THE TSS-GROUND COMMUNICATION CHANNEL: THE DETECTION OF TSS-ULF/ELF/VLF EMISSIONS ON THE EARTH SURFACE AND SEA BOTTOM

P.NICOLAS*-E.J.SULLIVAN*-G.TACCONI**-A.TIANO***

* SACLANTCEN, LA SPEZIA- ITALY
** Department of Biophysical and Electronic Engineering (DIBE) - UNIV.GENOA - ITALY
*** Istituto di Automazione Navale (IAN) - CNR - GENOVA - ITALY

Le système de satellite a antenne remarque (tether) (TSS) du project PSN (*) - NASA èst constitue d'un "tether" de 24 Km et de ses éléments associés. Ce système est suppose rayonner dans les bandes de fréquence ULF/ELF/VLF par intéraction du "tether" avec le champ magnétique terrestre et la ionosphere. Le travail présent consiste en une etude du système de réception terrestre, nécessaire à la détection des radiations. Deux modes possibles de propagation sont discutés, le mode de propagation direct et une excitation Terre-Ionosphère. Les difficultés liées a la modale prediction théorique du niveau du signal recu et la combinaison des deux modes de propagation sont aussi etudiés dans le but de définir des méthodes appropriées de traitement du signal. Enfin, des résultats préliminaires d'une comparaison de methodes possíbles de traitment son présentees.

The Tether Satellite System (TSS) of the NASA PSN Project, which consists of a 20 Km tether and its associated system components is expected to generate electromagnetic radiation in the ULF/ELF/VLF bands via the interaction of the tether with the Earth's magnetic field and Ionoshere. The work presented here reports on a study of the ground-based system necessary to receive and verify the existence of the radiation. The possibility of two modes of propagation- direct and Earth-Ionosphere modal excitation- is discussed. The difficulties associated with reliable theoretical predictions of the expected signal level and mixture of these two modes is also discussed in its relationship to possible processing schemes. Also, preliminary results on a comparative study of possible signal processing methods are presented.

(*) The Piano Spaziale Nazionale of the Consiglio Nazionale delle Ricerche, Italy - Contratto CNR PSN/85/080.

1. INTRODUCTION

The NASA/PSN/TSS (Tethered Satellite System) experiment and, in particular the attempt to receive on the Earth surface possible signals generated by the TSS located in the ionosphere can be concisely described as a source/receiver system through a non-uniform stratified medium. The origin of the radiation is based on an electro-dynamic transformation of the kinetic energy of the orbiting system (TSS) into electromagnetic energy radiated by a line antenna (the conducting tether) transiting in a magnetic field (the Earth's magnetic field) and immersed in a conducting medium (the ionosphere). A general view of the scenario is given in Fig. 1.

The approach to be taken here will be to attempt to define the expected configuration of the signal, in order to facilitate the definition of the receiving and processing methods. Preliminary results on a comparative study of some possible processing schemes are presented.

Since 1972 several special projects have been involved with the tether programme. The late Dr. Giuseppe Colombo and Dr. Mario D. Grossi of the SAO (Harvard Smithsonian Astrophysical Observatory, Cambridge, Mass.) jointly hold the fundamental patent on the device (N. 4.097.010 dated 6/27/78), that was originally conceived by Grossi as a spaceborn antenna and as a tethered satellite to measure its radiation pattern. The disaster of the Challenger of January 1986, has generated a delay of the first mission which has been, recently scheduled for October 1990.

1. THE GENERATION AND PROPAGATION MECHANISM

The generation of electromagnetic emission by the tether has been investigated theoretically by the Smithsonian Astrophysical Observatory (SAO) Cambridge Mass. The results of their research are summarized in their proposal to NASA (1). The estimate by the SAO of the signal intensity is a preliminary finding and is based on the following two assumptions:

I) -Guided propagation in the Earth-Ionosphere cavity

II)-Non-guided, isotropic, propagation through the Earth's Atmoshere.

