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Design and Construction of Receiving Antennas

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ABSTRACT The construction of receiving antennas does not present major technical difficulties, as it only requires combining copper wire with coaxial cable. However, designing an antenna to capture specific frequencies poses a significant challenge. This report documents the construction of a helical antenna and a small loop antenna, using materials such as copper wire, coaxial cable, PLA, soldering iron, and solder. The helical antenna was evaluated with a USB network adapter, achieving a reception of 13.06 dB, which represents a 3.25-fold increase compared to the original signal. The small loop antenna was tested with a conventional television, successfully capturing channels in VHF and UHF frequencies. The main difficulties arose in soldering and impedance matching between the antennas and the coaxial cable. Therefore, the use of an impedance matcher is recommended to improve power and signal reception.

INDEX TERMS Helical antenna, loop antenna, Directivity, Frequency, Impedance

I. CONCEPTUAL FRAMEWORK

A. INTRODUCTION

B. SMALL LOOP ANTENNA [BALANIS2016]

1) Field Radiated by a Loop with $N = 1$ Turn

The magnetic moment of a current-carrying loop is:

$$\mathbf{m} = I_0 A\,\hat{z},$$

where $A = \pi R^2$ is the area of the loop and I_0 is the maximum current.

The far electric field produced by a magnetic moment $\mathbf{m}$ is written as:

$$E_\phi = \frac{\mu_0 I_0 A \omega^2}{4\pi c^2 r} \sin\theta e^{-j\beta r},$$

where:

- r: Distance to the observation point.
- $\beta = \frac{2\pi}{\lambda}$: Wave number.
- $\omega = 2\pi f$: Angular frequency.
- $\sin\theta$: Characteristic angular dependence of the loop.

2) Contribution of N Turns

For a loop with N turns, the total magnetic moment is multiplied by N due to the superposition of individual magnetic moments:

$$\mathbf{m}_{\text{total}} = N \cdot (I_0 A).$$

Therefore, the radiated electric field is proportional to N^2, since both the current and the effective area of the loop are multiplied by N:

$$E_\phi = \frac{\mu_0 N^2 I_0 A \omega^2}{4\pi c^2 r} \sin\theta e^{-j\beta r}.$$

3) Associated Magnetic Field

The corresponding magnetic field in the far field is related to the electric field by the characteristic impedance of free space, $\eta = 120\pi$:

$$H_\phi = \frac{E_\phi}{\eta}.$$

Substituting E_ϕ:

$$H_\phi = \frac{N^2 I_0 A \omega^2}{4\pi c r} \sin\theta e^{-j\beta r}.$$

4) Dependence of Radiation on N

The total radiation from the antenna increases proportionally to N^2 due to constructive reinforcement of the field generated by additional turns.

5) Relationship Between Radius and Frequency

First, the wavelength λ is related to the frequency f and the speed of light c by the formula:

$$\lambda = \frac{c}{f}$$

Then, the perimeter P of a loop antenna with n turns is given by:

$$P = n \times 2\pi r$$

At resonance, the perimeter of the antenna is approximately equal to the wavelength, i.e.:

$$P \approx \lambda$$

Substituting $P = n \times 2\pi r$ into the resonance equation, we obtain:

$$n \times 2\pi r \approx \lambda$$

Substituting the expression for λ in terms of f:

$$n \times 2\pi r \approx \frac{c}{f}$$

Finally, solving for the frequency f, we get:

$$f \approx \frac{c}{2\pi n r}$$

6) Impedance and Directivity

The impedance Z of a small loop antenna depends on the radius of the antenna and the number of turns. For a small loop antenna at resonance, the typical impedance is:

$$Z \approx 30 \times \frac{N}{r}$$

Where:

- Z is the antenna impedance.
- N is the number of turns.
- r is the radius of each turn of the antenna.

The directivity D of a loop antenna is related to its radiation pattern. For a single-turn loop antenna, the directivity can be approximated as:

$$D \approx \frac{4\pi A}{\lambda^2}$$

Substituting the area $A = \pi r^2$, we get:

$$D \approx \frac{4\pi \cdot \pi r^2}{\lambda^2} = \frac{4\pi^2 r^2}{\lambda^2}$$

For a loop antenna with N turns, the directivity is adjusted by the number of turns and can be calculated as:

$$D \approx \frac{N^2 \cdot 4\pi r^2}{\lambda^2}$$

C. HELICAL ANTENNAS [BALANIS2016]

Helical antennas are widely used in telecommunications applications due to their unique radiation properties and design versatility. They consist of a geometric structure in the form of a helix, characterized by the number of turns N, diameter D, and spacing between turns S.

