EXPECTATIONS FROM EMET AND OESEE GROUND LISTENING OF POSSIBLE E.M. EVENTS GENERATED BY THE TSS 1R

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ABSTRACT - On 22nd February '96, the space mission STS 75 started ,from the NASA facilities at Cape Canaveral. Such a mission consists in the launch of the shuttle Columbia in order to carry out two experiments in the space: the TSS 1R (Tethered Satellite Sistem 1 Refliight) and the USMP (United States Microgravity Payload). The TSS 1R is a replica of a similar mission TSS 1 ('92) . The TSS space programme is a bilateral scientific cooperation between the USA space agency NASA (National Aeronautics and Space Agency) and the ASI (Italian Space Agency). The TSS 1R system consists on the shuttle Columbia which deploys, up-ward, by means a conducting tether 20 km long, a spherical satellite (1.5 mt diameter) containing scientific instrumentation. This system, orbiting at about 300 km from the Earth's surface, represents, presently, the largest experimental space structure. Due to its dimensions, flexibility and conducting properties of the tether, the system interacts, in a quite complex manner, wih the earth magnetic field and the ionospheric plasma, in a way that the total system behaves as an electromagnetic radiating antenna as well as an electric power generator. Twelve scientific experiments have been assessed by US and italian scientists in order to study the electrodynamic behaviour of the structure orbiting in the ionos phere. Two experiments have been prepared in the attempt to receive on the Earth's surface possible electromagnetic events radiated by the TSS 1R. The project EMET (Electro Magnetic Emissions from Tether) ,USA and the project OESEE (Observations on the Earth Surface of Electromagnetic Emissions) Italy, consist in a coordinated programme of passive detection of such possible e.m. emissions. This detection will supply the verification of some thoretical hypotheses on the electrodynamic interactions between the orbiting system, the Earth's magnetic field and the ionospheric plasma with two principal aims as the technological assesment of the system concept as well as a deeper knowledge of the ionosphere properties for future space applications. A theoretical model that keeps the peculiarities of tether emissionsis being developed for signal prediction at constant tether current. As a step previous to the calculation of the expected ground signal , the Alfven-wave signature left by the tether far back in the ionosphere has been determined. The scientific expectations from the combined effort to measure the entity of those perturbations will be outlined taking in to account the used ground track sensor systems.

1. Introduction

The EMET and OESEE observation programme , represents the *receiver* on the Earth's surface of a possible signal generated and irradiated by the TSS 1R orbiting system considered as the *transmitter*. The most promising Earth's surface positions for receiving stations are points on the ground track . The selected receiving sites are : Mona Island , Arecibo (Portorico) and Breebie Island (Australia) are under the EMET responsability, the other two stations , at Canary Islands (Spain) and Malindi (Kenya) are under the OESEE responsability. Based on previous theoretical studies, [1, 2, 3] an estimation on some measurable parameters of the expected signal at the ground station has been deduced. The generation/radiation

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mechanisms are strongly dependent from time and space due to a variety of phenomenologies related to the Earth's magnetic distribution, to the ionospheric plasma, to the propagation boundaries *conditions* . *In addition, the inherent* electrodynamic interactions of the ionosphere with the orbiting huge and flexible structure, makes the modelling of the global behaviour extremely complicated and il-posed , with drastic reduction of the quality of the parametric estimations and predictions in terms of accuracy, precision, stability. In spite of the above considerations the theoretical study of modelling approach has produced several hints for the assessment of high quality e.m. detection systems suitable to be deployed at the selected receiving sites. A tethered system as a result of its interaction with the earth's magnetic field and with the plasma can radiate *spontaneous* radiations as well as *artificial* emissions generated on board of the system by means of planned modulating devices. Each of those possibilities requires an ad hoc detection/estimation strategy. Since these waves are the means by which current closure is achieved in the ionosphere , understanding them is of fundamental importance to understanding the basic physics of the system , Additionally, knowlwdge of the propagation characteristics of these waves is important for their possible applications to communication systems. In its basic form, an electrodynamic tether can be viewed as a single orbiting system with a long electrically conducting cable thais insulated from the ionosphere and stretches along the vertical with terminating masses at each end which are in contact with the ionosphere. As the system passes through the geomagnetic field , the system experiences an induced emf between the tether ends that is given by $\left(\bar{V}\times\bar{B}\right)\cdot\bar{L}/c$, where $\bar{V},\bar{B}$ and $\bar{L}$, are, rispectively, the system velocity, the geomagnetic field vector and the vector parallel to the tether whose magnitude is the tether length L. The motion induced emf produces a near-steady current flow in the tether as long as the terminal masses (the shuttle and the satellite) can exchange charge with the ambient plasma [4]. the terminal masses *must provide* good contact with the ionosphere or the system ability to draw the current will be restricted. If current collection *is insufficient , most of the motion induced emf* will go into charging the terminal masses to large potentials and diminish the intensity of electromagnetic emissions. Many studies have been done wich address the issue of wave excited by a conducting mass moving through a magnetized plasma . Some of these have specifically addressed the tether problem . Although it has been demonstrated that the tether of the kind employed for TSS will give rise to propagating electromagnetic waves , the production of waves which are intense enough to be observed by ground-based receiving systems has not been well established.

