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LETTER *Special Issue on Historical Review of Antenna Systems in Japan*

Tokyo Tower

Tetsuya ITSUKI[†a)], ***Nonmember***, **Kazuyoshi SHOGEN**[†], ***Regular Member***,
Toshiki KURASHIMA[†], **Kazumi NOGAMI**[†], ***and*** **Masahiko ARISHIRO**[†], ***Nonmembers***

SUMMARY The Tokyo Tower is the highest self-supporting steel tower in the world. Since it was built in 1958, the Tower has been a symbol of Tokyo and a well-known, major tourist attraction in Japan. The number of visitors reached 130 million in 1998. The highest number of visitors in one day was 40,000. The original purpose of the Tower was the transmitting of TV signals to the entire Tokyo Metropolitan area. As time passed, FM radio antennas and other equipment for public use were added to the Tower. Recently digital terrestrial antennas were installed on the Tower, a remarkable moment in its history. Digital broadcasting will start in 2003, using these antennas. This paper introduces the Tokyo Tower and its antennas, giving its construction history and its future in the coming digital broadcasting era.

key words: *Tower, digital broadcasting, TV broadcasting, FM radio broadcasting*

1. Introduction ([1], [2])

The Tokyo Tower is 333 meters tall, making it the tallest self-supporting steel tower in the world. It only weighs 4,000 tons, owing to remarkable advances in steel manufacturing and construction technology. You can see that the Tower is light for a metal tower if you compare it to the famous iron tower in Paris, the Eiffel Tower, which is 320 meters tall and weighs 7,000 tons. The Tower is repainted every 5 years, requiring 28,000 liters of paint to cover its surface. It is painted white and international orange according to aviation safety regulations. At night, the Tower is illuminated white in summer and orange in winter with 164 floodlights. This Tokyo landmark is very familiar to both tourists and natives.

The Tower is famous for the series of antennas used for terrestrial TV broadcasting. These TV antennas transmit nine channels. Their emissions cover about 12 million households in the Tokyo Metropolitan area, within a radius of about 100 km. Below the TV antennas, FM radio antennas are vertically aligned on the Tower. They radiate five FM radio signals for five stations [4]. The antennas currently mounted on the Tokyo Tower are shown in Fig. 13, and include digital broadcasting antennas.The transmitters for these TV and FM radio stations are located in the building at the foot of the Tower.

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[†]The authors are with NHK, Shibuya-ku, Tokyo, 150-8001, Japan.
a) E-mail: itsuki.t-gs@nhk.or.jp

Fig. 1 The Tokyo Tower.

Aside from broadcasting, the Tower is used for many public utilities. It has a strong-motion seismograph, a wind gauge, a camera for traffic control, and equipment to assess air pollution.

2. The History of Its Construction

In Japan, two stations in Tokyo; NHK-General and NTV, began TV broadcasting in 1953. An additional station; TBS, started in 1955. These three stations were broadcasting with their own TV towers when the government decided to license three more stations;

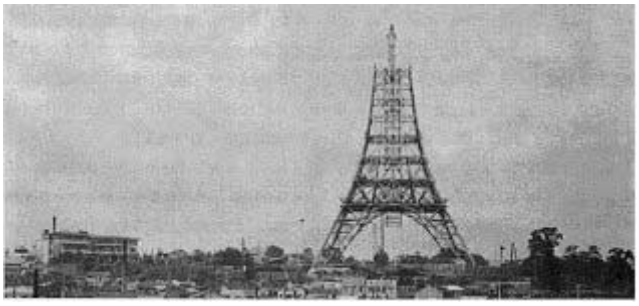

Fig. 2 The body of the Tower was completed on Aug 23, 1958.

