The TSS-1 mission: Results on satellite charging (*)

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Summary. — In the present paper we first give a short account of the mission TSS-1 flown on the Shuttle sts-46 in August 1992 and its basic electrical configurations. We then show some results obtained from the experiment RETE on board the satellite which are relevant for the issue of satellite charging.

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1. – Introduction

In this paper we give a short overview of the first TSS mission (TSS-1) which flew on the Shuttle Atlantis in August 1992. We will also show that, although the mission was not nominal, some of the data obtained are quite interesting with respect to the issue of satellite charging that was one of the primary objectives of the mission.

The project TSS was developed to provide the capability of deploying satellites on long, gravity-gradient–stabilized tethers from the Space Shuttle. It was proposed to NASA and the Italian Space Agency in the early 70's by M. Grossi of the Smithsonian Astrophysical Observatory and G. Colombo of the University of Padova. It became a reality in 1984 when NASA and ASI signed a Memorandum of Understanding in which NASA agreed to develop a deployer system and tether and ASI to develop the satellite.

The goals of TSS-1 were to demonstrate the feasibility of deploying and controlling long tethers in space and to demonstrate some of the unique applications of this system as a tool for research in space plasma physics.

During TSS-1 the satellite was supposed to be deployed 20 km outward into space above the Shuttle on a conducting tether. It is the use of the conducting tether which makes TSS a unique active experiment in space plasma physics.

The motional e.m.f. induced by the motion of the system through the Earth's magnetic field and the consequent electrodynamic interaction of the system with the ionosphere opens up, in fact, several areas of investigation on basic plasma processes.

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TABLE I. – TSS-1 *science investigations.*

Acronym	Title	Principal Investigator	Organization
CORE	Core Equipment	C. Bonifazi	ASI
SPREE	Shuttle Potential & Return Electron Experiment	D. Hardy	AFGL
SETS	Space Electrodynamic Tether System	P. Banks	Univ of Stanford
ROPE	Research on Orbital Plasma Electrodynamics	N. Stone	MSFC
RETE	Research on Electrodynamic Tehater Effects	M. Dobrowolny	CNR
TEMAG	Magnetic Field Experiment for TSS Missions	F. Mariani	Univ. of Rome
EMET	Investigation of EM Emissions by the Electrodynamic Tether	R. Estes	SAO
TEID	Theoretical & Experimental Investigation on TSS Dynamics	S. Bergamaschi	Univ. of Padova
IMDN	Investigation and Measurement of Dynamic Noise	D. Gullahorn	SAO
TMST	Theory and Modelling in Support of Tether	A. Drobot	SAIC
OESEE	Observations at the Earth's Surface of EM Emission by TSS	G. Tacconi	Univ. of Genova
TOP	Tether Optical Phenomena	S. Mende	Lockheed

Table I gives a list of the investigations selected for TSS-1 with the corresponding Principal Investigators. Two investigations refer to tether dynamics (PIs Gullahorn and Bergamaschi). A third one (PI Drobot) refers to theoretical electrodynamic studies. The remaining investigations all involve instrumentation which is on the Orbiter, on the satellite and within ground-based facilities.

The present paper, after a short discussion on the electrical configuration of TSS-1 and a general account of the first mission will concentrate on data results on satellite charging obtained mainly with the experiment RETE. For a detailed discussion on the remaining TSS-1 instruments as well as a discussion of the science issues of this project we refer to ref. [1].

2. – TSS-1 **electrical configurations**

Figure 1 shows the basic electrical configurations of TSS-1. This diagram, which refers to the instrumentation on the Orbiter, has its two main elements in two electron guns called EGA (Electron Gun Assembly) and FPEG (Fast Pulsed Electron Gun).

EGA is an electron gun capable of giving 0.7 A at 5 kVolt, whose main feature is that of having the cathode connected to the tether, whereas the anode is grounded to the Orbiter [2]. In this way, the gun is powered by the tether electromotive force. This type of connection was undoubtedly the basic electrical configuration of TSS-1 from the point of view of electrodynamic science. With EGA, one had the additional possibility of requiring a certain current value, which was reached and maintained through a feedback loop on the temperature of the filament emitting electrons. When this is actually achieved, the satellite voltage with respect to the ionosphere is also controlled. By varying the gun current (and when the required values can be actually obtained) one obtains, in fact, the current-voltage characteristics of the satellite and of the entire tether system as well.