According to this oversimplified model, the region of the Earth's surface that is illuminated by the e.m. waves due to the TSS tether is a limited area located on the vertical that contains the TSS. This area can be called the "hot-spot" and it is possible to visualise it as a circle with radius of about 250 Km. In this "hot-spot" wa can estimate the signal intensity due to the tether to be about $4.28x10^{-8}$ At/m, if we assume that the orbital inclination is 28° and the observations are made at night. If the measurements are integrated for 100 seconds, we can expect a signal-to-noise ratio as high as + 12.6 dB. According to the "hot-spot"model (assumption II), the receiving site should be selected as close as possible to the ground path of the orbiting TSS. Other models, worked out by other investigators, would give more optimistic results concerning the distance away from the TSS vertical at which our receiving site could be deployed. According to the calculation of C.E. Rasmussen we could be as far away as 1000 Km. This theory is based on emissions by a 20 Km tether and the related field intensity formulas are derived under far-field conditions. Some of the analytical derivations have to be carefully verified. Many simplifications that this Author has adopted might affect adversely these estimates. Two additional theories have appeared in the literature: Pappert (3) and Wait and Einaudi (4). These are very valuable papers because they take in to account the excitation by an external source of the so-called Earth-Ionosphere-Cavity.

Guided propagation in this cavity to extreme distances has been the basis for all signal intensity predictions up to now, since the estimate, based on assumption II are too uncertain. The problem with (3) and (4) is that the source, embedded in the ionosphere, is an elementary dipole (of infinitesimal length, and this is an incorrect model for the very long tether of the TSS. If the conclusions reached in these two references were directly applicable to our case, we could locate our receiving site wherever we would find it logistically convenient. It is clear that no existing theory directly applicable to our case can be utilized to formulate rigorous, reliable predictions of signal intensity.

A joint essential research programme is needed for the development of a rigous approach. The intentions of SAO are to carry out a careful verification in order to assess the suitability of the "hot-spot" model or the guided propagation model. As proposed by Dr. D.D. Estes of SAO (5), the theoretical verification should be ascertained by modifying a software code that was developed at MIT by Prof. J.A. Kong, to include atmospheric stratification for application to a flat lithospheric stratification model. The medium will be modelled as a non-isotropic magneto-ionic flat stratification with the index of refraction variable with height, reproducing a typical ionosphere refractivity profile and with realistic angular relationships between the vector of the geometric fied and the stratification. At the moment this verification, essential to define the most suitable receiving site as well as the parameters of the expected signal and consequently the optimal receiving system, has not yet been performed.

2. SOME HYPHOTESIS ON THE EXPECTED SIGNAL

In spite of the lack of complete knowledge of the characteristics of the expected signal, some likely hypotheses can be made in order to approach a definition of a suitable processing method.

With the assumption of far-field conditions the physics of the situation suggests that the expected signal should consist of an increase of level in the appropriate frequency band, which reaches a maximum for the closest point of approach, and finally an analogous decrease. The TSS will act as a transiting source with a certain, a priori known, transit time.

Because of the relatively limited size of the hot-spot, and the precession of the orbit, the transit of the TSS over the selected location with one single receiver will happen only once during the mission.In this case the attempt to detect such a signal can be made with appropriate modalities. The problem is equivalent to that of detecting a noisy object travelling on a constant velocity straight line at a given minimum distance from the receiver (closest point of approach). The object (the TSS) is assumed to emit a noise-like signal having an approximately known spectral density. In addition to the signal from the TSS, the sensor receives a more or less steady noise-the local natural and/or man-made background noise.
Unlike conventional signal processors that try to detect the presence of the signal in

real time, the detector responds only after the completion of the variable component of the total input signal. Such variable component can have a typical and defined form changing with time. The receiving system can be characterized as an after-the-fact detector of a complete slowly varying event. (Hunt, (6)).

The approximate duration T of the event to be detected can be taken to be 6 minutes for the hot-spot model and 20 minutes for an intermediate model.
In the case of guided propagation, the energy leaks through the ionosphere lower bound into the Earth's atmosphere and should propagate in the earth-ionosphere cavity (standing waves). We then can presume that from the time at deployment of the tether until its recovery, the TSS will inject energy into the Earth-Ionosphere cavity. In this case the receiver can be placed anywhere on the earth's surface.

The problem is then to detect the presence of the radiated energy for the total duration of the active part of the mission. From Fig. 2 which shows the TSS operations timeline we can see that the 20 Km tether will remain deployed for 20 hours. Making a comparison between the received signal in the absence of the TSS in space (noise) and the signal during the mission (noise + TSS emission) it should be possible to estimate the injcted energy. In addition, in principle, it should be possible to detect the different long transients of 10 and 6 hours respectively which arise due to the partial lengths of the tether during the deploying operation.

3. POSSIBLE PROCESSING METHODS

The problem of detecting a transient signal has been investigated by several workers (Hunt (6), Curry (9) and Tuteur (8)). Tuteur showed that the optimum detector was a matched filter but that the results were reasonably insensitive to the shape of the signal and depended more strongly on the duration of the signal. Neverthless improvements can be made by including a priori information. This has been done recently by Porat and Friedlander (7) where they implement an ARMA model of the processing scheme. Thus, they have effectively combined detection and estimation methods. Their approach is based on a Modified Generalized Likelihood Ratio Test with the assumption of Gaussian noise.