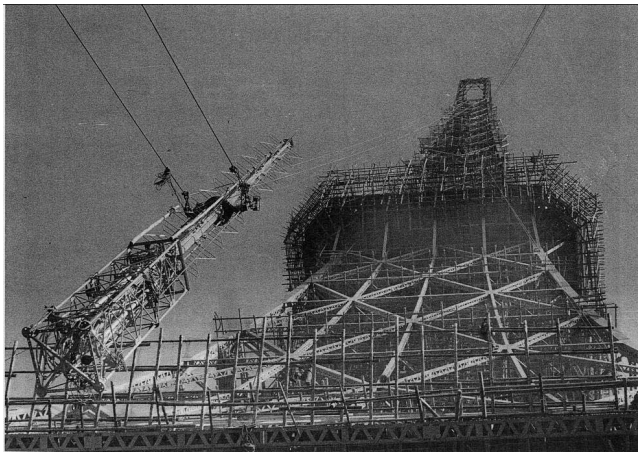

Fig. 3 The antennas being lifted to the top.

NHK-Educational, CX, and ANB, in 1956. If each new station had built its own tower, six TV towers in different places would have been transmitting signals and TV viewers would have been puzzled trying to decide which direction to point their receiving antennas. In order to avoid this bad situation for TV reception, it was necessary to build a multi-antenna TV tower that could be used for all TV services.

For TV signals to cover the entire Tokyo Metropolitan area, the height of the tower had to be over 300m. However, construction of a tower of this height was expected to be troublesome, because Japan is often struck by typhoons and earthquakes, which meant that the tower had to be as low as possible. The height of the tower depended on that of the antennas on top. In the first architectural plan, the height of the antennas was expected to be 60m; on the other hand, they were much higher in the broadcasters' plan. After careful consideration and severe negotiations about the type and stack count for each antenna, the total height of the antennas was finally set at 80 m. It was not intentional that the tower became "333m" high.

Construction of the tower began on June 29, 1957. In October, 1958, after inviting the public to make suggestions, the tower was named the "Tokyo Tower." Construction was completed on December 23, 1958. It is not an exaggeration to say that the fact that the construction only took 543 days was a miracle. The total cost was about 4.5 billion yen and the workers put in a total of 219,355 man-days.

Fig. 4 The super-turnstile antenna on the top of the Tower.

3. The TV Broadcasting Antennas([3], [4])

On the top of the Tower, a 6-stack super-turnstile antenna is emitting signals for the NHK programs broadcast on ch1 and ch3. A super-turnstile antenna is a typical TV broadcasting antenna used for the VHF band. It consists of stacked pairs of batwing antennas. Each pair is designed to intersect at right angles at their centers.

The antenna, which was the prime of its kind in the world, faced its first big challenge by having to meet several requirements. One of these requirements

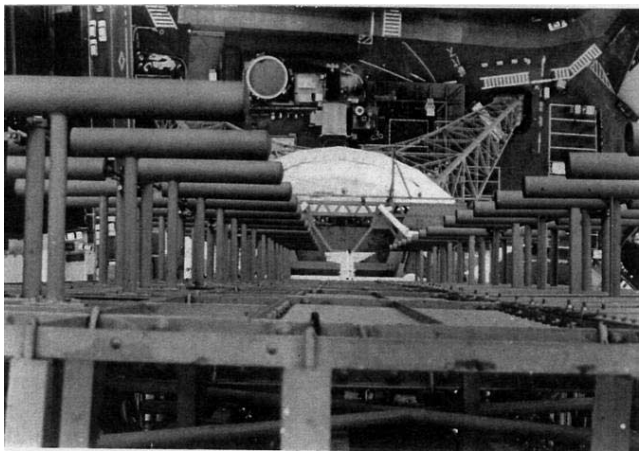

Fig. 5 The 2-dipole antennas on the Tower(downward view).

was that it had to emit ch1 and ch3 simultaneously, which meant that the properties of the antenna had to remain constant over a wide range of frequencies. It was very difficult to construct an antenna with those kind of frequency characteristics in those days. However, it was accomplished by adding a $\lambda/4$ stub to the feeder point of each batwing antenna. Another requirement concerned the power supply arrangements. The power supply had to separately provide high power to the upper 3 stacks and the lower 3 stacks for redundancy. This duplicated electrical feeder system had to use four feeder lines. The given space for feeder lines was small while the supply power was high. A new type of feeder line was developed because no existing feeder lines could supply such high power (50 kW $\times$ 2 channels) through the given small space.

