Review Series to Celebrate Our 100th Volume

First English article of Yagi–Uda antenna

On the 100th anniversary of birth of Yagi–Uda antenna

By Qiang Chen[*1,†]

(Edited by Makoto Kobayashi, m.j.a.)

Abstract: Herein, the first English article demonstrating the Yagi–Uda antenna is introduced. The article was originally published in the *Proceedings of the Imperial Academy of Japan* in 1926.

Keywords: Yagi–Uda antenna, antenna, array antenna, directive antenna

In 1995, the IEEE Milestone was dedicated to Tohoku University for honoring the great invention of the Yagi–Uda antenna. On the plaque, the following text was noted:

> In these laboratories, beginning in 1924, Professor Hidetsugu Yagi and his assistant, Shintaro Uda, designed and constructed a sensitive and highly-directional antenna using closely-coupled parasitic elements. The antenna, which is effective in the higher-frequency ranges, has been important for radar, television, and amateur radio.

The IEEE Milestones program honors remarkable technical achievements in all IEEE-associated fields. The Yagi–Uda Milestone was the first to be dedicated to IEEE Region 10, which includes the IEEE Sections in Asian and Pacific regions. At present, the plaque is located in the Katahira Campus of Tohoku University (Fig. 1).

Fig. 1. IEEE plaque milestone of Yagi–Uda antenna, mounted in Katahira Campus of Tohoku University. (captured in April, 2024)

The Yagi–Uda antenna comprises parallel linear conducting dipole elements arranged in an endfire array, a driven element, several directing elements (directors), and reflecting elements (reflectors). It was the first directive antenna to utilize directors positioned in front of the driven element for narrowing the beam. The Yagi–Uda antenna was invented considering that the antenna's directivity can be increased when the lengths of the directors and spacing between the array elements are well designed. An antenna with high directivity can radiate radio waves in a narrow beam, allowing the transmission of signals over longer distances than an antenna with low directivity. Nowadays, the Yagi–Uda antenna is recognized as crucial with high directivity. Because of its characteristics of high directivity, simple feeding structure, and low wind-pressure, the antenna is widely used in radar, wireless communications, and broadcasting systems. Figure 2 shows a typical Yagi–Uda antenna used for UHF band terrestrial digital TV broadcasting in Japan.

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This paper commemorates the 100th anniversary of this journal and introduces the following paper previously published in this journal. Yagi, H. and Uda, S. (1926) Projector of the sharpest beam of electric waves. Proc. Imp. Acad. **2** (2), 49–52 (https://doi.org/10.2183/pjab1912.2.49).

doi: 10.2183/pjab.101.001

Fig. 2. (Color online) Typical Yagi–Uda antenna for TV reception; reprinted with permission from the website of Nippon Antenna Co., Ltd.

Tohoku University was found in Sendai in 1907 as Tohoku Imperial University, and the School of Engineering, initially comprising the departments of Mechanical Engineering, Electrical Engineering, and Applied Chemistry, was established in 1919. Hidetsugu Yagi, a founding professor of the Department of Electrical Engineering, advocated for research in telecommunications engineering focusing on areas such as vacuum tubes and antennas rather than the high-power electrical engineering fields such as generators and transformers, which were popular research topics during that time; the Yagi–Uda antenna was invented under these circumstances.

In 1925, Shintaro Uda presented the first report on measurement results, demonstrating that a narrow beam can be easily formed by accurately arranging parasitic elements.[1] However, only an abstract in Japanese appeared in the report.

In 1926, Yagi and Uda published the first English article on the Yagi–Uda antenna in the *Proceedings of the Imperial Academy of Japan*.[2] This was the first detailed description of the Yagi–Uda antenna, covering its geometry and characteristics. The Yagi–Uda antenna, comprising several straight metallic rods acting as reflectors and directors, was demonstrated in this article. The antenna's geometry, including the length of the directors and reflectors, as well as the spacing between them, was indicated, along with measured radiation patterns that demonstrated its high-directivity characteristics. To visually convey how the radio waves were directed along the director array, they used the term *wave canal* to illustrate the function of the directors.

