High Resolution Faraday Angle Measurements of VHF Signals from Low Orbit Satellites

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ABSTRACT

Ionospheric scintillations have many deleterious effects on Earth-satellite radio links using frequencies upto 6 GHz. In order to quantify the problem of signal degradation and to work out the engineering remedies for the user, it is desirable to study the spatial distribution of ionospheric scintillations. This paper presents the principle of operation and experimental details of a polarimeter of high resolution for measurements of Faraday angle in VHF signals from low orbit satellites. The polarimeter is very suitable for the investigation of spatial gradients in ionozation content. Essential ameliorations and electronic system miniaturization of the polarimeter for its mass utilization are also discussed.

Key Words : *Ionospheric scintillations, VHF signals, satellite communication, polarimeter*

1. Introduction

In satellite communication systems, the satellite acts as a powerful repeater in the sky. It provides broadband coverage in a conventional as well as intercontinental sense. The satellite channel also provides access to remote areas not covered by conventional means or by fiber optic cables. In most of satellite communication systems, the satellites are placed in geo-stationary orbit. In this situation the satellite always appears to be stationary when viewed from the Earth. In fact three geo-stationary satellites spaced 120 degrees apart could cover the entire globe with reasonable overlap. The satellite communication also offers commercial advantage, as the communication cost is independent of distance. Typical commercial communication satellites use a frequency band of 500MHz bandwidth at around 6 GHz for uplink and another 500MHz at about 4GHz for downlink. The 500MHz bandwidth is divided among 12 transponders. Each transponder uses approximately 36MHz bandwidth. A single transponder can carry one color TV signal, 1200 voice circuits or the digital data at the rate of about 50 M bits per second. In addition to application transponders, in every satellite there is a radio channel that is responsible for tracking, telemetry and command. Its carrier frequency is referred to as beacon signal.

The earlier satellites used HF (e.g. 40 MHz) radio beacons, which were used for the study of F-region of the ionosphere. Subsequently, in Application Technology Satellites (e.g. ATS-3, ATS-5, ATS-F and ATS-G) VHF signals (e.g. 137MHz) were used as *beacons*. The amplitude, phase and angle of arrival of satellite beacon signals that have traversed through the non-homogenous ionosphere are found to fluctuate at the receiver. These fluctuations are called *scintillations* and are serious hazard for satellite communication. In this paper we present a discussion on the measurement of ionospheric scintillations to work out the engineering remedies of their deleterious effects.

2. Faraday Angle Measurements

The polarization angle of a radio wave rotates during its transionospheric propagation by an amount, which depends on the number of free electrons along the ray path. Measurements of the polarization rotation (more commonly called as Faraday rotation) angle of satellite signals have been utilized for several years for ionospheric studies. The ionospheric quantity widely studied in this connection is total electron content, N_T. The low orbit satellites sweep across the sky in a very short time so that essentially a frozen picture of ionosphere is obtained and hence these satellites are suitable for the investigations of ionospheric spatial gradients. So far most of the Faraday rotation angle measurements using low orbit satellites have been made by simple experimental arrangement which involved the amplitude recording of the satellite signals and the signals used were the HF carrier transmissions. Such measurement could give the electron content values on the points corresponding to "Faraday Null" which considerably limited the resolution of measurements, secondly at high frequency the non-linearity of ionospheric refractive index and the ray refraction (especially at high elevation angles) also set the limits on the accuracy of the electron content calculations. Rao [1] tried to improve the resolution by making the amplitude recordings using a rotating antenna. This system gave only a partial success since the reversals in Faraday rotations could not be detected by this arrangement. However, a rotating antenna based VHF polarimeter directly recording the Faraday rotation angle of geo-stationary satellite signals was developed by Tithridge [2] and has since been used for studying such ionospheric processes as spread – F, multiple reflecting layers and traveling ionospheric disturbances ([3-8] Waldmann and Rosa, 1971; Kaushika, 1974: Kaushika and Mendonca, 1974; Bowmen, 1991; Xue, 1993; Dabas etal.2003). It has been shown that the use of geostationary satellites provides an ideal method for investigating various communication problems dealing with short and long term changes in the ionospheric non homogenieties (scintillations). Subsequently, we (N.D.K) have employed such a polarimeter for low orbit satellite signals. Present note embodies the experimental details of the set up. This type of polarimeter proved very useful for the investigation of non homogenieties and spatial gradients in ionospheric region.