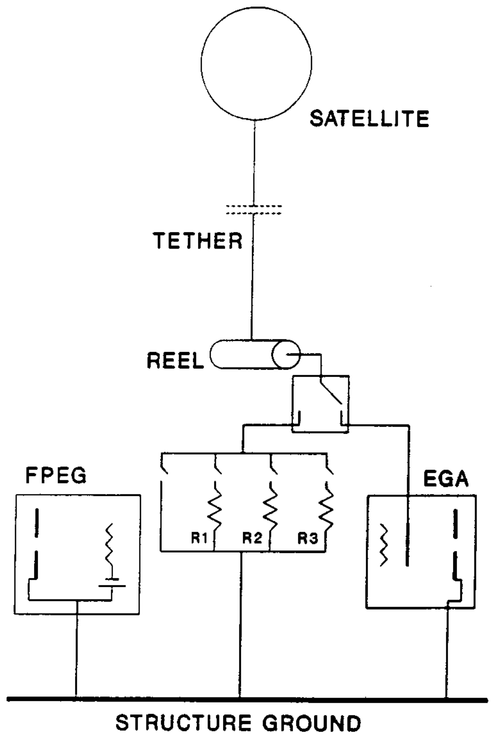

Fig. 1. – TSS-1 electrical configuration.

Notice, however, that this capability of current control may not always be possible. In particular, when requiring high currents from the EGA gun, the ionosphere at the satellite end may not be able to supply the required amount of electrons to sustain the commanded current. This is especially true at night time, when the electron density is minimum.

Coming back to fig. 1, the second electron gun FPEG, which is part of the experiment SETS, is a pulsed electron gun with its own power supply and therefore independent of the tether electromotive force. A second important electrical configuration was the one where the tether was connected (through a variable resistor) to the Orbiter ground and the FPEG operating and ejecting an electron beam in the ionosphere. The maximum current capability of FPEG is 100 mA.

It must be stressed that the two configurations (with either the EGA or the FPEG inserted into the circuit) are basically different. The FPEG gives first of all the possibility of performing electron beam experiments in the ionospheric plasma. However, when the tether is grounded to the Orbiter, it also induces some current in the tether in a way which depends on the interaction of the beam with the surrounding plasma and the return currents to the Shuttle. In addition, when both electron guns are operating, the current emission from FPEG allows to avoid Orbiter charging related to leakage currents from the EGA gun.

Most of the TSS-1 nominal mission was configured, from an operational point of view, as a sequence of cycles where either one or the other of the above electrical configurations (each with several variations) were adopted. The actual cycles according to which the mission was planned are described in detail in ref. [3].

3. – Description of the August 1992 mission

Several problems in the Deployer mechanism caused the TSS-1 mission to be far from nominal and, in fact, the satellite ended up to be deployed at a maximum distance of only 256 m (instead of the nominal 20 km). When, after many attempts, the satellite was unlocked from this position, there was general uncertainty as to the emerged problems. As a consequence, there was significant concern that further attempts to deploy migth, on the one hand, not lead to a sufficient distance to fulfill primary electrodynamic objectives but, on the other hand, could probably result in a loss of the satellite. This led to a unanimous consensus among the science and engineering teams to start a satellite retrieval which was then successfully accomplished. In all, the satellite stayed about 20 hours at the maximum distance with all the experiments (both on the satellite and on the Orbiter) operating during most of the mission duration.

We will give here some comments on the significance of what has been achieved in the first TSS-1 mission. A main goal of TSS-1, although of an engineering nature, was obviously that of proving the dynamics of the system. Although the deployment obtained was clearly insufficient to prove dynamics fully, there were about 20 hours of stable deployment in the near vicinity of the Shuttle and the operations at such distances, which were supposed to be critical for the mission, were fully tested with complete control of the tether and satellite dynamics. This experience will certainly be of great significance to the future use of long tethers in space because it showed the TSS to be safe, stable and easy to control.

