

Wireless Identifying System Based on Nano-tags

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Abstract— Currently quite a lot of attention is paid to research in the field of Nano Communications. The use of nanomachines leads to improvement of existing applications. Example of such applications is wireless identifying system based on nano-tags. This article considers system that identifying items using passive nano-tags (harvesting energy from external electromagnetic waves). The article also considers the use THz band to transmit data and the numerical estimation of communication channel characteristics for the first "window of transparency".

Keywords — energy harvesting, nanonetworks, nano-tag, THz band

I. INTRODUCTION

The development of nanotechnologies allows creating integrated devices of microscopic dimensions equipped with internal memory, sensors, computing and communication modules. Such devices are capable to perform primitive operations and are utilized in various fields: medicine, multimedia, manufacturing, military applications, etc. Some of them are can be useful for all areas, for example identification system based on nano-tags can be implemented in automatic product sorting using a unique identifier, counterfeiting control, which is very important in prescription medicines sales and so on. Having much smaller dimensions than conventional RFID (Radio Frequency IDentification) tags the nano-sized tags are not visible when viewed externally, but can become a problem for those who try to counterfeit them. In addition, reducing the size of identifiers will make it possible to use them in areas where the size of modern tags is commensurable or greater than the object of identification itself.

Recent research demonstrates that graphene nano antennas can support electromagnetic communications in the terahertz range (0.1-10 THz). On the other hand, the distance of communication is very short because of large impact of molecular absorption. In addition, due to size and power supply limitations of nanomachines, methods based on signal transmission with a long duration, which are generally used in the WSN (wireless sensor networks), can not be used in the WNSN (wireless nano sensor networks).

As one of the solutions, a TS-OOK modulation scheme was suggested by J. M. Jornet, which implies the exchange of short pulses propagating throughout the entire spectrum, the logical sequence of "1" and "0" encoded with the help of such pulses: logical "1" is transmitted via a short pulse, and "0" is encoded as silence. TS-OOK seems to be the most attractive

technology to be applied given that it provides high energy efficiency and communication. [1]

In addition, is it possible to use external power supplies. This article considers the energy supply of a nanodevice by using energy of EM waves, the energy of which upon transformation into electrical energy will be used to power a nanodevice, like in the case of passive RFID tags.

The article is organized as follows: Section 2 describes the proposed application, its operation principle and structure; Section 3 is devoted to calculating the energy consumption of nano-tag; Section 4 examines the features of the application, specifically the terahertz frequency band; Section 5 is devoted to numerical estimations; the results of the performed work are analyzed and ideas for future work are considered in the Conclusion.

II. DESCRIPTION OF THE APPLICATION

In case of factory, nano-tag placed on the product, can be identified by the THz-reader on the conveyor, after which sorting is performed according to the established rules or destination. As long as the nano-tag can contain information not only about the type of goods, but also about the packet number and expiration date, and perhaps even a digital signature of the manufacturer, the use of this technology will eliminate the possibility of counterfeit or copyright infringement.

In case it is required to register a large number of tags in a relatively small area, it is justified to use tunnels or boxes containing antennas surrounding the registration area and external shielding elements to prevent spurious registrations of the tags outside. Therefore, it was decided to take the "tunnel" reader technology (Figure 1) as an example, which will consider the remote power supply of the nanodevice, where the distance from the reader to the nanodevice does not exceed 50 cm.

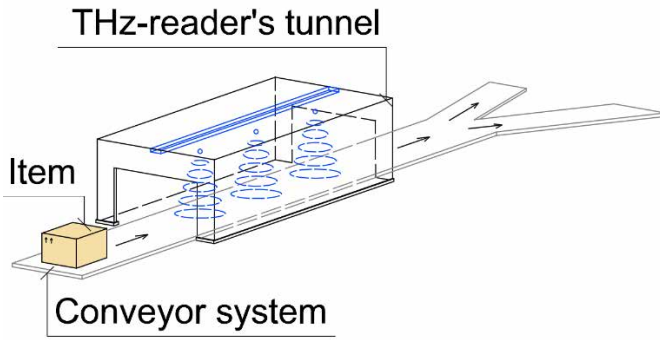


Figure 1. THz-reader

Some goods require special conditions of storage and transportation (medicinal products being an example), in this case it is relevant task to use nanosensors that would measure the environmental conditions of product storage or the conditions inside the package (temperature, humidity) and determine the integrity of the package itself. The scheme of the THz identification application is shown in Figure 2.

