Electrostatic modelling of the Groza-2 discharge sensor on the Venera missions to Venus

P Sukanjanajtee and K L Aplin

Faculty of Engineering, University of Bristol, Queen's Building, University Walk, Bristol, BS8 1TR

karen.aplin@bristol.ac.uk

Abstract. The Soviet Venera 13 and 14 missions landed on the surface of Venus five days apart in 1982. An instrument called Groza-2, designed to search for thunderstorms, carried an electrode that recorded discharge currents in the lower atmosphere. In this paper a possible location and likely geometry of the electrode are deduced using the limited information available on Groza-2, combined with electrostatic modelling. The spacecraft's geometry significantly screens the electrode potential, which helps to constrain the sensor's size, shape and location. Due to its high atmospheric pressure, Venus is anticipated to have a high breakdown field, approximately 300 MV/m near the surface if linear scaling with pressure is assumed. The existence of a signal in the discharge sensor combined with the electrostatic screening of the spacecraft geometry implies there is a substantial potential difference between the atmosphere and the electrode.

1. Introduction

The Soviet space programme sent a series of successful landers to Venus for scientific investigations in the 1970s and 1980s [1]. The Venera 11 and 12 missions carried an instrument called "Groza" comprising a magnetic field antenna and a microphone for detection of thunder. These missions detected suggestive low-frequency electromagnetic signals [2], so the next missions were upgraded to "Groza-2", which added an electrode intended to detect discharges. Venera 13 and 14 landed on Venus five days apart, in similar areas of the planet, in March 1982. The discharge current electrodes (DCE) on each lander detected comparable currents of 10-50nA, increasing during descent from 35km to the surface [2]. The consistency of the measurements suggests the signals are real rather than an instrument artefact.

There is no technical description of the DCE in the literature, so very little is known about its siting on the spacecraft, complicating aspects such as determining the geometric field enhancement, which would permit a more detailed analysis of the signal. The approach taken here is to use the existing limited information on the spacecraft and sensor – modern scale drawings recreated from photographs and museum exhibits, and a photo of the first Groza instrument – to reconstruct the likely location of the electrode and interpret its results.

2. Overview of the Venera 13/14 spacecraft

Engineering drawings of the Venera landers, reconstructed from various sources, are presented in [1]. Photographs of the earlier Groza instrument, which did not include the DCE, are also available, and show the location of the ring antenna and a microphone (to listen for thunder) near the base of the spacecraft [2]. Figure 1 shows the Venera 13 and 14 spacecraft with the Groza-2 ring antenna indicated. The location of the DCE is not shown.

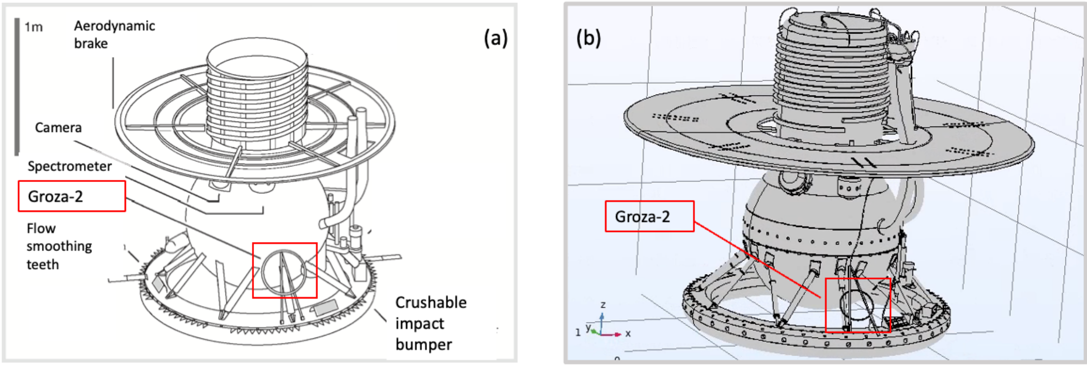

Figure 1 The Venera 13 and 14 probes (a) labelled scale diagram after [1], with key aspects highlighted (b) 3D CAD version. The Groza-2 ring antenna is located slightly differently on each diagram and the discharge current electrode location is not indicated.

The principle of operation of the DCE is the same as point discharge sensors used in terrestrial atmospheric electrostatics. During atmospheric electrical activity the local electric field is enhanced causing local breakdown and current flow. To maximise the field enhancement these sensors are typically a pointed geometry [3]. Here it is assumed that the DCE is a needle geometry, like other airborne discharge current sensors e.g. [3,4], and that it is located near the Groza-2 ring antenna. An electrostatic model of the spacecraft was used to investigate possible locations for the electrode.

