Arboreal Aerials – Or Using Trees As Antennas

by Brian Austin, G0GSF

In 1975 a paper with the intriguing title of *Trees Performing as Radio Antennas* was published in the prestigious *IEEE Transactions on Antennas and Propagation* [1]. The fact that it appeared in the January issue and not that of April derailed the suggestions of some that this might be some sort of editorial wind-up. Interest was further increased when we noted that it was written by three authors whose affiliation with the US Army Electronics Command at Fort Monmouth indicated that someone, at least, was taking this work seriously.

The fact, too, that the Vietnam War had, by then, been underway for more a decade may well have had something to do with this research. And so it had.

Radio In The Jungle

The research started many years before in the early 1960s with the driving force behind it being the problem of communicating by radio through the dense jungles typical of parts of south-east Asia. The US Army carried out some work directly and also sponsored research by various universities and research institutes. Naturally, given the range of equipment used by the Army, both HF and VHF were involved and this necessitated looking at both radio propagation and antenna issues across a wide frequency range.

It is particularly interesting to note from the various reports and papers that were published during this time that interest soon began to focus on the use of the ionosphere, even for communications over very short distances of just a few miles. The reason was that the wet vegetation in the jungle brought about significant attenuation of signals at VHF – the frequency range that was used predominantly by all armies after the Second World War for such short-range communications – and so some alternative was sought, and this involved HF.

It is somewhat ironic, given the experience of the British Army (especially at Arnhem) not many years before, when its horribly under-powered HF equipment was found so wanting, that now those same frequencies in the low megahertz range were once again in favour. But there was one very significant difference. The requirement in the 1960s was to launch not the ground wave, but rather a sky wave at very high take-off angles and to use the ionosphere to reflect the signal almost straight back in order to produce coverage over distances of just a few miles that were quite impossible at VHF because of the high jungle attenuation.

The peculiar mode of propagation involved is now known as Near Vertical Incidence Skywave or NVIS for short, but this catchy title seemingly took quite some time to emerge. The earliest mention of it that I have found appeared in a 1979 publication by the US Army [2]. Until then the terminology concentrated more on the antennas than the propagation mode with 'field-expedient antennas' being very much the major interest of the researchers.

One should be aware that the British Army, through the involvement of its Army Operational Research Group (AORG) as long ago as 1943, fully appreciated the problems of using VHF in the jungle and also the advantages of using a high angle mode at HF to overcome them. Three reports, dealing specifically with these issues, were published that year by the AORG [3,4,5] and all had been prompted by the war in Burma, then in full swing. Twenty years later, anti-communist forces led by the United States became involved in a bitter battle against North Vietnam and its allies. Again, radio communications proved difficult in the jungle and much US Army-sponsored research went into finding possible solutions. NVIS was undoubtedly one of them, but even more radical ideas were looked at too.

Maybe There's Another Way?

It is clear that a considerable amount of lateral thinking went on at the US Army Electronics Command research laboratories in Fort Monmouth, N.J., and the man responsible for much of it was Dr Kurt Ikrath, a physicist and prolific generator of patents covering a wide swathe of military communications. One of Ikrath's interests was the challenge of using various natural and man-made objects and structures (including the human body) as antennas.

Trees possessed many characteristics that seemed well suited to such a role; they were often tall, usually vertical and they contained a fluid or sap transportation system known by their exotic botanical names of phloem and xylem. These tissues allowed the movement of the various fluids which supported tree growth and kept it alive. Since the xylem transported mainly water and inorganic ions from the soil upwards through the trunk and branches it should, thought Ikrath, lead to living trees being reasonable conductors of electricity. And if a radio frequency electrical current could be caused to flow within the tree then radiation would occur as a natural consequence of Maxwell's equations. The problem was how to induce that current into the tree and hence into the xylem. And this is where the HEMAC came in.

