

# Power Transmission Technology Using Electric Field Surface Waves— Future Energy Infrastructure Expanding into Space

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## Abstract

Power transmission technology using electric field surface waves excited by electric field resonance can deliver power by using a variety of surrounding substances instead of cables, which makes for flexible application. This article describes the basic principle of this technology and its envisioned use on the lunar surface.

*Keywords: electric field surface waves, power transmission, electric field resonance*

## 1. Introduction

The Artemis program of the United States' National Aeronautics and Space Administration (NASA) aims to construct a long-term base on the lunar surface in the latter half of the 2020s. To achieve this, a sustainable supply of energy to support activities on the lunar surface will be essential. This means finding solutions to all types of issues including the use of solar power, supply of power to diverse types of equipment on the lunar surface including mobile vehicles, and construction and efficient operation of various types of infrastructures needed for base and lunar-surface activities.

Transporting and installing a large number of power cables from Earth to the Moon for constructing a power supply network for a lunar base is unrealistic. This is because the cost of transporting a 1-kg load to the Moon is said to be about 100 million yen. The use of batteries is also limited on the Moon. They are vulnerable to the cold, and according to observations of the Moon near its equator, temperatures can reach 110°C during the day and drop to -170°C at night indicating a harsh environment in which battery per-

formance can significantly drop. It is thus common for an unmanned rover running on the lunar surface to generate solar power on its own without relying on batteries to power its activities. However, depending on sunlight to operate comes with major constraints. For example, equipment cannot be operated during the two-week lunar night. Many people may also remember how the Smart Lander for Investigating Moon (SLIM) of the Japan Aerospace Exploration Agency (JAXA), the first in history to successfully execute a pinpoint landing on the lunar surface in 2024, unfortunately landed at an angle different from the original plan making it unable to sufficiently obtain solar power, which limited its activities. In response to these issues, there are high hopes for technology that can supply power wirelessly to equipment such as rovers on the lunar surface.

## 2. Wireless power transmission technologies

Technology for transmitting power wirelessly has become part of our daily lives as typified by the wireless charging of smartphones. Today, humans are working to expand the range of their activities in

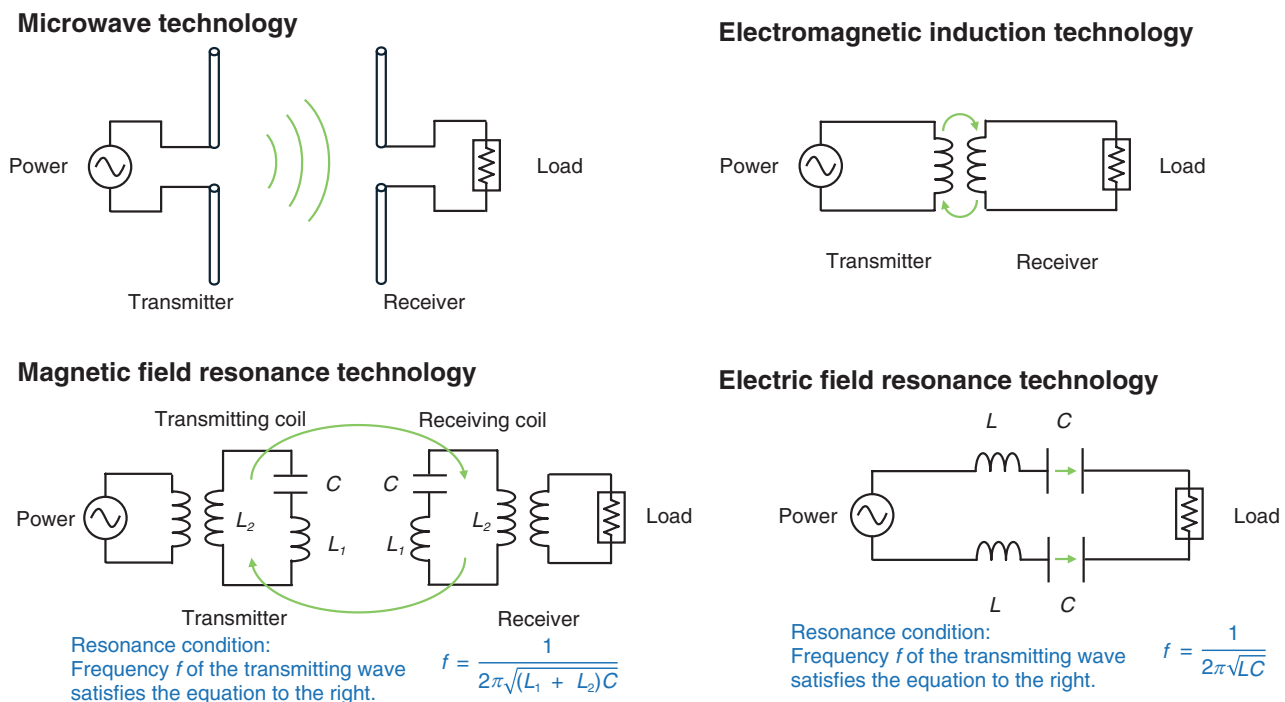


Fig. 1. Various wireless power transmission technologies using electromagnetic fields.

