Research article

A novel quadband ultra miniaturized planar antenna with metallic vias and defected ground structure for portable devices

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ABSTRACT

A novel heart-shaped monopole antenna used in wireless portable communication devices is proposed and discussed in this paper. The antenna has a radiant patch surface area of 28.504 mm², the physical size of 15 × 12.5 mm², and electrical dimensions of 0.095λ₀ × 0.079λ₀ × 0.006λ₀, where λ₀ denotes the wavelength of the free space at 1.89 GHz. Its prototype is printed on FR4 HTG-175, having a permittivity of 4.2 and a loss tangent of 0.019 at 1 GHz. The partial ground plane and two metallic vias connecting two open-ended branches of the slitted radiating patch to a parasitic conductor element results in about 98% miniaturization of the active patch area, as compared to the conventional antenna. The proposed antenna exhibits nearly an omnidirectional pattern in the elevation plane with a maximum radiation efficiency of 82.78% at 3.99 GHz, while a peak gain of 4.7 dBi is obtained at 6.5 GHz. The measured -6 dB impedance bandwidths demonstrate that the proposed quadband antenna operates in all the frequency bands of mobile telecommunication standards (2G/3G/4G/5G) and other applications, including WLAN, WiMAX, ISM, meteorological services, IEEE 802.11y, and C-band satellite communications. This antenna is easy to manufacture and can be used in most portable devices as a compact internal antenna. After simulating the modeled antenna using HFSS, a prototype was experimentally tested, and the measured results were compared with the data obtained by simulation. The parameters analyzed are return loss, bandwidth, and gain on all frequency bands. The fabricated prototype guarantees a minimum -10 dB bandwidth of 110 MHz and a maximum return loss of -12.2 dB, despite its low radiation efficiency of 21.43 % in the lower band dedicated to GSM applications. Furthermore, the proposed antenna operates as a narrowband and wideband.

1. Introduction

The commercial mobile communications industry has been the catalyst for the recent explosive growth in antenna design needs [1]. These technologies include the mobile telecommunication standards (GSM, DCS, PCS UMTS, LTE, 5G NR) and other modern wireless applications (WLAN, WiMAX, GPS, and so forth), which need to coexist as one in a single portable device. Multiple antennas can be used to cover different frequency bands dedicated to each wireless application. However, this results into a problem of mutual coupling or isolation [2, 3] in addition to the challenge of accommodating several internal antennas into limited space on mobile terminals [4]. Besides, a broadband antenna, covering a wide frequency range to accommodate different wireless applications in a single band, may suffer from interference problem. To address this, antennas with the capability of operating in several frequency bands while being small in size is a vital issue in wireless communications [5]. Owing to their attractive features of low cost, lightweight, small size, ease of fabrication, and wide bandwidth, planar monopole antennas are among the preferred technologies for meeting the mobile terminals’ antenna requirements [6]. They are mostly designed using either microstrip feedline [7, 8] or grounded/ungrounded coplanar waveguide feed [9, 10, 11].

For mobile communication applications, the wireless terminals, such as cell phones, portable access points, laptops, and so on, are usually with...
small volumes. The antenna structures dedicated to being mounted inside such terminals must be designed with small volumetric size, specific shapes, and areas [12]. Several promising techniques have been reported in the literature meant to reduce the microstrip antenna’s size [13, 14, 15]. These techniques include the defected ground structure [16, 17, 18] approach, which is also used for antenna performance enhancement [19], high permittivity material loading [13], slots or slits loading, metamaterials [20, 21], shorting pins between the patch and the ground plane [22], use of partially shorted patch [23]. By exploiting each technique’s benefits, some of the aforementioned have been combined [24] to meet some design requirements. For instance, the authors in [25] and in [26] achieved multiband and antenna size reduction using the defected ground structure (DGS) and slots techniques. A similar approach was used to design a small antenna for 2G, 3G, LTE, WLAN, and WiMAX applications in [27]. Recently, an antenna covering 2G, 3G, 4G, 5G, and WLAN applications has been proposed in [28].

Achieving miniaturization, along with good antenna performance, remains a real challenge [29, 30] in designing internal antennas with a simple structure [31] for multiband applications. The electromagnetic performances are significantly affected by the antenna geometry [32], the feeding technique [33], and the substrate material on which the antenna is printed [6].

