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COMPACT UHF AMATEUR RADIO QUAD ANTENNA FOR INDOOR USE

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Abstract: Due to the confined space in which they are typically used, directional ultra–high frequency (UHF) antennas for indoor use should be particularly compact. Also, due to the frequent need to manually direct (rotate) the antenna, it must be relatively light with good mechanical characteristics. By simultaneously considering the compactness of various types of antennas, weight, electrical, electromagnetic, mechanical, and radiation properties of antennas, several types of antennas are particularly suitable for directional UHF amateur radio antennas for indoor use. In this sense, various types of quad antennas stand out. Despite the fact that Quad antennas have excellent performance and electromagnetic properties, because of their complicated and slow construction, they are not popular among radio amateurs. This article presents a new idea in the selection of materials for the construction and construction solution of Quad antennas for indoor use. The presented construction solution simultaneously ensures a simple construction but with significantly reinforced mechanical characteristics compared to the typical constructions of Quad antennas. This article presents the design of compact UHF Quad antennas suitable for indoor applications. The presented antennas are dual stacked Quad antennas. Impedance matching was achieved by coaxial cables. The antennas are built for the frequency of 446 MHz, the so–called personal mobile radio (PMR). Both antennas were tested for mechanical stress typical for their use such us moving and rotating the antennas. After prolonged use, no damage, deformation, or weakening of the joints was observed. Numerical calculations and optimizations of the presented antennas were performed using 4nec2 software. The measured voltage standing wave ratio (VSWR) of the presented antennas is below 1.5.
Keywords: amateur radio, compact antenna, quad antenna, PMR radio, stacked antenna

1. INTRODUCTION

More and more people, and thus also radio amateurs, live in urban areas. Typical for urban environments is a very scarce (limited) space in which radio amateurs can install antennas. Also, when directional antennas are installed in buildings, in a space such as a balcony, the antenna must be of small dimensions. Given that the physical dimensions of antennas are to a certain extent proportional to the wavelength of the electromagnetic wave, ultra–high frequencies (UHF) are suitable for antennas of smaller dimensions. These are the main reasons why frequencies, below the very–high frequency (VHF) (more precisely, below 144 MHz) are becoming less and less popular among radio amateurs. Due to the reasonably small dimensions of the antennas, UHF is extremely popular. Reasonably small dimensions of UHF antennas open the possibility of their indoor use. The above is of particular interest to radio amateurs who live in buildings without balconies where antennas could be installed. Also, directional antennas for indoor use can be rotated easily by hand without the need to use a rotator. Furthermore, in the winter period, it is not necessary to go out on the balcony to change the orientation of the antenna if it does not have a built–in rotator. Unlike antennas for outdoor installation, where free space can be provided around the antenna to prevent unwanted interference, this is often not the case with antennas for indoor use. Therefore, when choosing an antenna for indoor use, types of antennas that are naturally not susceptible to interference should be preferred. The above is valid for both reception and transmission (common mode currents). Also, radio amateur antennas for indoor use need to be rotated often, their position changed, and they should be stored after use. As a result of the mentioned actions, there is a possibility of their accidental mechanical damage. That is, the mechanical and electrical connections on the antenna can weaken. Accidental impacts to the antenna elements are also possible and they can be deformed or become misaligned. The above may cause a change in the electromagnetic properties of the antenna, which will result in unstable communication with possible interference. Therefore, when designing antennas, a special attention should be given to the mechanical properties of antennas.

Due to the limited available space in the typical use of directional antennas for indoor use, they are expected to be extremely compact, i.e. the maximum possible gain for a certain boom length. Several types of antennas are particularly suitable for building UHF amateur radio antennas for indoor use. The types of Quad antennas [1–3] such as, ordinary Quad, BiQuad, DoubleQuad and Hentenna stand out in particular. Quad antennas have an excellent radiation pattern, electromagnetic properties and a relatively high gain for a certain boom length. With careful design of the Quad antenna, a wave impedance of exactly 50 ohms can be achieved [1]. Also, they are significantly less prone to problems caused by common mode currents compared to Yagi antennas. Because of the above, they can be fed directly with a coaxial cable. That is, when using them, it is not necessary to adjust the impedance, nor is it necessary to use special techniques to attenuate common mode currents, except in rare cases. Also, for the same boom length,