outer space, and when facing new issues in a new environment, technology will further evolve. Amid this trend, NTT Space Environment and Energy Laboratories proposed power transmission technology using electric field surface waves by electric field resonance. This technology will make it possible to transmit power via a conductor, such as the frame of a rover, or a dielectric, such as lunar sand, instead of a cable, which makes them promising for use in locations such as the lunar surface and space where materials available for use are limited. We describe the basic principle of electric field resonance and the mechanism for generating electric field surface waves. We also explore the applicability of this technology on the lunar surface while clarifying how it differs from current technologies.

There are four main wireless power transmission technologies using electromagnetic fields, as shown in **Fig. 1**. The advantages and issues associated with each of these technologies are summarized below.

#### (1) Microwave technology

This technology for transmitting power using radio waves has been used for some time in wireless communications. It can carry power to distant locations while the electric and magnetic fields exchange energy. However, as the distance increases, the radio

waves spread out in other directions, which makes it necessary to install an array antenna consisting of multiple antennas to increase gain. Therefore, transmission efficiency is not very high.

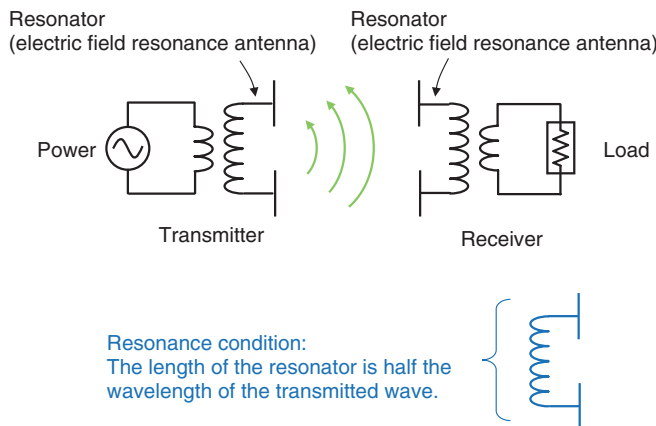
#### (2) Electromagnetic induction technology

The electromagnetic induction technology makes use of the law of electromagnetic induction discovered by Michael Faraday in the 19th century to transmit power via coils. It is widely used today for various purposes such as wireless charging technology for smartphones (Qi standard). A key feature of this technology is a simple structure that makes it easy to implement, but efficiency drops rapidly as the distance between the transmitting and receiving coils increases. This is because much of the generated magnetic flux never reaches the receiving side, resulting in a loss of energy. The electromagnetic induction technology is therefore applicable to short-range power transmission as when placing a device on a charging stand. It is not, however, meant to be used for power transmission that exceeds distances of several meters.

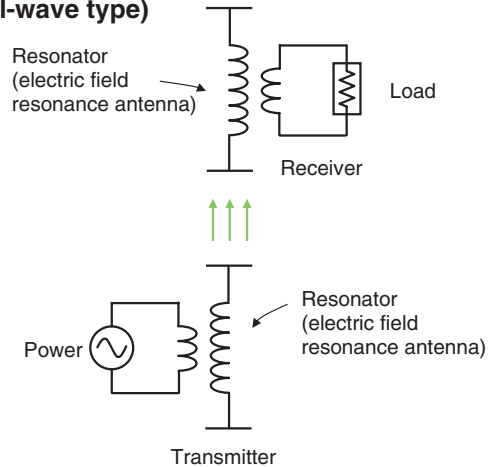
#### (3) Magnetic field resonance technology

The magnetic field resonance technology consists of technology announced by a research team at the Massachusetts Institute of Technology (MIT) in

**Electric field resonance antenna (transverse-wave type)**



**Electric field resonance antenna (longitudinal-wave type)**



- The resonant frequency is unchanged even if the inter-antenna distance changes, enabling power transmission over long distances.
- It is robust to lateral displacement, making precise alignment unnecessary.

