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POSSIBILITIES FOR DISSEMINATION OF STANDARD TIME AND FREQUENCY SIGNALS WITH METROLOGICAL ACCURACY VIA TERRESTRIAL TV NETWORK AND SATELLITES

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Abstract. This paper presents methods for clock comparison and frequency source calibration by means of standard time and frequency signals separated from TV signal. High accuracy achieved with standard signals disseminated via terrestrial TV network is a result of stable microwave link propagation characteristic. Geostationary satellites have recently become widely used for TV broadcast. Methods developed to determine accuracy limits for standard signals disseminated via satellite are also presented. Standard signals are extracted from TV signal in a specially designed receiver. Reference signals, used in measurements, are separated from high quality local quartz oscillators.

Key words: Dissemination of time, dissemination of frequency signal, TV network, geostationary satellite.

1. Introduction

Dissemination of standard time and frequency signals with metrological accuracy has a great importance for clock comparison and frequency source calibration, time scale coordination, telecommunications, scientific research, etc. Time and frequency standard signals have some advantage over other physical quantities' standards since they can be broadcast to a wide range of users. The broadest possibilities for transmission are offered by terrestrial TV networks and recently by geostationary TV satellites, because a relatively small capital investment is required for adaptation of the existing TV system.

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Regular dissemination of standard time and frequency signal via terrestrial TV network began in Belgrade TV studio, Yugoslavia in 1974 with the introduction of the Synchro-active TV system [1]. Excellent characteristics of the system are the result of both a high resolution signal transmission due to wide bandwidth and a stable microwave link propagation characteristics. The basic disadvantage of the terrestrial TV system lies in the fact that it necessitates a large number of links and transmitters for a wide area coverage. As a direct consequence, there is a serious difficulty in the determination of the propagation delay, which is an important factor when clock comparison is carried out since microwave link could be re-routed without prior notice.

The Belgrade TV studio recently began its TV broadcast via EUTELSAT-II-F4 geosationary satellite. The aforementioned terrestrial TV network disadvantages are partially eliminated by the use of the geostationary TV broadcasting satellite because a wide area is relatively uniformly covered by a single transmitter. The major drawback concerning time and frequency standard signals dissemination via TV satellite is the satellite diurnal motion around its nominal geostationary orbital position, resulting in propagation delay variations which limit accuracy of separated standard signals.

The basic methods for clock comparison and oscillator frequency calibration using standard time and frequency signals separated (extracted) from TV signal will be presented, as well as the corresponding achieved results. There will also be presented methods developed in order to determine accuracy limits of standard signals distributed via satellite. A special receiver for the standard signal separation from TV signal is designed. Reference signals used in measurements are separated from high quality quartz oscillators. Sources of measurement error are analyzed.

2. Description of comparison methods

The main feature of the Yugoslav synchro-active TV system lies in the fact that the second pulses and composite TV sync pulses are derived from the same atomic clock located within the TV studio premises, assuring complete synchronization between the TV frame (picture) and the second pulses. In addition to that, all TV format frequencies preserve excellent long-term frequency stability of the atomic clock. In this system, second pulses and coded time of day are inserted in some of the free lines of the vertical blanking interval.

Measurement methods for clock comparison and frequency source calibration using separated standard signals are shown in Figure 1. TV signal is received by commercial TV tuner and IF amplifier (designed for B-30 chassis TV sets manufactured by EI Niš, Yugoslavia). Standard signals are then separated from video signal in a specially designed circuit.

