fixed in cars (at least 2 mil. In Japan);
- Realizing maps of some regions including finding some optimal routes according to the destination for cars;
- Astronomic observatories;
- Research laboratories where the time signal precision is controlled by GPS receptors.

We mention that the atomic clock price varies between 50.000 and 100.000 $ and the time information provided by the satellite frees the laboratories of important investments.

The access to the GPS users and precision classes
The access to the actual GPS system is characterized by very precise norms and rules.
From the user quality point of view in the GPS system are definite two categories:

- Authorized users (military and governmental links)
- Mutual users (commercial and individual links)

According to the two users categories there are two precision classes in the USA Federal Navigation Program (Federal Radio Navigation Plane) mainly:

- Service for Standard Positioning (SPS)
- Service for Precise Positioning (PPS)

For making the difference and for protecting the users is used the accessing modality with selective access SA (Selective Availability) with restrictive access AS (Anti Spoofing).
The first code is C/A (Coarse Acquisition) is modeled for L_1 frequency, available for the civil use and is specially omitted on the L_2 frequency.
The second cod P (Precise) is modeled on both frequencies being reserved for the military and governmental field.

Error sources in the GPS system and the system precision – differential system DGPS
Main factors influencing the GPS system precision are the following:

- Satellites orbit modeling errors are influenced by the earth magnetic anomalies, the earth shape is not spherical but ellipsoid, the cosmic radiations pressure, the planets gravitational attraction near the earth;
- Errors of spreading the signal in ionosphere and troposphere
- Errors of the signals reflection (multi path)
- Geometrical distribution of the satellites during observations
- Errors because of the precession movement of the earth
- Non inertial of the reference earth Cartesian system
- Errors of time measurement

Generally the influence of these factors is evaluated in positioning error, mainly in meters.
Thus are estimated the following positioning errors:

- Because of the time measurement error: 1 meter
- Because of the refraction in troposphere: 1 meter
- Because of the refraction in ionosphere: 10 meter
- Because of the "multi path" effect: 0,5 meters

The precision of the GPS system:
The precision of the GPS system according to the two applications:
SPS (Standard Positioning Service):

- Horizontal positioning: 100 meters
- Vertical positioning: 156 meters
- Time precision: 340 nano seconds

PPS (Precise Positioning Service)

- Horizontal positioning: 22 meters
- Vertical positioning: 27,7 meters
- Time precision: 200 nano seconds

These data are relative exact because the GPS system is improved every year with consequences over the precision improvement.
For a better positioning precision it is used the DGPS differential system it means that are used two GPS receptors, one of them is fixed in a known coordinates point measuring

the difference between the known coordinates and the coordinates resulted from the GPS signals analyze.
For working in real time these differences may be recorded in a message type RTCM (Radio Technical Commission for Marine) and are transmitted by the help of a radio emitter (in this situation the GPS receptor needs a supplementary antenna for the RTCM signal reception).
Thus are eliminated the perturbing factors from the atmosphere, the precision depends on the distance between the two receptors and the quality of the receptor. Thus are possible positioning precisions of 1÷10 meters at a distance between receptors of 100 km.
The positioning precision depends on the receptors quality and thus its price varies.

Thus the GPS receptors may be classified in four categories:

- decreased price, SPS receptor – precision 100 meters
- medium price, SPS receptor – precision 1 ÷10 meters
- high price, PPS receptor – precision 2 meters
- very high price, special receptor – precision 1 cm

Prices may vary from 200 $ to 5.000 $ according the requested precision.

Antenna for the GPS time signals reception
The signal emitted by the GPS satellites has the frequency L_1 with a min. level of 162,0 dBW.
Because this level is relative small the visual field of the antenna must have a vide opening (high visibility) in order to avoid the presence of different obstacles (buildings) in the visual field. The ideal is a visual field of 360^0
In the mean time it is important the connection cable length, usually a coaxial cable, between the antenna and the receptor.
Usually are used two types of antenna according the time signal desired precision.
Antenna for exterior is used for applications where is desired a nano seconds precision towards UTC (universal time coordinates).
The antenna positioning is done so that the "multi path" effect is as small as possible.
The "multi path" effect is as big as the angular elevation of the satellite is small.
It is recommended the positioning of the antenna at a minim distance of 3 m towards the reflected surfaces.