2.1. COMSOL modelling

A freely available 3D CAD model of the Venera landers was used as a basis for 2D electrostatic modelling with COMSOL (https://www.autodesk.com/community/gallery/project/135452/venera-13-probe). The landers are not axially symmetric, as Figure 1 shows. The cross section of the spacecraft was manually edited to include the electrical connections between, for example, the main body of the spacecraft through the struts supporting the impact bumper at the base, Figure 2.

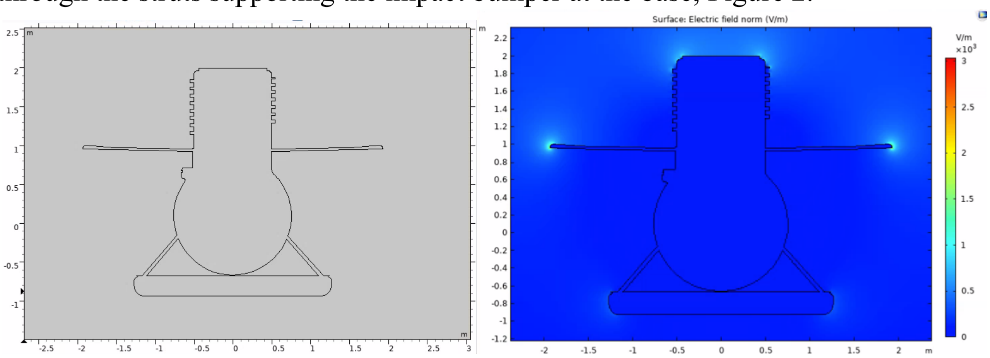

Figure 2 (left) Modified 2D section of Venera 13/14 based on the 3D version shown in Figure 1. (right) example electrostatic model showing the spacecraft at a potential of 1500V in a local electric field of 100V/m.

Due to the structural requirements of the mission and atmospheric entry, it is most likely the lander was made of mainly aluminium, steel, and titanium alloys, however the results were insensitive to the choice of material, so high conductivity material such as copper was arbitrarily chosen. After verification of the electrostatic model, the spacecraft was placed in an arbitrary atmospheric electric field of 100V/m, and spacecraft potential of 1500V, to assess the geometric field enhancement, Figure 2b. Most of the field enhancement occurs around the aerodynamic brake at the top of the spacecraft with a small enhancement near the bumper at the base. The cross section shown in Figure 2 was used as a basis for assessing possible locations for the DCE.

3. Design and location of the discharge current electrode

Terrestrial discharge electrodes typically have a base of 0.5 – 1 mm with a sharpened point e.g. [5,6], but the high pressure (90 bar) at the surface of Venus implies the electrodes would need to be mechanically stronger than this. An electrode with a base of 10mm and a point of 1mm diameter was therefore assumed. Based on the Groza-2 geometry (Figure 1) the DCE could only realistically be mounted in the centre or at the base of the ring antenna. Sensor lengths ranging from 100mm to 500mm were tried, on the basis that the sensor is unlikely to be larger than the rest of Groza-2. The angle of the electrode was also varied, and the results are shown in Figure 3.