From the literature, most of the proposed antennas dedicated to mobile devices and covering the 2G, 3G, 4G, 5G along with other wireless applications simultaneously, are metal-frame based structures, MIMO or planar monopole configurations with large size. In contrast, the other design configurations cover only a limited number of mobile telecommunications standards. In [34], a compact, multiband, uniplanar monopole antenna covering the GSM, UMTS, WLAN, WiMAX, and LTE bands was proposed. However, it requires an extensive system board with an overall size of 110 × 50 × 0.8 mm³, limiting its applications in some handheld devices. A compact multiband antenna for mobile terminal applications for GSM, DCS, PCS, UMTS, and LTE was presented in [35] and also in [36] with a footprint of 60 × 115 mm² and 75 × 120 mm², respectively. Another nona-band narrow-frame antenna design configuration for mobile phone applications was proposed in [37]. The antenna covers the 2G, 3G, 4G, and 5G applications, but has a large volumetric size of 80 × 140 × 0.8 mm³ using FR4 substrate. A hepta-band metal-frame antenna for LTE/WWAN full-screen smartphone was recently proposed and presented in [38]. Like the aforementioned design structures, the antenna has an overall size of 50 mm × 70 mm × 6mm while being designed on FR4 substrate with a footprint of 154 mm × 72 mm. This makes it difficult to integrate within small portable communication devices. In [39], a design of an internal compact printed loop antenna is presented for WWAN/WLAN/ISM/LTE smartphone applications. The structure exhibits good electromagnetic performance, but its large dimension of 120 × 60 × 1.6 mm³ does not facilitate its applications in many wireless portable devices.

Trying to find one solution among several researchers, a miniaturized quadband heart-shaped planar monopole antenna (QHPMA) is proposed and discussed in this paper. This antenna is modeled and manufactured

Table 1. Antenna design parameters.

| Design parameter | Value (mm) |
|------------------|------------|
| $L_S$            | 15         |
| $W_S$            | 12.5       |
| $L$              | 6.242      |
| $W$              | 6.828      |
| $a$              | 2          |
| $a_1$            | 1.67       |
| $a_2$            | 1.25       |
| $a_3$            | 1          |
| $p$              | 4.422      |
| $h$              | 1          |
| $t$              | 0.035      |
| $L_g$            | 3          |
| $W_f$            | 0.5        |
from the combination of the DGS, and the metallic vias that connect the parasitic conductor element placed on the bottom of the insulator material to the slitted radiating patch. This downsized antenna has been tested to demonstrate its ease of operating as a wide and narrowband device. The proposed antenna covers all cellular networks, namely the

Figure 2. Simulated and measured reflection coefficients.

Figure 3. Measured reflection coefficient comparison.

Figure 4. Zoom of the measured reflection coefficient comparison.

Figure 5. Impact of the parasitic element’s shape.

Figure 6. Photograph of the fabricated antenna: top and bottom views.

Figure 7. Simulated and measured reflection coefficients of the QHPMA.
second generation (2G), the third-generation (3G), the fourth generation (4G), and the fifth-generation (5G). Also, other and essential standards such as Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), Industrial, Scientific and Medical (ISM) frequency band, and C-band satellites communications band are covered by this proposed antenna.

2. Quad-band antenna design

Figure 1 illustrates the proposed QHPMA geometry's view: the front view, the back view, and the side view. The top surface consists of two circular parts with a radius of 2 mm, merged to a 45° rotated square leading to the heart-shaped radiating patch. Two metallic vias are connected to a parasitic conductor element, placed on the insulator's bottom. The use of parasitic elements helps enhance bandwidth or create multi-band behavior [40]. In contrast, the radiating part is on the insulator's top to improve the device's return loss and create a fourth band whereas retrieving the 2G tape. A microstrip feed line is used, and the antenna is printed on an FR-4 HTG-175 which has 4.2 as a relative permittivity and 0.019 as loss tangent, determined at 1 GHz. Both values are frequency dependent and their accuracy depends on the extraction method [41, 42]. This insulator has a thickness of 1 mm. All the optimized design parameters of the proposed antenna are listed in Table 1.