Apart from the dynamic goals, TSS-1 was supposed to constitute a unique active experiment in the ionospheric plasma, the most interesting phenomena being related to the $V \times B \cdot L$ voltages associated with the long tether.

Turning then to electrodynamics, with the maximum deployed tether length of 256 m, the e.m.f. maximum voltage was around 50 V, far below the high-voltage range corresponding to the primary electrodynamic objectives of the mission. No substantial

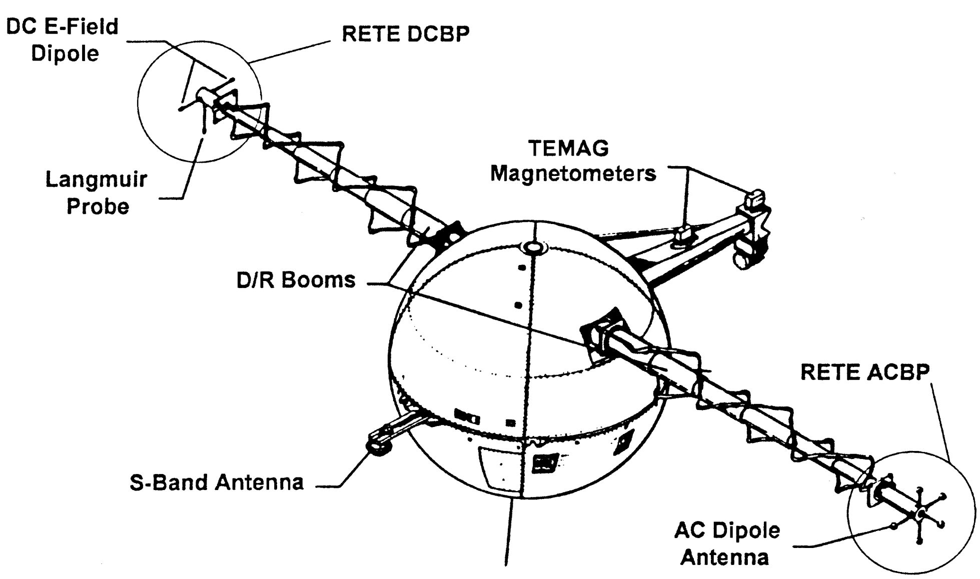

Fig. 2. – Location of the Italian experiments on the TSS satellite.