1) Geometric Properties

The total length of the helical antenna is given by:

$$L = NS,$$

and the total length of the wire forming the helix is:

$$L_n = N\sqrt{S^2 + C^2},$$

where $C = \pi D$ is the circumference of the helix.

The *pitch angle* α, which determines the inclination of the helix, is defined as:

$$\alpha = \tan^{-1}\left(\frac{S}{\pi D}\right).$$

2) Operating Modes

The helical antenna can operate in two main modes: the *normal* (broadside) mode and the *axial* (end-fire) mode.

3) Axial Mode

In the axial mode, the maximum radiation intensity occurs along the axis of the helix, while minor lobes appear at oblique angles. This mode is especially useful for circular polarization applications, as it provides a wider operating bandwidth.

To excite this mode, the dimensions must meet the following conditions:

- $\frac{3}{4} < \frac{C}{\lambda_0} < \frac{4}{3}$, with $C/\lambda_0 \approx 1$ as the optimal value.
- Spacing between turns $S \approx \lambda_0/4$.
- Pitch angle $12^\circ \leq \alpha \leq 14^\circ$.

Typically, a ground plane of at least $\lambda_0/2$ in diameter is used, and the antenna is fed by a coaxial line. Although other feeding configurations, such as waveguides or dielectric rods, are possible, especially at microwave frequencies.

The radiation pattern in the axial mode can be described by:

$$E = \sin\left(\frac{\pi}{2N}\cos\theta\right)\frac{\sin\left(\frac{N}{2}\psi\right)}{\sin\left(\frac{\psi}{2}\right)},$$

where:

$$\psi = k_0\left(S\cos\theta - \frac{L_0}{p}\right).$$

The radiation efficiency in this mode depends on the relationship between the wave velocity in the helical wire and in free space, with p values given by:

$$p = \frac{L_0/\lambda_0}{S/\lambda_0 + 1} \quad \text{(ordinary end-fire radiation)},$$

$$p = \frac{L_0/\lambda_0}{S/\lambda_0 + \frac{2N+1}{2N}} \quad \text{(Hansen-Woodyard end-fire radiation)}.$$

4) Impedance and Directivity

The terminal impedance of a helix in the axial mode is almost resistive, with values between 100 and 200 ohms. The impedance is given by the following empirical expression:

$$Z_0 = 140\frac{C}{\lambda}$$

The directivity is given by:

$$D_0 = \frac{15NC^2S}{\lambda_0^3},$$

and the beamwidth between nulls (FNBW) is:

$$\mathrm{FNBW} = \frac{115\lambda_0^{3/2}}{C\sqrt{NS}}.$$

II. OBJECTIVES

- Design and build two antennas: a small loop antenna capable of receiving television frequencies (MHz) and a helical antenna capable of receiving Wi-Fi frequencies (GHz).
- Compare the download and upload speed (Mbps) captured by a homemade helical antenna with that of a USB network adapter, as well as the VHF and UHF frequencies received by a small loop antenna.

III. MATERIALS AND METHODS

A. MATERIALS

1) Small Loop Antenna

- 0.7 m of enameled copper wire, 16 AWG gauge
- 3 m of RG6 coaxial cable
- Conventional television
- MDF board
- Laser cutter
- Sandpaper
- Pliers
- Wire stripper
- Soldering iron
- Solder
- Soldering paste
- Electrical tape

2) Helical Antenna

- RG6 coaxial cable
- 3D printer and PLA
- AWG 24 copper wire
- PCB board
- Soldering iron
- Solder
- TL-WN722N USB network adapter

B. METHODOLOGY

1) Small Loop Antenna

The construction of the antenna begins with cutting a circular MDF board piece with a diameter of 9 cm, which will serve as the base for winding the enameled wire. A free space of at least 5 cm should be left at both ends of the wire. Subsequently, 3 cm of one end of the wire is sanded to ensure better adhesion. To maintain the circular shape of the antenna, electrical tape is wrapped at at least four points distributed at 90 degrees along the perimeter, ensuring that the ends of the wire are at the bottom. Next, 10 cm is cut from one end of the coaxial cable, the insulation and fiber are stripped, leaving at least 1 cm of bare copper at the tip. Then, the enameled wire is wrapped around the bare copper of the coaxial cable, and soldering is performed using solder and soldering paste to facilitate the union. Finally, the antenna is tested by connecting it to a conventional television to verify its operation.