The compact miniaturized heart-shaped planar monopole antenna has been achieved in three main steps:

- • GSM1800 (1710–1880 MHz)
- • GSM1900 (1850–1990 MHz)
- • UMTS band II (1850–1990 MHz)
- • UMTS band I (1920–2170 MHz)
- • LTE FDD, B2 (1850–1990)
- • LTE FDD, B3 (1710–1880)
- • Meteorological services (1690–1700 MHz)

- • 5G NR, n78 (3300–3800 MHz)
- • 5G NR, n77 (3300–4200 MHz)
- • WiMAX (3300–3800 MHz)
- • LTE TDD, B42 (3400–3600)
- • LTE TDD, B43 (3600–3800)
- • IEEE 802.11y (3650–3700 MHz)

- • WiMAX (5250–5850 MHz)
- • IEEE 802.11a and other C-band applications, including satellite communications.
- • 5G Unlicensed band (5.2–5.7 GHz)

- • Satellites communications

Table 2. Wireless applications covered by the proposed antenna.

| Band       | Bandwidth (GHz) | Applications                                      |
|------------|-----------------|---------------------------------------------------|
| Band I     | 1.66–2.04       | • GSM1800 (1710–1880 MHz)                         |
|            |                 | • GSM1900 (1850–1990 MHz)                         |
|            |                 | • UMTS band II (1850–1990 MHz)                    |
|            |                 | • UMTS band I (1920–2170 MHz)                     |
|            |                 | • LTE FDD, B2 (1850–1990)                         |
|            |                 | • LTE FDD, B3 (1710–1880)                         |
|            |                 | • Meteorological services (1690–1700 MHz)         |
| Band II    | 3.45–5.01       | • 5G NR, n78 (3300–3800 MHz)                      |
|            |                 | • 5G NR, n77 (3300–4200 MHz)                      |
|            |                 | • WiMAX (3300–3800 MHz)                           |
|            |                 | • LTE TDD, B42 (3400–3600)                        |
|            |                 | • LTE TDD, B43 (3600–3800)                        |
|            |                 | • IEEE 802.11y (3650–3700 MHz)                    |
| Band III   | 5.19–6.07       | • WLAN (5150–5350, 5725–5825 MHz)                 |
|            |                 | • ISM (5725–5825 MHz)                             |
|            |                 | • WiMAX (5250–5850 MHz)                           |
|            |                 | • IEEE 802.11a and other C-band applications, including satellite communications. |
|            |                 | • 5G Unlicensed band (5.2–5.7 GHz)                |
| Band IV    | 6.09–7.06       | • Satellites communications                       |

| Band       | Bandwidth (GHz) | Applications                                      |
|------------|-----------------|---------------------------------------------------|
| Band I     | 1.89–2.00       | • UMTS band I (1920–2170 MHz)                     |
|            |                 | • 4G LTE FDD, B1 (1920–2170 MHz)                  |
| Band II    | 3.74–4.77       | • 5G (3200–3800 MHz)                              |
|            |                 | • C-band downlink Satellite communication (3700–4200 MHz) |
|            |                 | • IMT (3G/4G) (3400–4200, 4400–4900 MHz)          |
| Band III   | 5.28–5.63       | • WiMAX (5250–5850 MHz)                           |
|            |                 | • IEEE 802.11a (5.47–5.725GHz)                    |
|            |                 | • 5G Unlicensed band (5.2–5.7GHz)                 |
| Band IV    | 6.24–6.46       | • Satellites communications                       |
A single band and monopole heart-shaped antenna is designed to operate at 3.345 GHz. Following the planar monopole antennas’ design theory described in [43], the lower frequency for the heart-shaped geometry can be approximated as

$$f_r = \frac{7.2}{\sqrt{\epsilon_{\text{eff}} \left( 3.121 \alpha + \frac{1}{\epsilon_{\text{eff}}^2 \alpha^2} \left[ 7.142 \alpha^2 - \left( \frac{h}{\alpha} \right)^2 \right] + p \right) }}$$

(1)

where $p$ is the gap between the radiator and the ground plane, $W_f$ the width of the microstrip feedline, “$\alpha$” the radius of the antenna’s circular part, and $\epsilon_{\text{eff}}$ the effective permittivity of the structure given by

$$\epsilon_{\text{eff}} = \frac{\epsilon_r + 1}{2} \left[ 1 + \frac{\epsilon_r - 1}{2} \left( 1 + \frac{h}{(3.414\alpha)^{-0.5}} \right)^{-1} \right]$$