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they have a higher gain than Yagi antennas [1]. However, by using typical construction solutions for making Quad antennas it is difficult to achieve satisfactory mechanical characteristics of Quad antennas for indoor use. In contrast, as shown in the article, the use of aluminium L profiles for the production of Quad loops and PVC L profiles for supporting Quad loops significantly improves the mechanical characteristics of the Quad antenna [4]. This paper presents a new technical solution in the design and construction of a Quad antenna that has reinforced mechanical characteristics. In order to achieve the highest possible gain, without increasing the length of the boom, the technique of stacking antennas was used. Thus, high gain and compactness of the antenna were achieved simultaneously. Two compact Quad antennas for indoor use have been built. One with a total of six, and the other with a total of eight elements (loops) has been built. Modelling, simulation and optimization of antenna parameters were performed using 4nec2 software [5]. The operating frequency of the presented antennas is 446 MHz (so–called personal mobile radio (PMR)). Common electrical parameters and VSWR were measured using a vector analyzer.

2. QUAD ANTENNA CONSTRUCTION

In this section, we will look briefly at the typical construction solutions of Quad antennas, and then at the improvements we have introduced in order to reinforce mechanical construction Quad antennas. Typically, Quad antenna elements are mounted on a horizontal boom either by using a spreader (Figure 1.a [4]) or by laying the element on the boom (Figure 2.b [4]). Common to both construction solutions is that the elements (loops) can be easily damaged (deformed) or twist and become misaligned under the action of external forces. For example: during very strong wind, during contact with a tree branch, etc. Such simple technical solutions meet the needs of most radio amateurs if the antenna is used as a stationary antenna (with or without rotator). In the beginning of use of Quad antennas they were used for short–wave (SW) frequencies. Due to the fact that the wavelength on the SW frequencies is of the order of tens of meters, the loops are made of thin wire. A thin wire is stretched around the spreader, which gives the loops a rectangular shape. The spreader is made of insulating material, typically wood or plastic so that the loops are galvanically isolated from other metal parts of the antenna. The spreader is fixed to a horizontal boom and the boom is fixed to a vertical mast (Figure1a).

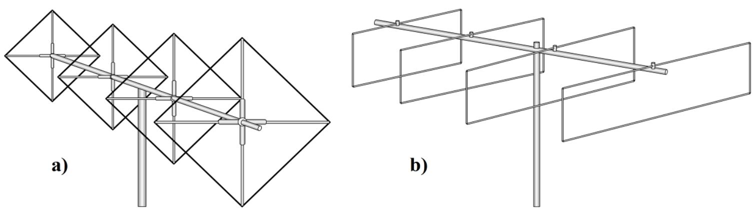

Figure 1. Four elements Quad antenna, a) typical construction using a spreader, b) oblong type Quad antenna, construction where the elements lie on the boom

Radio amateurs continued to use this typical design on both VHF and UHF. In the meantime, aluminium tubes began to be used instead of thin wire to make loops (reflectors, drivers and directors) of Quad antennas. Due to the mechanical stability of loops made of aluminium tubes, new structural designs have appeared as shown in Figure 1b. By using aluminium tubes to make Quad antenna loops, they become self–supporting with a consistent loop shape. This eliminates the need to use a spreader to maintain the shape of a rectangular loop, and at the same time, its role as a loop carrier disappears. This led to the emergence of Quad antenna versions in which the loops were fixed to the boom using plastic clamps (Figure 1b). The listed technical solutions for manufacturing Quad antennas have satisfactory resistance to mechanical stresses that typically occur during their use. However, if there is a need to build a Quad antenna that is light but mechanically more resistant to mechanical stress, it is necessary to change the approach to structural design [4].