2) Helical Antenna

The construction of the antenna was carried out following these steps:

- The base was designed by adjusting the dimensions to the wavelength of interest so that the circumference of one turn was very similar to the wavelength.
- A 3D printer was used to print the base.
- The copper wire was wound onto the base, trying to make the helix as uniform as possible.
- A PCB was cut so that its width resembled the wavelength used; this will serve as the antenna reflector.
- A hole was made in the PCB at the point where the copper wire begins.
- A piece of coaxial cable was prepared to connect the antenna to the signal receiver, in this case a USB network adapter.
- One end of the coaxial cable was soldered to the power input for the antenna. At this junction, a piece of copper was also soldered to allow impedance matching between the antenna and the coaxial cable.
- The coaxial cable was soldered to the USB network adapter.
- A signal analyzer was used to see how the antenna responded.

C. DIAGRAM

Figure 1: Helical antenna assembly

Figure 2: Small loop antenna assembly

IV. RESULTS

A. HELICAL ANTENNA

Table 1: Dimensions and characteristics of the helical antenna at 2.4 GHz.

Parameter	**Value**	**Unit**
Wavelength (λ_0)	0.125	m
Diameter (D)	0.0398	m
Circumference (C)	0.125	m
Spacing between turns (S)	0.0313	m
Total length (L)	0.1875	m
Wire length (L_{wire})	0.7731	m
Directivity (D_0)	22.5	—
Gain (G)	13.06	dB
Impedance (Z_0)	140	Ω

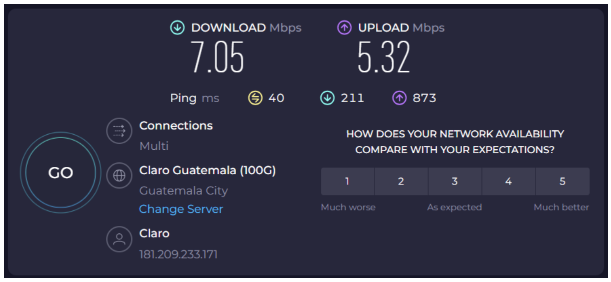

Figure 3: Speed captured with the original 4dB antenna

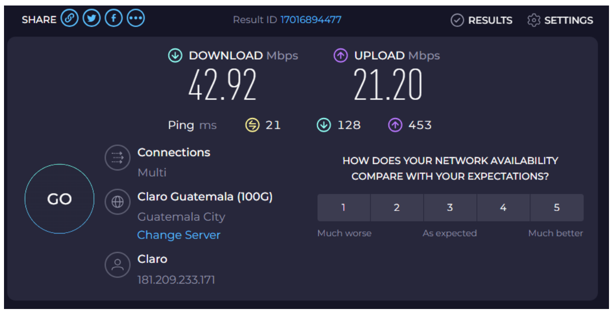

Figure 4: Speed captured with the 13.06dB helical antenna

B. SMALL LOOP ANTENNA

Table 2: Dimensions and characteristics of the small loop antenna

Parameter	**Value**	**Unit**
Wavelength (λ)	0.57	m
Radius (r)	0.045	m
Number of turns (N)	2	—
Frequency (f)	530.52	MHz
Impedance (Z)	1,333.33	Ω
Gain (G)	10.99	dB
Directivity (D)	0.32	—

Table 3: Channels captured by the small loop antenna

Channel	Frequency	Captured	Quality
Channel 3	VHF	Yes	Poor
Channel 7	VHF	Yes	Fair
Channel 11	VHF	Yes	Fair
Channel 13	VHF	Yes	Excellent
TN23	UHF	Yes	Excellent
Guatevisión	UHF	Yes	Fair
TV Azteca Guate	UHF	Yes	Fair
Channel 27	UHF	Yes	Excellent
T. Arquidiocesana	UHF	Yes	Excellent
Channel 9	TDT	No	NA

V. DISCUSSION

A. HELICAL ANTENNA

It is possible to observe the improvement in Wi-Fi signal reception when using the helical antenna compared to the original antenna that comes with the adapter. This is mainly due to the increase in the gain of the antenna used. It is worth noting that the gain of the helical antenna depends on its dimensions and the number of turns; the built antenna has 6 turns, which, as shown in Table 1, results in a gain of 13.06 dB, 3.25 times greater than the 4 dB gain of the original TL-WN722N product.