(2)

To create multiband characteristics, multiple resonant structures through slots are used. Two open-ended branches and a heart-shaped slot at the center of the radiating element are created to generate three resonant frequencies, as depicted in Figure 2. In the geometry, the corresponding resonant path lengths $L_i$ ($i = 1, 2, 3$) are close to quarter-wavelength at their fundamental resonant frequencies and can be computed as follow:

Figure 10. Measured 2D radiation patterns of the antenna at: (a) 1.95 GHz, (b) 4.16 GHz, (c) 5.35 GHz, (d) 6.33 GHz.

Table 3. Simulated efficiency of the proposed antenna.

| Simulated results | Resonant frequency | 1.95 GHz | 3.99 GHz | 5.14 GHz | 6.27 GHz |
|-------------------|-------------------|---------|---------|---------|---------|
| Radiated power (mW) |                   | 17.48   | 391.26  | 267.51  | 305.09  |
| Accepted power (mW) |                   | 81.58   | 472.65  | 478.01  | 525.58  |
| Incident power (mW) |                   | 1000    | 1000    | 1000    | 1000    |
| Radiation efficiency (%) |             | 21.43   | 82.78   | 55.96   | 58.05   |
| Total efficiency (%) |                   | 1.75    | 39.13   | 26.75   | 30.51   |

Figure 11. Simulated and measured gain of the proposed antenna.
This second step of the design procedure is experimentally tested through the fabrication and measurement of the triband antenna prototype presented in Figure 2. The measured results show that the triband resonates at 2.89 GHz, 3.73 GHz, and 6.73 GHz. The first to the thirds band's return loss is about -19.6 dB, -40.93 dB, and -21.58 dB, respectively.

Two metallic vias, and a parasitic conductor element has been added to the antenna design structure to achieve the proposed antenna's desired performance. This yielded in lowering the resonant frequency of the first band, generating a fourth band, and improving the return loss level, as shown in Figure 3. This made it possible for the proposed antenna to operate in GSM1800, GSM1900, and 5 GHz WLAN bands.

By reducing the dynamic range of the reflection coefficient plots presented in Figure 3, from -12 dB to 0, the following Figure 4 is obtained.

It is important to note that the shape of the parasitic conductor element placed at the bottom of the dielectric material influences the results. Three shapes with the same surface area of 32.64 mm² have been simulated to evaluate the parasitic conductor element's effect on the antenna performance. The circular shape has a radius of 3.22 mm, whereas the square shape's edges length is about 5.71 mm. The results are presented in Figure 5.

It can be observed that the proposed shape yields better results (in terms of matching level) as compared to the circular and square shapes.

From all the details presented above, the proposed antenna design methodology can be summarized as follows:

- Design of a monoband heart-shaped planar monopole antenna resonating at 3.345 GHz using Eqs. (1) and (2);
- Creation of multiband characteristic by making two open-ended heart-shaped branches through slits and a slot of identical shape, located at the center of the main radiating element. The Eqs. (2), (3), and (4) are employed for estimating and achieving the desired results;
- Insertion of a parasitic conducting element which is connected to the slitted patch by two metallic vias.

3. Simulated and measured results

Figure 6 illustrates the manufactured prototypes of the proposed quadband antenna. The top radiating element area is about 28.504 mm², placed on a 1.25 × 1.5 cm² insulator. The two metallic vias are identical and have a diameter of 100 μm. The ground plane's surface area is about 1.25 × 0.3 cm², whereas the parasitic conductor element at the bottom of the substrate has an active area of approximately 32.64 mm².

3.1. Antenna return loss

The simulated and measured return loss results are presented in Figure 7. The experimental and simulation results agree with some discrepancies observed at certain frequencies from the frequency response plots, but the graphs have the same trend.

As for Figure 3, Figure 7 is zoomed in by reducing the dynamic range and plotting the results from -12 dB to 0 (see Figure 8).

By considering all the frequency bands covered by the predefined limit for mobile terminal antennas ($|S_{11}| \leq -6$ dB) [44, 45, 46, 47], the experimental frequency response results demonstrate that antenna exhibits a minimum bandwidth of 380 MHz at its lower band and can operate across the GSM, UMTS, LTE, 5G, WLAN, WiMAX, ISM, and C-band satellite communication bands.