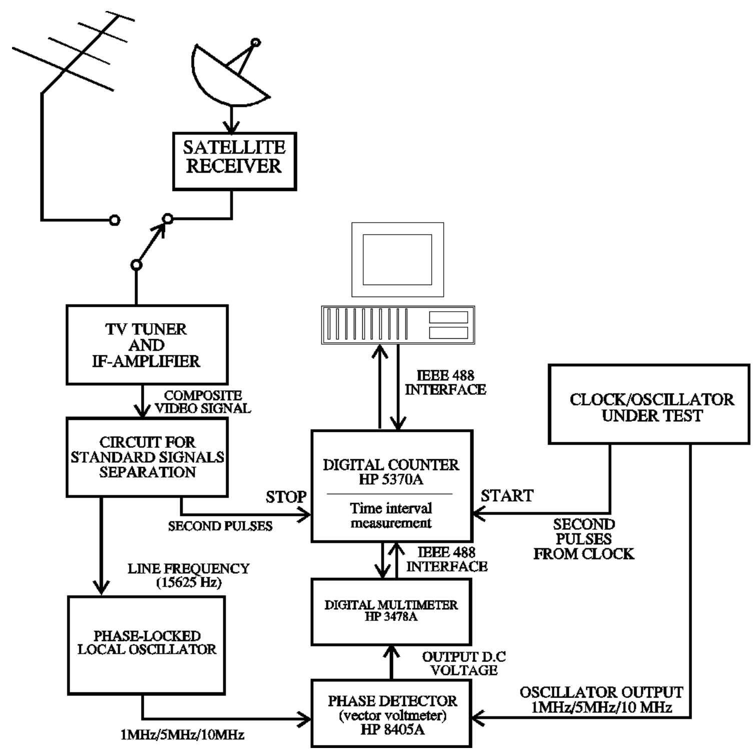

Fig. 1. Measurement methods for clock comparison and oscillator frequency calibration using standard signals disseminated via TV system

2.1. Dissemination via terrestrial TV network

Line frequency (15625 Hz) is used as a frequency standard. It is relatively low to be directly used for calibration because output frequencies of oscillators under test usually lie in the range from 1 MHz to 10 MHz. Therefore, high quality quartz oscillator HP 10544A, whose nominal output frequency is 10 MHz, is phase-locked to line frequency in an analog PLL. Low-pass filter has decisive influence on PLL behavior. Loop time constant has to be of the order of about 1 second in order to effectively filter out the noise and line frequency jitter. Good short-term frequency stability of the HP 10544A is preserved in that way, while on the other hand long-term frequency stability is transferred from the atomic clock to HP 10544A

[2,4].The output frequency of the locked oscillator is then divided down to usual nominal values, i.e. to 5 MHz and 1 MHz.

Signals from both the phase-locked quartz oscillator and the oscillator under test, with the same nominal frequencies, are applied to phase detector - vector voltmeter HP 8405A. Its output D.C. voltage, proportional to the instant phase difference, is measured by digital multimeter HP 3478A. PC compatible computer controls the multimeter and stores the measurement results. Frequency difference between oscillators causes characteristic voltage ramp (phase difference accumulation) whose slope is used for determination of the relative frequency difference (offset) according to the following equation:

$$OFFSET = \frac{f_{TEST} - f_{LOCK}}{f_{LOCK}} = \frac{\Delta\Phi}{2\pi f_{LOCK} T_M} = \frac{SLOPE}{\omega_{LOCK}}, \tag{1}$$

where $\Delta\Phi$ is the phase difference accumulated during total measurement (averaging) time T_M, f_{TEST} is the oscillator under test frequency and f_{LOCK} is the phase-locked oscillator frequency. It is possible to determine frequency offset of the order of 10^{-11} for averaging time of 1000 seconds [2].

Separated second pulses are used as time standard signal for clock comparison. Computer controlled digital counter HP 5370A operates in a time interval measurement mode. The counter, which is started by second pulses from the clock under test and stopped by separated second pulses, measures the time interval Δt

$$\Delta t = (t_{ac} + t_{pd}) - t_{test} \tag{2}$$

where t_{ac} is the time of the atomic clock, t_{test} is the time of the clock under test, and t_{pd} is the propagation delay along the microwave link plus the equipment delay. The time error of the clock under test is then determined by

$$CLOCK\ ERROR = t_{test} - t_{ac} = t_{pd} - \Delta t \tag{3}$$

The accuracy of measurement (clock error) is limited mostly by the uncertainty of t_{pd} because digital counter has an excellent resolution of 20 picoseconds. The equipment delay could be measured, while the propagation delay could be computed from the exact knowledge of geographic coordinates of each relay along the microwave link. However, the most accurate result is obtained when transport clock method is used to measure the total delay t_{pd} directly.

The measurement statistics is improved when repeated time interval measurement results are averaged. It is possible to obtain the clock comparison precision of the order of 5 nanoseconds [3] which is limited by TV tuner and IF amplifier imperfections, as well as by short-term phase instabilities introduced by the microwave link [5].

The separate methods described in [2] and [3] are now combined into a measurement system, shown in Fig.1, capable of performing simultaneous clock comparison and frequency calibration due to the introduction of computer controlled instruments. Phase difference measured during the frequency calibration is now automatically stored in the computer memory instead of being recorded by a strip chart recorder, therefore allowing more precise computation according to (1).

