The 40m Band 3λ Square Loop Antenna

Enjoy All-Season, All-Band Operation by Combining the Best Features of the Wullenweber Antenna (Elephant Cage) and the Rhombic Antenna!

Yoshinori Ideno
JP3WVZ/JA1BBE

Introduction

In order to expand radio wave resources, the effective use of radio frequencies is becoming increasingly important, even in the amateur radio community. This includes technologies that improve frequency efficiency, promote frequency sharing, or facilitate the transition to higher frequencies. Enthusiasts who independently enjoy amateur radio communication using digital technologies such as FT8 and FreeDV are seen as an advanced group dedicated to utilizing radio resources efficiently, earning recognition and expectations from around the world, including Japan.

Moreover, these individuals demonstrate remarkable adaptability to changing radio environments. Their creative approach to antenna design reflects the true spirit of amateur radio, with frequent exchanges of ideas and information taking place during communications. Even with the ongoing shift toward digital technologies, "antennas remain crucial in radio communication." Amateur radio operators take pride in designing antennas that achieve greater distances and stronger signals while ensuring that installation and maintenance can be managed independently. Sustainability – the ability to sustain communication activities independently – is a key aspect that adds to the joy of the hobby. This emphasis on problem-solving and innovation fosters a sense of fulfillment, ensuring that amateur radio remains a vibrant and enjoyable pastime.

With this in mind, we set out to develop a high-performance 40m Band antenna that combines superior transmission and reception capabilities with cost efficiency. Leveraging our national qualifications, we undertook new design and development challenges to achieve this goal.

1. Development Background

If a high-gain antenna can be used on the 40m band, it becomes possible to enjoy long-distance communication with overseas stations over 12,000 km away throughout the year, particularly during the nighttime hours (from evening to early morning), despite seasonal variations.

However, commercially available high-gain antennas, while attractive in performance, are often large and heavy, making installation difficult for individuals. Ensuring safe installation typically requires hiring a professional antenna contractor, which not only diminishes the DIY enjoyment that many amateur radio operators value but also demands significant costs for purchase, installation, and maintenance.

Recognizing the diverse needs of amateur radio operators – such as affordability, high gain, safety and reliability, and unique ingenuity – we identified a gap in the market for a 40m band high-performance antenna that satisfies these requirements. This led us to pursue a new design and development approach that incorporates innovative technologies to achieve our goal.

2. New Technology Design and Development

Before the development and implementation of satellites, military HF-band radio interception facilities utilized the Wullenweber antenna (commonly known as the *"Elephant Cage"*) as an omnidirectional receiving antenna. For long-distance international communication, the Rhombic antenna, known for its sharp directional pattern with a low radiation angle, was widely employed. Both of these loop antennas are large in size but offer exceptional performance suited to their respective applications.
By reproducing or adapting these advanced technologies, we believed we could overcome the challenges associated with 40m band antennas. With a focus on maintaining the flexibility and creativity that characterize amateur radio experimentation – rather than pursuing a commercial product – we embarked on the design and prototyping of a new antenna.

3. Overview of the Newly Designed Antenna

Fig.1 shows a schematic diagram of the newly designed 40m Band 3λ Square Loop Antenna. The total length of the element is 3λ (with each side measuring 3/4λ). The loop plane is positioned horizontally relative to the ground, forming a square shape when viewed from above. The element is installed at a height of approximately 6 meters above the ground, making the installation process remarkably simple.
An essential feature is the feed point, which must be positioned at one of the corners of the square. This configuration effectively creates a beamforming pattern similar to that of a Rhombic antenna.
Furthermore, by shifting the feed point to the adjacent corner, the beamforming direction rotates 90 degrees, providing flexible directional control.