2. The Spontaneous Emission Model

Properly equipped satellites already in orbit might be used to measure waves left behind in the ionosphere by tethers as well as appropriate sensors sytems located at the Earth's surface on the ground track. A good theoretical representation of the plasma waves [5] associated with a tether hundreds of kilometers from the satellite might guide the planning of data collection and analysis, which could in turn validate the theory. The considered signature is that generated by a tether of length L , operating as truster or generator, and thus supporting a near steady current I . In addition to cold-plasma thory , can be assumed an infinite , uniforme ionosphere; constant, horizontal tether velocity $\bar{V}$ and a constant geomagnetic field, perpendicular to $\bar{V}$ but tilt at an angle θ with respect to the horizontal, Fig.1. As a steady current flows through the tether, by means of continual charge exchange with the ambient plasma at end contactors, circuit closure is accomplished by charge-carrying electromagnetic waves radiated to "infinity" by the passage of the system . The constraints of steady-state operation and negligible (thermal) damping restricts rdiation to 2 brabches of the cold-plasma dispersion relation: Fast Magnetosonic (Lower Hybrid range rather than whistler's) and Alfven branches . The "wing" structure of Alfven-wave packets , is considered (frequencies below the ion gyrofrequency Ω_i).

Electric and magnetic fields $\bar{E},\bar{B}$ in the Alfven pachet written in terms of a potential field [11],

$$\bar{E}=-\nabla_\perp\phi\ ,\qquad \partial\bar{B}/\partial t=-c\nabla\wedge\left(\bar{1}_z\partial\phi/\partial z\right)\ ,$$

$$\phi(\bar{r})=\frac{I}{\pi}\iiint\frac{d^3kg(\bar{k})e^{i\bar{k}\cdot\bar{r}}}{\omega k_\perp^2\left[\varepsilon_1(\omega)-(ck_z/\omega)^2\right]}\ ,\quad (1)$$

$\underline{r}\equiv(x-Vt,y,z)$; $\omega=k_x V$ (steady state);

$\perp$ ≡ perpendicular to the geomagnetic field;

$$\varepsilon_1(\omega)=\frac{c^2/V_A^2}{1-\left(\omega/\Omega_i^2\right)}\ ,\qquad V_A\equiv\text{Alfven speed}, \quad (2)$$

(diagonal component of cold-plasma dielectric tensor perpendicular to geomagnetic field)

$$g(\bar{k})=\frac{-i}{2\pi I}\iiint d^3r\nabla\cdot\bar{J}_{source}e^{-i\bar{k}\cdot\bar{r}} \quad (3)$$

$\bar{J}_{source}(\bar{r})$ is current density in the tether, regions of net cgarge continually created in the plasma as it flows by the contactors, excite the waves. For (contactor length along x) << $V/\Omega_i\cong 36$ m,

$$g=\frac{1}{\pi}sin\left(\frac{L}{2}k_y'\right)\equiv\frac{1}{\pi}sin\left[\frac{L}{2}\left(k_y\cos\theta-k_Z sin\theta\right)\right] \quad (4)$$

Fields decay exponentially away from the planes $y=\pm 1/2\,L\cos\theta$.

Alfven wave-packets are called wings; they are disjoint if

$$L\cos\theta\ \rangle\ 4|x|^{1/3}(V/\Omega_i)^{2/3}\ ,\ \text{roughly} \quad (5)$$

Leading front (of top wing, at $y = 1/2\cos\theta$) occurs at

$$\frac{|x|}{z+1/2Lsin\theta}\cong\frac{V}{V_A}\cong\frac{1}{40}$$

$$\frac{|x|}{z+1/2Lsin\theta}\cong\frac{V}{V_A}\cong\frac{1}{40}\ .(6)$$

Collision destroy the wing at a distance along the front , z ~ 600 km, or $x\cong zV/V_A\cong 15\ km$.

Front has Airy-function structure, Fig.2,

$$E_y=\frac{V_AI}{c^2}\frac{\pi(2/3)^{1/3}}{|x|^{1/3}(V/\Omega_i)^{2/3}}\times A_i(\zeta)\times sign(y-L/2\cos\theta) \quad (7)$$

$$E_x=\frac{V_AI}{c^2}\frac{\pi(2/3)^{1/3}}{|x|^{1/3}(V/\Omega_i)^{2/3}}\times G_i(\zeta)$$

$$\text{with}\ \ \zeta\equiv\frac{x+(z+1/2Lsin\theta)V/V_A}{|x|^{1/3}(V/\Omega_i)^{2/3}}\left(\frac{2}{3}\right)^{1/3}.$$

Front thikness grows as (distance along the front)$^{1/3}$, amplitude decays as inverse of thikness.

Frequencies in the range :

$$\omega/\Omega_i\le 0\left[\left(V/|x|\Omega_i\right)^{1/3}\right]\quad \text{contribute to the}$$

front structure.