Antenna for the room (for "window") used for applications where is desired a precision of the time signal of micro seconds.
The antenna positioning is made at the window which provides to the exterior an open visual field, preferably on the east – west direction.
If the connection cable length between the antenna and the receptor unit overpasses 45 m it is recommended to fix on the wire a linear amplifier or a converter for the cable length up to 500 meters (note that the signal delay is of about 4 nano seconds).
For big length up to 1500 meters is recommended the use of optic fiber cables providing the signal level and precision maintenance.

System for GPS important time
The fundamental time scale is the atomic international time (TAI) based on the time unit provided by the atomic clock.

Because TAI is an uniform time scale it is not a synchronization with the solar day (because of the earth rotation) being a difference of approx. 1 second per year.
Because of this reason was introduced the Universal time (UTC) coordinate system which periodically is adjusted with one second usually at the end of December (December 31).
The GPS time is a "composite" time connected to the YTC (to a difference of max. 10 nano seconds).
The time signal emitted by the GPS satellites is synchronized with the atomic clock from the control central station from Colorado.
For special applications the weeks are numbered starting with January 6, 1980) (the numbering starts with Saturday midnight when it is considered to start the week in the GPS system), also for special applications the first day of the week is Sunday.
Local time stated towards UTC/Greenwich according to the location (time fuse) between (-11 ÷ +12) hours, North and South America has the local declared time (-3 ÷ - 11) hours and Europe, Africa, Asia and Australia with (+ 1 ÷ + 12) hours.
There are arias where the local time is delayed with hours and half of hours
(e.i. Afghanistan +4 **½** ; Saudi Arabia +3 ½ etc.).

The change of the local time summer, winter
(DST – daylight savings time) starts in the first Sunday from April and ends in the last Sunday of October.
The time information presentation formats named TM (Time Cods) were developed over the years according to the technological development in this field and according to the use purpose: civil or military.

The TC 76 format was developed during the 70 and expresses the digital information with 6 digits for time without the AM (antemeridian) and the PM (post meridian) specification and four digits for data.

The TC 89 format adds two bits for AM and PM because were realized clocks with a new micro processor which recognizes this information.

SMPTE/EBU formats are designed for audio and video field and for the TV and Radio emission stations.
SMPTE (Society for Motion Picture, Television Engineers) rolls the images with a speed of 29,97 images per second and EBU (European Broadcasting Union) with a speed of 25 images per second. The time, minute, second, the display time, month and year are displayed (shoot, transmission).

IRIG format (Inter – Rage Instrumentation Group) is specific to the military industry and governmental communications.
The most used variant is IRIG – B where the time information is presented in the following order: day, year, time, minute, second.
Other variants of time format in the military field are "NASA", "XR3", "2137".

ASCII format is designed to display the information for computers by the help of an interface type RS-232 or RS-422.
Usually the information is presented in the following order: month, ay, year no. of the day in the year, time, minute, second.
I.e. 04-18-96-109:12:57:15
The most used time formats are TC89 and ASCII.

The use of the GPS signal for time information processing in order to realize the master clock installations was highlighted mostly after 1990, the first companies starting the production and spreading on the market such products were those from USA and Japan.
The functions provided by a master clock installation are improved such as:

- presentation of the time information in different formats SEMPTE/EBU, IRIG, ASCII;
- the possibility of programming (pre selecting) the local time in gamma (-11,5 ÷ + 12) hours towards the UTC with increment of 30 minutes (half of an hour);
- the automate change of the hour indication for passing to the summer time (April-September);
- programming functions for desired hours of some sound signals (mostly for schools);
- facile coupling with the computer by the help of a serial interface.

Referring to the secondary clocks it is noted the tendency of positioning them in the "doisy chain" configuration (each controls the next) multiplying the secondary clocks that may be ordered.

