Difference between nanotube antennas and classic antennas (wave speed in nanotubes is about one hundred times slower than the speed of light)

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- **Abstract:**

- Note: Many features make nanotube antennas behave very differently from classical antennas. The main difference is that the current distribution is alternating with a wavelength that is 100 times smaller than the free space wavelength for a given thermal frequency. The wavelength of the current distribution depends on the wave speed in that mode.

- **Keywords:** Nanocommunications , terahertz , electromagnetic waves , nanoantenna

Introduction •

The main difference between nanotube antennas and classical antennas is that if the wave speed is the speed of light, the current distribution wavelength is the wavelength of electromagnetic waves in free space. On the other hand, the wave speed in nanotubes is about a hundred times slower than the speed of light. This is because in circuit theory, the wave speed is equal to the inverse square root of the capacitive capacitance per unit length multiplied by the inductive capacitance per unit length.Nano-networks have greater communication and processing potentials that overcome the limitations of independent nano-devices through the cooperation of nano-devices. One of the problems that has not yet been well solved in nanotechnology is how to establish electrical communication between nano-electronic devices and the macroscopic world without losing the capabilities of these nano-elements. One of these new areas and functions of nano-technology is nano-antennas , which are used in various fields such as nano-sensors, communication nano-networks, electrical energy generation and other similar topics and are considered as one of the current areas of nano-technology development. At the nano-scale, graphene-based antennas are used to transmit EM waves. Graphene is a very thin single-atom sheet of confined carbon atoms placed on a crystal lattice . Given the very small dimensions of nano-sensors, nano-antennas need to have a very high operating frequency in order to be usable. However, the use of graphene helps to solve this problem to a large extent. With the development of nanoscale device fabrication technology, it has become possible to fabricate nanoantennas and use them in various applications. Communication between nanodevices is a major challenge related to the development of nanoantennas and related electromagnetic receivers. Reducing the size of traditional antennas to hundreds of nanometers leads to very high operating frequencies . At THz band frequencies, the very large bandwidth available leads to much higher path loss than lower frequency bands . Nanoantennas can be made from metallic materials such as silver , aluminum, chromium , gold, and copper, or they can be made from new materials such as CNTs and graphene, which are attractive choices for nanoantennas. Using graphene to fabricate antennas can overcome size and communication limitations. In addition, the resonant frequency of nanoantennas based on graphene can be up to two orders of magnitude larger than that of nanoantennas made with other materials.

Optical nanoantennas (a practical solution with high efficiency compared to other technologies)

Since the use of optical nano-antennas for solar energy harvesting offers a practical solution with high efficiency compared to other common photovoltaic technologies such as solar panels, it has led to rapid development in the nano- and optical materials industry.When a solar electromagnetic wave strikes the surface of a nanoantenna, a time-varying current is generated on the surface of the nanoantenna, resulting in a voltage at its feed gap. An antenna is a device that can receive electromagnetic waves in space. In order for an antenna to receive a solar electromagnetic wave, the dimensions of the antenna must be on the order of the wavelength of the incoming wave to its surface. Therefore, an antenna with nanometer dimensions is needed to receive solar radiation that includes infrared, visible, and ultraviolet wavelengths. Since the use of optical nanoantennas for solar energy collection provides a practical solution with high efficiency compared to other common photovoltaic technologies such as solar panels, it has led to rapid development in the nano and optical materials industry.An optical nanoantenna with linear polarization and length $2/\lambda$, which has a relative bandwidth of 11%, will be able to collect about 75.2 pW. For the same specifications, if an antenna with dual polarization is used, the power will be 5.5 pW. Due to the low received power of each independent nano-antenna, it is common to use arrays of antennas in this cell, which also have their own rules and methods. An antenna is a device that can receive electromagnetic waves in space. In order for an antenna to receive a solar electromagnetic wave, the dimensions of the antenna must be on the order of the wavelength entering its surface. Therefore, in order to receive solar radiation that includes infrared, visible, and ultraviolet wavelengths, an antenna with nanometer dimensions is needed. Since the use of optical nano-antennas for collecting solar energy provides a practical solution with high efficiency compared to other common photovoltaic technologies such as solar panels, it has led to rapid development in the nano and optical materials industry.

