When I Think Back...

by Neville Williams

Hidetsugu Yagi: A pioneer who gave radio antennas a sense of direction

Look up the word `Yagi' in almost any book on radio communications, and you will be told that it refers to directional antennas of a particular kind. Rarely do the authors have much to say about the Japanese inventor, whose memory it perpetuates. So who was he, and why does his name now occupy such a conspicuous place in the predominantly 'western' jargon of modern electronics?

In my younger days, it took a while to catch up with the idea of designing wireless/radio antennas to have specific properties — beyond, perhaps, the broad assumption that big was beautiful! In fact, we didn't even talk about antennas.

In the bush, we put up 'aerials', signifying 100-odd feet of stranded copper wire suspended by insulators 30 feet or so above ground. There was nothing very scientific about the design, the physical details depending mainly on the space and resources available to each individual set owner.

For sure, we used to argue about insulators of one kind and another, or which way an aerial should face — but at the end of the day, there seemed little to choose between them.

Later, when I came to live and work in the suburbs, I found that aerials had been scaled down to a few pathetic yards of insulated bell wire draped from the chimney to an outhouse, or simply tacked to the picture rail around the living room.

Dictated by expediency, the chief requirements were ease of erection, and their ability to bring in the full complement of local stations.

Then, around 1936, I experienced the first faint nibbles by the hypothetical amateur radio 'bug' — as evidenced from the fact that I bought a copy of the *1936 ARRL Radio Amateur's Handbook*, which I still have.

The emphasis in those days was on long distance HF (high frequency) communication on the 80, 40 and 20-metre 'ham' bands and for such a purpose, I discovered, aerials could no longer be random lengths of wire — long or short.

They needed to be erected out of doors in an approved manner, cut to specified dimensions and coupled to the transmitter and receiver in a particular way.

In the amateur world, there were grounded antennas, Hertz antennas, doublets and zeppelins, centre fed, end-fed and so on.

They were all subject to mathematical calculation, and exhibited predictable directional properties and effective 'gain'. I was face to face with what the technical fraternity commonly refers to as 'antennas', designed for specific roles.

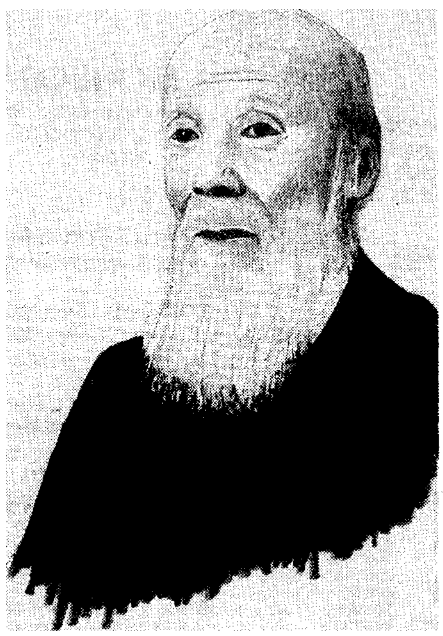

Fig.1: We haven't been able to obtain an original photo of Professor Yagi, but this artist's sketch is a good likeness.

UHF bands & equipment

The *1936 ARRL Handbook* also included special chapters on so-called 'UHF' receivers and transmitters. But the designs were still relatively primitive and the associated discussion of UHF antennas was, at best, sketchy and concluded thus:

'A final firm suggestion is that a directive array should be used for UHF working wherever possible. Using a directive array is an exceedingly inexpensive way of getting a substantial increase in effective transmitted power'.

Logically, one would have expected to find reasonable coverage in the handbook of the very practical Yagi-style VHF/UHF directional beams that had been developed and documented in Japan some 10 years before. Instead, I found one lone and non-committal reference to them, amounting to less than a half-column.

It would seem that, while the ARRL editorial team was aware of the generalities of directional UHF arrays, they hadn't got around to much in the way of what we might now visualise as practical UHF antenna 'plumbing', using off-the-shelf aluminium rods and tubing.