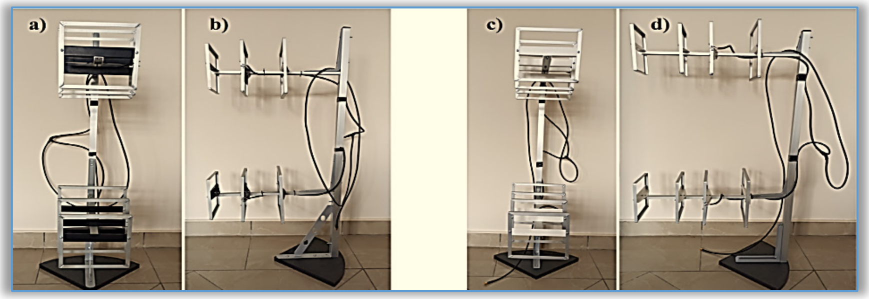

Figure 2. Stacked antennas for indoor use. The antennas consist of a pair of Quad antennas. a) Front view and b) side view of two stacked Quad antennas, each with three elements. c) Front view and d) side view of two stacked Quad antennas, each with four elements.

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In order to achieve this, we made the elements of the antenna (reflector, driver and directors) from an aluminium L profile (10 mm x 10 mm x 1 mm) (Figures 2a and 2b, antennas assembled by the authors). Supports of loops are made of PVC L–profiles (25 mm x 25 mm x 1.5 mm) (Figures 3a and 3b). Supports of Quad elements and elements are connected using M3x10mm screws. Supports of elements are connected to boom using the same type of screws. The boom is secured to the mast using a factory made aluminium bracket. The mast is an aluminium tube with a rectangular cross–section (25 mm x 25 mm), one meter high. We have assembled two antennas. Both are so–called stack antennas, composed of two identical antennas placed one above the other vertically.

The mast is fixed to the wooden base using a factory–made aluminium bracket. A special feature of vertically stacked antennas is that they have a wide horizontal radiation pattern (radiation beam). Extra gain (theoretically +3 dBi) in relation to the individual antennas was achieved by vertical narrowing of the radiation beam. Due to the relatively wide horizontal beam of radiation, this directional antenna is suitable in situations where one of the operators is mobile and its exact location is not exactly known. Feeding of the antenna is described in more detail in the following chapter.

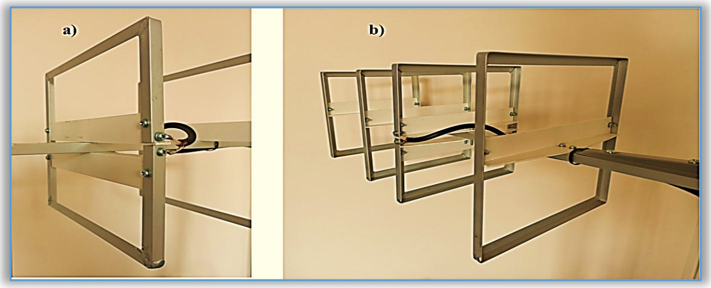

Figure 3. a) A detailed view of the feed point. b) A detailed view of the loops supports

3. FEEDING TWO ANTENNAS

Properly feeding two 50 ohm antennas requires equal power distribution between the two antennas and maintaining the entire system at impedance of 50 ohms [6]. One way this can be achieved is by using 75 ohm impedance coaxial cables. If, at the model level, a coaxial cable is represented as a transmission line (Figure 4. [7]) and the antenna impedance as a load connected to the transmission line, then the input impedance at the beginning of the coaxial cable can be determined by the expression [7]:

$$\underline{Z}_{\text{in}} = \underline{Z}_0 \cdot \frac{\underline{Z}_{\text{L}} \cdot \cos(\beta \cdot l) + \text{j} \cdot \underline{Z}_0 \cdot \sin(\beta \cdot l)}{\underline{Z}_0 \cdot \cos(\beta \cdot l) + \text{j} \cdot \underline{Z}_{\text{L}} \cdot \sin(\beta \cdot l)}. \quad (1)$$

where: $\underline{Z}_{\text{in}}$ – is input impedance, $\underline{Z}_0$ – is characteristic impedance of a transmission line, $\underline{Z}_{\text{L}}$ – is load impedance, β – is wavenumber ($2\pi/\lambda$), l – is transmission line (coaxial cable) length.

