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Behavior of CAD 110 Copper (Heat Sink Material) as a Fractal Structured RFID Antenna in High Temperature Operation

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There is a high demand for Radio Frequency Identification (RFID) antennas to be installed in high temperature environments. For these applications, new material combinations are being pursued to deal with heat dissipation and faster heat transfer, without compromise in antenna performance. These materials should perform accurately in withstanding volatile environments. In this manuscript, an RFID antenna for 900 MHz frequency has been proposed and prepared on a 1.35 mm thick CAD 100 copper sheet, which is a heat sink material. The antenna is intended to identify processed and partly processed products during fabrication in manufacturing industries. Variations in input impedance were observed on increasing the testing temperatures. It was found that the read range of the antenna decreased at higher temperatures. At working environment of 130 °C-150 °C, a fractal structured RFID antenna using CAD 110 copper material could be detected at around 40 cm distance. This better read range helps in identification at a safe distance, which prevents injury and hazard to workers operating near it.

Keywords: CAD 110 copper, Fractal structured antenna, High temperature operation, Radio frequency identification, Read range.

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1. INTRODUCTION

In recent times, Radio Frequency Identification (RFID) technology is being used in manufacturing industries, power plants, oil and gas industries for identification (Srivastava, 2004). High frequency RFID systems are being used in animal tracking (Catarinucci et al., 2014), vehicle management (Hannan et al., 2011), and partly processed products tracking in fabrication industries. Miniaturized antennas have become essential for wireless and radar communication (Merli et al., 2011). Depending on the structure and design of an antenna, its operation differs. The fractal structure contributes to size reduction and multi-band operation. Metals and metallic components and products with different shapes and sizes are being used in high temperature thermal power generation industries and heavy manufacturing industries. They should be uniquely labeled for identification. The labeled products should be under supervision and on-line inspection throughout its manufacturing process. Part processes such as filing, drilling, welding, hammering, sliding cause an increase in the surface temperature of the products (Kim, 2014 and Yang et al., 2015). For this purpose, metal attachable small sized RFID identifiers are being preferred. RFID antenna components are being operated at different frequencies to meet the various demands and execution levels (Yagi et al., 2005). Physical dimensions of the antenna and resonating frequency are some of the important aspects, which should be considered while designing RFID antennas. The material from which the antenna is made also determines its operation, accuracy and read range. Generally, RFID antennas are developed as an inverted F-shaped antenna (Panda and Kshetrimayum, 2010), a planar inverted antenna (Hirvonen et al., 2004) and a patch structured antenna (Holub and Polivka, 2008). A lot of investigations have been conducted using RFID antennas.

A micro-strip patch antenna for 5G-based vehicle obtained an overall gain in the operating band with a most directive and effective range of operation (Rahim et al., 2020). Another study discusses the fractal structures in Euclidean space by applying iterated function system (IFS) in patch antennas. The impacts of fractal structures were analyzed on MIMO antennas and the ascendancy fractal structures were also discussed through cross-referencing the important parameters of the antenna (Ezhumalai et al., 2021). An ultra-wide band monopole antenna using compact hexagonal-square shaped fractal geometry provides 146 % bandwidth, extending from 2.1-13.5 GHz with a – 25 dB return loss (Kumar et al., 2021). Even though much research has been done on RFID antennas, operation and efficiency of antennas in high temperature environments has not been evaluated.

In this investigation, an attempt has been made to develop an RFID reader antenna in the fractal structure using CAD110 copper heat sink material and investigate its performance at high temperature environments.

2. MATERIALS AND METHODS

A fractal structured RFID antenna has been developed on a 1.35 mm thick CAD 110 copper sheet (ε_r = 8.85 and tanδ = 0.0003). The antenna feed was a coplanar waveguide. The overall size of the antenna was designed as 80 mm length and 60 mm breadth. For better antenna performance, two equilateral triangular patches were modeled and designed. The first fractal triangle was made with an apex angle of 32° (25.4 mm length) and the second was made with 34° (20.8 mm length). CST Microwave Studio commercial software was utilized to simulate the fractal geometry reader antenna.

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The antenna was accommodated in a stainless-steel metal box of 120 mm length, 120 mm breadth and 5 mm thickness. This box was attributed to be an appropriate cavity size in fabricated products in the production line. The size of the cavity was intended to be small so as to be accommodated in products with complicated sizes. The size of the antenna should not be very small as the size of the antenna determines its radiation efficiency and read range.