The most important parameters of each nano antenna (from electromagnetic current distribution to examining important properties of nano antennas)

One of the most important parameters of any nanoantenna is the current distribution on it. This characteristic determines the radiation pattern, radiation resistance and reactance, and many important properties of the nanoantenna. Despite the possibilities of making nanotubes with a length of several centimeters, it is possible to make electrical conductors with a length-to-width ratio of the order of 10^7 . At first glance, nanotube antennas give the impression that they are similar to dipole antennas designed in small dimensions. But in fact, this is not the case. In the main theory of dipole antennas, to determine the current distribution on the antenna, the dipole radius is larger than the skin depth and the resistance losses are so small that they can be ignored. Since the nanodipole L/d is significantly reduced, it becomes unusable. In one-dimensional electrical conductors such as nanotubes, the skin depth mode is completely eliminated. This is because here the electrons are only allowed to move along the conductor strand and therefore the current distribution is effectively one-dimensional. In addition to the fact that the electrons move in only one dimension, two other important issues also occur, inductance and large resistance. These features create a very different behavior for nanotube antennas compared to classical antennas.The kinetic inductance per unit length of a nanotube is ten thousand times greater than the magnetic inductance per unit length of conventional antennas. Therefore, the wave speed will be 100 times smaller than the speed of light. The efficiency of a classic nanotube antenna is of the order of -90 dB, which will be due to resistive losses. This is while the dimensions of the antenna and the nanosystem or nanosensor assembly, operating frequency, power losses, range and dimensions of the sensor network, the structure and facilities of the power supply system and the physical communication platform between the different parts of a nanosystem are major factors and parameters, each of which is in some way decisive and determines the manufacturing capability and performance of the final system.

Nano-antenna as a primary tool for absorbing nano-electromagnetic waves in nano-communications

Nano antennas are considered as the primary means of absorbing electromagnetic nanowaves in space and nanocommunications, and have their own related engineering knowledge, which is very developed and extensive.In general, in order to receive an electromagnetic wave in space, the dimensions of the antenna must be on the order of the wavelength entering its surface. Given the very small dimensions of nanosensors, nanoantennas need to have a very high operating frequency in order to be usable. The use of graphene helps to solve this problem to a large extent. The propagation speed of waves in CNTs and GNRs can be up to 100 times lower than its speed in vacuum, and this is due to the physical structure, temperature and energy. Accordingly, the resonant frequency of graphene-based nanoantennas can be two orders of magnitude lower than that of nanoantennas based on nanocarbon materials. It has been proven mathematically and theoretically that a quasi-metallic carbon nanotube can have terahertz radiation when a time-varying voltage is applied to its sides.One of the most important parameters of any nanoantenna is the current distribution on it. This characteristic determines the radiation pattern, radiation resistance and reactance, and many important properties of the antenna. Despite the possibilities of manufacturing nanotubes with a length of several centimeters, it is possible to manufacture electrical conductors with a length to width ratio of the order of 10^7 . Nanotube antennas at first glance give us the impression that they are similar to a dipole antenna designed in small dimensions. But in fact, this is not the case . In the main theory of dipole antennas to determine the current distribution on the antenna, the dipole radius is larger than the skin depth and the resistance losses are so small that they can be ignored. Given that the nanodipole L/d is significantly reduced, it becomes unusable. In one-dimensional electrical conductors such as nanotubes, the skin depth mode is completely eliminated. Because here the electrons are only allowed to move along the length of the conductor, and so the current distribution is effectively one-dimensional. In addition to the fact that the electrons move in only one dimension, two other important issues arise: large inductance and resistance. These features give nanotube antennas a very different behavior than classical antennas. The main difference is that the current distribution is alternating with a wavelength that is 100 times smaller than the free-space wavelength for a given thermal frequency. The wavelength of the current distribution depends on the wave speed in that mode. If the wave speed is the speed of light, the wavelength of the current distribution is the wavelength of electromagnetic waves in free space. On the other hand, the wave speed in nanotubes is about a hundred times slower than the speed of light. This is because in circuit theory, the wave speed is equal to the inverse square root of the capacitive capacitance per unit length multiplied by the inductive capacitance per unit length.

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