2.2. Dissemination via satellite

Measurement methods for clock comparison and frequency calibration using standard signals disseminated via geostationary satellite are the same as for terrestrial TV network, Fig. 1. Satellite antenna and satellite receiver are additionally required equipment. Propagation delay is much greater than in terrestrial TV network due to a large distance between the Earth and the satellite and amounts up to about 250 milliseconds.

The satellite is affected by various perturbation forces causing diurnal satellite oscillations around its nominal geostationary position. The motion of satellite relative to Earth gives rise to the following unwanted effects:

- standard frequency is Doppler shifted, which limits frequency calibration accuracy,
- there is a propagation delay variation limiting clock comparison accuracy.

These variations are approximately sinusoidal in their nature, with period of about 24 hours. It is necessary to determine accuracy limitations for clock comparison and frequency calibration using standard signals disseminated via satellite. Methods for separated standard signals variations measurement are developed for this purpose and presented in the block diagram of Figure 2. TV tuner and IF amplifier receive the TV signal from satellite receiver. Video signal, obtained at the output of IF amplifier, is applied to specially designed circuit where standard signals are separated. Line frequency, i.e. the separated frequency standard, is directly measured by digital counter HP 5345A. Averaging (Gate) time should be sufficiently long, at least 10 seconds, in order to achieve acceptable measurement results resolution. Maximum frequency variation is easily determined when experiment lasts at least 24 hours because the whole day variation must be recorded. It is expected that maximum Doppler frequency shift will lie in the range from 10^{-7} to 10^{-9}.

The signal corresponding to field frequency, with nominal value of 50 Hz, is convenient to be used for propagation delay variation measurement. Local oscillator-synthesizer ND 30M brings out the 5 MHz sine wave which is converted into square wave. The reference 50 Hz signal is obtained after synchronous division by 10^5. The 50 Hz signals are then applied to START and STOP inputs of HP 5370A digital counter measuring the time interval.

The 50 Hz signals are convenient for this purpose because their period of 20 milliseconds is sufficiently longer than the expected propagation delay variation, which is of the order of up to 1 millisecond. At the beginning of the experiment the counter will measure a time interval shorter than 20 milliseconds, whose exact value depends on the initial phase difference between the 50 Hz signals. The phase of the 50 Hz signal separated from video signal will vary during the day as satellite moves around its nominal geostationary position, i.e. the measured time interval will vary during the day around its initial value. The maximum diurnal delay variation will easily be determined if experiment lasts at least 24 hours.

The propagation delay variation of Belgrade studio TV program broadcast via EUTELSAT- II-F4 satellite has already been measured according to similar method [6].The main difference from block diagram of Fig. 2 is in the fact that the reference 50 Hz was separated from terrestrial TV network. The satellite broadcast is limited to 6 hours during which a variation of about 100 microseconds was measured. It was not possible to determine the maximum diurnal variation due to limited duration of experiment. For that reason, the continuous foreign satellite TV channels are used for measurements described in this paper.

The ND 30M synthesizer is used for obtaining the reference signal because it is necessary to equalize the frequencies of the reference 50 Hz signal and the 50 Hz signal separated from TV signal before the measurement is started. The initial frequency offset, producing a ramp on which a variation to be measured is superposed, has decisive influence on whether the experimental results are usable or not. For example, if initial frequency offset is 10^{-7} then time interval measurement error accumulated due to ramp amounts to 8.64 milliseconds. That is almost two orders of magnitude greater than expected variation, so there is no sense in making correction of the experimental results. Therefore, relative frequency offset must be reduced to the value of about 10^{-9} by fine adjustment of the synthesizer's output fre-