The advantage of this approach over that of the methods based on pure detection can be seen in Fig. 3 where the probability of detection for both Tuteur's methods and that of Porat and Friendlander are compared. Here the probability of false alarm is 10^{-1} and the signal model is an ARMA of order (1,2). As can be seen, the improvement in performance is significant for signal-to-noise ratios above -10 dB.

Based on these preliminary results, present work is aimed at removing the restriction of gaussian noise and a priori knowledge of the noise characteristics.

4. CONCLUDING REMARKS

It is expected that the tether will generate a signal that will be some combination of direct propagation and Earth-Ionosphere cavity modal excitations. There remains some uncertainity concerning the expected level of the signal due to the difficulty of modelling a moving electromagnetic source of this length imbedded in the ionosphere. Work aimed at overcoming this obstacle is being carried out at M.I.T., in cooperation with SAO, by Prof. A.J. Kong who is developing a model specifically for this purpose.

Present processing schemes are based on the assumption that the signal is transient and short-term (Assumption II). It is intended to investigate schemes based on the assumption that the signal is dominated by excitations of the Earth-Ionosphere cavity (Assumption I). This is important since, even if the modelling results indicate that contributions based on Assumption I are very small, this component of the signal will have a characteristic time of 20 hours, thus it could be equivalent to a shorter term signal of very high energy.

5. REFERENCES

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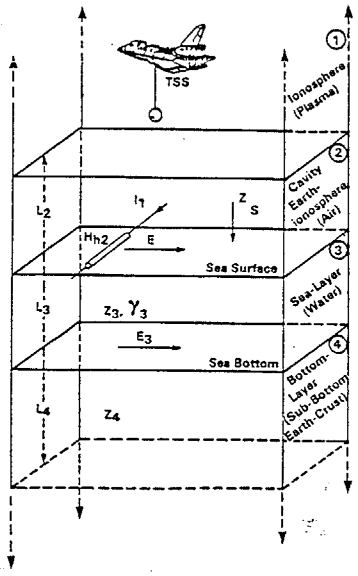

Fig. 1 - The propagation scenario

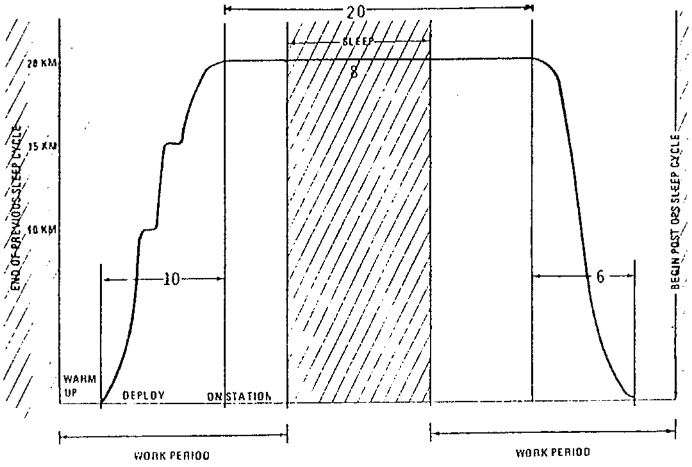

Fig. 2 - TSS operations time schedule with deploying and recovering phases

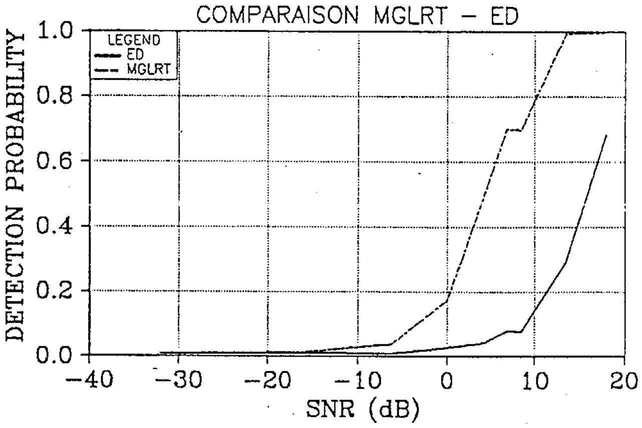

Fig. 3 - Comparison between Teteur method (ED) and Porat-Friedlander method (MGLRT) in the case of an ARMA model of order (1,2). The probability of false alarm is 10^{-2}