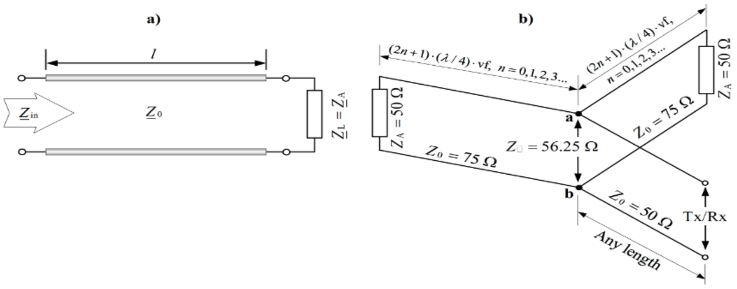

Figure 4. a) Coaxial cable presented as a transmission line. b) Schematic diagram showing the parallel connection of two coaxial cables with a characteristic impedance of 75 ohms on coaxial cable with a characteristic impedance of 50 ohms. Coaxial cables are presented as a transmission line.

If the length of the transmission line is exactly one–quarter wavelength ($l = \lambda / 4$), then the factor $\beta \cdot l$ is: $\beta \cdot l = (2\pi / \lambda) \cdot (\lambda / 4) = \pi / 2$, therefore it is $\cos(\beta l) = \cos(\pi / 2) = 0$, $\sin(\beta l) = \sin(\pi / 2) = 1$. This allows the expression (1) to be simplified to the form [7]:

$$\underline{Z}_{\text{in}} = \frac{\underline{Z}_0^2}{\underline{Z}_{\text{L}}} \quad (2)$$

Using an analogous procedure for $L = 3\lambda / 4$ the same expression for the input impedance is obtained. Expression (2) holds for any odd multiple of a quarter of the wavelength (λ/4, 3λ/4, 5λ/4, 7λ/4…). That is, taking into account the velocity factor (vf):

$$l = (2n+1) \cdot \frac{\lambda}{4} \cdot \text{vf}, \quad n = 0,1,2,3,\ldots\infty \quad (3)$$

Using the obtained expressions, it is possible to determine equivalent impedance obtained after matching the impedances using a 75 ohm coaxial cable as the impedance transformer. It is objective to assume that

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each of the antennas is electrically well built and its impedance is purely ohmic in nature and is 50 ohms ($\underline{Z}_A \approx 50\ \Omega$). From the perspective of a 75 ohm coaxial cable, the impedance of the antenna corresponds to the load at its end i.e. $\underline{Z}_L = \underline{Z}_A \approx 50\ \Omega$. The characteristic impedance of a 75 ohm cable is $Z_0 = 75\ \Omega$. The input impedance, ie the impedance at the end of the coaxial cable opposite to the antenna according to expression (2) is $\underline{Z}_{in} = 75^2 / 50 = 112.5\ \Omega$. The equivalent impedance between points "a" and "b" (Figure 4.) corresponds to the equivalent impedance of the parallel connection of the previously obtained impedance, i.e.

$$\underline{Z}_{\square} = \frac{\underline{Z}_{in} \cdot \underline{Z}_{in}}{\underline{Z}_{in} + \underline{Z}_{in}} = \frac{1}{2} \cdot \underline{Z}_{in} = \frac{1}{2} \cdot 112.5 = 56.25\ \Omega . \quad (4)$$

Although stacking two identical antennas theoretically increases the gain by 3 dBi, due to the losses in the coaxial cable, the practical increase in the gain of the stacked antenna is smaller. One part of the losses is in the main 50 ohm cable, and the other part of the losses is in the 75 ohm cables that are connected to each individual antenna. We used the same types and lengths of coaxial cables for both stacked antennas. The length of each branch of the 75 ohm coaxial cable is approximately 79 cm. The length of the 50 Ohm coaxial cable is two meters. Considering the attenuation in coaxial cables (0.3 dB/m), the equivalent attenuation is 0.9 dBi. That is, approximately one dBi. Therefore, in both cases of stacked antennas, the gain is approximately +2 dBi higher than the gain of an individual antenna.