3. Experimental Setup & Illustrative Recordings

The experiment was set up by one of us (NDK) at Sao Jose dos Campos (23° S) in 1973 for studying the telemetry or tracking signals of the satellites, NOAA-2 and ESSA-8. The experimental set up is shown in Fig.1. It consists of the following unit:

- 3.1 Antenna and rotor system
- 3.2 Preamplifier
- 3.3 Converter
- 3.4 Receiver

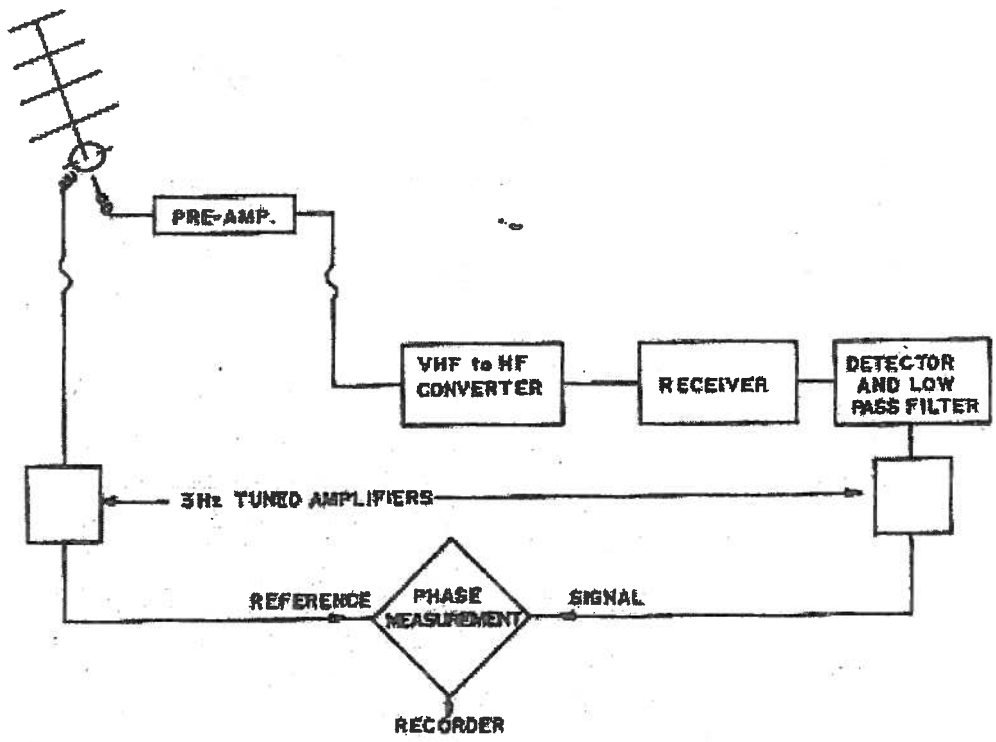

Figure 1 Block Diagram of VHF Polarimeter

3.5 Phase comparator

3.1 Antena & Rotor System

The Antenna is a four element Yagi tuned to 137 MHz. It has a 152 cm boom, 108 cm reflector, 101 cm (in two sections of 50.5 cm each) driven element and first and second director of 96.5 cm and 94 cm respectively. The antenna was fed by a cable RG 174/U: Amphenol 21-598 passing through the boom. The surface shell of this cable is connected to the boom at a distance of $\frac{\lambda}{4}$ from the feed point. This arrangement ensures the surface current to be minimum. The antenna rotates at 90 rotations per minute by the motor and gear system. The entire antenna assembly including the rotor is mounted such that the antenna boom can be pointed to any desired value of elevation and azimuth.