When the reading reference is -10 dB, which is the most commonly used in microwave engineering, the proposed antenna can still cover several wireless applications such as UMTS, LTE, 5G, WLAN, WiMAX, and C-band applications. Table 2 summarizes the applications covered by the proposed antenna for $|S_{11}| \leq -6$ dB and $|S_{11}| \leq -10$ dB.

3.2. Voltage Standing Wave Ratio (VSWR)

Figure 9 displays the optimized quadband antenna’s impedance matching in terms of Voltage Standing Wave Ratio (VSWR). Both simulated and measured results are presented. It can be observed that the proposed compact antenna meets the requirement of 2:1 VSWR with a maximum value of 1.674 across all the operating frequency bands. This good impedance matching results in less reflected power at the antenna feed point.
3.3. Antenna radiation pattern, efficiency, and gain

The far-field radiation patterns of the proposed QHPMA are illustrated in Figure 10. A nearly omnidirectional characteristic is observed in the Elevation plane at all the operating frequency bands, except for the first band, where the pattern is quasi-directional. Similarly, in the Azimuth plane, a quasi-bidirectional characteristic is observed on the second, third, and fourth bands. The first band exhibits an arbitrary shape radiation pattern.

The proposed antenna’s simulated radiation efficiency is 21.43%, 82.78, 55.96%, and 58.05% at 1.95 GHz, 3.99 GHz, 5.14 GHz, and 6.27 GHz, respectively. The total efficiency includes the mismatch between the feedline/connector and the antenna given by [48].

\[
\eta_T = \frac{P_{\text{rad}}}{P_s} = \eta_{\text{rad}} \left[1 - |\Gamma|^2\right] 
\]

where \( P_{\text{rad}} \) is the total radiated power by the antenna, \( P_s \) the total power supplied to the antenna, \( \eta_{\text{rad}} \) the antenna’s radiation efficiency, and \( \Gamma \) is the reflection coefficient (the same as \( S_{11} \) or \( S_{22} \)). Based on the simulated results, the proposed antenna’s radiation characteristics are summarized in Table 3 below.

Figure 11 illustrates the simulated and measured gains for the proposed quadband antenna, and the plots show the same trend. The experimental results demonstrate that the maximum gain within the desired frequency bands is about -1.65 dBi at 1.88 GHz, 4.23 dBi at 3.91 GHz, -3.03 dBi at 5.46 GHz, and 4.7 dBi at 6.51 GHz for the first, the second, the third, and the fourth band, respectively. Moreover, the gains at the respective resonant frequencies 1.95 GHz, 4.16 GHz, 5.35 GHz, and 6.33 GHz are -3.08 dBi, -0.96 dBi, -8.52 dBi, and -7.46 dBi, respectively.

All the gain results presented above have been computed using a reference (receiving) antenna and applying the Two-Antenna Method [49] based on the Friis’ formula given by

\[
G_{\text{eff}} = S_{21} + 20 \log |\beta| + 20 \log |d| \quad (\text{dB})
\]

where \( G_t \) and \( G_{\text{ref}} \) denote respectively the gain of the transmitting and receiving antennas, \( f_0 \) the operating frequency, the distance between...
both antennas, and $S_{21}$ the transmission coefficient between both antennas.

The simulated gain is depicted in Figure 12, where it can be observed a gain of -4.8 dB, 1.4 dB, -0.5 dB, and 0.3 dB at 1.95 GHz, 3.99 GHz, 5.14 GHz, and 6.27 GHz, respectively.

The peak of the simulated gain is achieved at 3.99 GHz, with of value of 1.4 dB.

### 3.4. Current distribution

The surface current distribution of the proposed QHPMA at various resonant frequencies is presented in Figure 13. This reveals parts of the antenna that play a crucial role at the given frequency.

The results are plotted at 1.95 GHz, 3.99 GHz, 5.14 GHz, and 6.27 GHz. It can be observed that the current is higher at around the second open-ended branch and the third resonant frequencies. At 6.27 GHz, the surface current is more vivid in the upper band around the second open-ended branch and the third resonant frequencies. The maximum current is about 395.3 A/m and 129.7 A/m at the second and third open-ended branches, respectively.