In Australia, about this same time (pre-1936) the then-technical editor of *EA's* predecessor *Wireless Weekly* John Moyle, and a number of fellow amateurs were spending periodic weekends setting up 5-metre equipment on mountain outcrops south and west of Sydney, to identify accessible vantage points for UHF communication. In the process, contacts had been made over up to about 200km. That they were using resonant rod antennas goes without saying, but it is unclear whether they had made much use, either, of directional arrays with Yagi-style reflectors and directors.

Three years on, a report in what was then ***Radio & Hobbies*** for June 1939 indicates that by then, 5-metre amateur activities were on the increase around Sydney and Melbourne, and in Western Australia. It mentions that increasing use was being made of (unspecified) directional antennas, mostly vertically polarised.

Again, the August '39 issue of ***R&H*** carried a report of a `sensational contact' on five metres between an amateur station in England and another in Italy.

The British station was said to be using a four-element horizontal beam, comprising a driven element, a reflector and two directors. While it would almost certainly have ***been*** a Yagi-based parasitic array, the term still didn't make it into the text.

Wartime technology

World War II put an abrupt end to such activities, but a lot of amateurs (Editor John Moyle included) ended up in the armed forces and exposed to antennas of all shapes and sizes, among them — ironically — Yagi-based arrays.

After the war, when the affairs of ***Radio & Hobbies*** were restored to some semblance of normality, we found ourselves beseiged by amateurs keen to get back on the air. We also found truckloads of =plus VHF and UHF equipment and miles of high quality coaxial cable. There was a powerful urge to adapt both the equipment and the techniques developed during the war to post-war amateur communication.

Up-dated information was also available from post-war textbooks — as, for example, the diagram in Fig.2 from the 1948 edition of the ***ARRL Handbook,*** showing at a glance the essential dimensions for a 4-element 50MHz Yagi beam. The active element depicted is a folded dipole with the two parallel rods/tubes scaled in diameter to provide a suitable feedpoint for a 300-ohm feedline. In the postwar years, Yagi beams rapidly assumed a special fascination for mechanically minded amateurs, especially when appropriate rotational mechanism and/or other hardware could be 'scrounged' cheaply ex-disposals.

I vividly recall picking up a bundle of 1-1/4" (32mm) tubular duralumin struts, apparently discarded by the De Havilland workshops, from a scrap heap near Sydney's wartime Bankstown aerodrome.

I also remember Ron Bell of RCS Radio, ever on the lookout for an eye-catching product, making available 360° glass compass scales for use in back-lit wall displays of beam direction, when using ex-disposals **'Selsyn'** motors for driving a makeshift antenna rotator. The Selsyn motors in turn could be bought for a proverbial song from firms like Ace Radio.

No less to the point, it didn't take a genius to calculate a half-wavelength at the desired operating frequency and reduce it by about 5% for the driven element. Or to work to the original length for a reflector, or knock off a further 5% or so for the director(s).

Graphs and tables were also available, postwar, to help determine appropriate element spacing, estimate feedpoint impedance and work out how to reconcile it with the available feed cable.

Whether or not we stopped to think about it at the time, Yagi's pioneering research dating back into the mid-1920's had added immensely to the fun of being a postwar amateur, particularly on frequencies from 28MHz up.

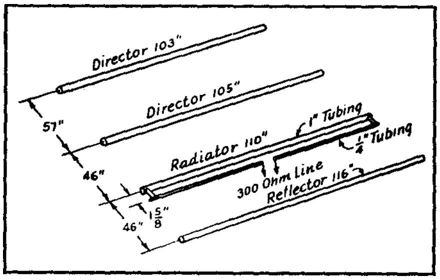

Fig.2: Diagram of a Yagi array for the 50MHz amateur band, from the 1948 ARRL Handbook. Construction of the beam and provision of a rotatable mounting mast made an interesting challenge, rewarded by more and stronger signals.

I recall embarking upon such exercises with considerable zeal and subsequently, along with John Moyle, keeping regular 6-metre **'scheds'** with amateurs in Canberra and in Young, the latter 270km away, on the far side of the Great Dividing Range. That done, we turned our attention to the 2-metre (144MHz) band, with 'stacked' Yagi beams to make the best of our still rather makeshift transmitters and receivers.

