IRIG-B Time Signal Distribution over Geostationary Satellites

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Abstract—A time dissemination system which distributes time signals over a geostationary satellite has been developed. The developed system utilizes IRIG-B format for time distribution and achieves accuracy figures better than 1 ms over Turkey. Time information in IRIG-B is inserted into the audio channel of digital TV. IRIG-B delay correction hardware is developed to correct the time difference between the time signal received from the satellite and the reference atomic clock on the ground. A standard DVB-S receiver and satellite antenna is sufficient to decode the time signal, omitting the use of any special equipment for the end user.

Key words: time dissemination, atomic clock, geostationary satellite, IRIG-B

I. INTRODUCTION

High-precision time information is essential for many applications and systems, such as electrical power distribution, computer networks, missile systems, financial systems, scientific research and communications links. Even though atomic clocks are the primary source of precision time information, their wide spread use is hampered by the high cost and dimensions. Therefore, for many applications, dissemination of precise time information is the preferred over using an actual atomic clock.

Communication lines, radio broadcasts and satellite systems are employed for the delivery of precise time signals to users. The U.S. National Institute of Standards and Technology initiated the wireless distribution of time signals in 1923. The WWV radio station in Fort Collins, CO, still actively transmitting the 2.5 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz carrier signals, is used for this purpose and provides accuracy better than 10 milliseconds across the U.S. [1].

Geostationary satellite based dissemination of time and frequency information to large coverage areas started in the 70s. Early applications were used to bi-directionally transmit time and frequency information between research laboratories scattered around different regions of the world [2,3]. In 1977, NBS (National Bureau of Standards) commenced the GOES (Geostationary Operational Environmental Satellites) program, which was a time code dissemination system. The system worked at two modes, namely corrected and uncorrected modes. In uncorrected mode, the satellite coordinates are unknown to the terminals; therefore, accuracy of the system throughout the U.S.A. was ± 16 milliseconds. In corrected mode, using the location of the satellite and of the terminal, accuracy was improved up to ± 100 microseconds [4]. Widely used in electrical distribution systems and at airports, the GOES time service was terminated 2005, due to the better precision and widespread use of GPS.

Egypt’s Nilesat 101 satellite is used to distribute time code in a modified IRIG-B format using analog frequency modulation technique. In this application, signal delay of about 794 ms was measured and continued efforts to correct this delay were reported [5, 6]. The Chinese Beidou system, formed by geostationary satellites, is used to distribute time signal in one direction or two directions. A two-directional system can achieve 10 nanosecond precision by measuring the signal delay between the terminal and satellite. A one-directional system, on the other hand, can achieve 100 nanoseconds accuracy by utilizing the satellite location information embedded in the time signal [7, 8].

II. TIME DISSEMINATION SYSTEMS IN TURKEY

A time and frequency laboratory has been established in Turkey within the National Metrology Institute (UME) in order to meet national time and frequency needs. The time signal generated by cesium atomic clocks in this laboratory are distributed to various national intuitions over telephone lines. This distribution system, which reaches far too few users, can achieve only 5 milliseconds accuracy. Distribution via internet has worse accuracy. Due to poor time accuracy, this national time system is not preferred in critical military and civilian applications, and GPS is widely used instead. This necessitates a new, broadly available and more accurate national time system, which is the focus of this work.

In this study, the efforts to develop a national time distribution system together with measurement results are presented. These efforts are also considered as the basis of a system intended to be developed in the future. The planned regional positioning system will be developed using Turksat geostationary satellites, similar to Compass of China and QZSS of Japan [9, 10].