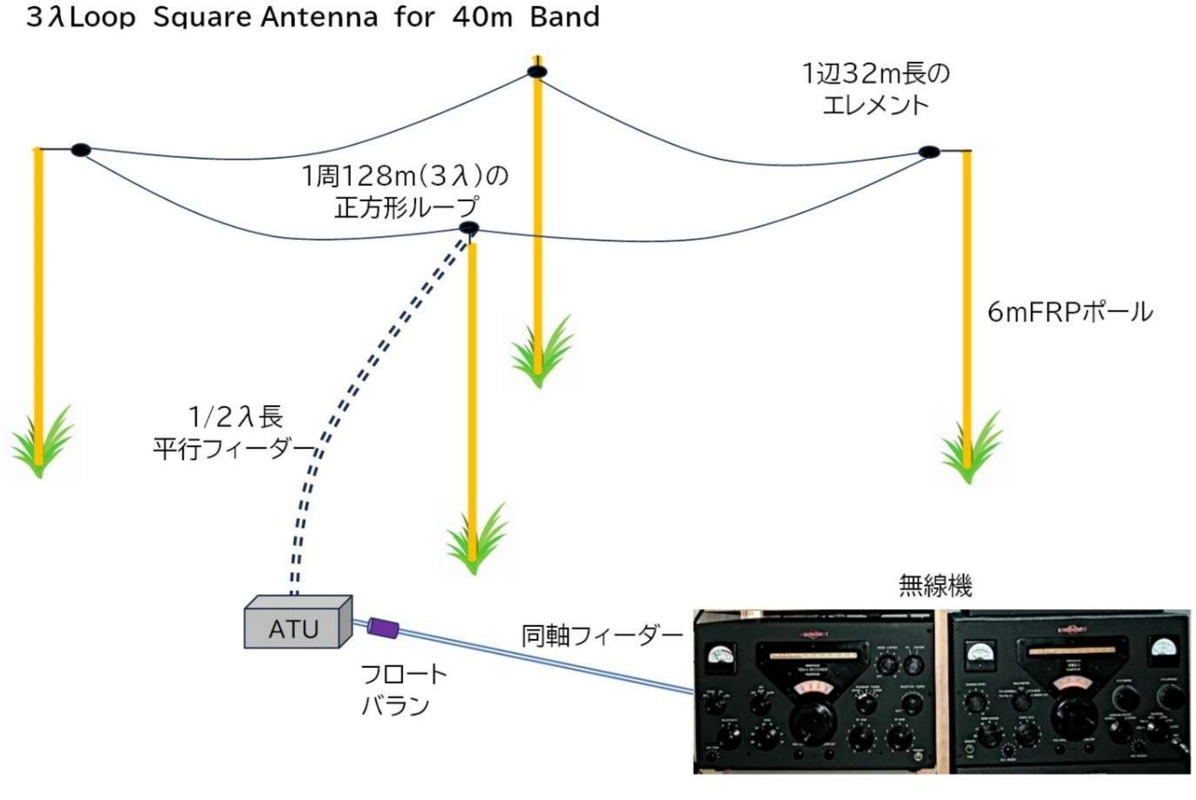

Fig.1 40m Band 3λ Square Loop Antenna

The design also considers multi-band operation from the initial stages. A unbalanced coaxial feeder (5D-2V) is used to connect the transceiver to the ATU (Antenna Tuning Unit), while a balanced parallel feeder with a characteristic impedance of 400Ω (Fig.2) is used to connect the ATU to the antenna.