I well remember numerous debates about beam design in the ***R&H*** office with John Moyle, another amateur Maurice Findlay, and Raymond Howe who had specialised in antenna design in the RAAF.

The debates were to take a new turn a little later, when we became involved in commercial VHF 2-way radio systems for the Sydney ***Sun*** newspaper and the ***Sydney Morning Herald,*** owned by our then parent company.

A certain awkwardness

But, on the presumption that confession is good for the soul, I must admit to a certain diffidence about using the term Yagi' in such discussions. Over the years, I had grown accustomed to the many 'western' names in electronic jargon — Ampere, Baird, Boyle, Crookes, Edison, Faraday, Fleming, Galvani and so on through the alphabet to Volta and Wheatstone. What was Yagi doing in such auspicious company? With one letter in the index all to himself?

Could it be that the early tardiness in taking on board the Yagi research and terminology was a akin to my own attitude?

Racist? Undoubtedly! But, since those far-off days, I've spent decades trying to rationalise the attitudes originally nurtured in a country school, where we were encouraged to be proud of **our** British heritage, of the many red areas in the wall map, and of the invincible British navy that 'rules the waves'; a school where we made 'big deal' out of Wattle Day and a weekly flag ceremony; an environment where we felt openly curious about — and condescendingly sorry for — people who were neither British nor white. How fortunate we were to be both, in this great land of the free!

Years later, it fell to my lot to lead a party of ***EA*** readers on a **'Technitour'** to Osaka in Japan, via Hong Kong and Taiwan, for 'Expo 70'. On that tour, many of us experienced for the first time what it was like to mingle, as foreigners, with other races in their own environment. I especially remember touring around the city of Osaka and noticing primary and secondary schoolchildren on class excursions, uniformly immaculate in both dress and behaviour. How very different from my own scruffy, bare-footed, noisy schooldays!

Outside tertiary training centres, we came upon rows of motor scooters draped with the rider's helmet, gloves and goggles — with obviously no fear of them being 'pinched'. Unbelievable!

And outside many homes, with no room elsewhere for greenery, the occupants had arranged their cherished potplants on the footpath — with no fear that they would be despoiled by local yobbos!

Very obviously, and for whatever reason, the inhabitants of Osaka were unconsciously demonstrating a standard of civic honesty and conduct that shamed our own British/Australian cities.

Yagi, the man

Only recently have I learned that Professor Hidetsugu Yagi, pioneer of the antenna configuration that bears his name, was born in that same city of Osaka, to a family that had a long and distinguished history in the area. As such, he had good reason to take as much pride in his heritage as we do in ours. So who was Yagi and how did his name get to be included in our technical jargon?

For a detailed answer to that question, I am indebted primarily to W.A. Atherton for his article in the venerable British magazine *Electronics & Wireless World,* for January 1989. He, in turn, acknowledges the assistance of Professor S. Adachi of Tohoku University, and of a Mr and Mrs J. Loftus who helped in translating the Japanese text. As already noted, other publications to hand deal variously with Yagi antennas, but make only the briefest reference — if any — to the inventor.

Well then, Hidetsugu Yagi was born on January 28 in 1886, one year before Heinrich Hertz' historic demonstration of generating, propagating and detecting radio waves. He was the second son in a family which, for generations, had held responsible positions under the contemporary shogun — hereditary commanders of the Japanese army, whose authority, for centuries, rivalled that of the Emperor.

When his older brother 'lost face' by dealing in stocks and shares (considered at the time to be little better than gambling), Hidetsugu became, to all intents and purposes, the eldest son in his family.

By conviction an idealist and a socialist, he was elected at one stage to the upper legislative house, roughly equivalent to Britain's House of Lords. It soon became evident, however, that his ideas were incompatible with those of his peers and he deliberately withdrew from traditional politics, preferring to air his views in print.

Yagi was, in fact, a prolific writer in newspapers and popular magazines, as well as in scientific journals. His wide-ranging interests covered working conditions and labour relations, society and its attitude to science, and the ends towards which he believed scientific research should logically be directed.

Communication by electrical means was also very much in his mind and, underlaying it all, was a fundamental `religious' conviction, a respect for a power beyond that of mere mortals.