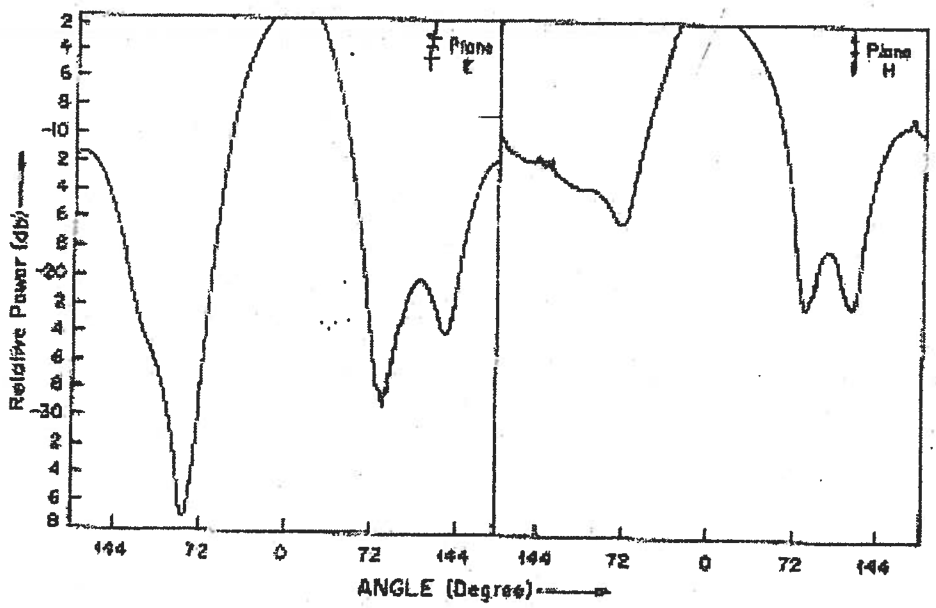

Figure 2: Variation of the relative power received by the antenna as a function of angular deviation from the direction of the boom of the antenna.

The radiation pattern of the antenna is shown in figure 2.

The signals received by the rotating antenna are brought out through two coils one mounted on one end of the aerial and the other stationary. These coils are tuned to 137 MHz and are slightly over coupled; this gives only a slight loss of signal and is much quieter and more reliable than the use of slip rings.

3.2. Preamplifier

The signal is amplified at the antenna by a low noise (2.5 db) solid-state preamplifier having a gain of 30 db. The power requirement for this unit is 12V and 8 – 15 mA. A gain control is provided on the gate of the second stage so as not to deteriorate the signal to noise ratio when the gain is reduced as well as not to overload the receiver during signal from the satellite.

3.3. Converter

The power requirements of this unit are 12V and 25mA. The crystal frequency is 38.33 MHz and its third harmonic is utilized in conversion. So the converter translates 136MHz into 21MHz. To reduce frequency drift, a temperature stabilized converter is often used. However in our setup instead of temperature stabilizing the converter we had placed the set up (receiver and phase meter) in a room where ambient temperature variations were rather minimum.

3.4. Receiver

The converter output is fed to a receiver with a bandwidth of few hundred cycles per second. The receiver operates with AGC off. The Drake model R-4B a double converter super-hetrodyne receiver with pre-selector was used in the system.

3.5. Phase Comparator

The signal is first processed through a low pass filter to remove the high frequency noise and passed through a tuned amplifier of high selectivity to obtain a clean 3 Hz signal wave form for Phase comparison. The phase reference signal is provided by the magnets fastened to rotating antenna. The magnets sweep across a coil and give 3 Hz output. The resultant rectangular waveform from flip-flop amplified and integrated to obtain a DC output proportional to phase, which is recorded on the servo type chart receiver. Two channels may be used to obtain unambiguous angle reading during the main channels retrace period.

The above-mentioned system makes it possible to record the Faraday rotation angle directly. In region near quasi – transverse the polarization becomes circular and is noticeable in the record (Fig.3a). For comparison a Faraday angle record taken with the same polarimeter using 137 MHz beacon signal from geostationary satellite is shown in (Fig.3b). The polarimeter samples the