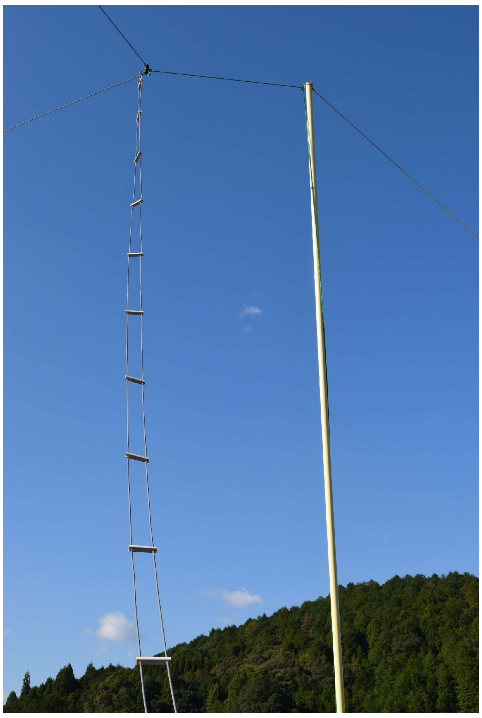

Fig.2: Feeding Method Using a Parallel Feeder

The ATU is a self-built unit, adopting the S-MATCH© design developed by PA0FRI (F.H.V. Geerligs) (Fig.3 and 4). This ATU effectively adapts the 3λ Square Loop Antenna for all bands from 1.8 MHz to 30 MHz in the MF and HF bands. Additionally, it excels in balanced feed operation.

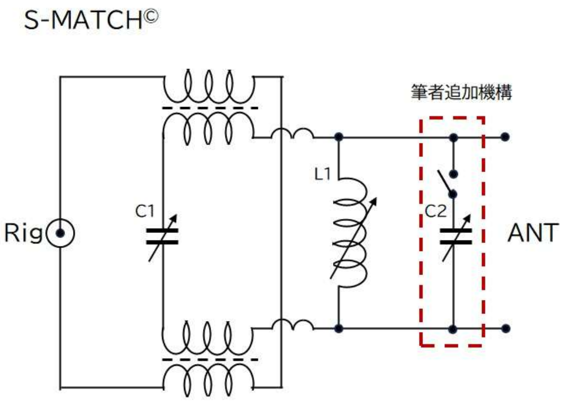

Fig.3: S-MATCH© circuit diagram

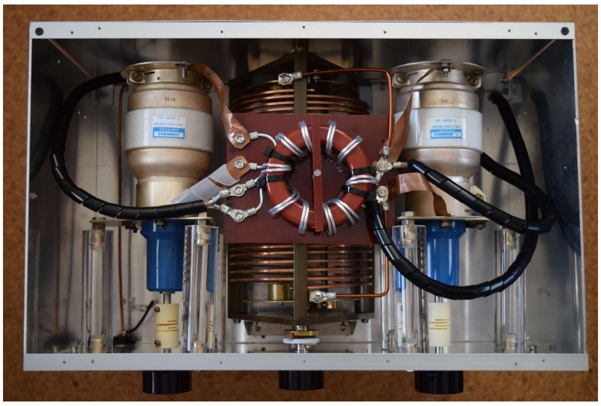

Fig.4: Homemade ATU

4. Performance check on each band

Fig.5 shows the simulation results for each band using MMANA-GAL. The antenna operates as a high-performance multi-band antenna on various bands, including 3.5 MHz (vertical polarization), 10 MHz (horizontal polarization), 14 MHz (horizontal polarization), and 21 MHz (horizontal polarization).
While its absolute gain is slightly lower compared to the 7 MHz band, it still demonstrates higher absolute gain than a dipole antenna or a G5RV antenna.

This improved performance is achieved by combining several factors: adjusting the electrical element length via the ATU, utilizing the antenna's functionality as a harmonic antenna, and effectively leveraging both standing wave and traveling wave antenna characteristics. These factors work together to expand the antenna's aperture and increase its effective surface area.

No.	F (MHz)	R (Ohm)	jX (Ohm)	SWR 50	Gh dBd	Ga dBi	F/B dB	Elev.	Ground	Add H.	Polar.
10	50.323	134.7	70.27	3.51	---	13.06	0.31	12.1	Real	4.0	hori.
9	28.074	225.8	94.01	5.33	---	8.19	5.31	41.7	Real	4.0	hori.
8	24.915	295.9	572.1	28.2	---	8.45	2.56	49.8	Real	4.0	hori.
7	21.074	279.9	64.61	5.91	---	8.0	2.26	58.2	Real	4.0	hori.
6	18.1	255.6	759.2	50.4	---	6.66	1.44	20.0	Real	4.0	hori.
5	14.074	85.39	52.71	2.55	---	9.67	1.33	25.8	Real	4.0	hori.
4	10.136	31.84	-89.68	7.12	---	9.48	0.71	37.1	Real	4.0	hori.
3	7.074	54.71	48.79	2.47	---	10.44	0.43	51.5	Real	4.0	hori.
2	3.574	4.488	39.52	18.1	---	8.8	-2.89	90.0	Real	4.0	vert.
1	1.84	2.358	-141.6	191	---	5.52	-1.96	90.0	Real	4.0	vert.

