C-11-2 IONOSPHERIC EFFECTS ON THE PROPAGATION OF GHZ BEACONS FROM ETS-II

Jun AWAKA, Masaharu FUJITA,
Kashima Branch,Radio Research Laboratories,Kashima,Ibaraki 314,Japan
and
Tadahiko OGAWA
Radio Research Laboratories,Koganei,Tokyo 184,Japan

Introduction

The Engineering Test Satellite Type-II (ETS-II), which was launched by the National Space Development Agency (NASDA) of Japan in a geostationary position at 130°E longitude, transmits mutually-coherent beacon signals of 1.7, 11.5 and 34.5 GHz. The propagation experiments having been made at the Kashima Branch of the Radio Research Laboratories (RRL) since April 1977 reveal that GHz waves are affected by the ionosphere in addition to the troposphere [1]. In this paper, we first describe an experimental technique for the total electron content (TEC) measurement by means of the differential phase shift between 1.7 and 11.5 GHz [2], and then present some observational results of TEC and of GHz scintillations caused by ionospheric electron density irregularities [3].

Observation of TEC

ETS-II has only one crystal oscillator of 17.76 MHz. This frequency is multiplied by 96, 648, and 1,944 to get the three beacon signals of 1.7, 11.5, and 34.5 GHz, respectively. Hence, these three signals are phase coherent to each other. The receiving system at the Kashima station can reproduce these phase coherent signals by using phase-lock-loop (PLL) technique. Either 1.7 or 11.5 GHz can be used as a reference signal. Measuring method of the differential phase shift between 1.7 and 11.5 GHz using 1.7 GHz signal as a reference is as follows (see Fig.1). When PLL is in phase lock state, the phase of the received 1.7 GHz signal can be written as

$$\theta_1(t) = 16\,\theta_{VCXO}(t) \qquad \cdots (1)$$

where θvcxo is the phase of the voltage controlled crystal oscillator (VCXO). On the other hand, the phase of the received 11.5 GHz signal is

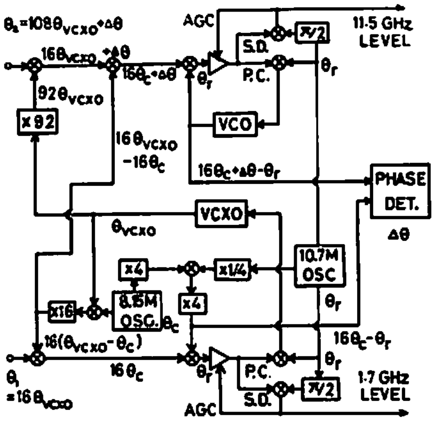

Fig.1 Block diagram for measuring differential phase shift between 1.7 and 11.5 GHz. VCXO; voltage controlled crystal oscillator, VCO; voltage controlled oscillator, PC; phase comparator, SD; synchronous detector, AGC; automatic gain controll.

given by

$$\theta_2(t) = 108\,\theta_{VCXO}(t) + \Delta\theta(t). \qquad \cdots (2)$$

From Eqs.(1) and (2) the measured differential phase shift, $\Delta\theta(t)$; between 1.7 and 11.5 GHz is given as follows.

$$\Delta\theta(t) = \theta_1(t) - (108/16)\,\theta_2(t). \qquad \cdots (3)$$

θ_i can be written as

$$\theta_i = 2\pi f_i t - \int_0^s k_i\,ds + \varphi_i \quad (i=1,2), \quad \cdots (4)$$

where f is the frequency, k is the propagation coefficient, and φ is the constant due to the circuitry path length of the transmitting and receiving systems. The integration in Eq.(4) is carried out along the propagation path.