Below the super-turnstile antenna, numerous 2-dipole antennas were stacked into five arrays aligned on the Tower for ch4 (NTV), ch6 (TBS), ch8 (CX), ch10 (ANB), and ch12 (TX). In order to provide equality among the channels' coverage areas, the higher the channel that they were used for, the higher on the Tower they were mounted.

The UHF TV stations using the Tower utilize twin loop antenna arrays for the ch14 (MX) and ch16 (UD) frequencies. The twin loop antenna was developed in Japan. Its constant characteristics over a wide range of frequencies enable frequency sharing. Another good point is its ease of maintainance, thanks to its simple structure and fewer number of parts. It has become very popular for UHF broadcasting in Japan. It is often used with a cover to avoid rain, snow, and so on

A twin loop antenna is often used as an "element" of an antenna array. This kind of array may have several stacks. Each stack is also an array consisting of several units, called "panels." Each panel has one or more elements, that is, twin loop antennas. Each element has an even number of radiators. An ordinal type has 2, 4, or 6 radiators, which are called 2L, 4L, or 6L

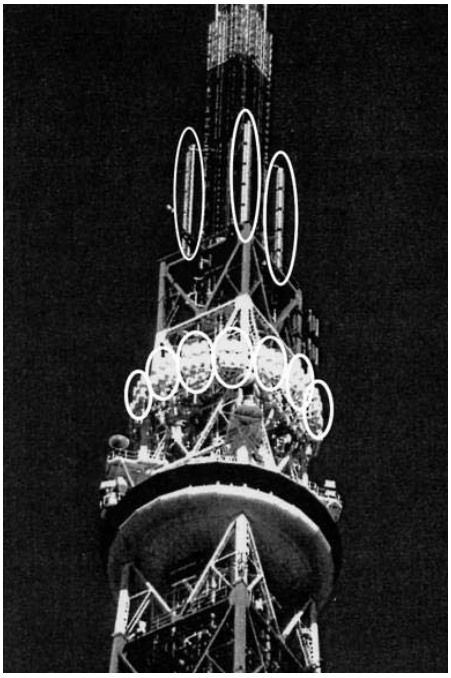

Fig. 6 The 5-stack twin loop antenna array in the upper white circles has four panels around the Tower. The 2-stack twin loop antenna array in the lower white circles has 15 panels.

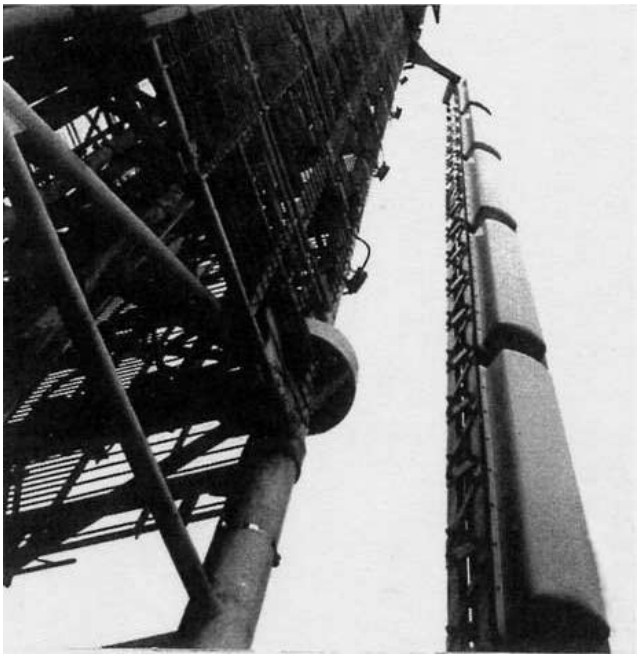

Fig. 7 A Close-up shot of 5 panels in the twin loop antenna array. Each panel has a 4L twin loop antenna.

twin loop antenna respectively. In a case where there are two or more elements on one panel, they are also usually combined into a small array.