In all experiments, the gap between the lateral walls of the cavity box and antenna edges was maintained. This gap was maintained to prevent short circuit between RFID antenna connections. The RFID antenna was powered by a 50 SMA connector. On either side of the coplanar waveguide (CPW) feed line, finite symmetrical ground plates were installed. The dual band feature was attained by combining triangular and rectangular ground. The magnitude of CPW feed line determines the upper resonance mode. The radiating patch causes a reduction in resonances. The bandwidth of the antenna can be optimized by varying the width of the triangles, width of the strips, the gap between the strips, and the width of the ground planes. The radiation patterns were developed.

The antenna was optimized to match the input impedance of commercial RFID antenna chips (Make – Hitachi, Standard – ITU-R SM.329). According to equivalent circuits developed by Adrion et al., 2020, the nominal chip impedance was identified. Input impedance of the proposed antenna at the two different operating frequencies was simulated and the return loss was identified. At room temperature, the nominal input impedance was Z_{IC} = 19.87 – j188.3 Ω. The input impedance of the antenna was optimized to be nearer to the chip input impedance.

The re-crystallization temperature of Cu is approximately 320 °C. Whereas Al reference antenna has a lower re-crystallization temperature of 195 °C. Hence, experiments were conducted within the range of 150 to 200 °C. The read range was calculated from the following equation:

$$Read_{range} = \frac{c}{2\omega}\sqrt{P_{EIR} \times D_{antenna} \times \eta_{antenna}\frac{\tau}{P_{Sen}}} . \quad (1)$$

In the above equation, c is the velocity of light; P_{IER} is the equivalent isotopic power of the detection equipment; $D_{antenna}$ is the directivity of the antenna; $\eta_{antenna}$ is the radiation efficiency of the antenna; τ is the power transmission coefficient; P_{sen} is the sensitivity of the chip at – 18 dBM. Power transmission coefficient is shown in the following equation:

$$\tau = 4\frac{R_{chip} \times R_{antenna}}{\left|Z_{chip} + Z_{antenna}\right|^2} . \quad (2)$$

In the above equation,

$$Z_{antenna} = R_{antenna} + j\, X_{antenna} Z_{antenna} , \quad (3)$$

$$Z_{chip} = Z_{chip} + j\, X_{chip} Z_{chip} . \quad (4)$$

Using Vector Network Analyzer measuring equipment, the input impedance in the chip was identified. This equipment was indigenously developed. According to the procedure developed by Ria et al. in 2020, impedance evaluation was conducted. Using a calibrated heating equipment (resolution of 5 °C), the temperature was increased. Using a temperature transducer (RTD Apoge Instruments), the temperature of the antenna assembly was identified. The RTD was connected to a decoder and then the readings were transferred to a computer via an analog/digital control interface. Using software control, a digital-to-analog converter was made to induce a potential difference on a non-inverting input. Using the analog-to-digital converter, the drop voltage across R_{sense} (100 Ω) was sent to the computer. After evaluating the variations at the input, the temperature was calculated. Using this setup, the input impedance in the chip was evaluated as a function of frequency (900 MHz) for different temperature values.

The effect of variations in temperature in the read range was identified by placing a commercial RFID reader at different distances such as 20, 30, 40, 50, 60, 70, 80, and 90 cm. Again, the environmental temperature of the antenna was increased from room temperature to 160 °C. Antenna tag sensitivity $S_{antenna}$ is shown in the following equation:

$$S_{antenna}(f,\theta,€) = \frac{S_{chip}}{\tau(f) \times G_{antenna}(f,\theta,€)} . \quad (5)$$

The minimum power required for activating the fractal structured RFID antenna from 30 °C to 160 °C was recorded. Sensitivity of the antenna is a measure to account the characteristics of a test antenna and a chip. In Eq. (5), S_{chip} is the sensitivity of the chip, τ is the coefficient of power transmission and $G_{antenna}$ is the gain of the antenna. Analysis was carried out in read range at a frequency of 900 MHz. In all experiments, the angles θ and φ were maintained as constant. The equation for effective isotopic radiation power is given below:

$$EFFIRP_T = \frac{S_{chip}(T)}{\tau(T)} \times \left(\frac{4\pi df}{c}\right)^2 \times \frac{1}{G_{antenna}\eta_{plf}A_{cable}} . (6)$$

In the above equation, η_{plf} is the polarization loss factor; A_{cable} is reader antenna attenuation. The effective isotopic radiation power was plotted as a function of temperature for the different distances.