III. DEVELOPED TIME DISSEMINATION SYSTEM

One of the main requirements of the system is to utilize the current satellite fleet of Turksat AS and to be compatible with widely available (more than 10 million in Turkey) satellite receivers and antennas. Turksat satellites operate at Ku-band, so the system naturally has to adopt this frequency range. At Ku-band, most satellite receivers are used to receive TV broadcasts and are compatible with DVB-S standards, so the time dissemination system is decided to be DVB-S compatible. The TURKSAT-3A satellite was chosen to broadcast the time signal and the carrier is multiplexed into a readily available DVB-S package at 11,746 GHz with vertical polarization, 27500 symbol rate and 5/6 FEC. This package is broadcast to East coverage area of the satellite, as shown in Figure 1. TV channels are generally multiplexed to a single carrier for efficient use of the bandwidth. A new TV channel named as “Turksat Clock TV” is generated and inserted into an existing DVB bouquet with other TV channels within a 36 MHz transponder.

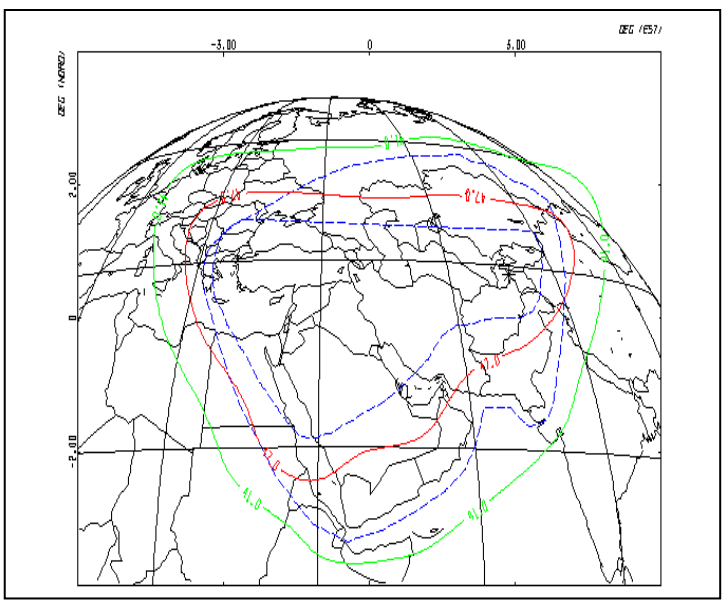

Figure 1. TURKSAT-3A East Coverage Area.

IRIG-B, originally developed in 1960 by the Inter-Range Instrumentation Group (IRIG), part of the Range Commanders Council (RCC) of the US Army, is chosen as the time code to distribute. IRIG-B is typically distributed as a DC level shift, pulse-width coded signal ("unmodulated IRIG-B") or as an amplitude-modulated signal based on a sine wave carrier with a frequency of 1kHz ("modulated IRIG-B") [11], of which the latter is selected for this application. This signal is suitable to for transmission through a DVB-S audio channel. This way, it is possible to recover the time code as an analog signal from the audio output of a standard DVB-S receiver.

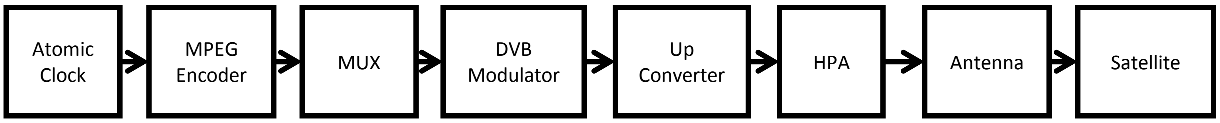

Figure 2. Communication system block diagram.

The IRIG-B signal, received from a rubidium atomic clock synced to GPS, has accuracy of 100 nanoseconds. This reference atomic clock signal is inserted to the MPEG encoder and sampled 256 kbps and then multiplexed with other MPEG carriers. After that, the signal is DVB modulated, upconverted to Ku-band frequencies, power amplified and transmitted to the satellite, as shown in Figure 2.

The system, as depicted in Figure 2, is initialized and the measurement results showed a time delay of about 6 seconds. Processing and propagation delays are suspected to be the reason for this delay.