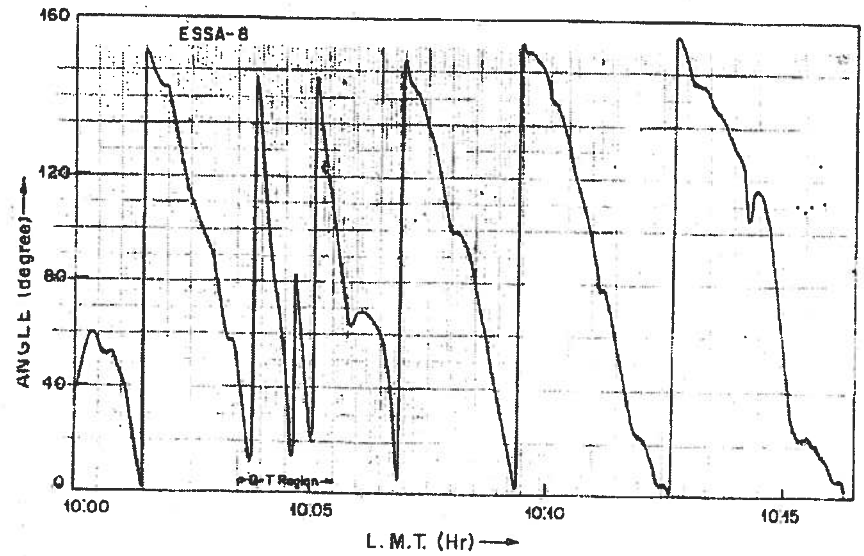

Figure 3 (a) : Illustrative Faraday angle recording using low orbit satellite signal

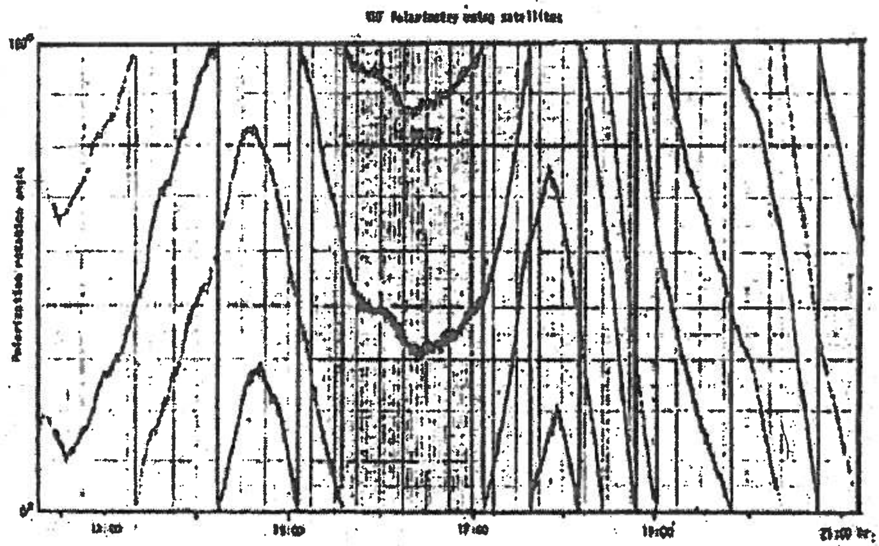

Figure 3 (b) : Illustrative Faraday angle recording using geostationary satellite signal

rotation angle every two seconds so that the horizontal gradients of all sizes more than about 10 Km can be conveniently studied with this polarimeter.

Discussion

The recordings of the Faraday angle made with the setup clearly indicate that direct Faraday angle measurement can be made using the low orbit satellite beacons and the measurements can be used for investigating the spatial gradient in the ionosphere. In recent years the spatial gradients in the ionosphere have also been investigated by several authors by setting up Faraday angle recordings polarimeters at spaced locations. For example Dabas etal. [8] made simultaneous recordings of Faraday rotation, in signals from geostationary satellite ETS II at five locations situated between 3^0 and 23^0 N magnetic latitudes along a common geographic meridian of 84^0 E. These authors used these recordings to investigate spatial gradients in ionospheric scintillations.

In quantitative measurements of low orbit satellite signals can only be made if the boom of the antenna always points towards the satellite. As the satellite sweeps across the sky, the azimuth and elevation of the boom must be changed. So the addition of a two axis-tracking unit is essential for the setup to be of the quantitative significance. Furthermore, the electronics used in the original setup also needs amelioration. The system can now be converted into a compact and miniature unit by replacing the discrete devices into related IC's available. In this process we can reduce the density and size of the PCB. The another advantage of the transformation is into the mass production of the whole unit. The data acquisition system can also be converted from direct recordings to computer based acquisition and analysis. Several supervisory control and data acquisition systems are now commercially available. We have carried out a feasibility study of these aspect of the development for various units and subsystems involved in the setup. The essential part of the study is as follows.

The compact substitutes of following units are now available

1. Integrated high frequency low noise preamplifiers
2. Compact satellite tuner with GaAs ICs.
3. Digital phase locked loop (PLL) for receiver with fitter bounded.
4. The substitute for recorder could be a simple supervisory control and data acquisition system.

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