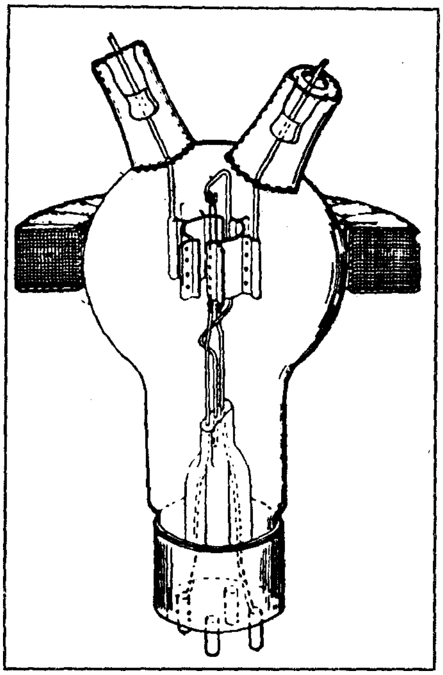

Fig.3: A split-anode magnetron, as Illustrated In Terman's Radio Engineer's Handbook (McGraw-Hill, 1943). It was developed from the original Hull/GEC magnetron, by Yagi and his student, Kinjiro Okabe.

Academic, lecturer

Back to his technical career, Yagi had graduated from the Tokyo Imperial University (now Tokyo University) at the age of 24, and became a teacher at the Sendai Engineering High School. Some 200 miles north of Tokyo, Sendai was a city in its own right with a population of a million or so people.

Four years later, the Ministry of Education sent him abroad to further his studies — a fairly common practice at that time. He found himself at the University of Dresden, involved in the broad study of resonance under Heinrick Barkhausen.

In due course (1919) Barkhausen was to go down in history as the discoverer of the magnetic domain effect, but in 1914 he was much more concerned with the generation of continuous electromagnetic (Hertzian) waves produced by arcs — a subject in which Yagi himself already had a longstanding interest. It so happened that Yagi was on a study tour of Austria, Switzerland and Italy when the Great War broke out, and instead of returning to Germany, he decided to abandon his study notes and make his way direct to England.

There, he made himself known to the famous J.A. Fleming, by then 65 years of age and Professor of electrical engineering at the University College, London.

Having been Marconi's engineering consultant for his historic work around the turn of the ***century, and*** as inventor of the thermionic diode valve, Fleming was a world authority on the technology of wireless communication.

Short of students at the time, he warmly welcomed the young Japanese graduate and readily agreed to monitor his already extensive studies in the subject. After a time with Fleming, Yagi moved on to the USA for a brief stay at Harvard University, before returning to Japan in 1916 to resume his teaching career.

Shortly afterwards, the Sendai High School was merged with the Tohoku Imperial University as the new Faculty of Engineering and, two years later (1921) Yagi received his doctorate. Historically, he is still acknowledged as one of the prominent figures whose original and creative research helped to establish the traditions and the reputation of the University's Engineering Department.

Modern electronics

Already well versed in the established electrical methods of producing continuous electromagnetic waves, Yagi's concepts took a quantum leap when a Japanese naval officer, returning from the USA, told him of the magnetron tube which had recently been invented by Albert Hull in the Research Laboratories of GEC (the General Electric Co) in New York.

Yagi seized the first chance to incorporate the magnetron into his own work and by 1927, one of his research students, Kinjiro Okabe, not only managed to produce oscillations with a wavelength of a few tens of centimetres, but obtained increased power levels with the invention of the split-anode magnetron (Fig.3).

Another of his research students, Shintaro Uda (see panel) supplemented ***this*** work by performing experiments under Yagi's supervision, which led to the development of directional antennas based on a 'wave canal' created by a series of self-resonant 'passive' (or 'parasitic') directors placed in front of the driven element.

The combination of the split-anode magnetron and the beam array proved a major contribution to the technology of UHF communication, and brought the Japanese research to the attention of western engineers.

In western literature, the hallmark paper is: H.Yagi, 'Beam transmission of ultra-short waves', in ***Proceedings of the***

IRE (USA) Vol.16, No.6, pages 715-741, June 1928. It was later reprinted in *Proc. IEEE*, Vol.72, 634-645, May 1984.