Fig. 2. Wireless power transmission using electric field resonance antennas.

2007. This technology can transmit power at distances longer than that of the conventional electromagnetic induction technology by resonating two coils. It can efficiently convey energy by having the power-transmitting and power-receiving coils resonate in a magnetic field, which enables transmission distance to be extended past that of the electromagnetic induction technology. With this technology, power can be transmitted at a maximum distance of 2 m. In an MIT experiment, a light bulb 2 m from a coil having a diameter of approximately 60 cm was successfully turned on with a transmission efficiency reaching 50% [1]. This technology, however, requires a large coil, so the difficulty of securing sufficient space for installation is an issue.

(4) Electric field resonance technology

The electric field resonance technology transmits power by having a transmitting electrode and receiving electrode resonate in an electric field. The mechanism used is to transmit power not by passing a large current but rather by applying a high voltage. Consequently, when transmitting a large amount of power, this technology can use thin and light antennas without the need for using thick wiring to handle large currents. Power is transmitted when two electrodes on the transmitting and receiving sides become capacitors and resonate at a specific frequency. However, resonance will collapse as distance increases or

if the transmitting and receiving sides become misaligned, which would make it difficult to transmit power efficiently.

**3. Electric field surface waves by electric field resonance**

Given the above issues, NTT developed a proprietary electric field resonance antenna that can keep the resonant frequency constant, enabling stable power transmission [2] (Fig. 2). This technology makes it possible to achieve high transmission efficiency over a wide range without having to precisely align antennas.

Additionally, as a property unique to electric fields not found in magnetic fields, any conductors or dielectrics lying between the power-transmitting and power-receiving electrodes become a medium for transmitting electric field waves, making it possible to dramatically extend the transmission area. NTT announced that the electric field resonance antenna it developed is capable of generating electric field surface waves on the surface of conductors and dielectrics and that this form of propagation enables efficient transmission of power over longer distances [3, 4] (Fig. 3). It thus becomes possible to supply power to a variety of locations where wireless power transmission had thus far been difficult.

The wireless power transmission technologies that use electromagnetic waves that can propagate over long distances through space do not require routing cables and are therefore relatively easy to use. However, the energy of electromagnetic waves will diffuse and deviate from the direction intended for power transmission, resulting in a drop in transmission efficiency. In contrast, wired power transmission using a cable can confine energy within the cable, making for high transmission efficiency, but this technology is not that easy to use. The proposed power transmission technology using electric field surface waves by electric field resonance makes it unnecessary to lay new cables and can use substances that are already present as an alternative to cables, which achieves the same level of convenience as wireless power transmission technology. Since energy is kept near the surface of conductors or dielectrics and cannot easily escape into space, this technology enables power to reach the receiver with high efficiency. The proposed technology, therefore, combines the best of wireless and wired schemes. It can enable, for example, the supply of power via walls or floors or the transmission of energy using rocks or soil on the lunar surface. Since most conventional wireless power transmission technologies transmit power from point to point in a pinpoint manner, they require the transmitter and receiver to be precisely aligned. On the other hand, applying the propagation of electric field surface waves generated by electric field resonance would make it possible to turn road lanes or the entire surface of a parking lot into a power transmission antenna, enabling the transmission of power over a wide range. Power can therefore be supplied in a stable manner even if positional alignments are somewhat off.

However, since various types of metals and dielectrics in the surrounding area can become a medium for transmitting electric field surface waves, attention must be given to the risk of power escaping to unexpected places or of making electronic equipment malfunction due to electric field noise. There is also the danger of an electrical discharge in the air in the form of static electricity owing to the application of a high voltage to the electrode of an electric field resonance antenna. Equipment design should therefore take safety into account. It is important that such design work be carried out while imagining the spread of electric fields that are invisible to the human eye.

While conventional wireless power transmission technologies each have suitable applications, the pro-

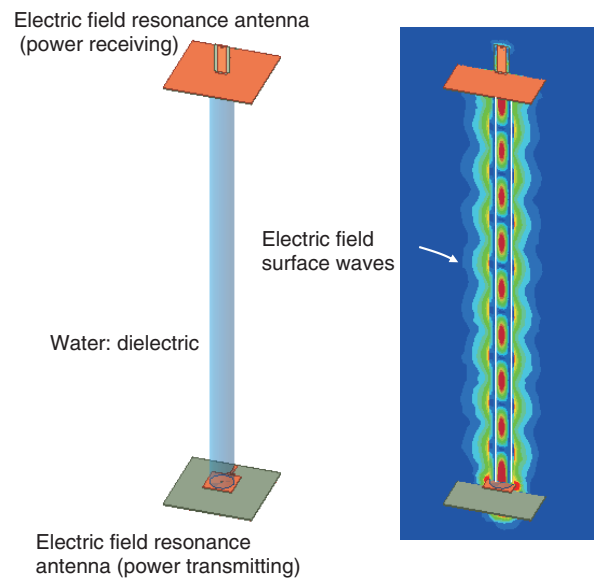


Fig. 3. Generation of surface waves by an electric field resonance antenna.