Behind the front,only wave components close to a single well defined frequency is found to radiate along each ray or direction. That frequency , ω_*, is given by :

$$\left(\frac{\omega_*}{\Omega_i}\right)^2 \equiv K_*^2 = 1-\left(\frac{V}{V_A}\,\frac{z+1/2L\sin\theta}{|x|}\right)^{2/3}$$

$$\left(\frac{\omega_*}{\Omega_i}\right)^2 \equiv K_*^2 = 1-\left(\frac{V}{V_A}\,\frac{z+1/2L\sin\theta}{|x|}\right)^{2/3} \qquad (8)$$

for the top contactor. The region behind the front is defined by the condition : $\omega_*/\Omega_i >> \left(V/\Omega_i|x|\right)^{1/3}$.

The far fields behind the front of the top wing are :

$$E_y = \Lambda\times\cos\left(\frac{x\Omega_i}{V}k_*^3+\frac{\pi}{4}\right)\times sign(y-L/2\cos\theta) \qquad (9)$$

$$E_x = \Lambda\times sin\left(\frac{x\Omega_i}{V}k_*^3+\frac{\pi}{4}\right)$$

with $\Lambda = \left(\frac{2\pi}{3}\right)^{1/2}\frac{V_A I}{c^2 k_*^{1/2}}\,\frac{1-k_*^2}{\left(|x|V/\Omega_i\right)^{1/2}}$

The decay as (distance)$^{-1/2}$

3. The Observational Program

In 1986, the Harvard-Smithsonian .Astrophysical Observatory (SAO) was selected by the National Aeronautics and Space Administration (NASA) to investigate analitically and observationally using ground based systems the detectability of emissions by tthe electrodynamic tether The title of this project was E M. Emissions from Tether (EMET) [12] Rice University is also associated to EMET with its experience in ground-based ionospheric observational systems. In 1987 the italian Space Agency approved the proposal of the University of Genoa for a similar program using coil and superconductive magnetometers (SQUID) in *two sites on the ground track of the orbiting* system. With the italian experiment the total of coordinated selected receiving locations where in Australia (Bribie Island), the Caribbean (Mona Island) ,thc Canary Islands (Tenerife), and Kenya (Malindi) . EMET programme included also additional observations during the overflights of the TSS 1 system using the Arecibo (Puerto Rico) 430 MHz radar facility. In Fig. 3 are indicated the above *mentioned coordinated receiving sites.* The Arecibo facility is ideal for diagnosing the effects of the TSS on the ionosphere and providing meaningful results to the programs global data pool. The combination of different data during the overflights, namely the minimal closest points of approach of the TSS orbiting system to the receiving sites in cronological succession (Mona, Canary, Kenya, Australia) all in the ground track zone, will provide data to perform different signal processing strategies including space correlation techniques with redundancy of data. The *selection of Kenya (Malindi) and Australian* sites (Brebie Island) , followed the selection of *Mona Island with its general location fixed by* the condition that are situated in the opposite hemisphere and along the orbital ground track that connects them to Mona and Canary Islands within the same orbital revolution. For TSS 1R the shuttle will launch due east from Kennedy Space Center and overfly points on the ground up to maximun longitudinal extent of 28.5 degree north and south. The australian facility was established by by the University of Queensland, Brisbane , Australia. The Canary Island facility was established by the Istituto Astrofisico de Canarias, Universidad de La Laguna , Tenerife, Spain. Theoretical studies on the exploitation of *correlated overflights have been performed to* estimate the processing gain of such a spatial *signal processing method, in particular for the* Mona-Canary islands configuration [6].

In 1993 an other attempt to receive e m.emissions by a tether was performed at Hawaii island. One OESEE triaxial magnetometer SQUID was located on the ground track of a NASA DELTA II SED system (Small Expendable Deployng System) For the experiment NASA Plasma Motor Generator , PMG '93. In tnat case the tether was long 500 m, and the on board generated current did not work at its maximum as *expected. Anyhow some coincidences have* been remarked between the tether current structure and the received signal at the OESEE ground station. Such a

result, has allowed some consequential considerations to formulate expectations for the successive tether experiment , namely the TSS 1R. The emf generated by the conducting tether during its flight in the ionosphere is expected to close its circuit through the ionospheric plasma. This ionospheric "closure" is a crucial argument for electrodynamic thether sistems. In Fig. 4 is pictorially represented this closure phenomenon, denominated peculiarly "phantom loop". Such a close current circuit has the associated magnetic moment expressed by the product of the current **I** in amps, by the loop area in square meters. From an estimation of the expexted magnetic moment of the TSS 1R '96 results at least two orders higher than that of PMG'93 tethered system [7]. Estimation of signal levels from reference [14] are shown in Figs. 5 and 6.

4. The Rationale of the Measurements

In principle, we should be in presence of a classical communication channel , with the signal radiated by the moving source , the TSS 1R, nearly "unknown or badly-known". A communication channel capacity depends mandatorily from the a-priori knowledge of both the transmitter and the receiver In the present case, the "transmitter" is represented by the double interaction of the orbiting system with the ionospheric plasma and the earth magnetic field and is expected to have a not-well-defined multi-variate transfer function. The inherent lack of accurate informations about the transmitter must be, then, compensate, somehow by a rigorous

definition of the receiving systemfeatures . The TSS radiating system is supposed to radiate fundamentally by two modes , the *spontaneous mode* (i.e. the generation of Alfven waves [9]) and the *stimulated mode* (the artificial modulation of tether current from board [8]).