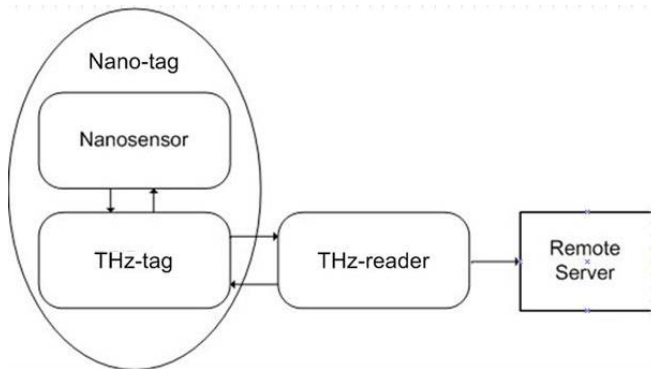


Figure 2. Structure of the THz identification application

Nano-tag converts the energy of electromagnetic waves radiated by THz-reader to electricity. After accumulating enough energy nano-tag makes the necessary parameter measurement using nano-sensor and sends the report back to the reader that acts as a gateway. Then the reports are sent to the remote server via the Internet-channel.

III. NANO-TAG ENERGY CONSUMPTION

At first it is necessary to calculate the electricity spent by the nano-tag on transmitting one sensory report to the THz-reader, which then transmits the received data to a remote server. It consists of energy spent on maintaining the sensor in operational condition (until it measures the required parameter), processing the measured results, forming the data packet and sending it to the reader (1).

$$E_{tot} = E_s + E_p + E_{packet-tx} \quad (1)$$

where, E_{tot} represents the total energy consumption for transmission of one sensory report; E_s - energy consumption for measuring the required parameter by the sensor; E_p -

energy consumption for information processing; $E_{packet-tx}$ - energy consumption for sending the packet.

In order to calculate the energy used for sending one packet of data an equation (2) was proposed in [2].

$$E_{packet-tx} = N_{bits} W E_{pulse-tx} \quad (2)$$

where N_{bits} is the number of bits contained in the transmitted packet, W is the code weight, which is the probability of transmitting the pulse ("1") instead of keeping the silence ("0"), $E_{pulse-tx}$ is the energy consumed for the transfer of the pulse.

In this paper, $E_{packet-tx}$ is a universal parameter for all systems that transmit information while E_s and E_p are directly dependent on the type of sensor selected and the computational module of the nano-tag.

Utilization of the terahertz range has a number of features that affect the process of nano-tag energy harvesting, which are considered in the following sections and must be taken into account when designing an application.

IV. THE TERAHERTZ CHANNEL MODEL

Knowing the total power consumption it is necessary to calculate the signal power that will be received by the nanodevice (3). This will allow determining the time during which nano-tag will accumulate enough energy for operating. Then we will calculate the total delay between the request for measurement and respond with result, it can be used to calculate the speed with which the goods should travel through the THz-reader's gate.

$$P_{rx} = \frac{P_{tx} \times G(f)}{A(f)} + N_T(f) + N_{mol}(f) \quad (3)$$

where P_{rx} and P_{tx} are the powers of the signal on the receiving and transmitting sides, respectively; $G(f)$ is the antenna gain power, $A(f)$ is the attenuation ratio; $N_T(f)$ is thermal noise; $N_{mol}(f)$ is the molecular absorption noise.

It is important to note that in case of using the graphene-based antennas, thermal noise is not fully understood at the moment, but it is assumed that it is negligible due to the properties of this material [3].