The basic structure of a twin loop antenna has two radiators as shown in Fig. 8. Two loop radiators, with a circumference of about one wavelength, are fixed in

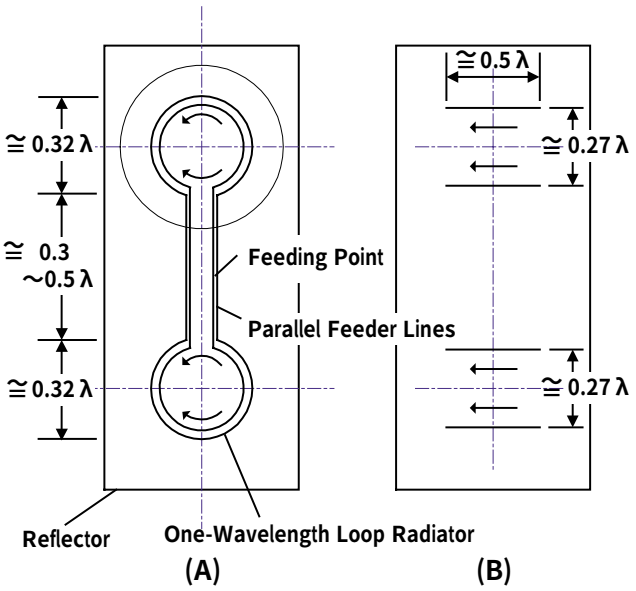

Fig. 8 (A)The circuit for a 2L twin loop antenna. (B)An equivalent dipole array.

front of a reflecting screen. They are connected by parallel feeder lines. The feeder points are at the center of these wires. Since an antenna is one-wavelength around, the radiation current flows along the loop as indicated by the arrows in Fig. 8. The radiators emit horizontally polarized waves just like the equivalent dipole array shown at (B) in Fig. 8. The vertical components of the wave on both sides of each loop kill each other, so do those on both radiators, because the feeder points are at the center of the feeder lines. The gain can be as high as 3 dB when 4 panels are fixed on the corners of a square to make a non-directional horizontal pattern, under the assumption that each panel has a 2L twin loop antenna with a reflecter 0.25 λ away from the radiators. It can be made higher by increasing the number of stacks, panels in one stack, elements on one panel, or radiators in one element.

4. The FM Broadcasting Antennas ([3], [4])

FM broadcasting in Japan was started on an experimental basis by NHK in 1957. Its transmitting antenna in Tokyo was located at Chiyoda. Nationwide FM broadcasting service began in 1969.

A 16-stack supergain antenna array was installed on the Tower in 1961. TFM started FM broadcasting in 1970, using the upper 8 stacks. In the same year, NHK-FM moved its transmitting site in Tokyo from Chiyoda to the Tower and began to use the same antennas as TFM, sharing the frequency band. The lower 8 stacks were used for back-up. J-wave started in 1965 and began to use the upper 8 stacks. It was first time in Japan that 3 high power transmitters shared the frequency band. (Fig. 9)

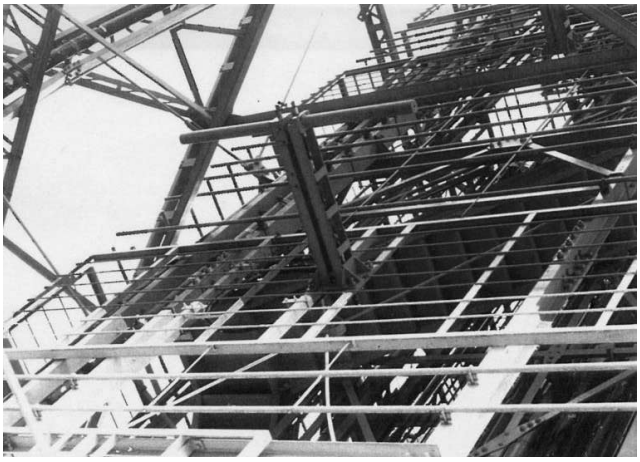

Fig. 9 The supergain antenna on the Tower.

Fig. 10 A twin loop antenna with rectangular radiators.

A twin loop antenna array can be used for FM broadcasting. UD and FM Interwave use twin loop antenna arrays. As shown in Fig. 10, the shape of the radiators can be rectangular. The shape doesn't matter as long as each radiator is looped into the same symmetrical shape with a size that is one-wavelength around.