The paper was in two parts, Part 1 dealing with performance of the Yagi-da antenna system at wavelengths of approximately 4.4 metres and 2.5 metres. By accident or design, these had direct implications for amateurs using the 5-metre and 2-metre bands.

Part 2 covered the generation of centimetre waves by split-anode magnetrons — on 8, 12, 19 and 40cm — with credit being given to GEC for the original magnetron and to Okabe and Uda for their respective and very considerable contributions to the research. While much of the presentation had already been published in Japan, Yagi promised that future publications on the subject would appear in English.

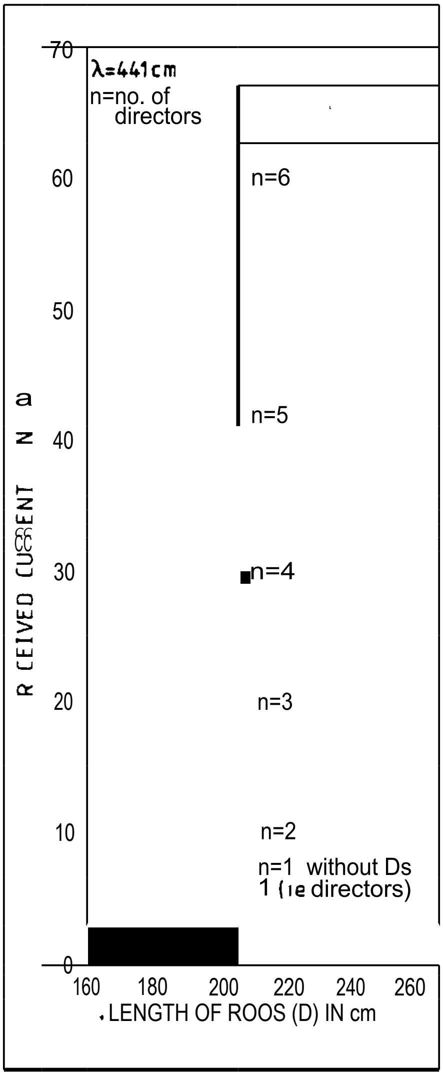

***Fig.4:** Curves from Yagi's paper to the IRE (USA), showing the relationship between received signal current and the number of directors in an experimental beam.*

Yagi fundamentals

In presenting an overview of the Yagi-Uda antenna, Yagi emphasised that metal rods (or tubes) of a finite length have a natural frequency of resonance, which can be used to take advantage of their natural directivity and/or their ability to act as reflectors or directors of energy in particular circumstances.

In a typical array, a triangle of three or five rods of appropriate length and spacing, behind and parallel to the driven element, could form a 'trigonal reflector' and concentrate the transmitted energy in a forward direction. Further elements cut to size and ranged in front of — and parallel to — the driven element would constitute a 'wave canal', further concentrating the frontal beam.

Some 22 figures in part 1 of the presentation illustrated the role of reflectors and directors, the effect of varying the number and spacing of elements, antenna height, polarisation and so on. It was noted that the findings were complementary for both transmitting and receiving — in one case as an effective power gain, in the other a similar improvement in effective sensitivity. Typical diagrams (Figs.4 and 5) show respectively the increase in received signal current with the addition of successive directors, and the gain and directivity of a complex array using one reflector and 20 directors.

Presentation of the papers prompted vigorous discussion, with J.H. Dellinger, Chief of the Radio Division of the US Bureau of Standards, rating the paper as one that was destined to become a classic in technical literature.

But despite the explicit nature of the presentation and its obvious relevance to amateur band communication, there appeared to be little immediate response by amateur station operators to the Yagi-Uda concept. In his comprehensive *Radio Handbook* (20th edition, 1975, Howard W.Sams & Co, Indiana USA), William On observes that the Yagi-Uda beam system was invented and publicised in Japan in 1926, and introduced into the USA via the IRE in 1928. Yet he notes that it was not until 1935 that it found any significant application in the amateur ranks, which accords with my own impression of the situation, as mentioned earlier.

Widely used post war

However, based on post-war experience, On was assuring his readers (in 1975) that: 'No other antenna exists which can compare, size for size, with the power gain and directional characteristics of the parasitic array'.