Transmission of electromagnetic waves in the THz band has many features, one of which is that it is necessary to take not only the attenuation of the signal during propagation in the A_{fspl} space into account, but also the molecular absorption of A_{mol} [4-6]. Thus, the overall signal back-off can be characterized by the equation (4):

$$A(f) = A_{fspl}(f) A_{mol}(f) \quad (4)$$

The loss of free space implies attenuation due to the expansion of the wave as it propagates in the medium [4]. The attenuation of the signal during propagation in space can be defined as

$$A_{fspl}(f) = \left(\frac{4\pi f d}{c} \right)^2 \quad (5)$$

Where

d - distance from the transmitter to the receiver;

f - transmission frequency;

c - speed of light.

A feature of using the THz band for wireless communication is the presence of molecular absorption caused by vibrations and rotation of molecules. Molecular absorption of EM radiation is an effect that occurs when the signal is transmitted at frequencies close to or equal to the resonance frequencies of molecules that absorb part of the signal energy and create $N_{mol}(f)$ noise at these frequencies due to the internal kinetic energy of the molecules.

$$A_{mol}(f) = e^{k(f)d} \quad (6)$$

where k is the average molecular absorption coefficient.

The molecular absorption coefficient determines the ability of a molecule to absorb energy and is determined by its physical properties (molecular bonds, spatial orientation, etc.). Among all components of the Earth's atmosphere, the greatest contribution is made by the water vapor molecules absorption [3]. According to [4], molecular absorption losses are calculated depending on the transmission frequency, the distance between the receiving and transmitting antenna as well as on the conditions and composition of the medium in which the signal propagates:

$$k(f) = \sum_{i,g} k^{i,g}(f) \quad (7)$$

$k^{i,g}$ is the individual absorption coefficient of the isotopology i of the gas g , which in turn is defined as (7):

$$k^{i,g}(f) = \frac{p}{p_0} \frac{T_0}{T} Q^{i,g} \sigma^{i,g}(f) \quad (8)$$

where p_0 and T_0 are the standard pressure and temperature, respectively, equal to 1 atm (10^5 Pa) and 273 K, $\sigma^{i,g}$ is the absorption cross section for the isotopology i of the gas g in $\text{m}^2/\text{molecule}$ (9); $Q^{i,g}$ is the molecular bulk density (10).

$$\sigma^{i,g}(f) = S^{i,g} G^{i,g}(f) \quad (9)$$

where $S^{i,g}$, $G^{i,g}$ are the intensity and shape of the spectral absorption line for the isotopology i of the gas g , respectively. The intensity of the line describes the amplification of the radiation in the spectral line, and the shape is respectively the shape of the spectral line and its width. $S^{i,g}$ and $G^{i,g}$ are calculated in accordance with [4,7,8].

The molecular bulk density $Q^{i,g}$ can be obtained using the ideal gas law (10):

$$Q^{i,g} = \frac{n}{V} q^{i,g} N_A = \frac{p}{RT} q^{i,g} N_A \quad (10)$$

where n is the total number of moles of the gas mixture in question, V is its volume, $q^{i,g}$ is the mixing ratio for the

isotopology i of the gas g , N_A is the Avogadro constant, and R is the gas constant.

In [3] and [4] it was determined that in some frequency ranges the absorption is excessively large and can cause a very small possible range of communication. However, there are so-called transparency windows, where absorption is significantly less than in other parts of the spectrum. Note that k does not depend on communication distance, but only on the properties of the medium and the frequency of the transmitted signal.

According to [3], with the transmittance of the medium below 94.5% (equivalent to the values of the absorption coefficient of the medium above 5.5%), the N_{mol} molecular absorption noise becomes equal to the maximum value of -203.89 dB/Hz (≈ 10 -20 W/Hz), which corresponds to the Johnson-Nyquist thermal noise level. It is worth noting that the noise increases in proportion to the bandwidth of the transmitted signal.