In the quasi-longitudinal approximation, the refractive index of the ionosphere is given by

$$n = 1 - 40.5\, N/(f \pm f_L)^2, \quad \cdots (5)$$

where N is the electron density (m^{-3}), f is the beacon frequency (Hz), and f_L is the longitudinal electron gyrofrequency (Hz). f_L is of the order of 1 MHz and therefore can be neglected compared with f (f=1.7 or 11.5 GHz). Hence,

$$n \simeq 1 - 40.5\, N/f^2. \quad \cdots (6)$$

The propagation coefficient k, then, becomes

$$\begin{aligned} k_i &= 2\pi f_i n/C \\ &= 2\pi f_i/C - 81\pi N/f_i C \quad (i=1,2), \cdots (7) \end{aligned}$$

From Eqs.(3),(4), and (7), $\Delta\theta$ becomes

$$\Delta\theta = (81\pi/f_1 c)(\alpha - 1/\alpha)\int_0^s N\,da + \text{const.}, \quad \cdots (8)$$

with

$\alpha = (f_2/f_1) = 11.5/1.7$ (actually 108/16),

where f_1 is the reference frequency (1.7 GHz in this case). Eq.(8) holds in general; f_2 is 11.5 or 34.5 GHz when f_1=1.7 GHz and f_2 is 1.7 or 34.5 GHz when f_1=11.5 GHz.

Measurements of the differential phase shift between 1.7 and 11.5 GHz and between 1.7 and 34.5 GHz, using 1.7 GHz signal as a reference, have been made since April, 1977. Since the phase of 34.5 GHz signal is modulated due to the satellite spinning motion, only the differential phase shift between 1.7 and 11.5 GHz signal is analyzed here. From Eq.(8), relative TEC is given as follows.

$$N_T \equiv \int_0^s N\,da = \Delta\theta/(1.05\times10^{-15}\pi) \quad [\text{electrons}/m^2]. \cdots (9)$$

Eq.(9) does not contain the term which is related to the geomagnetic field configuration because of the approximation of Eq.(6). This makes the method for measuring TEC by using GHz coherent signals to be advantageous over the Faraday rotation method which requires information about the geomagnetic field.

Fig.2 shows an example of the diurnal variation of TEC (a) and $(f_oF_2)^2$ (b), where f_oF_2 is the critical frequency of the F2-layer. TEC was observed at Kashima (geographic coordinates; 36.0°N, 140.7°E, geomagnetic latitude; 25.6°N) while f_oF_2 was at Kokubunji (geographic coordinates; 37.5°N, 139.5°E, geomagnetic latitude ; 25.5°N). An anomalous variation of TEC in the late afternoon of Feb. 15, 1978 was due to the magnetic storm. This will be discussed later. Fig.2 indicates that the correlation between TEC and $(f_oF_2)^2$ is very good as discussed by Kane [4]. Since the diurnal variation of the measured differential phase shift is very large (~400π radians), high sensitive observation of TEC is possible.

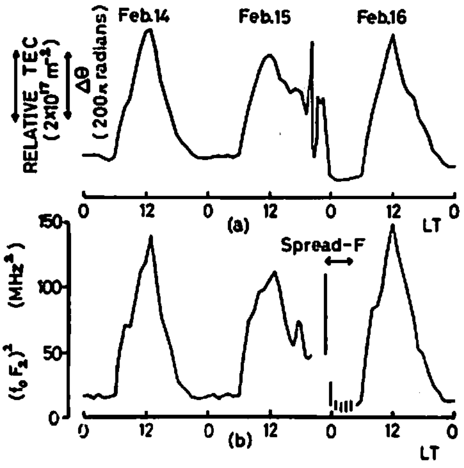

Fig.2 Diurnal variation of TEC (a) and $(f_0F_2)^2$ (b) during severe magnetic storm on February 1978.

Observation of 1.7 GHz scintillation

Recently, scintillations at 4 and 6 GHz on the INTELSAT network have been reported [5,6,7]. It is confirmed that these phenomena are due to the irregularities of electron density in the ionosphere.