Consequently, the OESEE and EMET measuremets can be considered rather a "listening" than a strictly "detection" operation. In the attempt to characterize and process the interferent noise structure, a particular attention have been devoted to a critical interpretation of the recorded data.

For both the radiating modes , the "physical" approach, namely the rigorous definition of the antenna transfer function , and the consequent structure of the radiated (and propagated) signal, is nearly unfeseable. Instead the "empirical" approach, namely the observation, on the Earth surface, and possibly estimate the received radiations emitted by a TSS will be, in any case adopted.

5. Preliminar OESEE Surveys and Site Selection

The receiving instrumentation , consisting in two tri-axial COIL magnetometers and two tri-axial SQUID systems suitable for installation have been assessed and deployed on the selected sites along the ground track of the two electrodynamic tether missions, that have been flown thus far. They where the TSS-1 of August 92 , and the DELTA II-PMG of June 1993. In reality the experimental activity started on October 89 with a test surveys on Tino island (Tirrenian sea) and on the selected site on top of the Tenerife Island of Canaries. Those preliminar experimental measurements where mandatory for the characterization of the local e.m. background natural and man-made noise. The two tri-axial COIL system have been supplied by the curtesy of NPGS , Monterey and NUSC New London (USA). The two SQUID sensors have been specially purchased by DIBE University of Genoa Italy, at the 2G Enterprise in California.In addition to the knowledge of the noise structure the equipment was assessed and calibrated

The first operation was the recording on the tri-axial components which after the processing showed clearly the Schuman modes, tipical of the natural background noise at ELF bands. 36 hours recording on the three axis where performed in order to verify the stationarity of the noise for a duration of time of the same order of the duration of the forseen TSS-1 mission. The use of a second receiving station at Malindi in Kenya was also considered in order to improve the probability of detection , on the ground track, of the expexted signals from the orbiting system. Other two receiving stations have been installed in other locations Mona Island (Portorico) and Bribie Island (Australia) under the responsability of the project EMET (SAO and Rice University USA). At this stage was started , in the DIBE, an investigation on the possibility to treat the ELF noise by the Higher Order Spectral (HOS) analysis in order to estimate the non-Gaussian character of the natural E.M. noise at ELF bands verified , otherwise , also from other scientists [Bernstein & other]. This techniques are expected to increase the probability of detection of week signals in presence of non-Gaussian noise.

5.1. The ELF Sensor : Monopole and Dipole Configurations

The same site , at Canary Islands has been used three years later in 1992 for the deploying of the final set up, inclusive of two SQUID magnetometers expecially builded in California. Taking into account the ground track of the orbiting system, the receiving properties of both Monopole and Dipole configurations have been considered. The first considered was the monopole configuration which represents the simplest receiving antenna. The possibility to install a second separate receiving station on the same ground track was also considered . The advantage of the Dipole Configuration, (one sensor located at Canary Islands and an identical one at Mona island-Portorico or at Malindi-Kenya) , considering the dipole distances (5/6 Mm)and the involved ELF bands. An ad hoc investigation has been carried out with the results that a processing gain increase of, at least, 6 dB, and consequently a higher probability of detection of the possible radiated signal, can be expected

This processing gain is due to both combined properties of the dipole configuration , namely the possibility to carry out "spatial processing" and the "transitting target detection " techniques (Fig 1 and 2) The non stationarity of the expected signal during any overflight can be exploited by the transiting target detector which was studied by Nicolas [10] . In this case , a pole-zero model of the signal is assumed and the model parameters are estimated in a maximum-likelihood sense. A generalized likelihood ratio test was then used for detection where the estimate is considered as true value of the received wave form . This scheme constitutes the optimum receiver in the Bayes sense. The possible modulation offers the opportunity of placing the energy in a part of the spectrum that will be more favorable to a given detection scheme. The passage over two receiving stations on the ground track (i.e. Mona-Tenerife and or Tenerife-Malindi dipoles) will provide a situation that can be exploited for spatial processing purposes. This property of the expected modulated signal, namely its deterministic generation , and the operative propagation conditions, make feseable the spatial processing. For instance , the spacing between the "elements" of one pair of receiving stations (Mona-Tenerife or Tenerife-Malindi) ranges from 5 to 6 thousands Km, representing half-wave length approximatly at 30 Hz, and a quarter-wave length at 15 Hz. With the adequate boundaries conditions [6] any signal energy in this frequency band can be processed by standard spatial processing techniques. Since the noise can be expected to have a generally horizontal directionality, and when the TSS-1 (and TSS-1R) system is overhead, the directionality of the signal can be expected to be generally downward, this receiving antenna , can be used to reject some of the noise . If, on the other hand , there is energy only at the very low end of the spectrum , the two receiving station configuration , can be used in two other schemes : a **spatial coincidence detector** and **a modified matched filter method.** In the event that the energy, in the 15-30 Hz spectral region, reach the ground with a level impossible to detect, a distinct possibility given by the complex "signal generation" mechanism, it is reasonable to expect that at least some energy in the 0 1 - 3 Hz region should be present. In this event , it is proposed that a set of filters to be used to look for this energy while using the transiting-target-processor independently and then looking for coincidences between the two receivers . Assuming the correlation time of the noise to be less than the travel time of the TSS-1 between the two receivers , this would provide a gain of approximatly 3 dB over a single receiver . More exactly the probability of detection is given by :

$$P_D = 2\,p_d - (p_d)^2 \qquad (10)$$

Where p_d is the probability of detection for a single receiver. The processing gain , from the above equation converges to 3 dB as p_d approaches zero.