The HEMAC

HEMAC is the acronym for Hybrid Electromagnetic Antenna Coupler. On

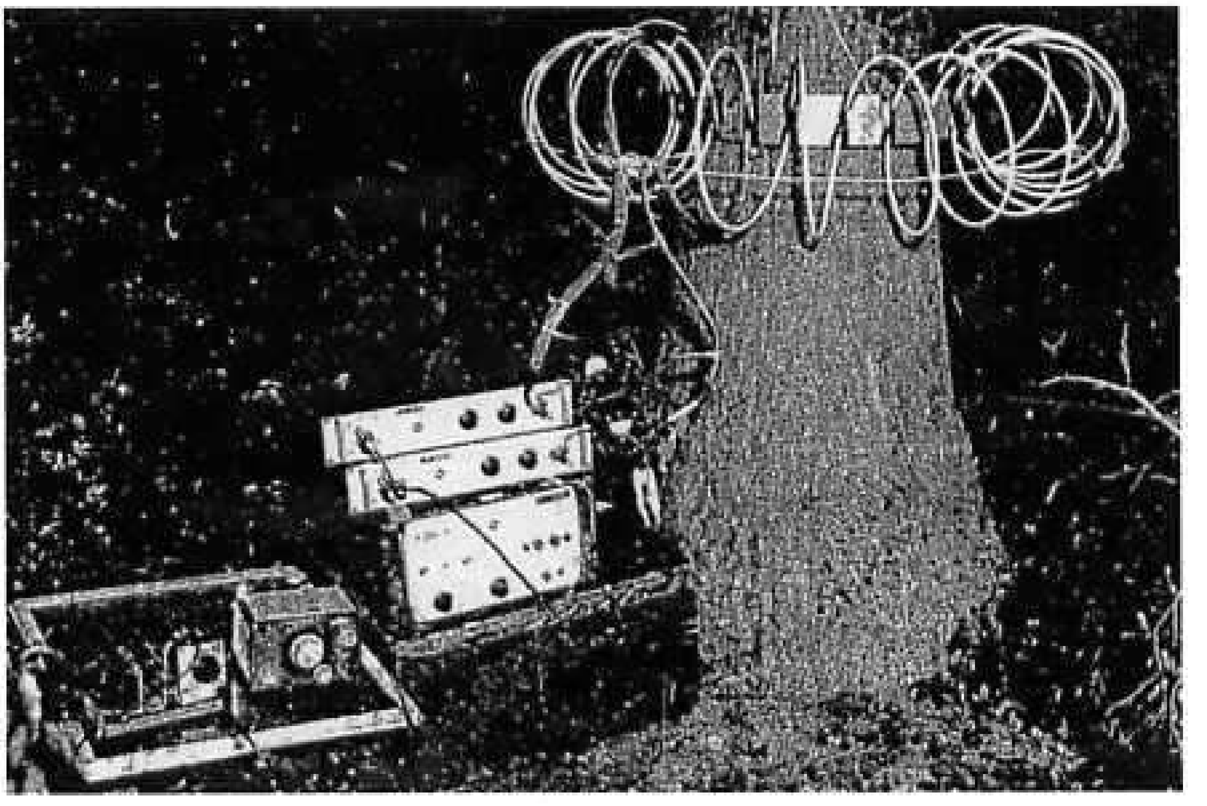


Fig.1. (left) The HEMAC (shown by the arrow) on a tree in the jungle. Reproduced with permission from Ikrath et al, IEEE Trans. on Antennas & Propagation, *Jan.1975, (©1975 IEEE)*

Fig.2. (above) An enlarged view of the HEMAC-coupled to a large oak tree

closer examination it turns out to be what might now be called a toroidal coupler, or current transformer, consisting of a torus-shaped coil of wire with a diameter large enough to be wrapped around the trunk of a tree. As Ikrath described it, a typical HEMAC might consist of 24 feet of insulated wire wound into a coil about eight inches in diameter that produced a flexible toroidal spiral of about eleven turns which can then be expanded and wrapped fairly uniformly around the tree trunk.

The transmitter is connected to the HEMAC through a variable capacitor so that, at resonance, maximum current can be driven through the toroid and the resulting circumferential magnetic field (around the tree trunk) then induces a secondary current (as in a transformer) which flows, or so it is hoped, longitudinally up and down the tree trunk. All of this is in line with the laws of electromagnetism and, if the tree is a reasonable electrical conductor, then some power should be radiated from it.

From the geometry of the HEMAC and the tree to which it is coupled we would expect the radiation to be vertically polarised and omnidirectional in terms of azimuth. That's the theory. But only experiments would show whether this actually happened in practice and, if so, how effective the process is. And so Kurt Ikrath and his colleagues at the US Army's Electronics Command set up an extensive experimental programme to test the theory and to evaluate the performance of trees as antennas. The initial decision was to use both medium frequencies, or MF, (0.3 to 3MHz) and HF (3 to 30MHz) to provide valuable information about the efficiency of the HEMAC-coupled antenna, as well as about signal propagation through the forest surrounding the radiating tree.

First Test Results

In 1969, a 450kHz transmitter, producing 35W, was matched to the impedance of the HEMAC-coupled tree. An HRO-500 receiver, which covered the very wide range from 5kHz to 30MHz, was mounted in a Jeep with a 15 foot vertical whip antenna and used to monitor the signals received within the test area around a military site in New Jersey. The results obtained were remarkable [6].