4. SIMULATION RESULTS

Modelling, simulation and optimization of antenna parameters were performed using 4nec2 software [5]. For numerical calculations, 4nec2 software uses the numerical method of moments. The simulations were performed for an operating frequency of 446 MHz (so–called personal mobile radio (PMR)). The L profiles from which the reflector, driver and directors (10 mm x 10 mm x 1 mm) are built are modelled using a corresponding equivalent complex structure consisting of cylindrical conductors (Figure 5). In doing so, it was adopted that each individual cylindrical conductor has a diameter which corresponds to the thickness of the L profile. During the process of optimizing the antennas, we purposefully sacrificed about 0.5 dBi so that the antennas have a wider bandwidth. The obtained dimensions of the elements of each antenna and element spacing are summarized in Tables 1–2.

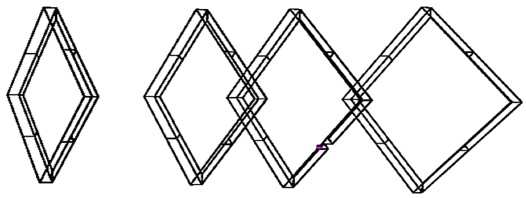

Figure 5. Three–dimensional view of antenna model

Table 1. Three elements Quad dimensions

	Dimensions	
	Expressed in wavelength	Expressed in cm
Wavelength	1.000	67.2
Reflector side	1.190	20.0
Driver side	1.095	18.4
Director1 side	0.980	16.5
Distance reflector–driver	0.186	12.5
Distance director–driver1	0.149	10.0

Table 2. Four elements Quad dimensions

	Dimensions	
	Expressed in wavelength	Expressed in cm
Wavelength	1.000	67.2
Reflector side	1.179	19.8
Driver side	1.071	18.0
Director1 side	1.011	17.0
Director2 side	0.950	16.0
Distance reflector–driver	0.200	13.5
Distance director–driver1	0.129	8.7
Distance driver1–driver2	0.190	12.8

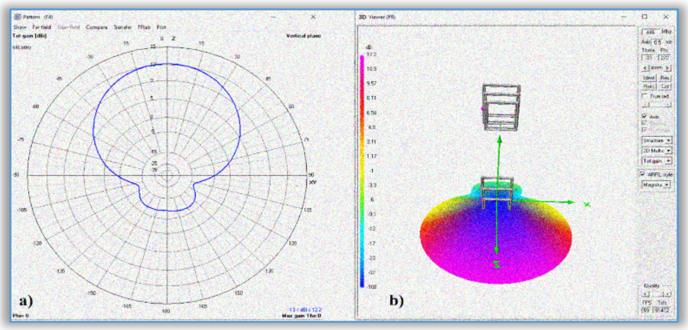

Figure 6. Two stacked Quad antennas, each with three elements, radiation pattern (total–gain in dBi), three–dimensional view of antenna model and radiation pattern (total gain in dBi)

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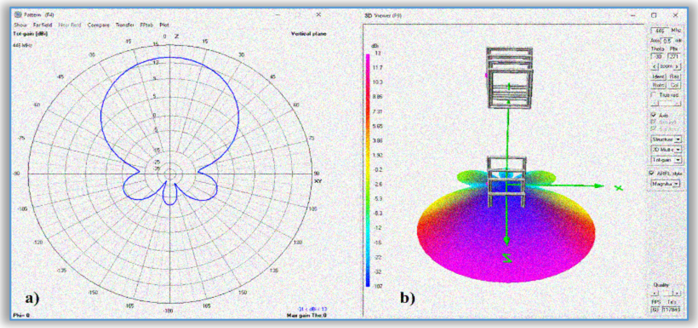

Figure 7. Two stacked Quad antennas, each with four elements, radiation pattern (total–gain in dBi), three–dimensional view of antenna model and radiation pattern (total gain in dBi)

Using the 4nec2 software, 2D and 3D radiation patterns were obtained (Figures 6 and 7). By repeatedly repeating the simulations for different vertical antenna distances (distances between the booms), we noticed that the maximum gain is achieved at a distance between the booms that corresponds to one wavelength. The radiation diagrams at maximum gain are shown in Figures 6 and Figures 7.

5. MEASUREMENT RESULTS

Common electrical parameters: impedance, components of complex impedance, S11 parameter, equivalent series capacitance (ESC), equivalent series inductance (ESL) and the voltage standing wave ratio (VSWR) were measured using the PS100 RF vector antenna analyzer meter [8]. Screen shots of the vector analyzer during the measurement are shown in Figures 8–9.