5.2. The Hawaii Islands Experiment : The DELTA II - PMG.

In June 1993, during the PMG experiment , in an approppriate location on the ground track at Hilo Hawaii, the OESEE receiving site used the single sensor configuration , consisting in a tri-axial SQUID magnetometer and peripheral electronics. The system was deployed to detect on the Earth surface, possible emissions from the DELTA II tether. A pre-processing monitoring system was also employed during the mission . The site showed a particular low level man-made noise. A multiple channels data acquisition system battery operated was used . This attempt to reveal at the closest points of approach the possible radiation emitted by the PMG payload carried into low Earth orbit on a DELTA II second stage . Our attention is devoted mainly to the analysis of the "listened" data at the Hilo OESEE receiving site during the flight (Fig. 8 and Fig. 9), and to compare them with the observed variations of some electrical parameters which represent the power source of the tethered antenna. The most significative appear to be the tether current and voltage profiles during continous Electrometer Reads [7].

During the DELTA II - PMG mission data continous recording where carried out by the OESEE equipment. Although the on line pre processing monitor system , no significative signal related with the overflight or any other phase of the mission has been observed. On the other hand the natural background noise at ELF band was clearly recognized in a short integration time by the presence of the Shuman modes . Such an integration time gave an estimation of the favourable conditions of the local man-made noise. The rational to perform an optimal detector scheme suggest a preliminar exaustive modelling of the radiating system as well as that of the propagation system . Unfortunatly, such a modelling was not carried out taking in to account the constraints and the boundary conditions of the PMG (or TSS). To make reliable prediction about the performances of any telecommunication channel , one essential quantity to be known is the radiating efficiency of the radiating antenna , which in this case is an electrodynamic tether orbiting in the ionosphere. In 1992, [2,3] stated a good compromise for the estimation of the radiated energy by a dipole antenna orbiting in the ionospheric plasma . The estimation of the radiating efficiency from a dipole antenna in the ionosphere has been deduced taking in to account the following conditions :

- f = 9 kHz radiating frequency;
- r = 400 km , distance from the transmitter in the ionosphere and the receiver on the earth surface;
- V_0 = 1 kVolt , the applied voltage to the antenna
- $E_\theta{}^r = 1.18 \times 10^{-5}$ V/m;
- $I_z(0)$ = 5.2 Amp, current at the driving point of the antenna;

One estimation of the radiating efficiency is given by the ratio of the input power to the driving point of the antenna orbiting in the ionospheric plasma and the power received at the earth receiving site at a distance on the earth surface of about 400 Km. This ratio is

$$\eta = \frac{3.7 \times 10^{-13}\ [\mathrm{W/m^2}]}{0.258 \times 10^{-8}\ [\mathrm{W/m^2}]} = 1.43 \times 10^{-4} \qquad (11)$$

This estimation of such efficiency is relevant to the conditions above mentioned and is inclusive not only of the effective antenna efficiency but also of the inherent propagation losses for reach the receiving site. In the case of the PMG must be noted that the driving voltage of the antenna is not a sinusoidal shape but a sort of square vave (wide band signal) with much lower frequency components , from the point of view of wavelength this should compensate the the assumption of 9 kHz.

The radiation efficiency , in the case of a vertical antenna with respect to the ground/air interface is represented by the ratio [2] :

$$\eta = \frac{P[a]}{P[a] + P[g]} \qquad (12)$$

with P[a] = power radiated in air and P[g] = power radiated in the ground. By analogy a linear antenna feeded by an asimmetrical signal can be considered as constituted of two half antennas with different electrical inpedences with consequent degradation of the radiating efficiency.

On the basis of the Schuman theory about the resonance cavity made up of the Earth surface with the Ionosphere, under the cut frequency of 2 KHz, the electromagnetic waves propagate in an almost transversal-magnetic (TEM) way, thus allowing the propagation to huge distances of perturbations due to atmospheric lightnings. The typical values for the first three frequencies are around 8, 14, and 21Hz.

6. Conclusions and Expectations from the TSS-1R (Feb.96)

The activity done by the EMET-OESEE teams since the first approach to the problem and after the various activities like sensors calibrations, configuration studies, noise characterization, signal processing some detection-estimation strategies have been assessed and they are ready to be used for the TSS-1R., for both the configurations : Single Receiving site or Two Receiving sites The used fundamental techniques to approach this singular problem of Detection - Estimation are indeed those of the electrical communication disciplines, but the problem can be considered from an other, more physical, point of view . Substantially the scientific relevance of a success (the detection on the earth surface of radiations coming from the orbiting system) resides in the fact that the joint observations of the EMET and OESEE projects provide the proof that tether-generated currents have circuit closure that is remote (along the lines of the geomagnetic field) rath er than local. This is an issue of electrodynamics of the ionosphere that has generated substantial debates in this past few years.