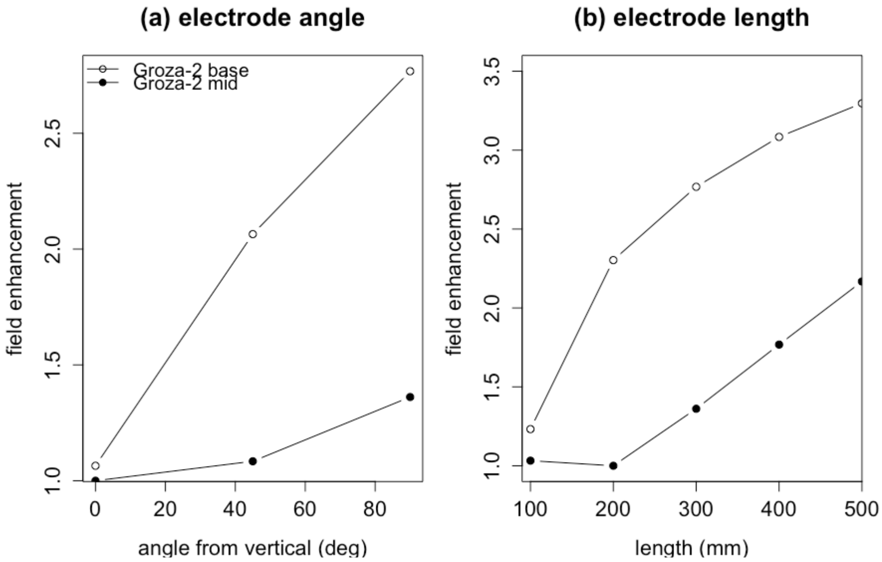

Figure 3 Normalised field enhancement factors for different discharge current electrode geometries on the Groza-2 instrument. (a) variation with angle for a 300 mm electrode, normalised to the minimum field enhancement factor, which was with the electrode mounted vertically at the midpoint of the ring antenna (b) variation with length for an electrode at 90°, normalised to the minimum field enhancement factor, which was for a 200mm electrode mounted vertically at the midpoint of the ring antenna.

The field enhancement factor is maximized at the base of the antenna rather than at the mid-point. This is likely because the further up the spacecraft, the nearer the electrostatic "shadow" of the protruding aerodynamic brake. For similar reasons, the field enhancement increases as the electrode protrudes more from the structure. Overall, the maximum field enhancement achieved, of ~6, is with a horizontal electrode of the maximum permitted length (500mm), located at the base of the Groza-2 antenna, just below the microphone. This length would make the electrode visible in photographs, however it has not been possible to obtain any photographs of Groza-2.

The detection of a nanoAmp discharge current by the Venera 13 and 14 landers is consistent with the DCE producing a pre-breakdown current often referred to as the "dark current" (e.g. [7]). The DCE response threshold is determined by the Paschen curve for the Venus CO_2 atmosphere, which shows that, over significant gaps, breakdown field scales with pressure. As the carbon dioxide and nitrogen breakdown curves are similar, the breakdown characteristics should be similar for Venus and Earth if pressure differences are accounted for [8]. The terrestrial breakdown field is ~3 MV/m at the surface, so, assuming a linear scaling with pressure, Venus is anticipated to have a breakdown field of ~300 MV/m near the surface [9]. This assumption is consistent with laboratory studies of carbon dioxide breakdown at high pressure [10]. Similarly, corona onset voltage is ~4kV near Earth's surface for a needle geometry, and this is also assumed to scale linearly with pressure, so corona would be anticipated at ~400kV on the DCE near the surface of Venus.

Even for the pre-corona dark current, these thresholds are so large that we assume the DCE must have been in a location with maximum field enhancement to measure any discharge currents at all, hence the electrode is assumed to be horizontal and located at the base of Groza-2. In the absence of known dimensions, a length of 500mm is also assumed.

4. Potential of the discharge current electrode

Having identified a possible design and location for the Groza-2 DCE, the potential difference between the spacecraft and the atmosphere is required to quantify the electric field at the electrode. These remain unknown, so a wide range of potential differences were assessed in the model by systematically varying both the upper potential of the 100m^2 spacecraft bounding box and the spacecraft potential. The DCE electrode was included at the base, as indicated in Figure 4.

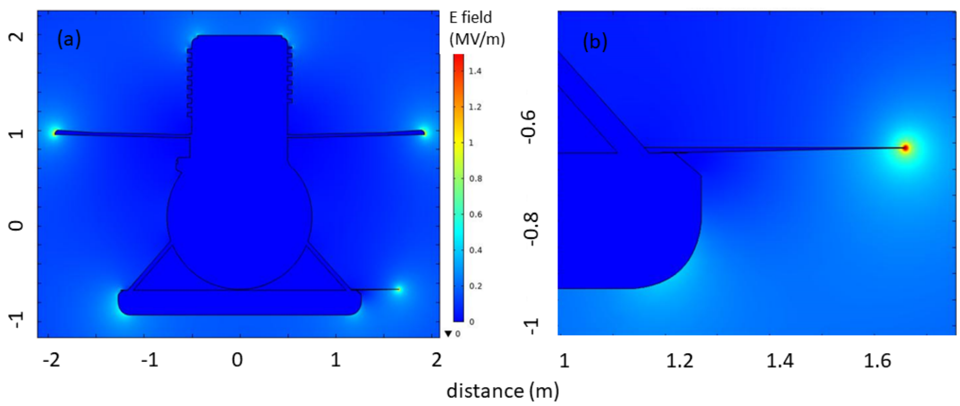

Figure 4 COMSOL 2D electrostatic model of (a) Venera 13/14 spacecraft including discharge current electrode (b) zoom of discharge current electrode. In this example the probe-atmosphere potential difference is 1.3 MV and the electric field at the DEC tip is 5.2 MV/m.