3. RESULTS AND DISCUSSION

3.1 Antenna Simulation

Simulation studies were conducted for the fractal structure antenna in transient domain solver and frequency in order to compare the results for further processing. Fig. 1a shows the current distribution in the upward direction and Fig. 1b shows the current distribution in the downward direction.

The down and up arrows represent the antenna surface current distribution orientation. The current dispersal is also geometrically distributed in the region of the antenna slots due to the geometrical disposition of the patch structure. The current between the triangle slot's lowest edges is much stronger at f = 5.5 GHz than in the other locations. The surface current will flow powerfully along the feed line through all slots.

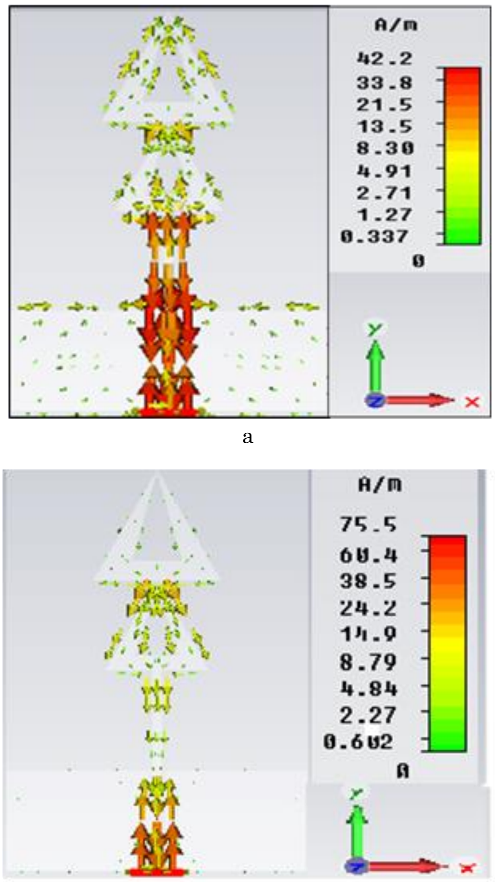

Fig. 1 – Current distribution through fractal geometry in the (a) upward direction, (b) downward direction

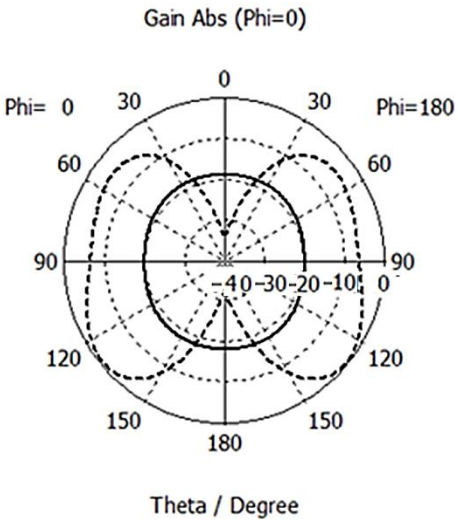

Fig. 2 – Radiation pattern of a fractal structured RFID antenna at 900 MHz

Currents are required to move around the triangular slot surface, resulting in prolonged current lines, while the need for equilateral triangular patch fractal geometry results in antenna miniaturization. As a result, it is completely obvious that the slots on the radiation patch control the resonances. Radiation pattern was simulated by using CST simulation software. The radiation pattern of the proposed fractal structured RFID antenna is shown in Fig. 2.