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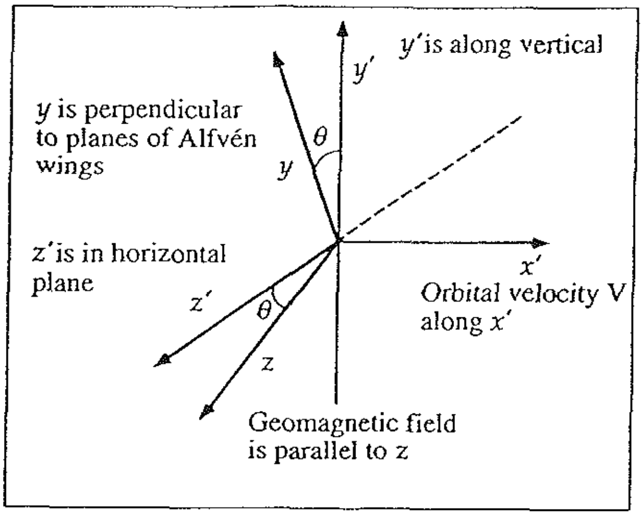


Figure 1: Co-ordinate system used in the analysis from [13].

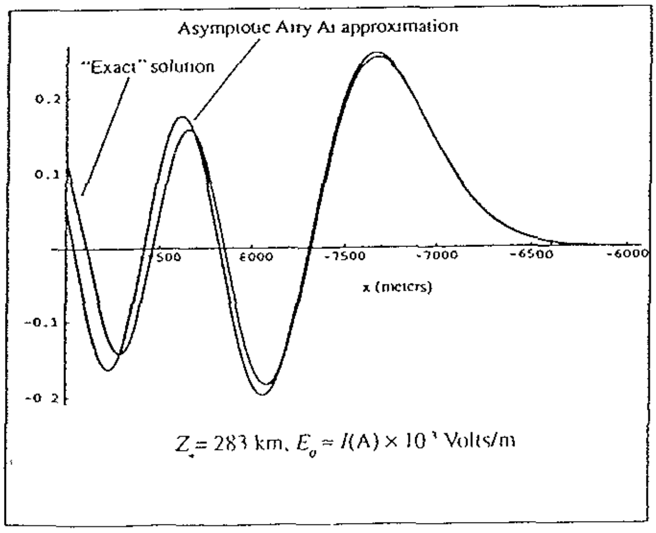


Figure 2: Comparison of asymptotic Alfven wing solution and numerically integrated exact solution of E_y/E_0 from [13].

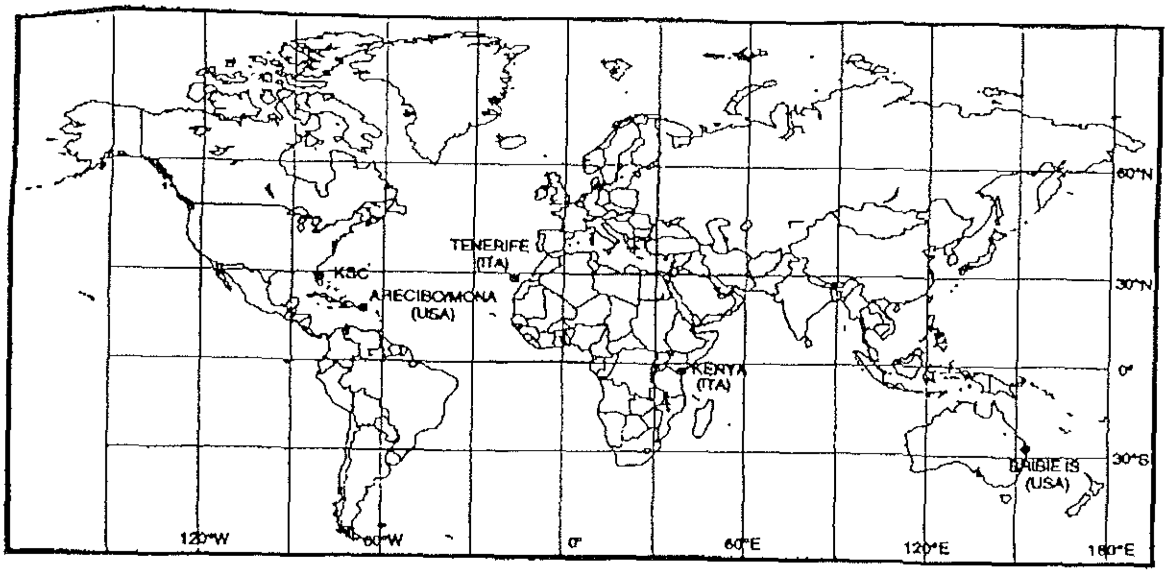
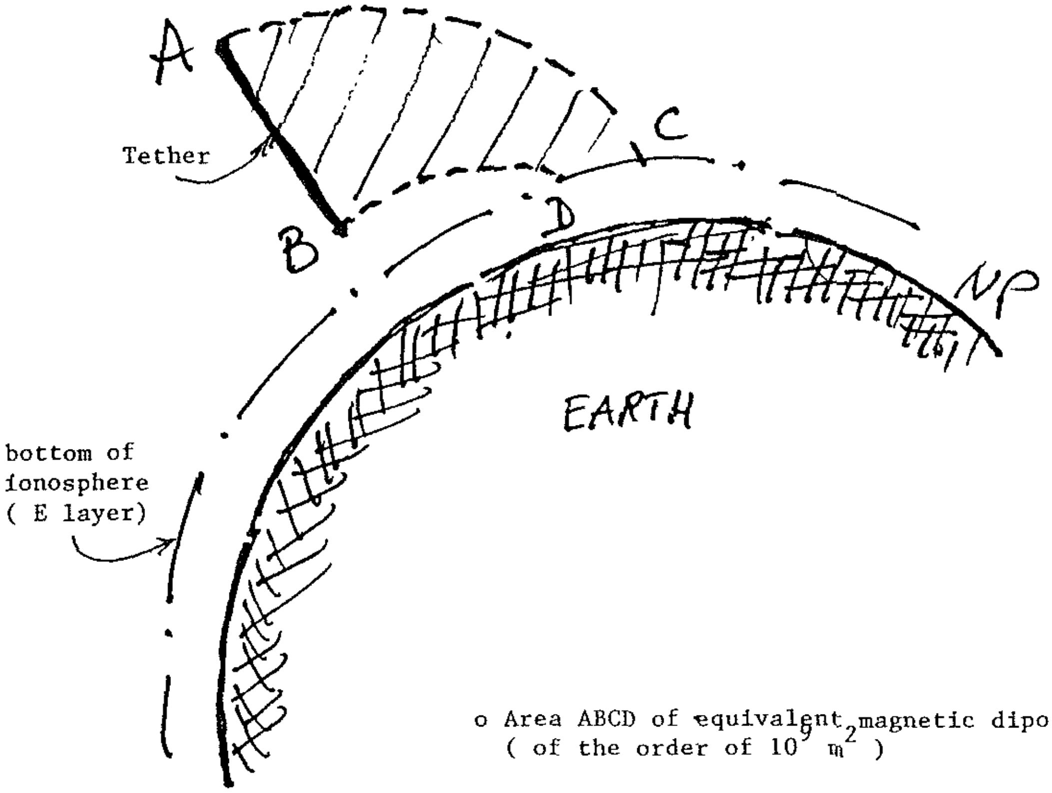