Figure 8. Common electrical parameters of a two stacked Quad antennas and VSWR vs frequency of a two stacked Quad antennas, each with three elements.

Figure 9. Common electrical parameters of a two stacked Quad antennas and VSWR vs frequency of a two stacked Quad antennas, each with four elements.

6. RESULTS AND DISCUSSION

The individual Quad antennas from which the presented stacked antennas for indoor use are made are well designed and have an impedance of approximately 50 ohms. According to the presented theoretical model (expression (4)), the expected impedance of a two stacked Quad antennas is approximately 56 ohms. Impedance of 54 ohms (Figure 8.) was determined by measurement for an antenna consisting of a two stacked Quad antennas, each with three elements. That is, the impedance of 56 ohms (Figure 9.) was determined by measurement for an antenna consisting of a two stacked Quad antennas, each with four elements. Both measured values are in high agreement with the theoretical prediction. At the operating frequency, both antennas have an VSWR lower than 1.5, which is considered an excellent result. According to Figures 8 and 9 (right figures), for VSWR lower than 1.5, both antennas have a bandwidth that is about 20 MHz wide. The theoretical gain for a stacked antenna consisting of two antennas, each with three elements, is 12 dBi (Figure 6.). The theoretical gain for a stacked antenna consisting of two antennas, each with four elements, is 13 dBi (Figure 7.). The obtained simulation results are consistent with the literature [1]. Considering the losses in coaxial cables, the actual gain is approximately one dBi lower for both

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antennas (see chapter feeding two antennas). Both antennas were tested and no problems with common mode currents were observed. The mechanical resistance to stress is excellent, after prolonged use, all connections remained tight. Also, several accidental impacts did not deform the loops, nor did they cause their misalignment.

7. CONCLUSION

Quad antennas have an excellent radiation pattern, electromagnetic properties and a relatively high gain for a certain boom length. With careful design of the Quad antenna, a wave impedance of exactly 50 ohms can be achieved. Also, they are significantly less prone to problems caused by common mode currents compared to Yagi antennas. Because of the above, they can be feed directly with a coaxial cable. That is, when using them, it is not necessary to adjust the impedance, nor is it necessary to use special techniques for attenuation of common mode currents, except in rare cases. Also, for the same boom length, they have a higher gain than Yagi antennas. However, by using typical construction solutions for making Quad antennas it is difficult to achieve satisfactory mechanical characteristics of Quad antennas for indoor use. In contrast, as shown in the article, the use of aluminium L profiles for the production of Quad loops and PVC L profiles for the production of supports of Quad loops, significantly improves the mechanical characteristics of the Quad antenna. As a disadvantage of the use of L profiles made of aluminium and PVC, we can state that the production of Quad antennas is significantly slower compared to using typical materials in a typical Quad design.

References

[1] K. Rothammel, Antennenbuch, Franckh, 1978, ISBN: 344004498–X
[2] S. D. Orr, W. I. Cowan, All About Cubical Quad Antennas, Radio Publications, 1978, ASIN: B001QLDS10
[3] B. Haviland, The Quad Antenna: A Comprehensive Guide to the Construction, Design, and Performance of Quad Antennas, Cq Communications, 1993, ISBN: 978–0943016054
[4] Tomislav Barić, Hrvoje Glavaš, Željko Hederić, "Handheld UHF Quad Antennas With Reinforced Mechanical Characteristics", 5th International Conference on Smart Systems and Technologies (SST), SST 2022, Osijek, Croatia, 2022
[5] Numerical electromagnetics code software 4nec2 is a completely free windows based tool for creating, viewing, optimizing and checking antenna geometry structures, available at: https://www.qsl.net/4nec2/ (accessed September 8, 2022)
[6] J. J. Carr, Practical Antenna Handbook, McGraw–Hill, 2001, ISBN: 978–0071374354
[7] W. Hayt, J. Buck, Engineering Electromagnetics, McGraw Hill, 8th edition, 2011, ISBN: 978–0–07–338066–7
[8] PS100+, N1201SA series vector impedance analyzer, Product manual, available at: https://img.banggood.com (accessed September 8, 2022)

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