Fig.5: Results of MMANA-GAL simulation

5. Transmitting and receiving performance verification test

First, the ATU is adjusted to tune the antenna system to 7.074 MHz, the FT8 frequency for international communication (Fig.6).
Using a Nano VNA allows for precise tuning in a short time, making it easy to determine the correct direction to turn the adjustment knobs. This enables quick and satisfying tuning adjustments.
The Smith chart can also be displayed on the Nano VNA screen alongside the SWR, making it an excellent tool for antenna tuning and verification.

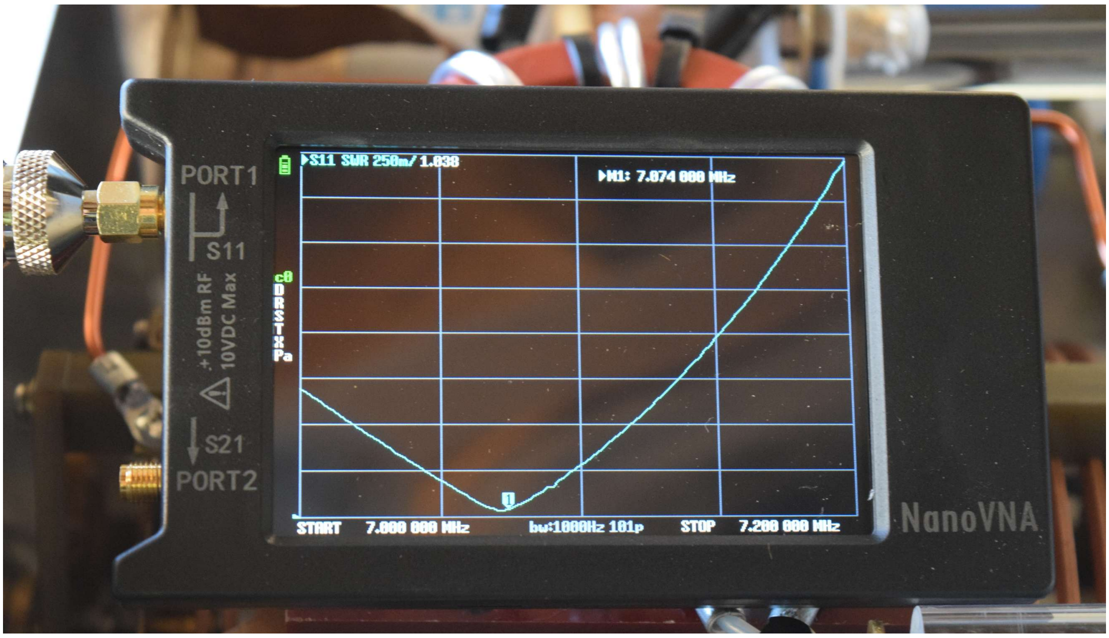

Fig.6: Antenna Preparation Before Operation

A transmission and reception performance test was conducted on 7.074 MHz FT8 from 5:00 PM on October 31st to 5:00 AM the following morning, during which communication was carried out intermittently. This experiment was conducted on a fall night when conditions were relatively favorable.
The results may vary slightly depending on the season, time of day, geomagnetic disturbances, and solar wind speed. Figure 7 shows a map indicating the origins of the received signals. During this test, signals were received from a total of 69 countries.
Demonstrating the characteristics of the Wullenweber antenna, the system effectively received signals arriving from all directions. Most of the received signals originated from stations located inside the gray zone and slightly outside the gray line.

At the beginning of the experiment, signals predominantly came from the eastern direction. As time progressed, the reception gradually shifted toward the west, and shortly before the experiment concluded, numerous signals from Europe were received.