It is evident that space plays a crucial role in restricting the antenna's characteristics. The helical antenna occupies much more space than the one that comes with the adapter, but without space constraints, the possibilities for improving signal reception expand. In addition to the advantage in antenna gain, the helical antenna is subject to circular polarization, allowing the signal to be perceived regardless of the type of antenna generating it. However, it is quite susceptible to directional changes, which is due to the antenna being designed in axial mode, which for a helical antenna implies a main and concentrated lobe due to the high gain. The axial mode and high gain allow for signal transmission with fewer losses.

The main difficulties encountered during the development of the antenna were during the connections. A coaxial cable was used as the signal transmitter, which was challenging because the impedance of the antenna and the coaxial cable are quite different, being 140 for the antenna and 60 for the coaxial cable. To allow good matching, a small plate was soldered at the first quarter turn of the antenna and at the coaxial connection point. This is a common recommendation found in the literature. The next challenge posed by this configuration is the connection to the SMA input of the USB adapter; the connection is extremely fragile, which limits the use of the antenna. It was not possible to find a coaxial-to-SMA adapter, so it was soldered directly.

Overall, the project objectives were achieved: a functional antenna was built, and its efficiency in receiving Wi-Fi waves was demonstrated. Practical knowledge of fundamental wave concepts, such as gain and the axial mode of an antenna, was gained. The use of adapters that facilitate the connection of parts is recommended to allow mobility and ease of handling of the antenna.

B. SMALL LOOP ANTENNA

For the small loop antenna, a frequency of 530.52 MHz was predicted. Evidence of this prediction was observed in the channels captured by the antenna. It is evident that subscription channels were not included in the reception; however, national very high frequency (VHF) channels, ranging from 3 to 300 MHz, were all captured, mostly with fair quality (channels 7 and 11) or excellent quality (channel 13). Nevertheless, channel 3 was also captured but with poor quality. On the other hand, ultra high frequency (UHF) channels, ranging from 300 MHz to 3 GHz, were also captured, with mostly fair or excellent quality. This behavior suggests that the antenna is better adapted to receive UHF frequency signals.

This phenomenon can be explained by the antenna design, which has a small radius and two turns. If the number of turns or the radius of the antenna were increased, a decrease in UHF frequency reception would be observed, but the reception quality of VHF signals would improve. This is because the antenna was not specifically designed to be broadband, although it performed this function to some extent.

Additionally, channel 9 could not be captured at any time, which may be attributed to this channel transmitting Digital Terrestrial Television (TDT) signals. The inability to capture this channel could be a consequence of the antenna design, which was not optimized to receive TDT signals. A similar behavior was observed in channel 3, which also suffered from low quality, as it operates in both the VHF and TDT ranges.

Other factors, such as the enamel coating of the antenna, the sanding of the end, the soldering with the coaxial cable, and the not perfectly circular shape of the antenna, may have affected the quality of the captured signal. Therefore, to improve the experiment's results, it is recommended to build a broadband antenna using a mold to melt the copper or a hammer to adjust any possible misconfigurations that may arise during the winding process. The use of a coil winding machine is also advisable, provided the base material is dielectric and the difference between the outer and inner radius is no greater than 1 cm.

Finally, the use of an impedance matcher is suggested, which could improve the signal by matching the antenna's impedance to that of the coaxial cable, thus optimizing power transfer and signal reception.

VI. CONCLUSIONS

- It was possible to successfully build and verify the efficiency of a helical antenna.
- A small loop antenna capable of capturing signals in the very high frequency (VHF) and ultra high frequency (UHF) ranges was built.

VII. BIBLIOGRAPHY

References

[1] Constantine A. Balanis, *Antenna Theory: Analysis and Design*, 4th edition, Wiley, 2016.