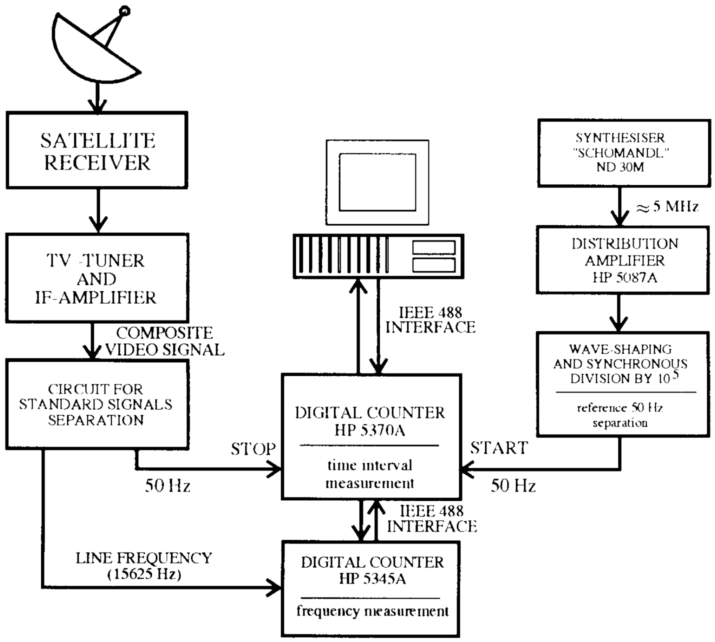

Fig. 2. Measurement methods for determination of diurnal variations of standard signals disseminated via satellite

quency before the measurement is started. The easiest and fastest way to do this is to use oscilloscope for frequency comparison. The error due to ramp is then much less, it is easily noticed and corrected.

3. Separation of Signals Used for Measurement

Line frequency and 50 Hz signal (field frequency) are an integral part of composite synchro pulses (CSP). Schematic diagram of the circuit by which line frequency and 50 Hz are separated from CSP is shown in Figure 3a., while characteristic waveforms are shown in Figure 3b.

The information of line frequency is carried by negative transitions of CSP. Therefore, negative transitions trigger the monostable multivibrator (MMV1) whose quasi-stable state lasts about 48 microseconds preventing equalizing pulses and vertical pulses located in the middle of line from triggering MMV1. Line frequency, whose nominal value is 15625 Hz, is obtained of the output of MMV1. The positive-going edge of MMV1(Q) or negative-

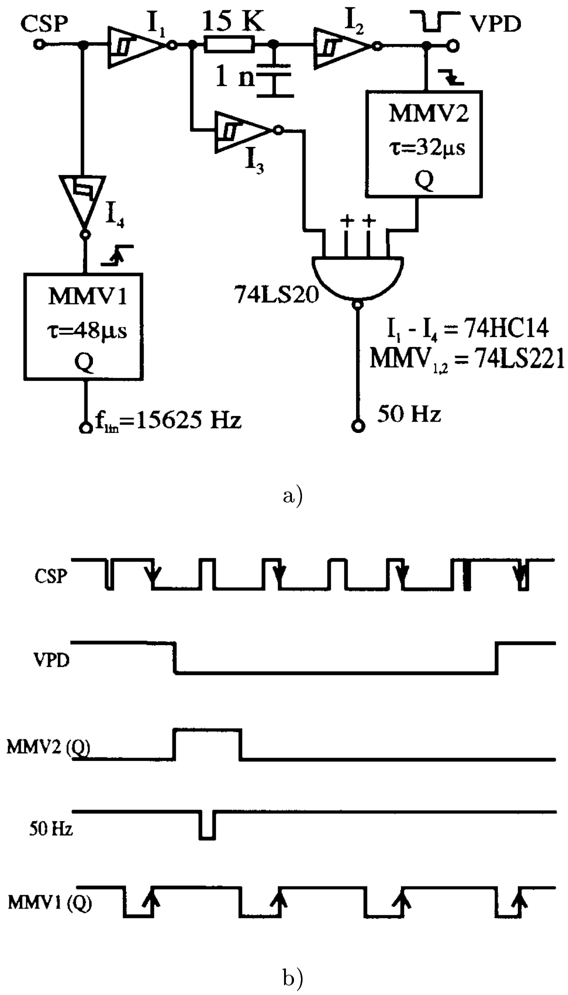

Fig. 3. a) Schematic of circuit for line frequency and 50Hz separation from CSP.
b) Characteristic waveforms illustrating of circuit from operation
Fig. 3a during vertical blanking interval

going edge of MMV1($\overline{Q}$) should be used because they are not affected by the time constant changes due to aging or environmental influence.

The 50 Hz signal is obtained when the first vertical pulse of each field is separated from CSP. Simple RC-network $(15k\Omega, 1nF)$ and two high speed CMOS Schmitt inverters perform vertical pulses detection (VPD) during which VPD signal is low. The negative-going edge of VPD triggers MMV2 forming selector interval of duration of about 32 microseconds which overlaps with the first vertical pulse. Short negative pulses lasting 4.7 microseconds whose nominal frequency is 50 Hz are obtained at the output of NAND-gate.