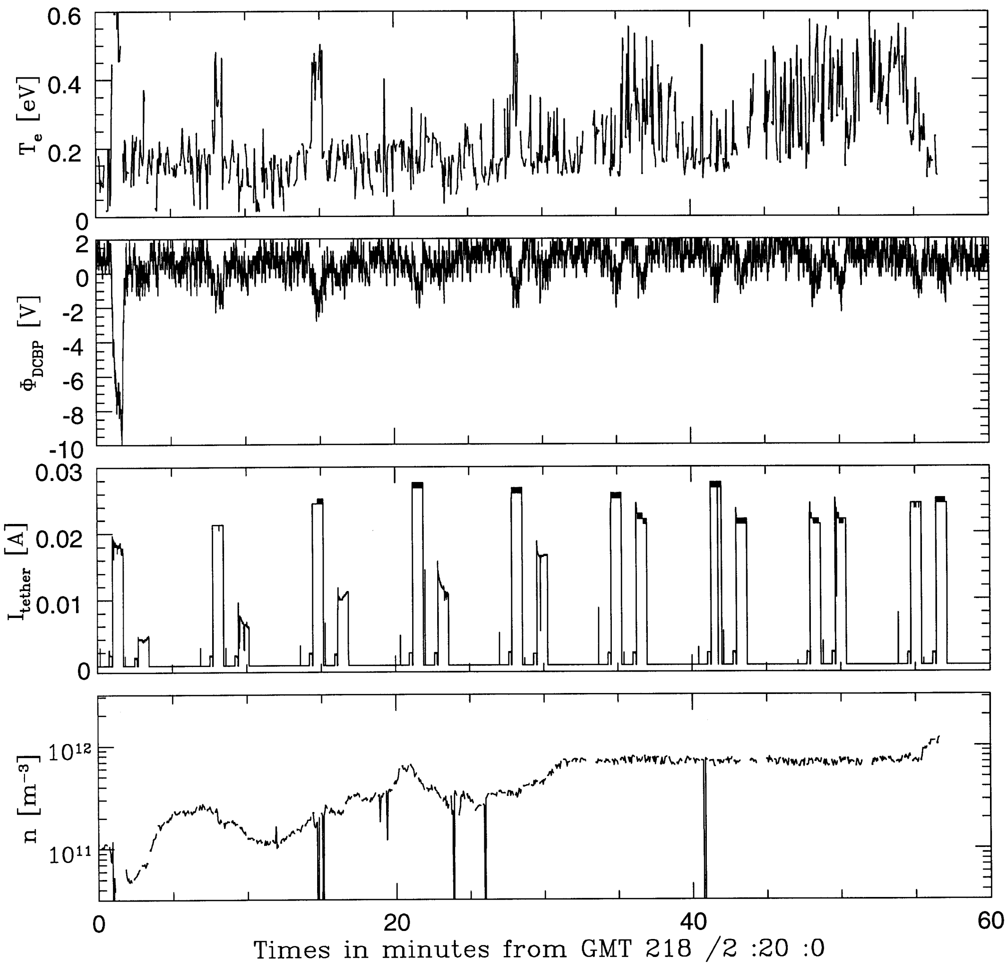

Fig. 3. – From top to bottom: electron temperature, DCBP potential, tether current and plasma density.

current was reached on the tether. More precisely, the current was around 20 mA with the tether connected to the Orbiter ground and the satellite was shown to be either not charged or charged to at most 10 V most of the time. Although it is still of interest to investigate *I-V* characteristics in the available range of current and voltages, it must be clearly stated that the primary objectives of the mission were not reached. There were, however, some other science objectives, which were considered as secondary in that not directly related to having long tether deployment, but still scientifically interesting. Examples include the investigation of electron beam dynamics (through the use of FPEG), Orbiter charging characteristics and Shuttle glow. These type of objectives were successfully accomplished. In fact, the type of experiments which were conducted were somewhat similar to those on the CHARGE 2 rocket with the difference, however, of a much longer measurement time and of a rather complete diagnostic instrumentation working both on the Orbiter and on the satellite side.

4. – Data results on satellite charging

In this section we will show some first results relevant to a primary objective of TSS-1, namely the issue of satellite charging. All of the data shown are from the experiment RETE and an ammeter on the satellite [3] giving the tether current.

The experiment RETE (Research on Electrodynamic Tether Effects) [4] had its sensors on two cylindrical canisters attached to two deployable booms (DRBs) as shown in fig. 2. One of the canisters, called ACBP (AC boom package), was containing electric dipoles, on three axes, and search coil antennas (on two axes). These allowed measurements of electric and magnetic fluctuations in the frequency range 160 Hz–12 MHz, which include all relevant characteristic frequencies of the ionospheric plasma. A second canister, called DCBP (DC boom package), on the other boom, was devoted to DC measurements and contained three Langmuir probes. Two of these were used as a dipole to obtain wave form electric fields from 0 to 175 Hz. The third was operated as a Langmuir probe properly to determine local potential, local electron density and temperature. In a nominal mission, with the DRBs moving, the