Notably, the Yagi–Uda antenna was invented through an experimental approach involving trial and error. However, the presented design provided considerable insights into how to increase antenna directivity via directors. The paper stated that the directors should have a length shorter than half a wavelength, arranged along a line with intervals equal to or greater than a quarter wavelength. Two design examples shown in Figs. 3 and 4 in the original paper indicated that the length of the directors was 0.41 wavelengths, and the interval was 0.34 wavelengths. This antenna design closely aligns with our typical modern design. For example, a four-director Yagi–Uda antenna, shown as a design example in the classic textbook,[3] had director lengths of 0.40–0.44 wavelengths, with intervals of 0.31 wavelengths between the directors. This design provided a maximum directivity of approximately 12 dBi and 3-dB bandwidth of 10%.

We do not have straightforward methods for designing the Yagi–Uda antenna using closed-form formulas when the antenna is composed of a large number of parasitic elements as the reflectors or directors. We must rely on computer simulations to understand the behavior of electromagnetic waves related to the antenna geometry by solving Maxwell's equations. Typically, for a given specification, such as antenna directivity, we first determine the number of directors and reflectors. Next, we optimize the directivity by individually adjusting the lengths of the directors and reflectors, as well as the array spacing, using computer simulations. A Yagi–Uda antenna with high directivity requires a large number of directors and reflectors, and optimizing such antennas often takes a substantial amount of CPU time.

After publishing the paper in the Imperial Academy in 1926, Prof. Yagi visited the USA and presented the Yagi–Uda antenna at several meetings organized by the Institute of Radio Engineers (IRE). In 1928, he published another paper under his name alone in the *Proceedings of the IRE*.[4] This paper attracted considerable attention from radio scientists and engineers in the USA and European countries, sparking worldwide interest in the technology of directive antennas at UHF band, which is why the antenna is sometimes called *the Yagi antenna* or simply *the Yagi*. However, referring to this antenna as *the Yagi–Uda antenna* in recognition of Uda's contribution is common and appropriate.

The history of invention of the Yagi–Uda antenna and the subsequent researches at Tohoku University were introduced in a review paper.[5)]

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Profile

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[From Proc. Imp. Acad., Vol. 2 No. 2, pp. 49–52 (1926)]

18. *Projector of the Sharpest Beam of Electric Waves.*

By Hidetsugu YAGI and Shintaro UDA.

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(Rec. Jan. 9, 1926. Comm. by Hantaro NAGAOKA, M.I.A., Jan. 12, 1926.)

Suppose that a vertical antenna is sending out electro magnetic wave in all directions around it. If a straight metallic rod of finite length be vertically erected within the field of its propagation, then the behavior of this metal rod will be as follows :—

When the length of this rod is equal to or slightly longer than a half wave length, the current induced in it will be in phase with or lagging behind the E.M.F. caused by the electric wave, and the rod will act as a " Wave reflector."

If, on the other hand, the length be made somewhat less than a half wave length, the current induced in it will be leading before the E. M. F., and the rod will act as a " Wave director ".

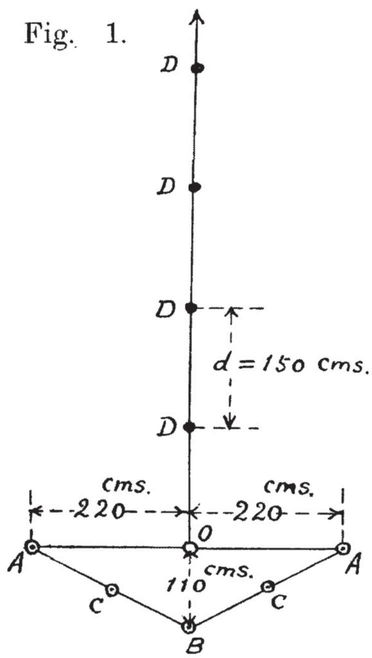
A single wave reflector placed behind a radiating antenna is sufficient to cause directive radiation of radio wave. It is especially efficient when placed a quarter wave length behind the radiating antenna. Again a wave director placed in front of and more than a quarter wave length distant from the radiating antenna is also effective in producing a directive radio wave.