In this article, the first transparency window corresponding to the frequency range of 0.1-0.56 THz is considered, and since the transmission coefficient of the medium in the transparency windows is always above 95.5% at small and medium distances, the molecular noise will be negligible [3].

Thus, by having obtained a common attenuation coefficient it becomes possible to calculate the signal power that has reached the receiving antenna.

TABLE 1. VARIABLE, CONSTANTS AND THEIR MEASUREMENT UNITS

Name	Symbol	Unit
Absorption ratio	k	m^{-1}
Absorption section	σ	$\text{m}^2/\text{molecule}$
Distance from the transmitter to the receiver	d	m
Transmission frequency	f	Hz
Molecular bulk density	Q	m^{-3}
Spectral line intensity	S	$\text{m}^{-1}/(\text{molecule} \cdot \text{m}^{-2})$
Spectral line shape	F	$1/\text{m}^{-1}$
Pressure	p	Pa
Temperature	T	K
Gas mixing ratio	q	$\%$
Avagadro Constant	N_A	$6,02214129 \cdot 10^{23} \text{ mole}^{-1}$
Gas constant	R	$8,3144621 \text{ J} \cdot \text{K}^{-1} \cdot \text{mole}^{-1}$
Reference pressure	p_0	10^5 Pa
Reference temperature	T_0	$273,15 \text{ K}$
Speed of light	c	$2,99792458 \cdot 10^8 \text{ m/sec}$

V. NUMERICAL RESULTS

In order to use the energy, obtained from EM waves, it is necessary to take the coefficient of conversion of electromagnetic energy into electric energy $r_c = 0.5$ (11) into account:

$$E_{re} = E_{rx} r_c \quad (11)$$

where E_{px} - the energy received by the receiving side, E_{re} - the transformed electric energy.

In accordance with [9], the number of "1" and "0" in the packet is approximately the same, hence $W = 0.5$. The energy

required for transmission of one pulse for distance of 10 mm is $E_{pulse-tx} = 1\text{pJ}$ [10]. As already mentioned, this article assumes a signal transmission on a distance of 50 cm (distance from the nano-tag to the reader) as the most difficult case of using the application, and therefore $E_{pulse-tx}$ was taken equal to 50 pJ. Thus, considering that the total volume of the packet containing the sensory report is assumed to be $v_s = 16$ bytes [11], it became possible to calculate the energy of one packet $E_{packet-tx} = 0.8\text{ nJ}$.

The [12] provides a comparison of the energy consumption of existing microcontrollers and image capture sensors with the developed Ultra-Low-Power Smart Visual Sensor. As far as we don't have data of nanodevice energy consumption it was decided to take it for calculation the lowest of those presented in [12], thus $E_p = 0.73\text{ }\mu\text{J}$ and $E_s = 1.06\text{ }\mu\text{J}$. The total energy consumption for transmitting one sensory report $E_{tot} \approx 1.79\text{ }\mu\text{J}$.

Further, using the HITRAN database [8, 13], attenuation coefficients were determined for the frequencies of the first transparency window taking into account that the distance between the nano-tag and THz-reader is 50 cm (d), and the ambient conditions correspond to the "USA model, mean latitude, summer", $H = 0$ (mixture ratios: $\text{H}_2\text{O} = 1.860000\%$, $\text{CO}_2 = 0.033000\%$, $\text{O}_3 = 0.000003\%$, $\text{N}_2\text{O} = 0.000032\%$, $\text{CO} = 0.000015\%$, $\text{CH}_4 = 0.000170$, $\text{O}_2 = 20.900001\%$, $\text{N}_2 = 77.206000\%$) at a temperature of 296 K and a pressure of 1 atm.