Not only were CW signals heard nearly 35 miles away, while an amplitude-modulated tone could be copied to beyond 15 miles from the transmitting site, but there was a marked directional effect as well. The HEMAC-tree combination not only radiated, but it also (somehow) produced significantly greater signal strengths to the south than to the north!

The author of the report offered various tentative suggestions as to what may have been causing this directional effect and he noted that the forest contained tall 45 foot oak trees to the north, in somewhat undulating ground that was predominantly moist, whereas to the south the trees were a mixture of considerably shorter oaks and pines, only about 25 feet high, while the soil was very much drier and the ground flatter. The transmitting site was within the oak forest but was very close to the boundary between the two arboreal regions.

Moving the transmitter east or west among the oaks caused no marked change in the directional effect whereas siting it just a short distance away to the south amongst the mixed forest of more uniform height and on level ground – while still using an oak tree as the 'antenna' – caused the coverage area to become almost omnidirectional. Though the directionality was both unexpected and rather surprising there was no doubt that the HEMAC-coupled tree performed rather well as an antenna. And there was even more to come.

HEMAC At HF

Initial tests were also conducted at HF using 12W of power at frequencies between 4 and 5MHz with a HEMAC connecting the transmitter to an oak tree. Transmissions ranges of between seven and eleven miles were achieved. Though this result, and those at MF, were extremely promising, the deciduous forests of New Jersey hardly represented the jungle in south-east Asia and so more