He goes on to discuss the properties of two-element and multi-element beams for the HF bands, along with derivatives such as stacked Yagis, loaded (shortened) elements and multi-band versions. Even the cubical quad finds a place in the scheme of things as an opened-out folded dipole, associated with similarly configured parasitic quad directors.

Ina separate chapter on VHF and UHF antennas, the Yagi configuration features prominently in handyman 'back-yard' arrays, for use on amateur bands from 50MHz up or for the reception of satellite signals. Much the same applies to other postwar textbooks covering amateur or other communications.

However, if there was ever any doubt that Yagi had 'arrived' post war, one need only scan the rooftops in any western environment to note the proliferation of television antennas. A few use multiple elements connected to the downlead, but the majority are derivatives of the Yagi formula, with one element — or one for each band — connected to the downlead and most of the others serving as parasitic reflectors or directors.

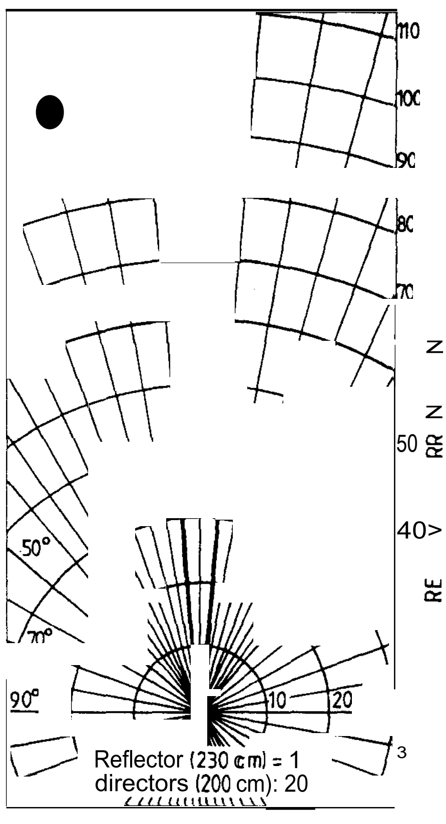

***Fig.5:** Another typical curve from Yagi's IRE paper, based on experimental work by Uda, showing the directivity pattern of an array involving one reflector and twenty directors.*

Over the years, television engineers worldwide have contorted the Yagi-Uda concept to achieve their own objectives. They have worked out the classical dimensions to suit the centre of the appropriate band, used folded dipoles for the active elements, stretched the reflectors and foreshortened the directors — in an attempt to cover more stations while still retaining some semblance of signal gain and directivity.

In Australia, they have pulled technical tricks by using long driven elements to function as simple dipoles for low-band VHF TV channels, and coaxed those same dipoles to function in harmonic mode for the high-band channels.

They have used separate long and short active elements to cover the low-end and high-end channels, coupling them both to the same downlead in a way which will hopefully prevent one from being adversely affected by the presence of the other.

But why do I keep saying `they'? With the willing co-operation of my one-time editorial offsider, Phil Walson, I remember setting aside the precision of the Yagi-Uda approach and going through exactly the same technical contortions to arrive at a TV multi-channel array which could be described for *EA* readers.

To assess its gain and directivity, we mounted it on exactly the same mast on my backyard shack which had served, years before, to support the 5-metre and 2-metre amateur band arrays.

Other fields

I was conscious at the time that we were all compromising Yagi's carefully researched design criteria, but I doubt that Yagi would have cared. By that time he had moved on to other things.

Yagi's team had broken up in the early 1930's with Uda becoming a professor in his own right in the Tohoku University and Okabe a professor at Osaka University, to which Yagi himself subsequently moved. There, Yagi and Okabe turned their attention to radar, working initially on an idea that Yagi claims first occurred to him during his visit to Germany before the outbreak of World War I.

It involved transmitting a continuous radio beam, on the assumption that an aircraft flying through it would cause partial reflection of the signal, which could hopefully be discerned by Doppler techniques.

Working on this system around 1936, Okabe is credited with having invented the first Japanese radar system.