posed technology is flexible in using substances that are already present in the target location instead of cables and extendibility in widening the area in which power transmission can be used. This technology is effective in supplying power over several tens of centimeters to several meters, thus is expected to be used particularly in environments in which cables are difficult to install such as in the field of space development. Electric power can be transmitted by using lunar sand as a cable or create a transmission path with a higher permittivity to supply power only to the target with high efficiency.

Next, to explore how the proposed technology can be used on the lunar surface, we introduce specific application scenarios.

#### 4. Use of electric field surface waves by electric field resonance on the lunar surface

The proposed technology is expected to be applied to constructing power infrastructures with more flexibility and less resources. If electric field surface waves can be used to supply energy generated on the Moon to an entire base via rocks or the ground, it will be possible to set up a power distribution network without having to lay cables thereby saving on resources.

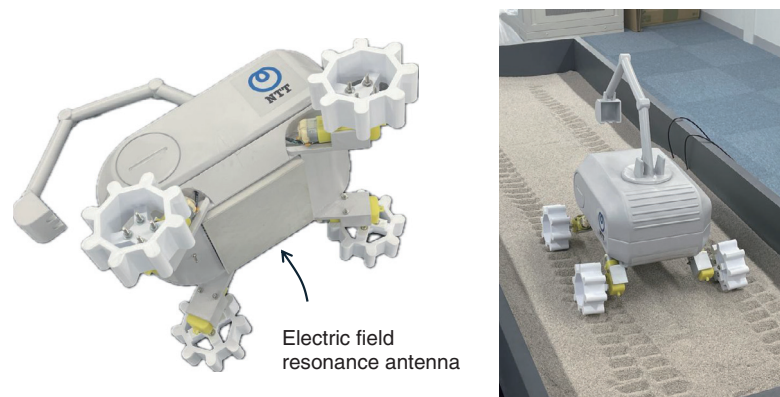


Fig. 4. Demonstration of a contactless power supply for an unmanned rover.

#### 4.1 Supplying power to a rover on the lunar surface

A rover on the lunar surface executes tasks such as exploration and mining while moving over a wide area. The proposed technology can supply power via the ground to a rover moving on the lunar surface regardless of the presence of sunlight and can therefore secure power to locations where sunlight does not reach. Therefore, the range of activities can be significantly expanded and more detailed surveys of the lunar surface can be conducted. The NTT R&D Forum 2024 included a demonstration of supplying power in a contactless manner from a power transmitting antenna to an unmanned rover traveling on a replica of the lunar surface (Fig. 4). Sand filling a sand box (Earth sand in this demonstration) efficiently carries electric field energy, improving the average power transmission efficiency over the entire sand box by about four times compared with the case of no sand.

#### 4.2 Mining for water resources

Water is indispensable for life on the Moon. It can be used not only for drinking water but also for rocket fuel (liquid hydrogen and liquid oxygen) through electrolysis. Although there is ice on the dark side of the Moon, solar power cannot be generated there. The proposed technology, which can supply power in a contactless manner, is therefore particularly important for rovers mining that ice. Particles making up the dusty lunar sand (regolith) are extremely fine, making it easy for them to clog up a connector, penetrate machines, and become the source of failures. There is therefore a need for technology that can transmit power in a contactless man-

ner from the outside. To this end, we propose that solar energy be converted to laser light at a power generation system installed on a lunar highland exposed to sunlight and that the power be delivered by laser to a tower installed within a crater through spatial transmission across several kilometers. We are also studying our proposed technology as a means of supplying power in the last mile of received power, that is, of supplying power from the lunar surface to ice mining machines and processing facilities moving around a receiving tower. An overview of this system is shown in Fig. 5. It will thus be possible to mine ice in a sustainable manner, which should contribute greatly to the efficient use of resources on the lunar surface.