CSP are obtained by applying a composite video signal (CVS) to the voltage comparator. However, CVS contains unwanted D.C. level variations due to TV tuner and IF amplifier imperfections. These variations must be compensated before CVS is applied to the voltage comparator, otherwise an additional jitter would be introduced. The method which is utilized for D.C. restoration is shown in Figure 4.

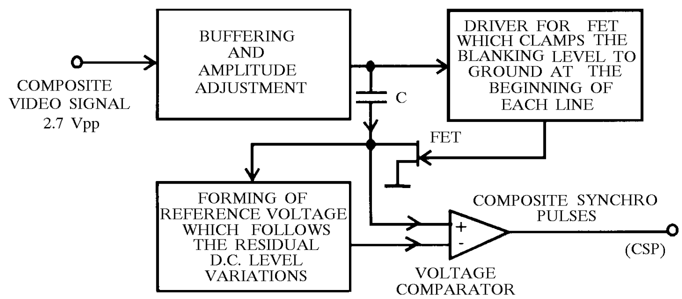

Fig. 4. Block diagram of D.C. restorer circuit

The CVS is capacitor-coupled to FET which is driven by the circuit detecting the appearance of the blanking level at the beginning of each line. The FET is brought into conduction for about 4 microseconds clamping the blanking level to the ground. Additional improvement is achieved by circuit forming reference voltage which follows the D.C. level variation residual after clamping. The reference voltage for comparator is set to about half of the synchro pulses amplitude. CSP are obtained at the output of the voltage comparator.

Schematic diagram of the circuit for obtaining the reference 50 Hz is shown in Figure 5. The amplitude of the 5 MHz signal from the synthesizer is reduced to about 2.5 Vpp and then applied to the emitter-follower with low output resistance. The emitter-follower output signal is applied to the sine to square wave converter realized with high speed CMOS Schmitt inverter 74HC14. Because of its input symmetry and capacitor-coupling, the Schmitt trigger is easily biased to achieve a 50% duty cycle square wave (clock). The reference 50 Hz signal is obtained when the 5 MHz clock is applied to a five-stage synchronous divider by 10^5 realized with synchronous digital counters 74LS168.

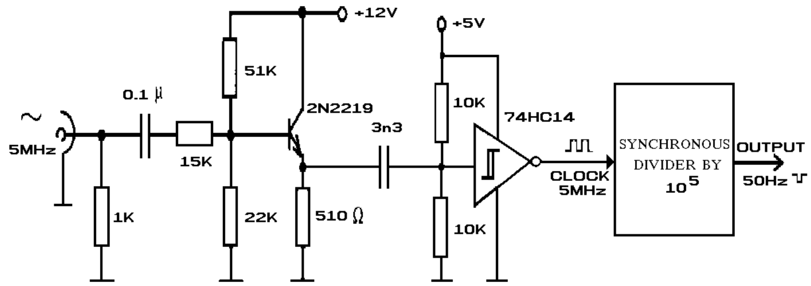

Fig. 5. Schematic of circuit for the reference 50 Hz separation from local oscillator (synthesizer)

4. Equipment Errors and Experimental Results

Time bases of the utilized digital counters and synthesizer are high quality quartz oscillators whose frequency drift due to aging is less than $5 \times 10^{-10}/day$. The aging rate influence on experimental results is negligible comparing it with the variations to be measured.

The jitter originated in D.C. restorer circuit, voltage comparator and circuit from Fig. 3a. is measured utilizing TEK 1411 sync generator operating in "A.C. BOUNCE" mode, where the generated composite video signal picture brightness changes abruptly from zero brightness (black picture) to maximum brightness (white picture). The output signals from circuit shown in Fig. 3 a) are then applied to digital counter HP 5370A which is capable of performing statistics computation on its input signals. Mean square value of the jitter does not exceed 1.2 nanoseconds. However, the jitter of received TV signals is always greater than 1.2 nanoseconds because of TV tuner and IF amplifier imperfections and additive noise. Its influence will be reduced when longer GATE (AVERAGING) TIME of digital counters is selected. The jitter of the reference 50 Hz is also measured, and it is found to be less then 0.2 nanoseconds.