Simultaneous observations of TEC and GHz scintillations have been made using the receiving system shown in Fig.1 since the beginning of May, 1977. Fig.3 shows the 1.7 GHz scintillation along with the variation of TEC observed on June 18,1977. The maximum fluctuation with 1 dB peak-to-peak occurred at 22:11 local time (LT). During the period of scintillations, TEC showed a large variation. This fact suggests the passage of irregularities of the electron

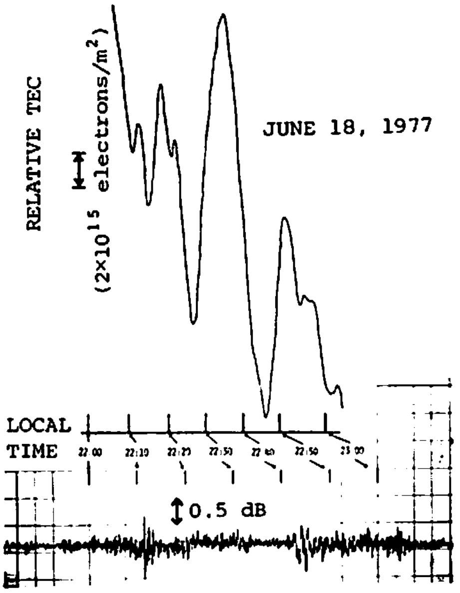

Fig.3 Example of nighttime scintillation (lower) and irregular variation of TEC (upper) observed at Kashima on June 18, 1977.

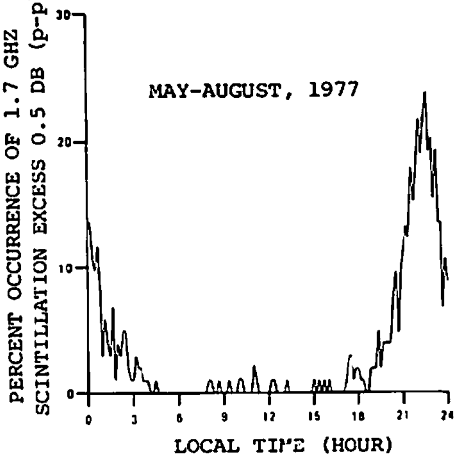

Fig.4 Diurnal pattern of percentage occurrence of 1.7 GHz scintillations exceeding 0.5 dB peak-to-peak during May-August in 1977.

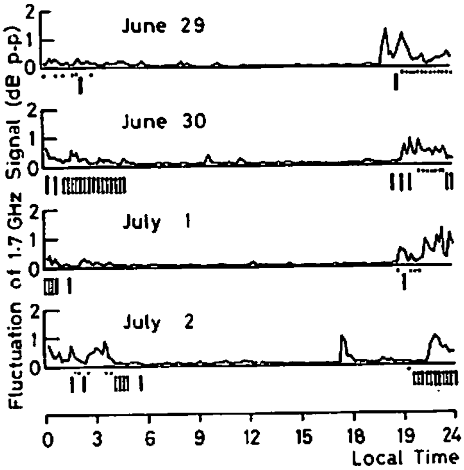

Fig.5 1.7 GHz scintillation and spread-F phenomena. |; spread-F, •; measurement of f_0F_2 is influenced by or impossible because of, interferences or atmospherics.

density across the propagation path from ETS-II to the Kashima station.

Fig.4 shows the diurnal variation of the percentage occurrence of 1.7 GHz scintillation in excess of 0.5 dB peak-to-peak, averaged during May-August, 1977. It is seen that the 1.7 GHz scintillation has the maximum activity around 22:30 LT.

Fig.5 shows the relation between 1.7 GHz scintillation observed at Kashima and the occurrence of spread-F phenomenon observed at Kokubunji during June 29-July 2, 1977. This figure shows that the 1.7 GHz scintillation and spread-F phenomenon have correlation. However, the scintillation is not always accompanied with spread-F. This may be attributed to the differences in size and height of irregularities which are responsible to these phenomena.

Fig.4 shows that the 1.7 GHz scintillation also occurs in daytime. The daytime scintillation is often accompanied with the fluctuation of TEC and also with the strong E_s layer over Kokubunji. Hence, the daytime 1.7 GHz scintillation seems to have an origin in the lower ionosphere.