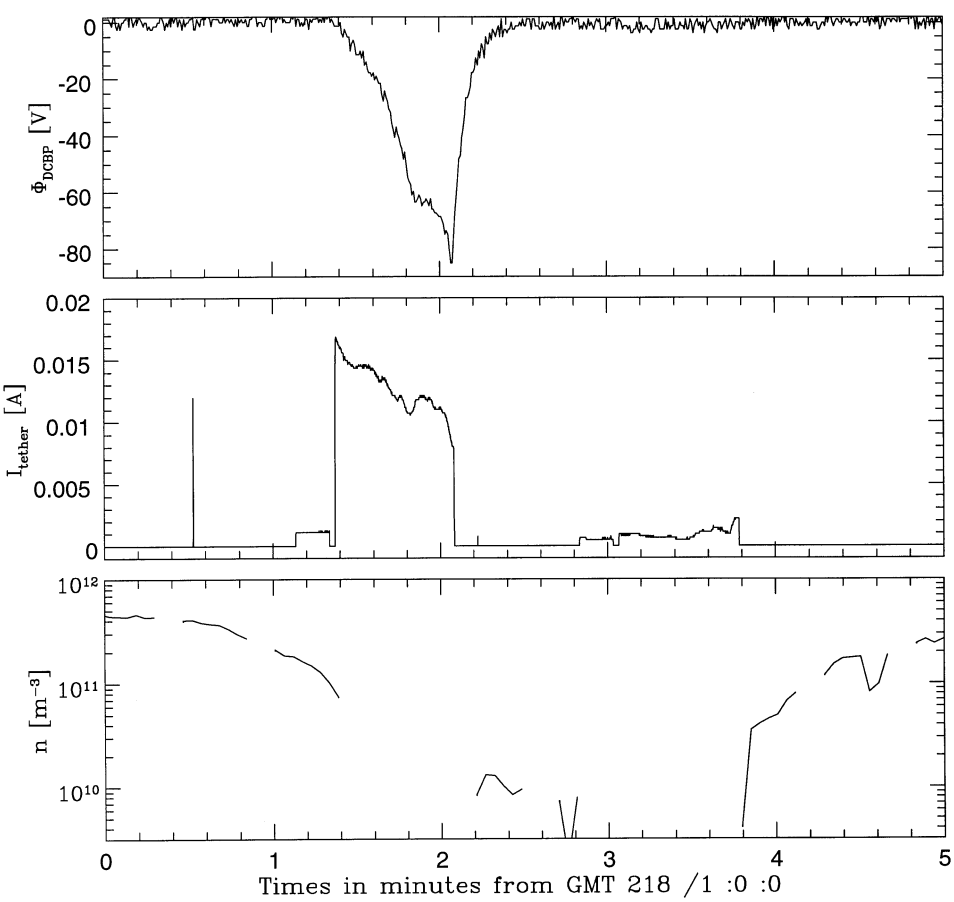

Fig. 4. – Satellite charging event during TSS-1. From top to bottom: DCBP potential, tether current and plasma density.