The longest wartime continuous-beam system actually set up by the Japanese reached from Japan to Taiwan — a distance of 650 miles — near enough to 1000km. (See R.I. Wilkinson, `Short Survey of Japanese Radar', in *Electrical Engineering* Aug/Sept. 1946, 370-377 and Oct. 1946, 455-463). In concentrating on a continuous beam, rather than time multiplexed pulsed transmission and reception, they had selected the wrong technology.

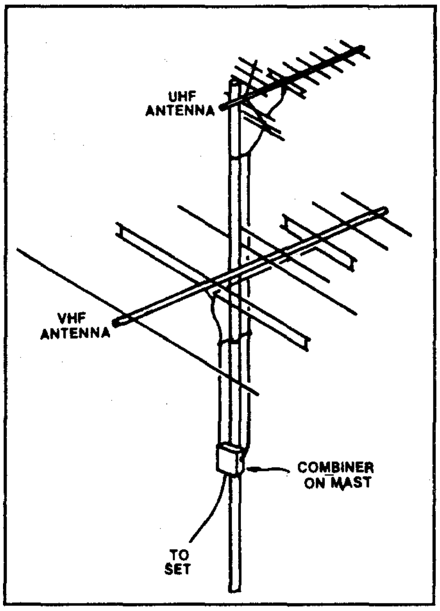

Fig.6: Reprinted from the April 1986 Issue of EA, this diagram shows a UHF TV Yagi at the top with folded dipole and trigonal reflector. Below is a composite Yagi with two sets of elements for the low-end and high-end VHF bands.

However, as the man nominally in charge of Japanese civilian fundamental research, Yagi bitterly criticised the Japanese High Command for their piecemeal approach to electronic research. The army and navy had policies of their own, but neither attached much importance to radar research.

Each saw radar as an essentially defensive measure, which would have little relevance to a future war in which they expected always to be on the offensive. This time Yagi was right but, ironically, his own home was firebombed in 1945 and much of the research data he had assembled over the preceding 30 years went up in flames along with it.

With hindsight, it is interesting to speculate what the scenario might have been, had the brilliant team of Yagi and Okabe received the backing of the Japanese High Command in the mid 1930's. Britain, perchance, might not have entered the war with such a commanding lead in radar research.

At the end of hostilities, Hidetsugu Yagi was questioned by the Allied War Commission about the scientific research he had undertaken during the war. His answer: "I did my best for my country. I did my best to defeat the Americans!"

Instead of denying all, as many others had done, he spoke proudly of his work, such that one of his American questioners walked over and shook his hand as a token of respect.

Upon retirement, he was recognised as an Emeritus Professor of both Tohoku and Osaka universities. He was a member of the Japan Academy and an adviser to the Yagi Antenna Company (which he founded in 1952), the Japan Television Broadcasting Network, the Tokyo Express Electric Railway, and various other scientific councils and government agencies.

In addition, he was a special correspondent for a large daily newspaper and chairman of a number of consumer-level associations. His last and perhaps most notable award was the Cultural Order of Merit, conferred upon him by Emperor Hirohito in 1976 -- the year in which he died at age 90.

Such are the reasons why he finds a place among the predominently western pioneers whose names feature in our western technical jargon. ■

Shintaro Uda (1896-1976)

Ten years younger than Yagi, Ude attended Tohoku University as a student in the 1920's while Yagi was lecturing there. He served as Yagi's student and research assistant, and performed many of the experiments which formed the basis of Yagi's paper to the American FIE in 1928.

Uda gained his bachelor's degree in 1924 and his doctorate in 1911. During that period, he wrote nine papers in Japan on the beam antenna system, and was co-author with Yagi of a number of others. Yagi acknowledged this fact in his presentation to the IRE, and his role is sometimes marked in technical literature by *references* to the Yagi-Uda antenna. ,

In 1932, Uda received an award from the Imperial Academy of Japan for his research into microwaves and, in 1936, was appointed Professor of Electrical Communication Engineer- at Tohoku University. in the period 1955-58 he served also as a UNESCO expert at the National Physical Laboratory in New Delhi, India.

Ude retired in 1960, becoming Professor Emeritus at Tohoku, but was thereafter appointed as a professor at the Yokohama University. He died in 1976, the same year as his one-time mentor.