When several wave director rods are arranged along a line with intervals equal to or more than a quarter wave length, the wave energy will be projected chiefly along this line, and the series of these wave directors forms what the authors will call a " Wave duct " or a " Wave canal '.

According to the authors' experience, a parabolic reflector is not necessary for producing a beam of radio wave. The simplest and comparatively effective reflector may be formed as stated below.

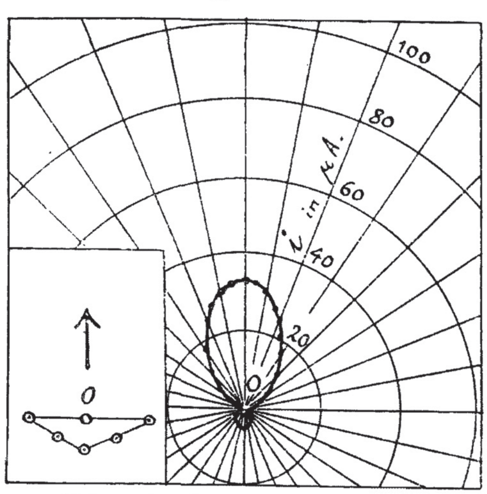
A wave reflector rod is placed a quarter wave behind the antenna and two more wave reflectors, one being on the left and the other on the right side of it, are placed a half wave distant from the antenna. (Fig. 1.) These three rods form a tri-antennary reflecting system which will hereafter be called a fundamental " Trigonal reflector ".

Fig. 1.



Wave length $\lambda = 400$ cs.
0 ......Sending or receiving antenna
A......Side reflectors
B......Back reflector
C......Screening reflectors
D......Wave directors
◉......Brass rod, 220 cms. long
●......Brass rod, 180 cms. long

Fig. 2.



Trigonal reflector with 5 rods.
Wave length = 440 cms.
Length of reflector rod = 220 cms.

Two more reflector rods C C are shown in Fig. 1. These are not as efficient as a reflector as A and B's, but their existence enables closer screening of waves in the backward direction, and when this reflector system is employed in a receiving station, they are specially effective to eliminate external disturbances from behind.

Combined with these screening rods, the trigonal reflector is now formed of five rods. The position of the screening rods are nearly midway between A nd B, and a slight variation of their position is practically ineffectual.

When the trigonal reflector is employed in a receiving station, it may better be called a " Trigonal collector ".

Now the projection of the sharpest beam ever produced of electric waves can be effected by the combination of a trigonal reflector and a wave duct. This combination will thus be called a "Wave projector." It is also very advantageous to employ a wave duct and a trigonal collector at receiving stations.

The directivity can be improved by increasing the number of wave director rods contained in the wave duct. As an extreme case, when the sending and the receiving stations are connected with a line of wave canal, the transmission of wave energy can be the most efficaciously accomplished.

Some typical results of observation with short electric wave are given below. Fig. 1. shows the plan view of the arrangement of conductors for the wave length