Figure 3: Map of ground stations



o Area ABCD of equivalent magnetic dipole (of the order of 10^9 m^2)

o Magnetic moment = Tether current x Area ABCD

o E.M. field intensities at the Earth surface can be computed according to Pappert, 1973, under the simplifying assumption of a magnetic dipole as a point source (Radio Science, Vol.8 n.6, pp 535-545).

(from PAPPERT 73)

Figure 4: Phantom Loop

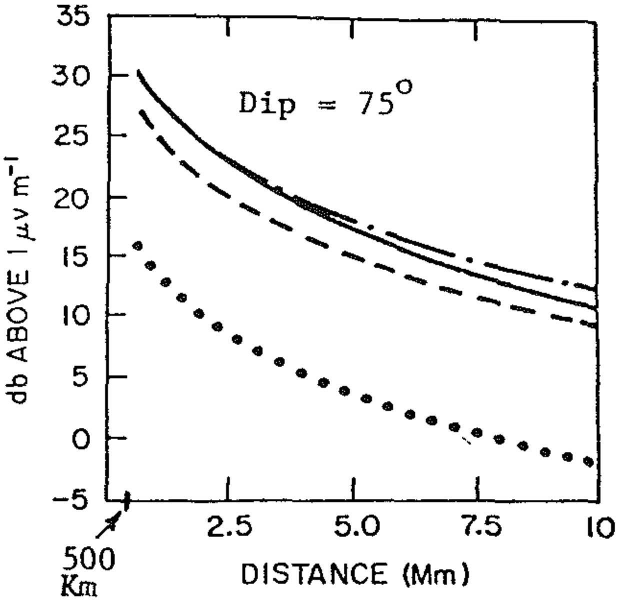


Figure 5: Signals levels versus distance. Signal levels for electric-dipole sources referred to a current moment of 3.18 x10^4 amp.-m. Signal levels for magnetic dipole sources referred to a current loop of 2.02x10^{10} vamp.-m^2. The azimuth is 90°, the dip is 75°; and the frequency is 75 Hz. Legend: ---- ground-based electric dipole, end fire, σ=10^{-4} mho/m; ●●● vertical electric dipole, 500 Km; _______ horizontal electric dipole, broadside and end fire, 500 Km; -.-.- horizontal magnetic dipole, broadside and end fire, 500 Km. (Pappert 73)