### Table 4. Comparison of the proposed antenna with some other multiband antennas.

| Ref. | Substrate | Size | Frequency band (GHz) | Applications | Gain | Radiation efficiency (%) | Proposed method | Operating bands |
|------|-----------|------|----------------------|--------------|------|--------------------------|-----------------|-----------------|
| [2]  | FR4 ($\varepsilon_r = 4.3$) | 0.2850 $\times$ 0.1800 $\times$ 0.0040 | 1.5–2.8 | GSM, UMTS, LTE, Wi-Fi, WiMAX, lower UWB application | 1.0–4.0 dBi | Not provided | Slots, slits, and DGS | Dual |
| [50] | Rogers RTDuroid5870 ($\varepsilon_r = 2.23$) | 0.1150 $\times$ 0.1290 $\times$ 0.0050 | 1.90–2.25 | UMTS, WLAN, WiMAX, Downlink Satellite System | 3.00–5.32 dBi | 89 | Slits, DGS, reconfigurable diodes | Quad |
| [51] | FR4 ($\varepsilon_r = 4.4$) | 0.2380 $\times$ 0.3290 $\times$ 0.0080 | 1.43–1.6 | GNSS, UMTS, WLAN, WiMAX | 1.08 dBi | Not provided | Multiple branches technique, DGS, slits, and stub | Quad |
| [52] | FR4 ($\varepsilon_r = 4.4$) | 0.2370 $\times$ 0.1420 $\times$ 0.0080 | 1.42–2.08 | GSM, WiMAX, WLAN, X-Band, Ku-Band | 2.1–6.5 dBi | Not provided | Stubs and DGS | Penta |
| [53] | FR4 ($\varepsilon_r = 4.4$) | 0.2710 $\times$ 0.2710 $\times$ 0.0090 | 1.69–1.94 | GSM, WiMAX | 2.1–7 dBi | 82–86 | Circular ring and U-shaped slots, and DGS | Dual |
| [54] | Rogers RO4533 ($\varepsilon_r = 3.45$) | 0.3550 $\times$ 0.0270 $\times$ 0.0030 | 1.61–2.21 | GSS phones (uplink), AWS, GSM, WCDMA/IMT-2000, UMTS, LTE bands. | 2.45 dBi | 34–48 | Slots and DGS | Single |
| [55] | FR4 ($\varepsilon_r = 4.5$) | 0.0860 $\times$ 0.0640 $\times$ 0.0030 | 0.6–0.64 | LTE, Bluetooth, WiMAX | 3.00–3.69 dBi | Not provided | Multiple branches technique, metamaterial, and DGS | Dual |
| This work | FR4 ($\varepsilon_r = 4.2$) | 0.0950 $\times$ 0.0790 $\times$ 0.0060 | 1.89–2.00 | GSM, UMTS, LTE, 5G, WLAN, WiMAX, ISM, C-band satellite communications | -7.46 – 4.7 dBi | 21.43–82.78 | Multiple branches technique, DGS, shorting pins (metallic via holes), and parasitic element | Quad |

4. Conclusion

In this paper, an ultra-miniaturized quadband heart-shaped monopole antenna (QHPMA) has been presented, analyzed and discussed. The desired antenna performances have been achieved due to the slits, the metallic vias, and the partial ground plane technique without an additional matching circuit. The agreement between the simulated and measured results validated the QHPMA design technology and its feasibility of implementation. The measured results demonstrate that the QHPMA achieves a minimum impedance bandwidth ([111] ≤ -10 dB) of 110 MHz and exhibits a peak gain of 4.7 dBi at 6.51 GHz. With an overall size of 0.095x0.079x0.0060 at 1.89 GHz, a radiation efficiency ranging from 21.43% to 82.78% has been found from simulation data. The designed QHPMA has its application in all the generations of mobile networks (2G, 3G, 4G, and 5G) in addition to other modern wireless applications, including WLAN, WiMAX, ISM, meteorological services, and C-band satellite communications. Its stunning performance and features make it an up-and-coming candidate in the smartphones and mobile terminal industries.

Declarations

Author contribution statement

Pierre Moukala Mpele: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Franck Moukanda Mbango: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Dominic B.O Konditi: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Fabien Ndagijimana: Performed the experiments.

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No data was used for the research described in the article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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