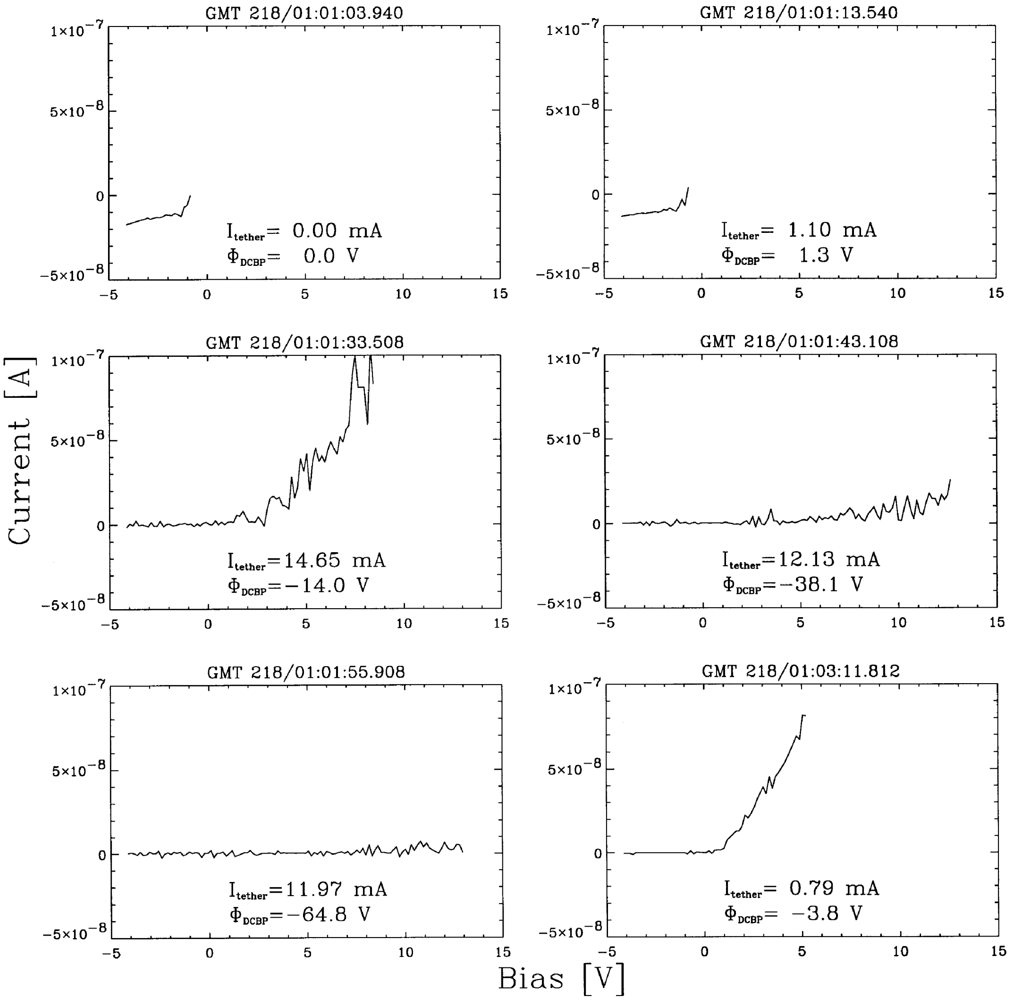

Fig. 5. – Sequence of Langmuir probe characteristics during the charging event of fig. 4.

RETE measurements were supposed to be taken at different radial distances from the satellite skin (and at different azimuths due to the satellite rotation), so as to clarify the structure of the space charge region around the satellite and the possible wave phenomena occurring there.

Figure 3 shows some interesting data in the context of satellite charging and, in general, *I*-*V* characteristics.

In the two middle panels we find the potential of the DCBP canister with respect to the spacecraft, as measured by RETE and the tether current as measured by an ammeter on the satellite [2]. The remaining two panels are electron temperature and plasma density as derived from Langmuir probe characteristics. Notice that there is a clear correspondence between current spikes and satellite charging. In fact the current spikes correspond to operations of the electron gun FPEG on the Orbiter side. When the gun fires electrons (up to 100 mA), the satellite, in order to collect that amount of current, has to charge. This type of data is now being used to derive current voltage characteristics of the satellite, although in a very modest current and voltage range with respect to that expected in a nominal mission.

As one can see, the maximum charging in the period shown in fig. 3 amounts to at most 10 V. Only once during the mission, corresponding to an exceptionally low ionospheric density, we measured a higher level of charging. This is shown in fig. 4 where the satellite potential is shown in the upper graph and tether current in the middle graph. The maximum charging obtained is in this case of about 80 V.

Figure 5 shows a sequence of Langmuir probe characteristics obtained along the charging event of fig. 4. One may notice the change in the appearance of such characteristics. The first three measurements are the typical characteristics of a Maxwellian unperturbed plasma (electrons are in the top part and ions in the lower part). Then, upon increase of charging, we see that the characteristics modify. They in fact develop an almost linear region which indicates the presence of an electron beam. The interpretation is that, upon increasing the charge of the satellite, the probe finds itself in the space charge region and there electrons from the unperturbed plasma are accelerated towards the satellite. In particular, the last but one I-V characteristics show no current. In this case, ions are completely repelled from the region where our probe system is sitting and it can be shown that, in this case, no more current is expected.

Sequences such as these, therefore, indicate the extent of the sheath surrounding the satellite. It is on the basis of these data, and the density and temperature derived from the Langmuir probe characteristics, that the analysis will proceed.

5. – Conclusions

In conclusion, the capability of deploying at some distance from the Orbiter and then retrieving a satellite was demonstrated by the first TSS mission. In addition, all the instrumentation aboard TSS-1 proved to work nominally. Finally, with respect to the electrodynamic objectives of the mission, we have obtained data which are significant for the issue of satellite charging and current-voltage characteristics of the system, although, obviously, in a much reduced range (of currents and voltages) with respect to that of a nominal mission.

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