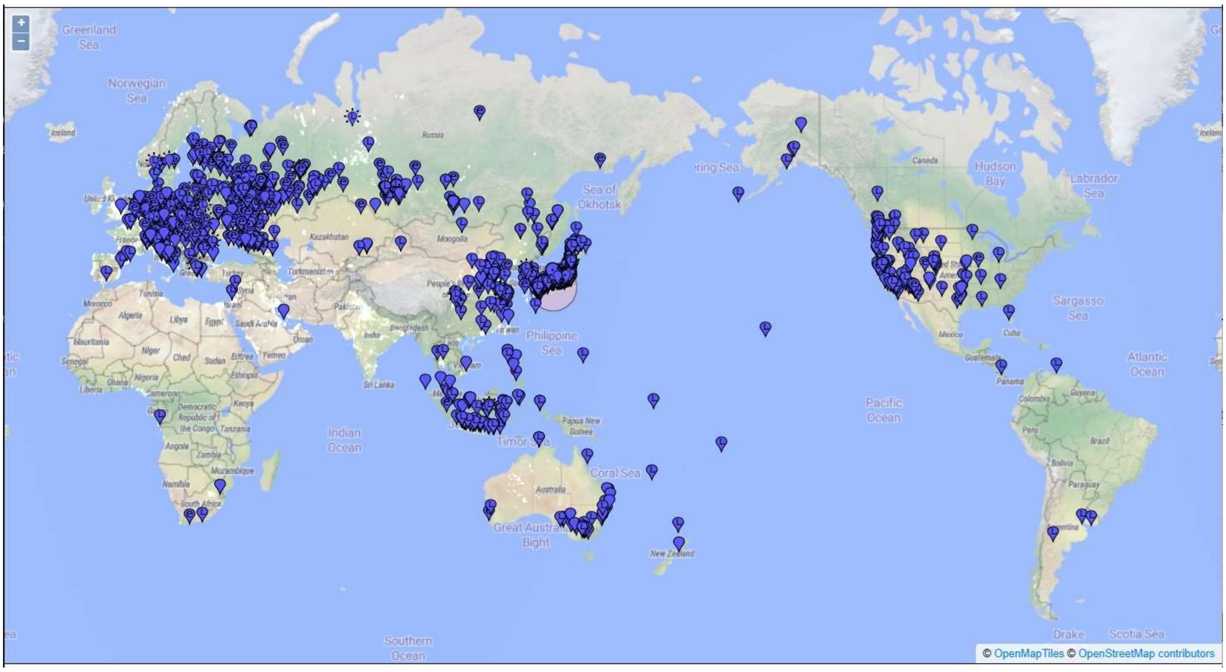

Fig.7: Reception result

Fig.8 shows the results uploaded to PSK Reporter by other stations that received transmission signals from the experimental station.
At the time of this test, the feed point was positioned at the southeastern corner, resulting in strong beamforming effects in the northwestern and southeastern directions, which provided an advantage in signal strength. The input power to the antenna was kept below 10W, and the grid locator for the test site was "PM75RE".
Despite the limited input power, the 40m Band 3λ Square Loop Antenna successfully transmitted signals across the globe, with the exception of Africa, where beamforming effects were less effective from the current feed point.