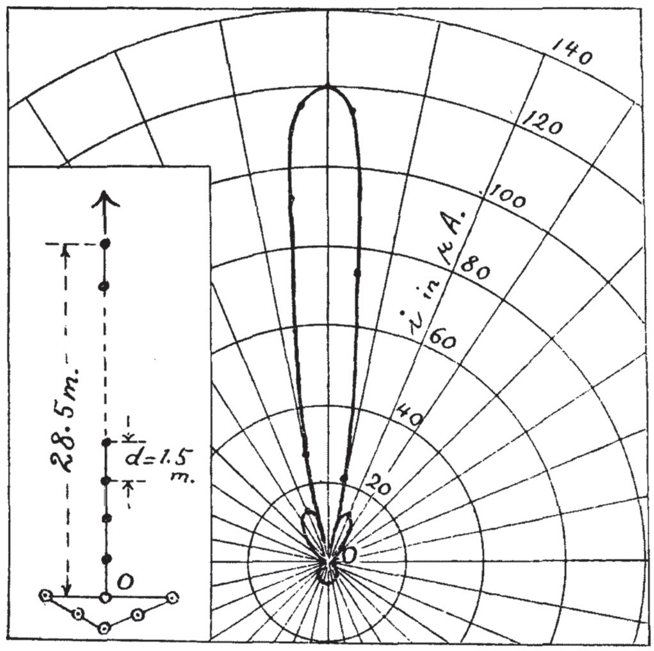


Fig. 3.

Wave projector.

Wave length = 400 cms.

◉ 5 rods, 220 cms. long

● 19 rods, 180 cms, long

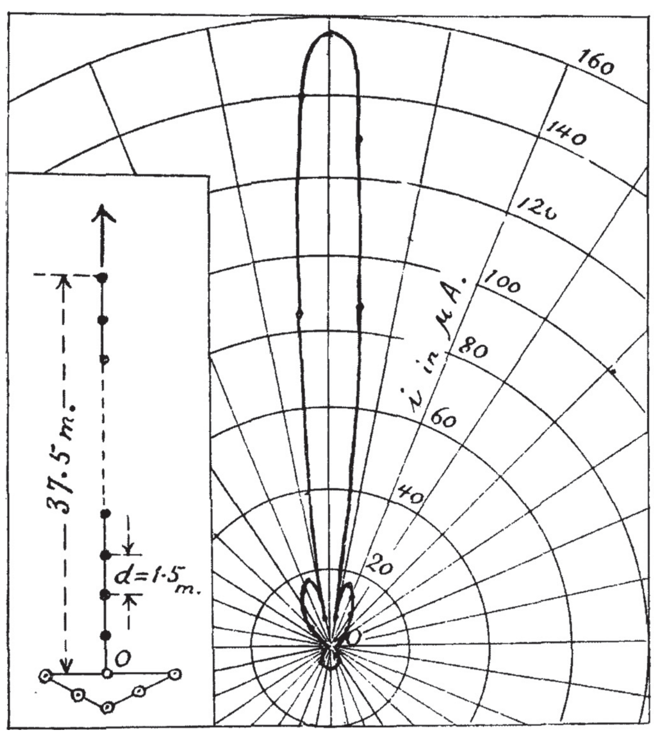


Fig. 4.

Wave projector.

Wave length = 400 cms.

◉ 5 rods, 220 cms. long

● 24 rods, 180 cms. long

of 4.4 metres.

In Fig. 2. is shown the directive effect of a trigonal reflector with five rods. No wave director is here employed, and the intensity is measured with a receiving system comprising a crystal detector and a galvanometer. It has been very carefully ascertained that this crystal system gives tde most consistent results throughout the long time of experiments.

In Figs. 2. 3. and 4., the radius vector of the polar diagram gives the measure of intensity in the receiving system placed in that direction, the distance from the sending station being kept constant.

Now if the wave duct or wave canal is provided, the directivity becomes remarkably augmented. In the case of Fig. 3., 19 rods of 180 cms. length (a half wave being equal to 220 cms.) were arranged along a line with interval of 150 cms. (a quarter wave being equal to 110 cms.). In the case of Fig. 4., 25 rods of 180 cms. length were set up with interval of 150 cms. The length of all the reflector rods was made equal to the half wave length, i.e. 200 cms.

The field measurements were made under the same conditions, and the short wave generator was also kept at exactly the same condition for all the observations of Fig. 2., Fig. 3. and Fig. 4.

It is easy to explain how the radiation in the side direction becomes minimum, and the polar diagrams prove the realization of the sharpest beam ever produced of electric waves.

Many observations of various cases have been made in the Tohoku Imperial University, Sendai, and further details will in time be published in the Journal of the Institute of Electrical Engineers of Japan.