Geostationary communication satellites orbit the earth approximately 35786 km away from the equator. The time signal sent from a ground station to the satellite can be received by any other receiver with at least 476ms propagation delay. This propagation delay G, can simply be calculated with the equation below, where *d* is the distance between the satellite and earth station and *c* is the speed of light.

$$G = 2.d/c \quad (1)$$

Delay changes with longitude, latitude of transmitter, receivers, satellite position and processing of electronic equipment in the chain. Geostationary satellites are kept within 0.1 degree angular box by performing regular orbit correction maneuvers. Main contribution to total delay is from processing delay of electronic equipment in uplink chain and receiver. Processing delay changes with video content of channels in the multiplexer and is not predictable. Total delay measured for our application was around 6 seconds. Since at least 238ms is coming from the propagation delay, other part is mainly caused by processing time of equipment.

If the delay is constant with time, it would be easy to compensate by adding an offset to the reference clock. Since delay is variable and unpredictable, dynamic delay correction was required for the proper operation. This special IRIG-B delay correction hardware measures the time difference between the IRIG-B signal received from the reference atomic clock and satellite return. Measured time difference is added to the clock transmitted to the satellite.

IV. IRIG-B DELAY COMPANSATION HARDWARE

For the purpose of this section the following nomenclature applies:

IRIG: Time code as defined per IRIG STANDARD 200-04.

$IRIG_R$: Reference IRIG time code with atomic clock accuracy.

$IRIG_C$: Corrected IRIG time code, generated from RUB GIDC and sent to satellite.

$IRIG_D$: Delayed IRIG time code, sent from satellite and received from RUB SIDC.

RUB GI_{DC}: IRIG generator module of the Alpermann+Velte RUBIDIUM Series with standard RUB GI hardware and special "Delay Compensation" firmware.

RUB SI_{DC}: IRIG monitoring and changeover module of the Alpermann+Velte RUBIDIUM Series with standard RUB SI hardware and special "Delay Compensation" firmware.

The operating principle of the time delay correction system is summarized here and presented in Figure 3. RUB GI_{DC} receives $IRIG_R$ for reference from the atomic clock and generates $IRIG_C$ which initially is adjusted in frequency and phase to $IRIG_R$. $IRIG_C$ is sent to TURKSAT- 3A satellite and transmitted back to earth. While travelling, the signal will be delayed because of propagation and processing. RUB SI_{DC} receives $IRIG_R$ and the delayed signal, denoted as $IRIG_D$. RUB SI_{DC} measures the difference of $IRIG_D$ against $IRIG_R$ and transmits the result to RUB GI_{DC} via serial interface.

RUB GI_{DC} receives the measurement results and corrects $IRIG_C$ in order to minimize the difference. Any signal shifting will be smooth; the IRIG signal always will be kept within the specified frequency range. At the end, all delays will be compensated by the advanced $IRIG_C$ and $IRIG_D$ will be equal to $IRIG_R$ within 100 µs accuracy.