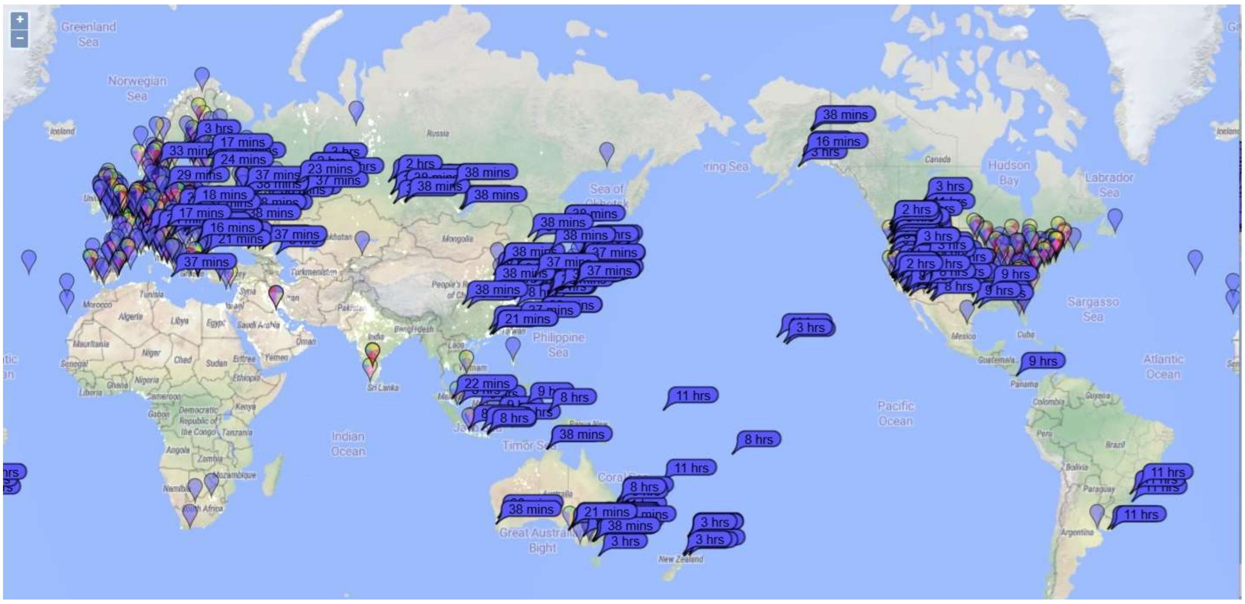

Fig.8: Transmission result

The first contact using the 40m Band 3λ Square Loop Antenna was with the station "CX1CW" in Uruguay, at a distance of 18,995.8 km. The received SNR value was -12 dB, which was returned by the other station. Receiving a response from nearly the opposite side of the Earth was quite an exciting moment.
The second contact was with the station "C21TS" in Nauru, at a distance of 5,147.9 km, with an SNR value of -6 dB.
During the JIDX Contest held from November 9 to 10, I participated in the 7 MHz band using SSB mode with power below 10W. I successfully communicated with numerous stations, including Uruguay (CX4DI), the United States, and several Southeast Asian countries. While my weak signal occasionally required the other party to ask for repeats, the only station that required a power increase to 50W for a successful contact was a station in Ukraine, which was positioned in the antenna's sidelobe area where beamforming effects were less effective.
In terms of transmission performance, the 40m Band 3λ Square Loop Antenna appears to be comparable to or slightly inferior to a 3-element Yagi antenna (KA1-406). However, in terms of reception performance, the 40m Band 3λ Square Loop Antenna demonstrates superior noise resistance, outperforming the Yagi antenna.
Even with extremely weak signals that barely move the S-meter, the antenna maintained a readability of 5, providing clear and effective support for voice (SSB) and Morse code (CW) communications. This clarity earns the antenna high praise as an "antenna with excellent intelligibility."
Fig.9 and 10 illustrate the difference in noise levels (focusing on white noise) between the two antennas. The improved noise performance of the Square Loop antenna is likely due to the following factors:
① The use of a parallel feeder for signal transmission.
② The adoption of a high-frequency transformer for balanced-to-unbalanced conversion, providing galvanic isolation.
In contrast, the KA1-406 Yagi antenna uses a coaxial cable for its transmission line. While coaxial cables are widely available and have become common in the amateur radio community, they are more prone to signal attenuation compared to parallel feeders. Additionally, coaxial cables are more susceptible to environmental noise.
Despite these drawbacks, coaxial cables offer practical benefits, such as the absence of the 1/2λ integer multiple length restriction and their cost-effectiveness. This makes them a convenient choice for tower-mounted antennas like the KA1-406.
Although coaxial cables have become standard in amateur radio due to their accessibility, parallel feeders continue to be utilized in professional communication systems today.