Clearly the DCE must have reached a significant voltage, approaching the corona threshold, for any signal to be recorded from it. The lowest breakdown thresholds are expected at the maximum altitude at which a signal was measured, 35 km, at which the pressure is ~6 bar. This would lead to a corona threshold potential of ~24kV and a breakdown field ~18MV/m. Trials with a range of spacecraft and atmospheric potentials show that the corona discharge threshold can be exceeded by the DCE from 35km downwards, but only if there is a substantial background atmospheric electric field. Atmospheric electric fields arise from local charge generating activity, such as thunderclouds or charged aerosol. If there is a global electric circuit on Venus, this would also cause a background electric field away from disturbed weather areas [9]. The maximum potential difference required between the lander and atmosphere for corona discharge at the surface is ~400kV, which is ~66kV if a field enhancement factor of 6 for the DEC is assumed.

5. Discussion

A discharge current electrode (DCE), part of the Groza-2 instrument on the Venera 13 and 14 landers, recorded repeatable current signals and profiles, suggesting atmospheric electrical activity. The high breakdown potential of the high-pressure Venusian lower atmosphere implies the DCE must have been located at a region of optimal field enhancement to record any signal. A simplified 2D electrostatic model was constructed from 3D drawings of the spacecraft, and a location for the DCE was identified at the base of Groza-2 which minimised electrostatic screening from the aerodynamic collar of the lander. DCE dimensions were estimated based on structural and electrostatic screening requirements. Potential differences of tens of kV between the spacecraft and atmosphere are required to cause discharge currents at the electrode tip. These potential differences must increase as altitude decreases to be consistent with the observed signal. Further work could use 3D electrostatic modelling to provide further detail on the likely geometric field enhancement factors of the DCE, as well as provide more detailed predictions of the breakdown thresholds in high pressure carbon dioxide. More realistic estimates of the DCE shape and size are also required.

It seems highly unlikely that repeatable signals measured by identical instruments on identical spacecraft landing at different regions of the planet are both spurious. These findings imply that there must be significant atmospheric electric fields in the lower atmosphere of Venus, otherwise there would simply have been no signal in the Groza-2 DCE. Triboelectrically charged aerosol has previously been suggested as an explanation for the Groza-2 DCE results [2], and could retain charge well in the poorly conducting lower atmosphere [11] but, even so, does not seem capable of generating big enough atmospheric electric fields to cause the discharge currents measured. Beyond the design of atmospheric electricity instrumentation, electrostatic modelling of spacecraft can help interpret anomalous results and provide insight into electrostatic discharge risks.

Acknowledgements

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References

[1] Ball A, Garry J, Lorenz R and Kerzhanovich V 2007 *Planetary Landers and Entry Probes* (Cambridge: Cambridge University Press)

[2] Lorenz R D 2018 Lightning detection on Venus: a critical review *Prog Earth Planet Sci* **5** 34

[3] Simpson G and Scrase F J 1937 The Distribution of Electricity in Thunderclouds *Proc R Soc Lond A Math Phys Sci* **161** 309–52

[4] Byrne G J, Few A A and Stewart M F 1986 The effects of atmospheric parameters on a corona probe used in measuring thunderstorm electric fields *Journal of Geophysical Research: Atmospheres* **91** 9911–20

[5] Jaworek A and Krupa A 1995 Corona discharge in multipoint-to-plane geometry *CONFERENCE SERIES-INSTITUTE OF PHYSICS* vol 143 pp 289–92

[6] Aplin K L and McPheat R A 2005 Absorption of infra-red radiation by atmospheric molecular cluster-ions *J Atmos Sol Terr Phys* **67**

[7] Gallo C F 1975 Coronas and Gas Discharges in Electrophotography: A Review *IEEE Trans Ind Appl* **IA-11** 739–48

[8] Manning H L K, ten Kate I L, Battel S J and Mahaffy P R 2010 Electric discharge in the Martian atmosphere, Paschen curves and implications for future missions *Advances in Space Research* **46** 1334–40

[9] Aplin K L 2006 Atmospheric electrification in the solar system *Surv Geophys* **27**

[10] Norman L, Silva K and Jones B 2021 *Effect of High Pressures on DC Voltage Breakdown*

[11] Borucki W J, Levin Z, Whitten R C, Keesee R G, Capone L A, Toon O B and Dubach J 1982 Predicted electrical conductivity between 0 and 80 km in the Venusian atmosphere *Icarus* **51** 302–21