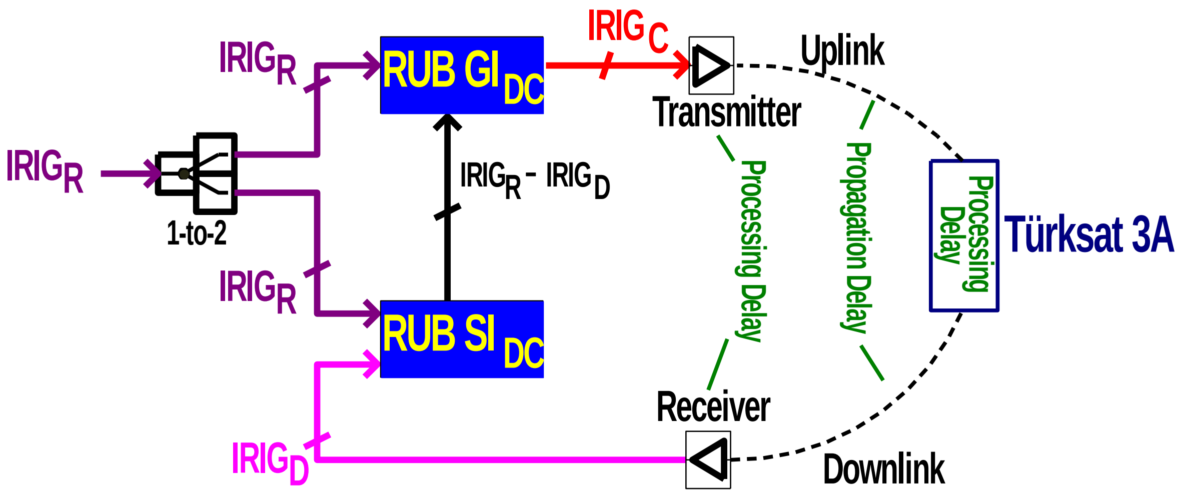

Figure 3. Time delay correction system block diagram.

A. Key Characteristics of the RUB SI_{DC} Module

RUB SI basically is an IRIG-B monitoring and changeover unit. The standard hardware of this module provides two balanced IRIG-B inputs. A simple A/D technique is used for amplitude and phase detection. This limits the accuracy of the phase difference measurement to ± 100 µs. Adding a separate phase detector for each signal input could improve the accuracy significantly.

RUB SI is equipped with flash programmable electronic parts. This allows upgrading a standard RUB SI module to RUB SI_{DC} with "Delay Compensation" firmware. RUB SI_{DC} measures the time difference between the IRIG-B inputs and transmits the result once per second via serial interface.

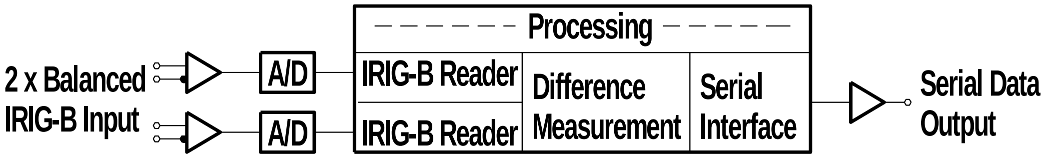

Figure 4. RUB SI_{DC} module block diagram.

B. Key Characteristics of the RUB GI_{DC} Module

RUB GI basically is an IRIG-B generator. The standard hardware of this module provides one balanced IRIG-B input for a reference signal and one balanced IRIG-B output. A serial interface allows communication for general purposes.

RUB GI is equipped with flash programmable electronic parts. This allows upgrading a standard RUB GI module to RUB GI_{DC} with "Delay Compensation" firmware.

After power has turned on, RUB GI_{DC} outputs an IRIG-B signal which is synchronized to the IRIG-B input signal. As soon as RUB GI_{DC} receives measurement results from RUB SI_{DC} via serial interface, it compensates any difference of seconds by a hard set of the IRIG data and then smoothly shifts the frequency of the IRIG-B 1 kHz carrier in order to minimize any time difference. RUB GI_{DC} is able to adjust the frequency with 0.1 ppm accuracy. Apart from one single time jump the generated IRIG-B time code keeps continuous and valid.

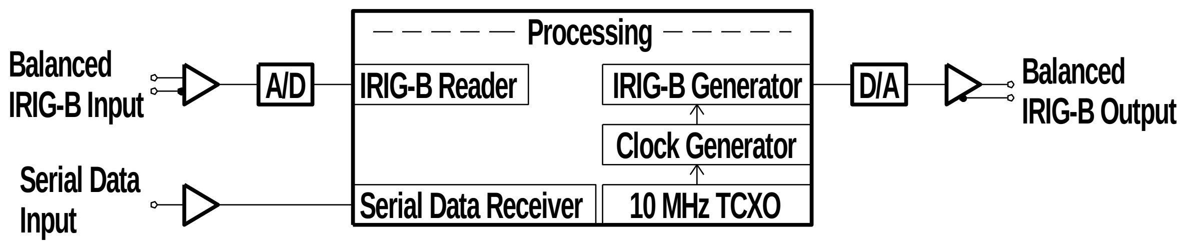

Figure 5. RUB GI_{DC} module block diagram.