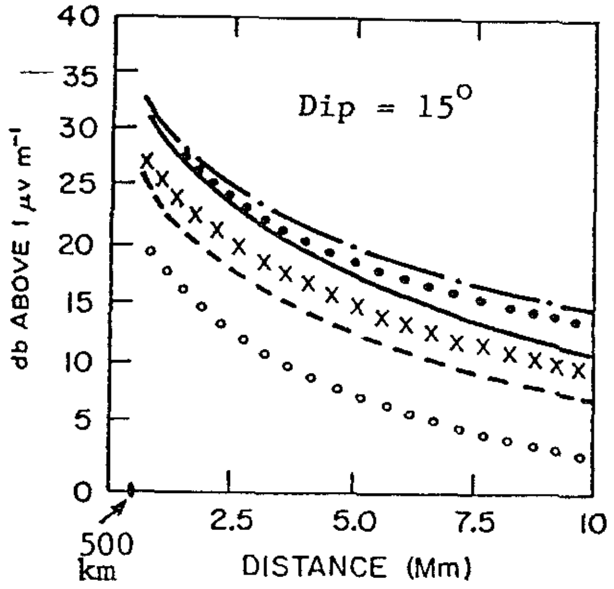


Figure 6: Signals levels versus distance Signal levels for electric-dipole sources referred to a current moment of 3.18 x10^6 amp.-m Signal levels for magnetic dipole sources referred to a current loop of 2.02x10^{10} vamp.-m^2. The azimuth is 90°, the dip is 15°, and the frequency is 75 Hz. Legend: ---- ground-based electric dipole end fire, σ=10^{-4} mho/m, ●●● vertical electric dipole, 500 Km; _______ horizontal electric dipole, end fire, 500 Km; ºººººº horizontal electric dipole, broadside, 500 Km; x x x horizontal magnetic dipole, endfire 500 Km - -.-.- horizontal magnetic dipole, broadside, 500 Km.. (Pappert 73)

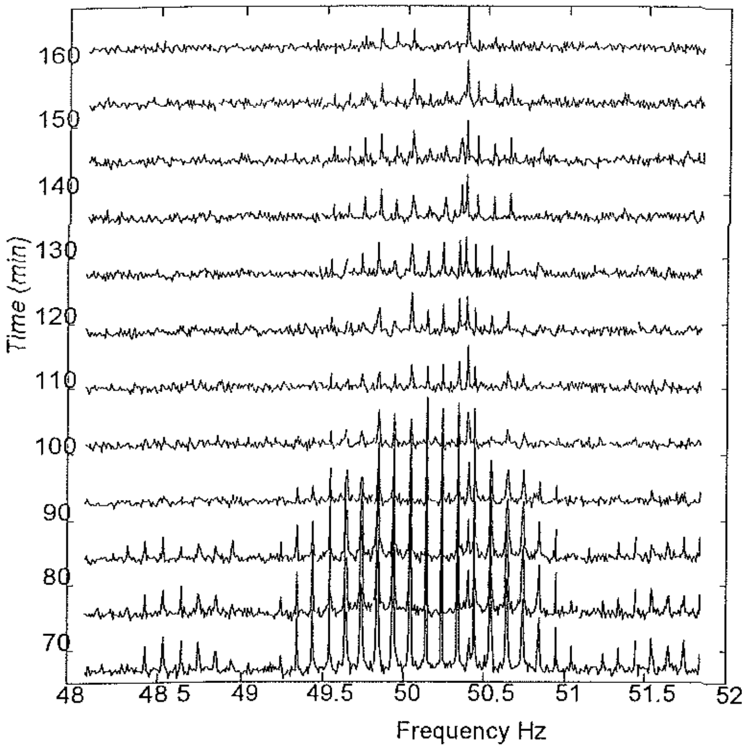


Figure 7: Variation of Power Spectra over Time PMG data from M.E.T 1:06 to M.E.T. 2:41.

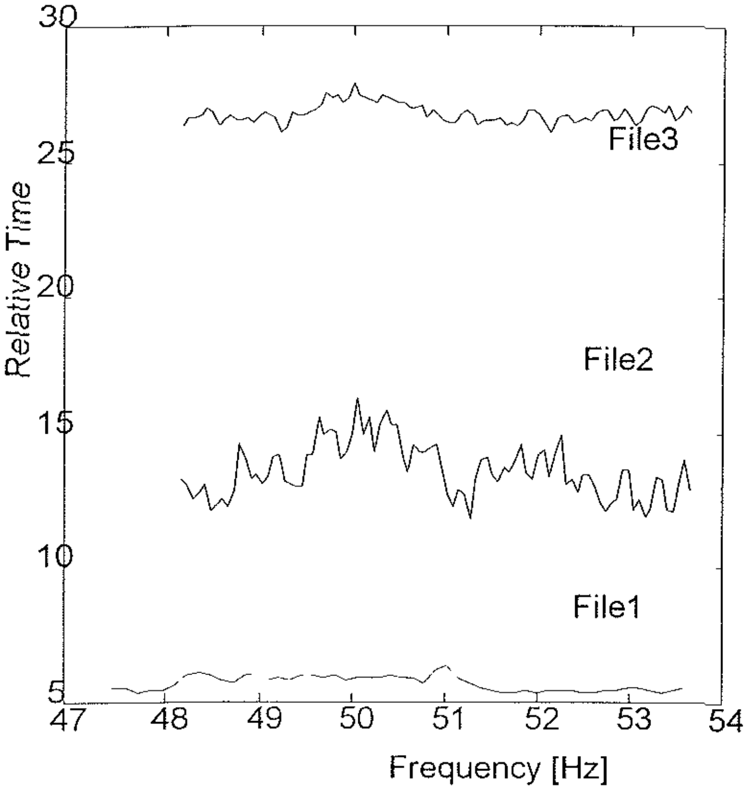


Figure 8: Variation of Power Spectra over Time. PMG noise-only data.