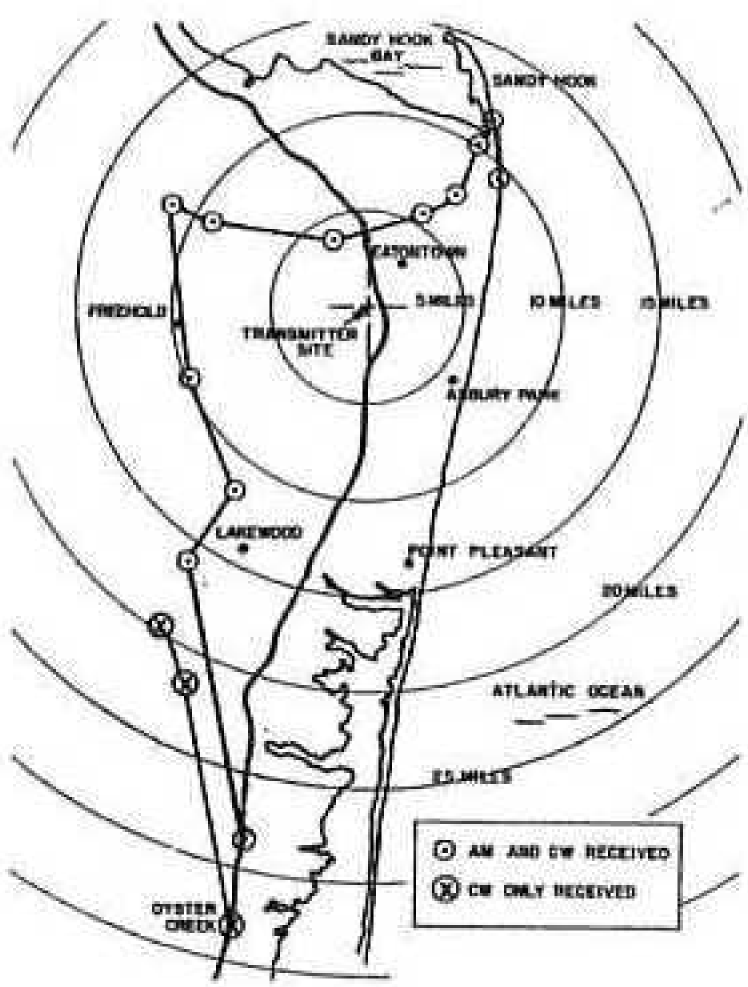


Fig.3. Experimental results at 450kHz in New Jersey

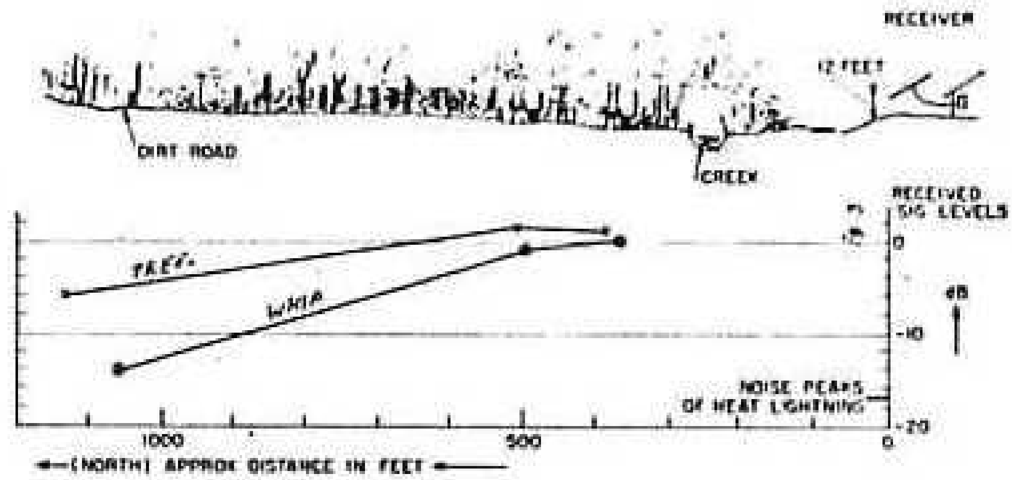
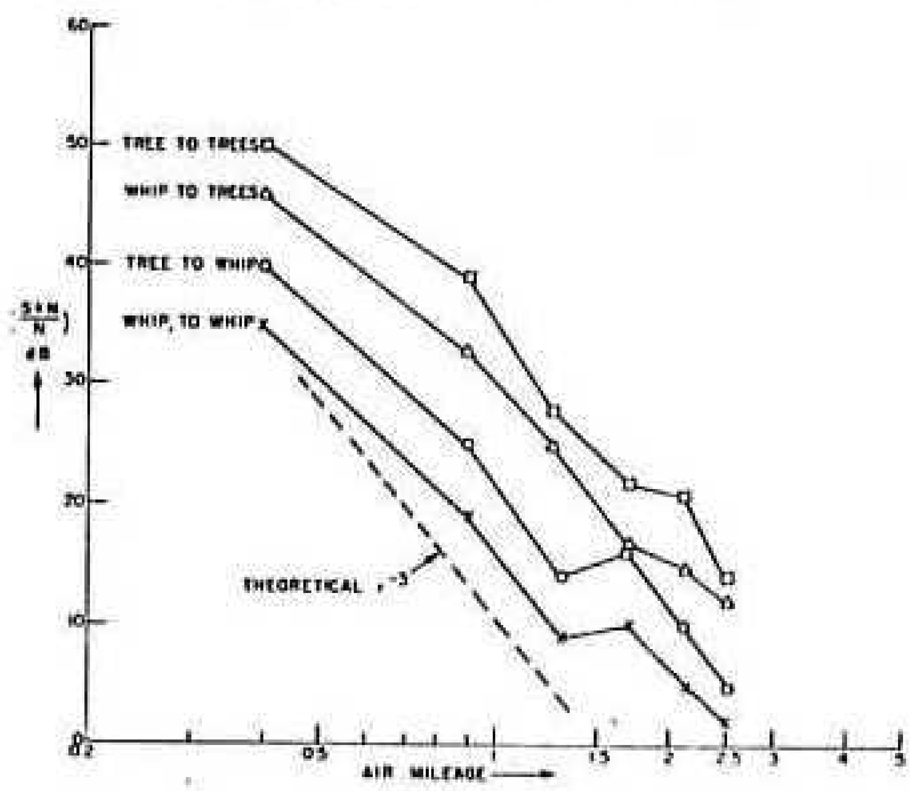


Fig.4. Relative levels at 4.650MHz from the tree and whip antennas. Reproduced with permission from Ikrath et al, IEEE Trans. on Antennas & Propagation, Jan.1975, (©1975 IEEE)

Fig.5. (right) Signal-to-noise ratios versus distance (in air miles) through the jungle for various combinations of Tx and Rx antennas. Reproduced with permission from Ikrath et al, IEEE Trans. on Antennas & Propagation, Jan.1975, (©1975 IEEE)



exhaustive tests were required in an area that did.

The Panama Canal Zone, in which the US military had considerable influence, provided an ideal test area for this purpose. Both the density of the vegetation and the types of trees there were typical of those in south-east Asia where ferns and palms regularly grow as tall as trees.

In August and September 1971 a series of tests was carried out in the Chiva Chiva area of the Canal Zone. The radio equipment used was the type PRC-74 manpack, then in service with the US military. It was an HF synthesized manpack capable of 15W output on CW and SSB from 2 to 12MHz. Its standard antenna was a centre-loaded nine foot whip. This was in the days before built-in automatic antenna tuning units and so the PRC-74 had to be manually adjusted by its operator to achieve maximum antenna current, as indicated by a small meter on the set's front panel. Two controls, one marked Antenna Tune and the other Antenna Load, were used for this purpose.