<u>The presentation of the master clock installation using the GPS signal</u>
INCDMF accomplished for the first time in the country an homologated prototype of "Master clock installation with GPS signal" with the following main technical characteristics:

- local time display: hour, minutes, seconds and data: day, month, year
- pre selection and display possibility of the local time towards UTC/Greenwith (-11,5 ; + 12) hours with increment of 30 minutes;
- Serial interface LS-232 for PC in order to present the time information in ASCII format;
- order of at least max. 255 secondary digital clocks (PUI)
- precision 100 μs
- output PPS (pulse per second) TTL level, precision 40 μs
- automate change of the hour indication for the passing to the summer time
- indication of the reception status of the GPS signal by LED
- antenna for the GPS signal reception with 8 frequency channels L_1- 1575 MHz, functioning in the temperature range (-40^0 ....+ 80^0) C;
- power consumed 10W
- use temperature (-10^0 ....+ 40^0)C

The block scheme of the installation is presented in fig.1 and the master clock installation with secondary clocks in fig.2

GPS module
The clock function is firstly linked by the GPS module. This module receptions the signal from the GPS satellites net providing serial data in ASCII format to the central unit. Data are updated each second.
The GPS module generates a pulse per second synchronized and a frequency of 10 KHz corrected at each second for high accuracy time measurement.
The GPS receptor module is based on the GPS SiRFstar™ II. By the encapsulated solution used the GPS TIM receptor represents the solution for serial applications where the space is limited. The RF entrance antenna is directly connected to one of the modules pines. Data of the integrated logger allows stocking the GPS data in the receptor. The module is an integrated receptor Global Positioning System (GPS). The integrated logging data function allows stocking of up to 100.000 events in the internal FLASH memory.
Functioning at the nominal tension of 3,3 volts, the module consumes under 0,5 W in continuous functioning. By implementing the operation module TricklePower TM consume may considerably be reduced in applications where it represents a major concern.

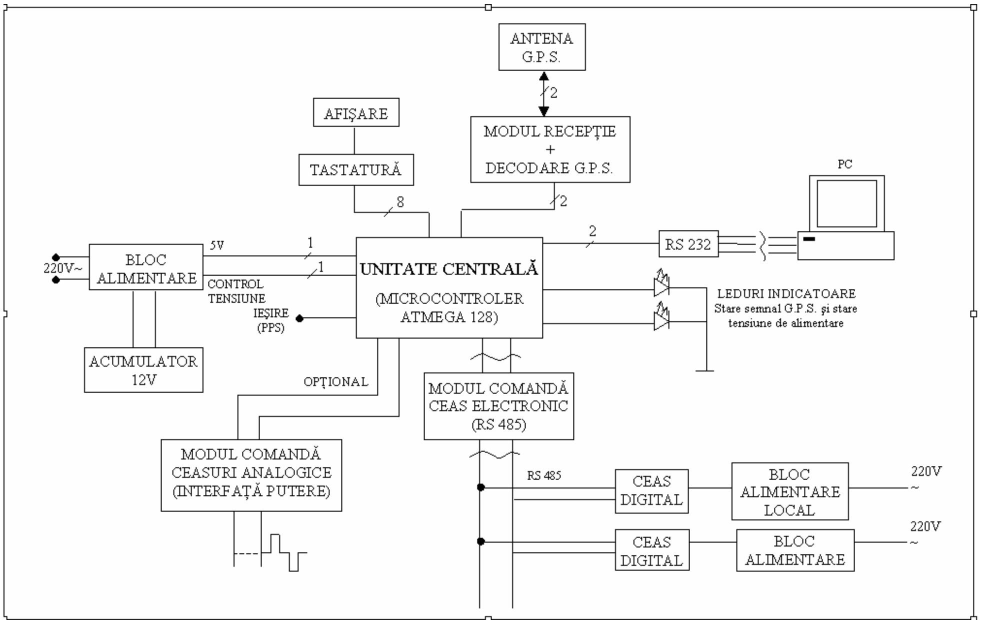

Fig. 1

Fig. 2

Characteristics:
-SiRF architecture star TM II:
* integrate circuit for interface RF type GRF2i;
* FLASH memory of 8 Mbit;
* amplifier with reduced noise
- Short time till the first localization (time to first fix)
- Immunity at RF interface
- Complete electromagnetic framing EMI
- Allows the use of passive and active antennas

- Reduced energy consume: Max. 0,5 W
- TricklePower TM module for consume of 10mA;
- Functioning tension: 2,75…3,45 V.