GHz scintillations during magnetic storm

On the late afternoon of Feb.15, 1978, TEC began to show an anomalous variation as shown in Fig.2. The first sudden increase of TEC began at 19:00 LT and reached to the maximum around 20:05 LT. This maximum value was larger than that around 12:00 LT. Then TEC suddenly decreased, again increased and decreased toward a normal midnight level. Before these anomalous changes of TEC, the horizontal component of the geomagnetic field observed at the Hiraiso Branch of RRL (geographic coordinates; 36.4°N, 140.6°E, geomagnetic latitude; 26.3°N) showed the sudden commencement (SC) at 6:45 LT on Feb.15,1978.

During the period of the TEC variation, 1.7 and 11.5 GHz scintillations were observed as shown in Fig.6. The 1.7 GHz scintillation began at 20:05 LT and ended around 23:40 LT. Very large 1.7 GHz scintillations with the amplitudes more than 10 dB peak-to-peak occurred between 20:16 and 20:30 LT and between 21:15 and 21:35 LT.

During this large 1.7 GHz scintillation, 11.5 GHz scintillations also occurred with the amplitudes less than 0.7 dB peak-to-peak. On the other hand, the 34.5 GHz signal showed no evidence of scintillation.

Acknowledgments

The authors wish to express sincere gratitude to many members of the ETS-II group of RRL for their support and hospitality to the experiment. Thanks are also due to the staff of the ETS-II group of the Kashima Branch (RRL) for their cooperation in data collections. We also thank the staff of NASDA for their operations of satellite control.

References

[1] Ihara.T. et al., this issue.
[2] Awaka,J. and Fujita,M., J.atmos.terr. Phys.,vol.39,p.1441,1977.
[3] Fujita,M.,Ogawa,T., and Koike,K. submitted to J.atmos.terr.Phys.
[4] Kane,R.P.,J.geophys.Res.,vol.80, p.3091,1975.
[5] Skinner,N.J. et al.,Nature,vol.232, p.19,1971.
[6] Taur,R.R.,COMSAT Technical Rev., vol.4,p.461,1974.
[7] Craft,H.D. and Westerlund,L.H.,AIAA paper,No.72-179,1972.

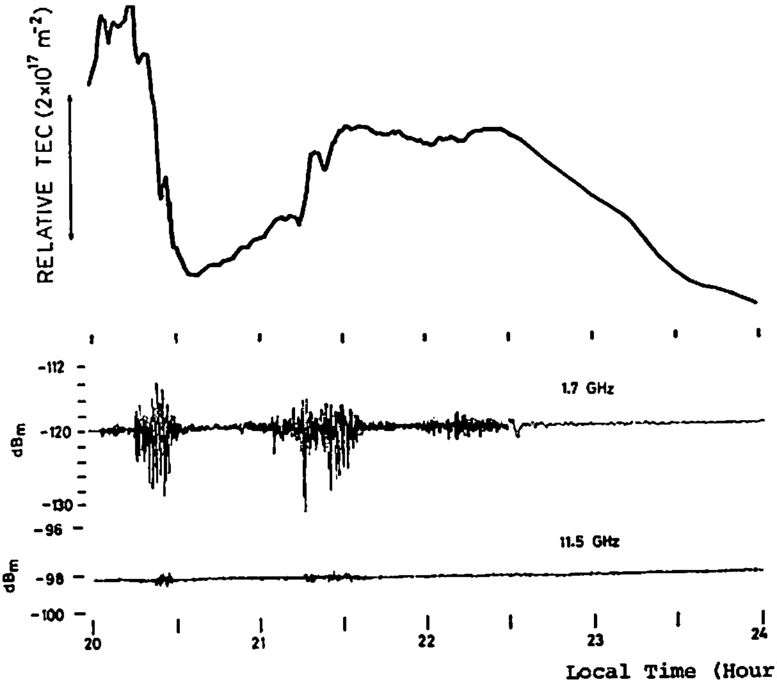

Fig.6 Anomalous variation of TEC (upper) and GHz scintillations (lower) during severe magnetic storm on February 1978.