The separated standard signals variations received from EUTELSAT-II-F4 are recorded according to methods shown in Fig. 2. For the sake of comparison, the same measurements are performed for ASTRA-1A satellite as well. Line frequency and propagation delay variation are simultaneously measured every 5 minutes and experimental results (recorded during July of 1993) are graphically presented in Fig. 6 and Fig. 7. Frequency measurement resolution is 10 microhertz (GATE TIME=10 seconds), while time interval measurement resolution is 20 picoseconds.

A scattering of the results around approximately sinusoidal line frequency diurnal variation may be observed. To a certain extent, it is due to the finite measurement resolution. However, the main cause of the scattering is line frequency jitter which is directly dependent on signal-to-noise (S/N) ratio. TV program received from EUTELSAT-II-F4 (SUPER CHANNEL) has higher S/N than TV program received from ASTRA-1A (MTV), therefore scattering of EUTELSAT-II-F4 experimental results is less.

Scattering of the propagation delay experimental results is negligible because the delay variation due to satellite motion is much larger than the jitter, therefore curves (graphics) look "smooth". However, a ramp, due to initial frequency offset between the 50 Hz signals, on which propagation delay variation is superposed, is clearly observed. In order to eliminate the ramp influence, maximum propagation delay variation is measured from the line which connects the midpoints of sinusoid sides.

Maximum variations (peak values) obtained by experimental results analysis are presented in the following table:

Table 1.

Satellite (received TV channel)	Maximum line frequency Doppler shift	Maximum propagation delay variation
EUTELSAT-II-F4 (SUPER CHANNEL)	0.93×10^{-8}	$114 \mu s$
ASTRA-1A (MTV)	1.23×10^{-8}	$180 \mu s$

Measured variations in fact present the accuracy limitations for clock comparison and frequency calibration using standard time and frequency signals disseminated via geostationary satellites. These results are several orders of magnitude inferior to those obtained by terrestrial TV network.

5. Conclusion

Methods for utilization of standard time and frequency signals disseminated via TV system are described in this paper. Terrestrial TV network allows high level of precision due to a stable microwave link propagation characteristic. The reception of Belgrade studio TV program via EUTELSAT-II-F4 satellite eliminates the problem of non-uniform TV program coverage which is the major drawback of terrestrial TV network. Methods for determining the maximum diurnal variations of standard signals disseminated

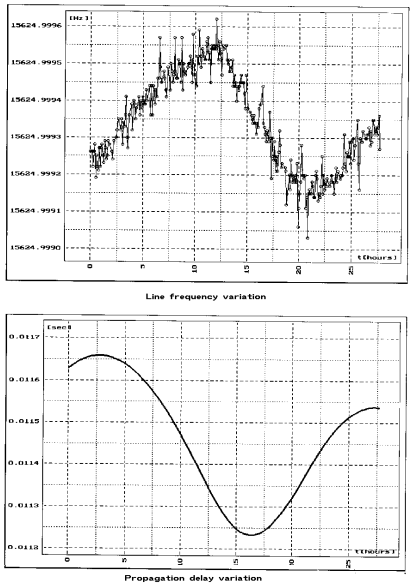

Fig. 6.*Experimental results for ASTRA-1A satellite*

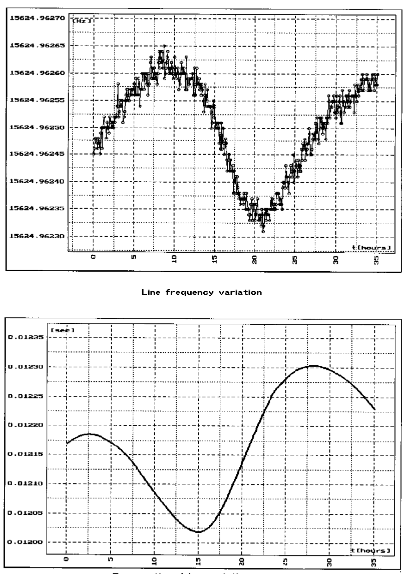

Fig. 7.*Experimental results for EUTELSAT-II-F4 satellite*

via satellite are developed. Experimental results for EUTELSAT-II-F4 and ASTRA-1A satellites are obtained. The measurement methods errors are either negligible compared to variations to be measured or could be estimated and corrected. Experimental results indicate that standard signals undergo significant degradation due to satellite motion relative to Earth.

However, these variations can be automatically compensated to a large extent by applying a compensation method described in [7] which is performed in TV studio itself and was tested practically. Such a way of dissemination assures high precision of the separated standard signals which is characteristic of terrestrial TV network, while a wide area is covered with a single transmitter.

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