This technology of generating electric field surface waves by electric field resonance holds the possibility of changing the way that energy is supplied on the lunar surface. It can provide an innovative means of achieving a stable power supply in the exploitation of ice resources in the permanent shadow of a crater, which is given particular importance in the Artemis program. The capability of transmitting power using lunar sand instead of cables is expected to open up new possibilities in supplying energy in space development.

### 5. Future developments

The flexibility and convenience of the proposed technology makes it applicable to a variety of applications including those on Earth. For example, many robots and sensors operate in a factory or warehouse, and the current approach to supplying them with power is to use batteries and wired power supplies.

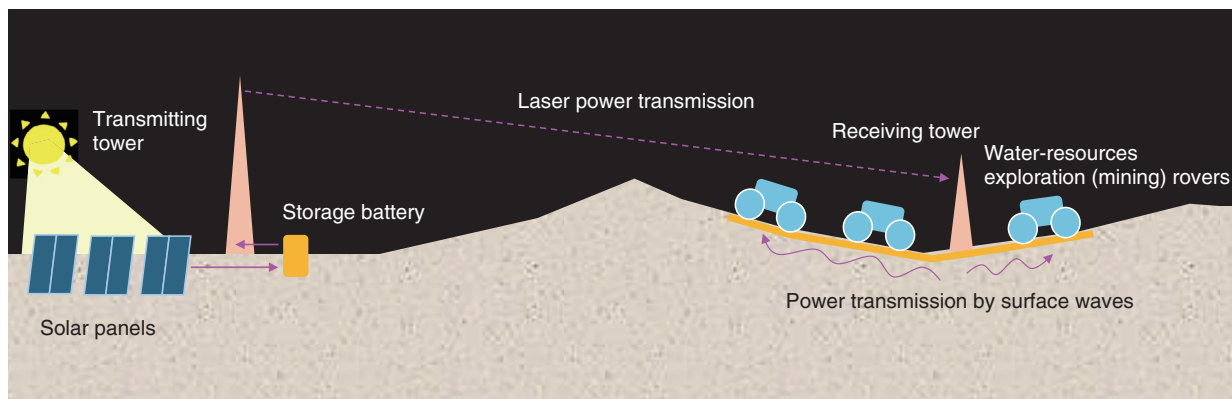


Fig. 5. Power supply system on the lunar surface.

Since the proposed technology can supply power to locations via metal plates laid on the floor without using cables, the range of motion of robots can be widened, making for more efficient automation. In addition, frequent battery replacement will become unnecessary and the maintenance load can be lightened. This technology can also be applied to the supply of power during a natural disaster such as an earthquake or typhoon that may result in damaged power transmission lines or wide-area power outages. It can quickly supply power to temporary housing and emergency shelters and accelerate the recovery of areas stricken by a disaster. It can also play a major role in maintaining infrastructures critical to life such as medical equipment and communication facilities.

The proposed technology also has the potential of significantly changing the charging method in the charging infrastructure for electric vehicles (EVs). Most EVs have to charge up by stopping at and plugging into a charging station. A technology using magnetic field resonance has also been proposed for supplying power wirelessly to a parked EV, but the magnetic field resonance technology transmits power in a pinpoint manner from one coil to another (point-to-point), making it unsuitable for transmitting power to a moving vehicle. With the proposed technology, however, the road can be made into a power transmission antenna, enabling dynamic wireless power transfer that can supply power along a road and charge a vehicle while moving. If such a system can be made practical, it would not only significantly reduce the time that a vehicle needs to stop for charging but also contribute to the downsizing of batteries, which should, in turn, reduce the weight and cost of the vehicle and extend its cruising range.

In space development, executing multiple functions with lighter and smaller components is vital, so the proposed technology can contribute to meeting this need by taking on the role of transmission cables to carry power to metallic components. For example, on the Lunar Orbital Platform “Gateway” scheduled to be the successor to the International Space Station (ISS), it is envisioned that multiple modules will operate while being mutually linked. If power and data can be transmitted on such a space platform using the outer walls of modules in the place of cables, humans will be freed not only from gravity but also from the restraints of cables, achieving an even greater degree of freedom.

## 6. Conclusion

The proposed power transmission technology using electric field surface waves by electric field resonance can expand the possibilities of achieving wireless power transmission in places where wireless technologies have so far not been usable due to a variety of constraints. The need for flexibility in dealing with new problems unique to evolving frontiers such as space is also attracting attention. Research and development at NTT Space Environment and Energy Laboratories aims to achieve sustainable energy systems from power generation to power transmission and efficient use of that power. Amid these efforts, we can investigate how the proposed technology can be made more practical. We thus ask our readers to look forward to future developments.

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