V. TEST RESULTS

The time difference between reference clock and satellite return was measured to be around 6 seconds before the delay correction system was implemented. After the implementation of the delay correction system, the delay was measured to be less than 100 microseconds, as expected. The measurement was performed by the aid of the RUB SI_{DC} module and verified by oscilloscope measurement, as shown in Figure 6.

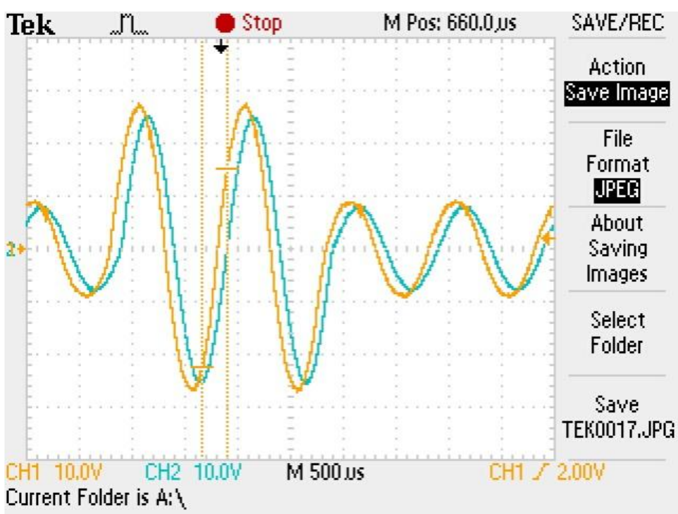

Figure 6. Time delay between the atomic clock and the clock received from the satellite.

The measurements are performed in Ankara, which is the location where the uplink signal is transmitted. The accuracy at any other location will suffer because the delay correction system can only correct the delay at the location of the transmitter. This can be better explained by the aid of Figure 7. The signal transmitted from Ankara reaches the satellite in T_u seconds. The re-transmitted signal reaches Ankara in T_g seconds. The time delay correction system corrects the processing delays and the $T_u + T_g$. However, for a terminal located at the far east of Turkey, the retransmission time T_1 is greater than T_g and the accuracy at this location suffers by the difference T_g-T_1. It is calculated that T_g-T_1 can be as much as 1 ms inside Turkey.

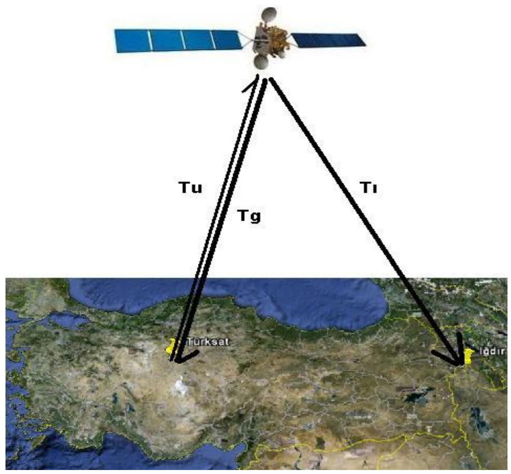

Figure 7. Dependency of the delay to the location.

VI. End User Equipment and Conclusions

End users do not need a special hardware clock to get the accurate clock disseminated. A standard satellite receiver connected to a TV screen will display the clock as shown on Figure 8. Audio channel of the Turksat Clock TV will provide IRIG-B signal for professional use, such as digital IRIG-B clocks, recorders etc.

An accurate clock dissemination system is developed with this project. Users can utilize this accurate clock without a need of special hardware. More than 10 million satellite receiver owners in Turkey can receive the accurate clock without any additional cost. Developed delay compensator hardware can be used by TV broadcasters to overcome their need to provide an accurate clock to their viewers.

Figure 8. Dependency of the delay to the location.

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