The central/main unit (with microcontroller Atmel 128) provides the management of the system functions.
It manages the communications with periphery data (GPS module, RS232 interface, control panel) data display and disturbances, communication with secondary clocks, adjustment by the control panel. It was preferred this microcontroller because of the reduced consume and because of the superior functioning speed towards other microcontrollers from the same class and also because of the periphery powerful control modules.
Master clock is developed around Atmega 128 having the functioning algorithm implemented by programming in the program memory high capacity type FLASH incorporated.
The processor may be re programmed for further changes of the functioning module by connecting to the PC by the help of an interface type ISP (In System Programming) without affecting the hardware system.
Communication between systems is realized serial with the baud rate according the data transmitting/reception unit. The GPS module has a communication established speed of 4800 bps and with PC and with the secondary clocks establishes a speed of 115200 bps.
For the communication with the PC is added in the scheme a microcontroller of small capacity type Atmel AVR 90S2313 having the implementation function of a serial interface type UART asynchrony because of the two existing units for the communication with the GPS and the secondary clocks.
Through a parallel port of 8 bits and with 3 control signals is controlled the display function type LCD, ASCII with 2X16 characters.

PC serial communication interface:
The main/central unit has an external serial interface activated by the help of a microcontroller from the same class but having a smaller communication capacity RS232 providing data transmitting to a PC by the MAX232 driver as translator at the electric level.
Communication implemented from the hard point of view provides a good protection during disturbing and a baud rate of up to 115200 bps.

Secondary clocks communication interface
For the communication between the master system and the secondary clocks is used the industrial standard RS485 by the driver MAX481, communication implemented from the hard point of view provides a good protection during disturbances and a baud rate of up to 2 Mb/s. The choused communication speed is 115200 bps.
Communication provides a bidirectional data change between the master system and the acquisition plate by a protocol type question/answer. The industrial standard RS485 is a bidirectional one and allows the data change establishing the moment communication sense through the implemented protocol.

The secondary clock is developed around AT90S8515 having the functioning algorithm implemented by programming in the program memory by the medium capacity included type FLASH.
The processor may be reprogrammed for further changes of the functioning module by connection to the PC by the help of an interface type ISP (In System Programming)

without affecting the hardware system. The reprogramming facility in the system provides the possibility of adding new further functions.
The microcontroller provides the management of the secondary clock having as main tasks intercommunication with the master system for data reception on a screen, the current time, with electro lighting diodes.

Display panel
The user interface is realized by the LCD 2X16 screen and two control keys. The display is controlled in 8 bit on a parallel port of the microcontroller adding the control pins as well.
After passing the reset and initiation sequences, the LCD display will update at each second the time provided by the central/main unit.
The supply source:
The main unit will be supplied from the 220 V net.
The digital part of the master clock and of the secondary clocks functions at a tension of 5 volts needing the use of the 5V 78LO5 regulator made by the Siemens company.
The supply source has a protection rapid diode against the short time transitory tension that may appear in industrial environments.
The product was presented at the international fairs: Hanovra, Milano, Cairo, Paris Research Show Room ant TIBCO – Bucharest.
The European Union by a public - private partnership will realize by the Galileo program, its own satellites system, similar to the GPS system, which is going to be functional after 2010.
Other applications of the GPS time signal
Portable time format generators
They are designed to obtain the time information in IRIG and ASCII format, in isolated places.
By the help of an antenna with 8 reception channels
Technical parameters:

- Supply 11-40 V.C.C.
- Out coming time formats IRIG and ASCII
- Automate correction for the summer time
- The possibility of correcting the local time towards U.T.C.
- Sending the time (format) information once per second
- PPS (pus per second) out coming with a precision of …in orig…
  - precision for IRIG format – 70 ms
  - if the GPS signal is missing ± 150 ms/day

Time servers
The server is used in the military, financial, technological processes control, telecommunication, etc. fields.
We mention that the time measuring laboratories having precision antennas and receptors provide very precise time measurements (precision of 1 nano second).
Thus there are concerns in the time laboratories from Germany, France, Austria, Great Britain, USA, Canada and New Zeeland.
From the market point of view there is a great potential of users for the master clock with GPS.
We mention the main users:

- education institutions (high schools and universities)
- hospitals, railway stations, airports
- banks, hotels, commercial societies, city halls, etc.