Fig. 9: Noise situation of KA1-406

Fig.10: Noise situation of 40mBand 3λSquare Loop

6. Multi-band use

As shown in Fig.11, the Nano VNA frequency range was set to 1.8 MHz to 1.9 MHz, and the SWR value of the 40m Band 3λ Square Loop Antenna was measured while adjusting the ATU.
A bottom point with an SWR value of 1.0 was successfully achieved at 1.840 MHz. Although the bandwidth is narrow, fine adjustments to the ATU allow the antenna to function effectively as a transmission and reception antenna at any desired frequency within the 160m Band.

Similar measurements were conducted for other bands, including 3.5 MHz, 3.8 MHz, 10 MHz, 14 MHz, 18 MHz, 21 MHz, 24 MHz, and 28 MHz. The results confirmed that the antenna can be used as a transmission and reception antenna across all these frequency bands.

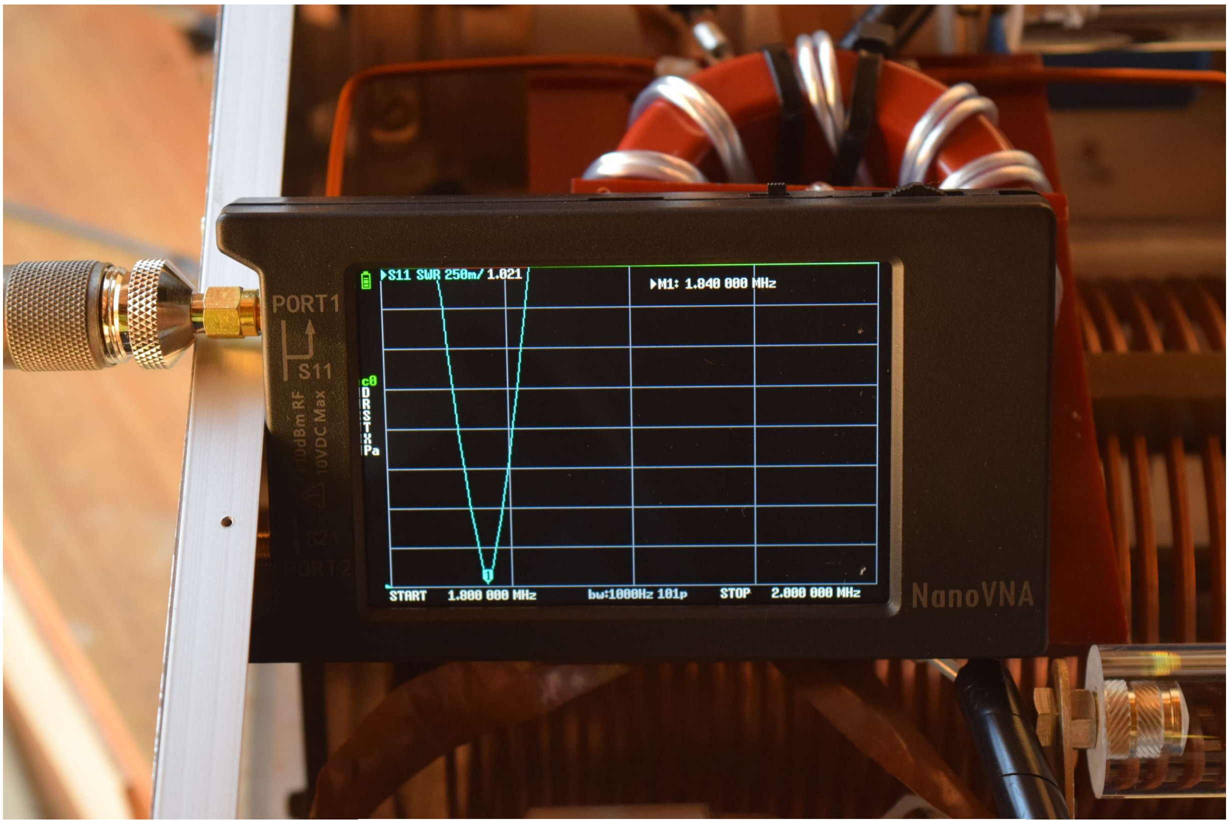

Fig.11: 1.8MHz SWR value measurement

On November 4, I conducted communications using SSB and FT8 on the 160m Band, confirming that QSOs with domestic and neighboring countries were possible.
Additionally, I carried out long-duration operation on the 160m Band FT8 with a transmission power exceeding 700W. No abnormalities were observed in the antenna system, demonstrating its suitability for high-power, extended operation.
However, caution is necessary regarding overheating of the ATU and the feeding system. For prolonged operation, such as during contests, it is advisable to ensure proper ventilation for heat dissipation and implement measures to prevent excessive heating for safer operation.
For frequencies above the 40m Band, this antenna allows enjoyable long-distance communication with a transmission power of 10W or less. Conversely, for successful long-distance QSOs on the 160m and 80m Bands, increasing the transmission power is likely necessary.

7. Conclusion

The 40m Band 3λ Square Loop Antenna has one major drawback – it requires a large area of 32m x 32m, which can be inconvenient, especially when adjusting the ATU at night.