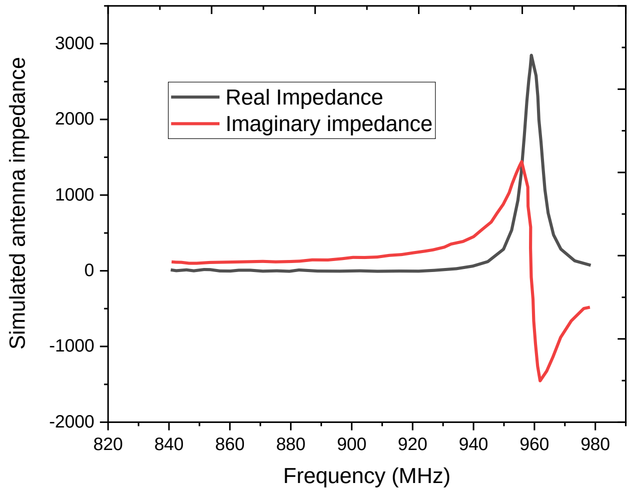

Fig. 3 – Variations in the real and imaginary parts of the input impedance

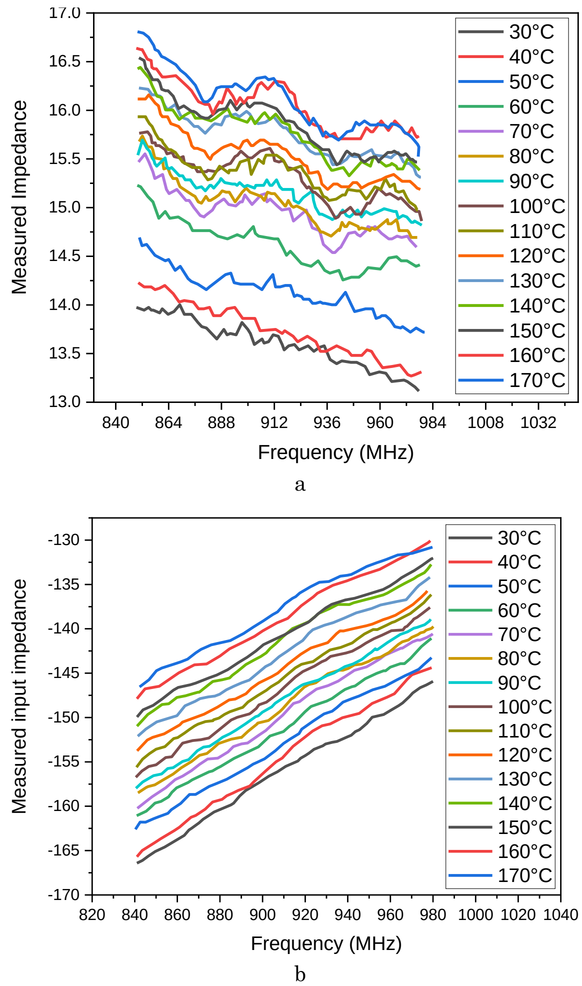

Fig. 4 – Variations in the input impedance for the (a) real and (b) imaginary parts of the chip input impedance at various temperatures

From the radiation pattern, the proposed antenna was found to be consistent. The doughnut shape of the radiation pattern indicated that the antenna would be ideal for RFID readers. The simulation model with the doughnut structure indicated an ideal RFID reader for identification purpose. The variation in the real and imaginary parts of the input impedance is shown in Fig. 3. The variations in the chip input impedance for the real part at different temperatures are shown in Fig. 4a and the variations in the chip impedance for the imaginary part are shown in Fig. 4b. From 840 to 980 MHz, the variations in the chip impedance were identified. A consistent increase in both the real and imaginary parts of the chip input impedance was observed. At a constant frequency of 900 MHz, the variations in the real and imaginary parts of the input impedance are shown in Fig. 5. The variations in the input impedance for the real part at a constant frequency of 900 MHz are shown in Fig. 5a. A continuous increase in the input impedance of the real part was observed. The variations in the input impedance for the imaginary part at a constant frequency of 900 MHz are shown in Fig. 5 b. At lower temperatures, the impedance was low, and at higher temperatures, the input impedance increased more.