5. The Digital Broadcasting Antennas ([5])

On June 6, 2002, the Tokyo Tower changed its appearance. Digital TV broadcasting antennas, as many as 300, had been placed around the Tower at a height of 250m as common equipment for six TV broadcasters. They are twin loop antennas that work as elements of two arrays, called "face-sharing omni-directional multi-

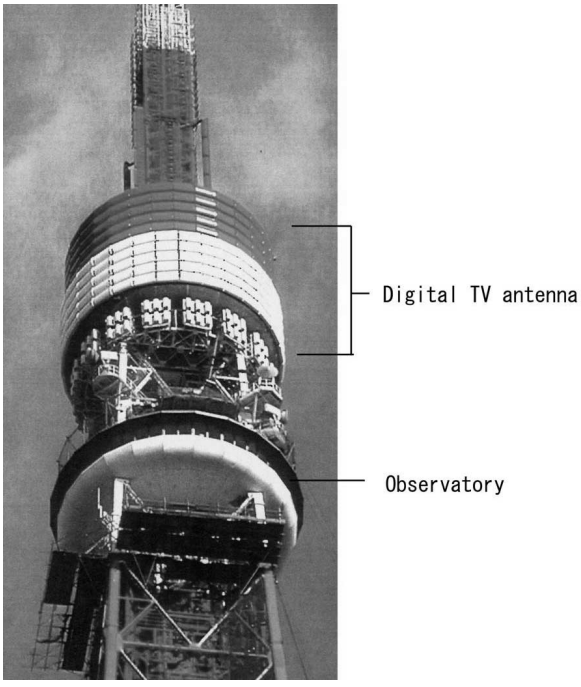

Fig. 11 The face-sharing omni-directional multi-panel antenna array for digital TV broadcasting.

panel antenna arrays"; one is painted white, and the other is international orange. Each array has 5 stacks. Each stack has two sets of 15 panels forming alternate circles. Each panel has 3 elements, which are 2L twin loop antennas.

The invention of this array solved two difficulties. One is the lack of space. The amount of room on the Tower for digital antennas is so small that the antenna array had to be compact. The other difficulty was in forming a non-directional array in a circle with a radius much larger than a wavelength. The radius of the circle is as long as over ten wavelengths. The maximum deviation in the horizontal pattern of directivity was successfully reduced to less than 4dB. Digital TV broadcasting will start in 2003 with channels in the UHF band.

Digital audio broadcasting will also start in 2003. A 2-stack array with 9 panels was installed around the Tower below the observatory on Oct 1, 2002. Its elements are 2L twin loop antennas. It is to be noted that vertical polarized waves will be used in this broadcasting, so the antennas were installed horizontally.

6. The Near Future in the Digital Era

Digital broadcasting in Japan is planned to start in 2003, but no other tower has been constructed and planned especially for digital broadcasting in Tokyo. Analog TV broadcasting service is planned to be continued for about a decade. Existing FM radio broadcasting service will last longer. Public instruments on the Tower will continue their important duties. The Tokyo Tower will play an even more important role after the beginning of digital broadcasting.

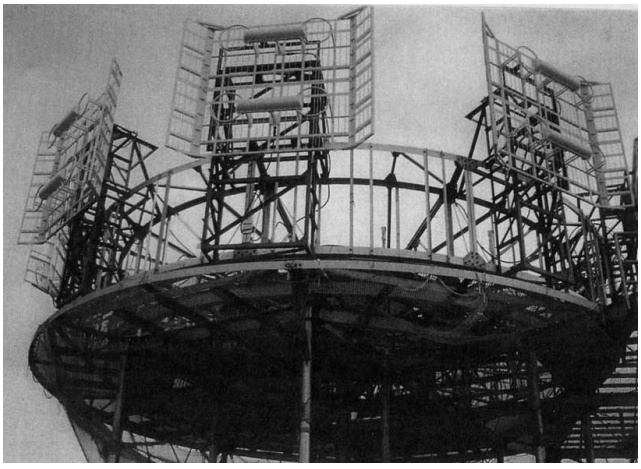

Fig. 12 The 2L twin loop antenna array for digital audio broadcasting, with 2 stacks and 9 panels, before the installation.