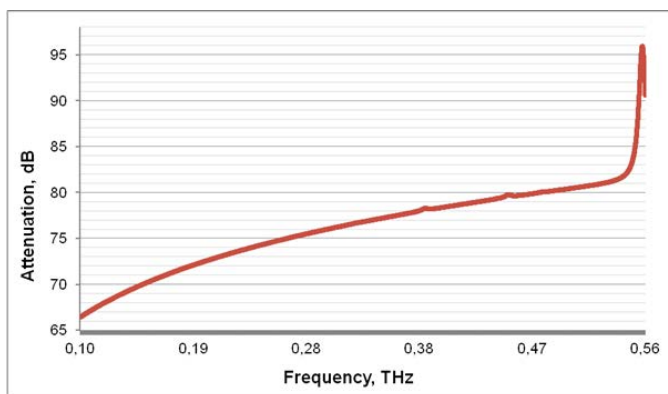


Figure 3. The attenuation coefficient

Since the system in development does not need high data exchange rate and therefore does not need to use large bandwidth, it is decided to use the bandwidth of 100 kHz within the model.

In order to determine the minimum power threshold at which the message will be transmitted without loss due to noise, it is necessary to take the signal-to-noise ratio into account. Assume that the thermal noise in case of graphene usage is negligible and the molecular noise at 1 Hz of the used frequency band is about 10-20 W, we obtain $N_{mol} = 1\text{ fW}$. Taking the signal-to-noise ratio $\text{SNR} = 10\text{ dB}$ as the normative, the signal power on the receiving side was equal to 10 fW. In accordance with (4), the calculations were made for the frequencies of the first transparency window, at which the attenuation coefficient $A(f)$ is minimum and maximum (up to

a sharp increase in the function), which corresponds to $f_1 = 0.1\text{ THz}$ and $f_2 = 0.54\text{ THz}$ with attenuation values equal to 66.41 dB and 81.06 dB, respectively. Thus, the values of power required to transmit the message without loss due to extraneous noise can be obtained, $P_{tx1} \cdot G = 43.79\text{ nW}$ and $P_{tx2} \cdot G = 1.44\text{ }\mu\text{W}$.

After calculating the signal power on the receiving side and the bandwidth at which the transmission will occur, it is possible to calculate the energy at the input of the system $E_{rx} = 1\text{ nJ}$.

Thus, using (14):

$$t = \frac{E_{tot}}{E_{re}} = \frac{E_{tot}}{E_{rx} \cdot f_c} \quad (14)$$

it became possible to calculate the maximum time necessary to communicate with a nano-tag at a distance of 50 cm, with maximum attenuation. However, when transmitting a signal with the above calculated powers, the charging of the system will take place excessively long (about three years), and therefore the use of this power in this situation is inexpedient. As an example of a calculation, let us take $P_{tx1} \cdot G$ and $P_{tx2} \cdot G$ equal to 1 mW, for which $P_{rx1} = 228.38\text{ pW}$ and $P_{rx2} = 6.92\text{ pW}$, and $t_1 = 0.15\text{ sec}$ and $t_2 = 5.17\text{ sec}$.

The choice of conveyor belt speed is influenced by many factors, for example: belt width, conveyor angle to the horizon, physical properties of the moved cargo, loading method, etc. The maximum permissible speed of the conveyor belt, which serves to move small pieces of cargo with its width equal to 400 mm is 1.6 m / s. Thus, it is fair to say that when using a frequency of 0.1 THz the product passing through the identification tunnel of 1 m long located on a conveyor will be identified. If the frequency is 0.54 THz, the nano-label will not have enough time to accumulate energy, and therefore either the power radiated by the reader should be increased or the speed of the conveyor belt should be reduced for the correct operation of the application.

VI. CONCLUSIONS

Using of nano-tags considered in this paper, can improve the quality and speed of internal business processes, and also due to size of nano-tags can be used for combating with counterfeit.

In this article considered the application of nano-tags, which serves to identify different kind of items using THz frequency range for wireless communication. The calculations in paper were performed for the existing sensors and devices, and they can be improved in future by using graphene based materials. Using devices based on graphene it is possible to reduce power consumption and the charging of the device will require less time. Finally it will lead to decrease of the delay, and then will be possible to use transmitters of lower power.

For future work we assume: development simulation model for considered application, determining optimal characteristics of devices (THz-reader and nano-tag); prototyping and practical testing of the application.

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