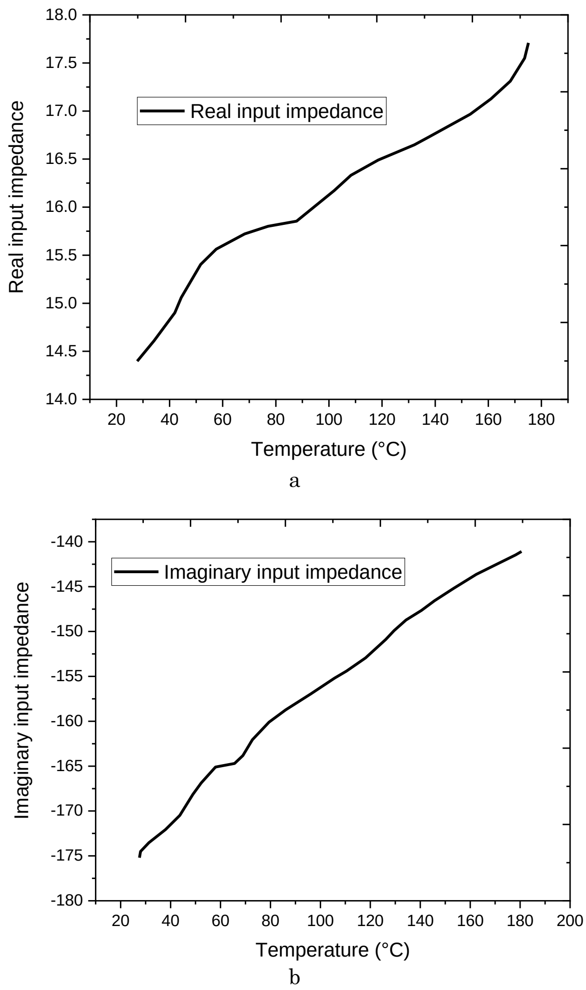

Fig. 5 – Variations in the input impedance for the (a) real and (b) imaginary parts of the chip input impedance at a constant frequency of 900 MHz

Variations in the estimated power transmission coefficient as a function of frequency at various temperatures are shown in Fig. 6. A consistent increase in the estimated power reflection coefficient (dB) was observed on increasing the environmental temperature.

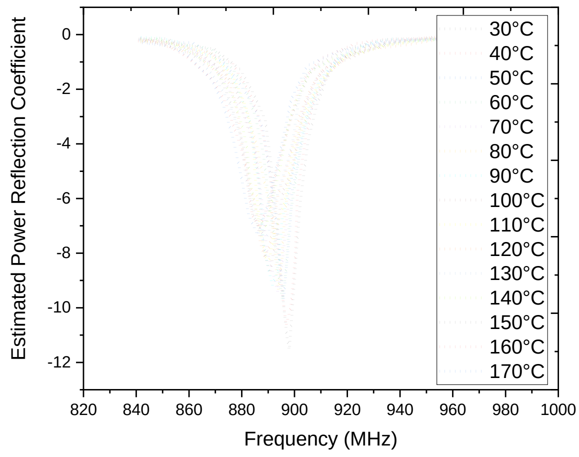

Fig. 6 – Variations in the estimated power reflection coefficient (dB) at different temperatures

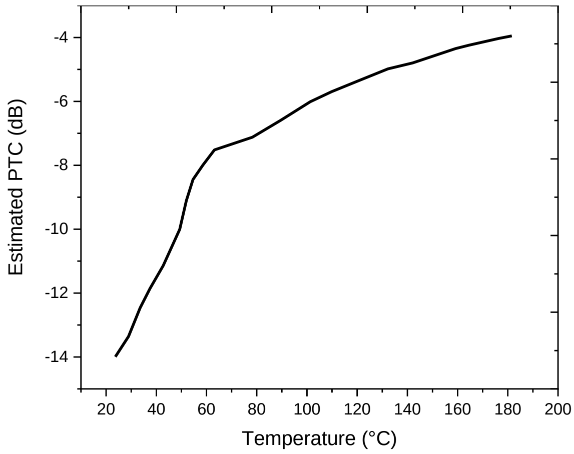

Fig. 7 – Variations in the estimated power reflection coefficient (dB) at different temperatures at a constant frequency of 900 MHz

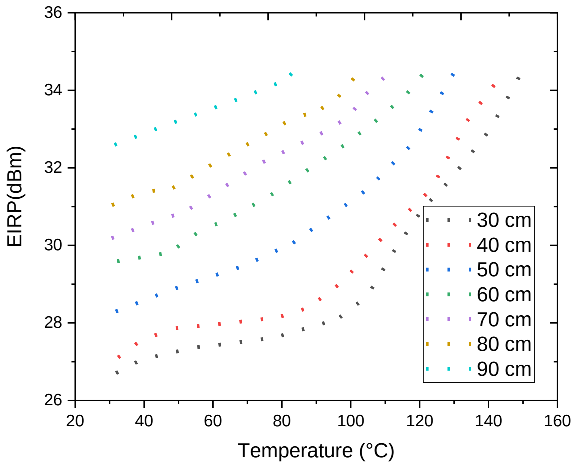

Fig. 8 – Minimum activation EIRP at different distances

Variations in the estimated power transmission coefficient at a constant frequency of 900 MHz are shown in Fig. 7. For identifying the variations in read range on increasing the working temperature, activation Effective Isotropic Radiated Power was used. The minimum value of activation Effective Isotropic Radiated Power at different antenna distances from 30 to 90 cm at different temperatures is shown in Fig. 8.