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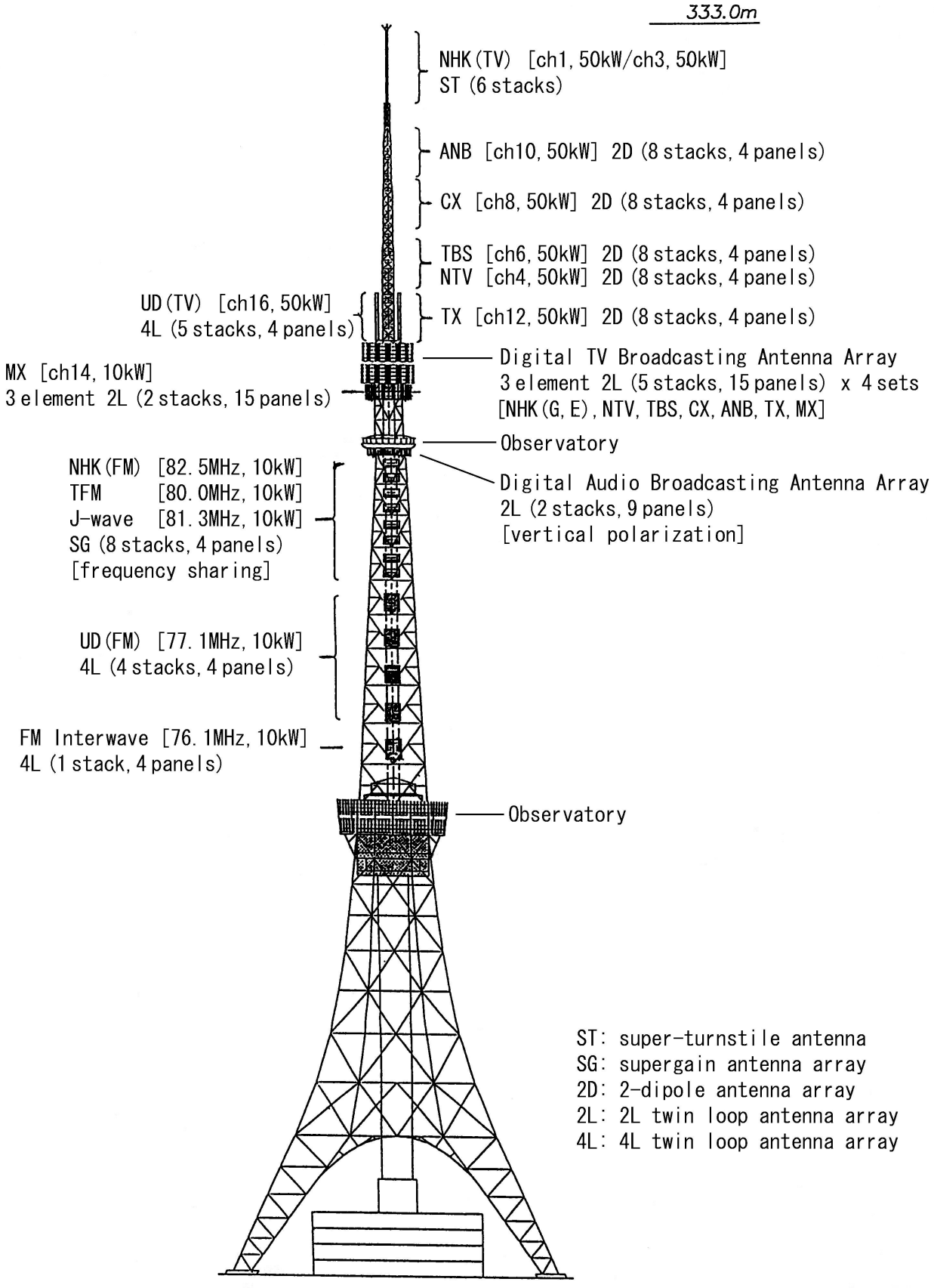

Fig. 13 The antennas on the Tower.