However, this antenna offers excellent cost performance by covering frequencies from the 160m Band to the 10m Band with high efficiency and performance. Its ease of installation and maintenance, along with its adaptability for disaster preparedness and opportunities for customization, can greatly enhance your amateur radio experience, providing more enjoyable operating moments.
To address the space limitation, incorporating linear loading presents a viable solution. This method allows the antenna to be installed in smaller spaces without compromising performance. I encourage you to take on this challenge.
Fig.12 shows a simulation result for a 10m x 54m rectangular loop with a feed point positioned

at one corner, elevated 6m above the ground. This design is suitable for narrow plots of land. Additionally, raising the antenna height to 20m lowers the radiation angle, enabling performance similar to that of a Rhombic antenna.

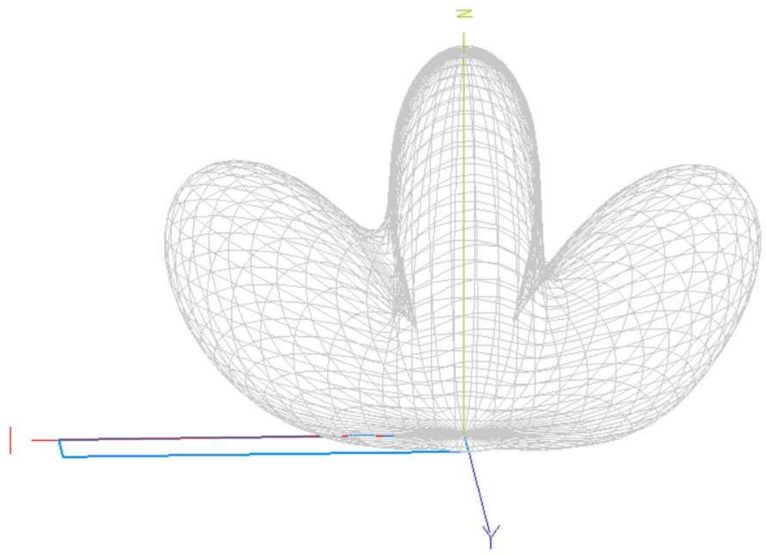

Fig.12: Example of installation on a long and narrow site

This antenna is highly recommended for installation in areas with height restrictions on structures or landscape regulations, such as scenic districts and resort areas, as well as for effective land use in farmlands, forests, wilderness, and coastal regions.
Its greatest appeal lies in the enjoyment and satisfaction of building a high-performance antenna with excellent natural noise resistance at low cost, relying solely on your own skills.
When installing the antenna alone, please pay special attention to wind protection and securing stable supports, and prioritize safe construction practices.
For a more detailed explanation of the construction process and analysis of experimental data, please refer to the following publications:

- **CQ ham radio QEX Japan No.54**
- **CQ ham radio QEX Japan No.55**

I highly recommend consulting No.54, titled *"40m Band 3λ Square Loop Antenna Experiment (Part 1)"*, and No.55, titled *"40m Band 3λ Square Loop Antenna Experiment (Part 2)"*, for additional insights and guidance.