From Fig. 8, it was observed that the minimum Effective Isotropic Radiated Power at the same distance increased with increasing the working temperature. It was found that when using a copper sink material, the read range of the fractal structured antenna was as high as 40 cm even at elevated temperatures. This material (CAD 110 copper) was found to be viable for RFID antenna material.

4. CONCLUSIONS

Thus, in this manuscript, the effect of the working temperature on a fractal structured RFID antenna using CAD 110 copper material was evaluated. To identify the variations in antenna performance, input impedance and power reflection coefficient were used. Using a calibration kit, variations in the chip input impedance and performance of the antenna were evaluated at elevated temperatures. The RFID antenna, which uses a CAD 110 copper heat sink material, exhibits good read range of 40 cm even at elevated operating temperatures. This read range helps in accurate identification and detection at a safe distance, preventing hazards to human beings operating near it.

REFERENCES

1. D. Abdul Rahim, P.K. Malik, V.S. Ponnapalli, *TEST Eng. Manag.* **83**, 26487 (2020).
2. F. Adrion, M. Keller, G.B. Bozzolini, C. Umstatter, *Sensors* **20** No 24, 7035 (2020).
3. L. Catarinucci, R. Colella, L. Mainetti, L. Patrono, S. Pieretti, A. Secco, I. Sergi, *LabAnim* **43** No 9, 321 (2014).
4. A. Ezhumalai, N. Ganesan, S. Balasubramaniyan, *Int. J. Commun. Syst.* **34** No 15, e4932 (2021).
5. M.A. Hannan, M. Arebey, R.A. Begum, H. Basri, *Waste Manag.* **31** No 12, 2406 (2011).
6. M. Hirvonen, P. Pursula, K. Jaakkola, K. Laukkanen, *Electron. Lett.* **40** No 14, 848 (2004).
7. A. Holub, M. Polivka, *IEEE 2008 14th Conference on Microwave Techniques* (IEEE: 2008).
8. J. Kim, *Mater. Lett.* **130**, 160 (2014).
9. R. Kumar, R. Sinha, A. Choubey, S.K. Mahto, *J. Electromag. Wave. Appl.* **35** No 2, 233 (2021).
10. F. Merli, L. Bolomey, J.F. Zurcher, G. Corradini, E. Meurville, A.K. Skrivervik, *IEEE Trans. Anten. Propag.* **59** No 10, 3544 (2011).
11. J.R. Panda, R.S. Kshetrimayum, *IEEE 2010 International Conference on Computer and Communication Technology (ICCCT)*, 789 (IEEE: 2010).
12. B. Srivastava, *Business Horizons* **47** No 6, 60 (2004).
13. J. Yagi, E. Arai, T. Arai, *Automat. Construct.* **14** No 4, 477 (2005).
14. P. Yang, S. Rong, X. Zhao, Y. Zhu, Y. Wu, X. Li, *2015 International Conference on Materials, Environmental and Biological Engineering*, 153 (Atlantis Press: 2015).

Поведінка міді CAD 110 (матеріал радіатора) як фрактальної структурованої антени RFID під час експлуатації при високій температурі

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Існує високий попит на антени радіочастотної ідентифікації (RFID), які встановлюються в середовищах з високою температурою. Для цих застосувань вивчаються нові комбінації матеріалів, щоб справлятися з розсіюванням тепла та швидшим теплообміном без компромісу в продуктивності антени. Ці матеріали повинні точно працювати в летких середовищах. У статті антена RFID для частоти 900 МГц була запропонована та виготовлена на аркуші міді CAD 100 товщиною 1,35 мм, який є матеріалом радіатора. Антена призначена для ідентифікації оброблених та частково оброблених продуктів під час виробництва в обробній промисловості. Зміни вхідного опору спостерігалися при підвищенні температури випробування. Було виявлено, що діапазон зчитування антени зменшується при більш високих температурах. У робочому середовищі 130-150 °C фрактальну структуровану антену RFID з використанням мідного матеріалу CAD 110 можна було виявити на відстані приблизно 40 см. Цей кращий діапазон зчитування допомагає ідентифікації на безпечній відстані, що запобігає травмам і небезпеці для працівників, які працюють поблизу.

Ключові слова: Мідь CAD 110, Фрактальна структурована антена, Високотемпературна робота, Радіочастотна ідентифікація, Діапазон зчитування.