When used in conjunction with the HEMAC, the series capacitor in the HEMAC 'matchbox' was adjusted for maximum received noise at the selected frequency and then those other two controls were adjusted for maximum antenna current when transmitting. It was possible by this method to drive between 0.75A and 1A of current through the HEMAC at 4.650MHz.

Preliminary results showed the HEMAC-tree combination outperformed the standard whip antenna at a distance of about one thousand feet from the transmitter. Of interest too is the possibly surprising fact that the strongest signals from both the HEMAC-tree and whip transmitting antennas were received on a horizontally polarised wire dipole at the receiver. This suggests significant depolarisation of the electromagnetic fields as they propagated through the forest canopy.

A Statistical Coincidence?

To eliminate the possibility that these results were just a statistical coincidence, given the small number of data points involved, a considerably larger test site within the Gambon Forest of the Panama Canal Zone was used for all further testing. This allowed tests to be carried out over a greater distance (up to 2.5 miles) and also made possible the collection of more data points. Signal decay rates with distance were then measured using four different combinations of antennas at both the transmit and receive ends of the path. To try to understand the coupling and polarisation processes at work measurements were made from whip-to-whip, whip-to-tree, tree-to-whip and tree-to-tree. Some of the results are shown in the graph above.

There is no doubt that in this series of tests – and at that particular site – the use of a HEMAC-coupled tree at both the transmitter and receiver produced the best results. It is also clear that whether that HEMAC-tree was used as a transmitter or as a receiver it always outperformed the conventional whip-to-whip combination. The tree-to-tree result was about 15dB better in SNR terms than the whip-to-whip case.

This suggests unequivocally that the trees, when appropriately energised, performed as more effective antennas in such dense jungle environments than did the whips. Ikrath and his co-authors concluded that this superior performance of the trees was, in large part, due to their ability to produce and to sense a horizontally polarised component of the radiating field in an environment which is essentially hostile to vertical polarisation.

The reason for that, they maintained, is what Ikrath called the 'vertically structured roughness' of both the terrain and the vegetation within the jungle. This is a reference both to the interesting directional results found during the tests in New Jersey at 450kHz, where the variation in forest and ground height near the transmitting 'tree' seemed responsible for the pronounced directionality they measured, as well as the natural dominance of vertically aligned tree trunks in any wooded area. In addition, they claimed that the propagation mechanism at work could be explained by treating the jungle 'as a maze of aperture-coupled screen(ed) rooms'. This needs some explanation.

Aperture Coupling Through The Jungle

Screened rooms play an important part in the testing of sensitive electronic apparatus where external RF interference has to be kept to a minimum. Essentially such rooms are just large metal boxes with RF-tight seals around the (metal) door and usually without windows (for the same reason). Cutting a slot or aperture in one of the walls will allow RF energy to pass through, but only if the size and shape of the aperture are appropriate to the frequency involved. In other words slots and apertures are, by their dimensions, similar to filters and, in this context, to antennas, in that they respond selectively to a range of radio frequencies by positively blocking the passage of those whose wavelengths are significantly larger than the largest dimension of the aperture, while allowing free passage to those of shorter wavelengths.

And, just as with antennas, the polarisation or alignment of the electric field must be appropriate to the slot or aperture's orientation for maximum energy transfer to occur. Thus, an aperture in the common wall between two screened rooms will allow energy to travel easily from one to the other if these conditions are satisfied. Slot antennas are a good example of this principle working in practice.

This idea can, with some engineering licence, be extended to a typical dense tropical jungle with its numerous tree trunks, plus the mass of vegetation generally disposed in all directions all about and above them. In view of the high water content in both the leaves and tree trunks (and the presumably water-sodden ground) it is not unreasonable to assume that the vertically-aligned trunks and the predominantly horizontal leaf canopy, and the ground surface, behave mainly as barriers (or at least attenuators) to the passage of electromagnetic waves. However, between and amongst them are a myriad of openings and apertures, of various shapes and sizes, which, according to Ikrath, permit the passage of horizontally polarised signals with less attenuation than their vertical counterparts.

Microwave Engineering

Why should this be so requires a call on microwave engineering for a possible explanation. Given the predominance of vertical structures (trees) in forests and the very close spacing between them, plus knowledge of the mechanism of coupling through apertures, which is common in the world of microwaves, this porous screened room model indeed has merit. Tall thin slots or apertures within conducting surfaces will favour horizontally polarised waves over those at right angles to them. Initially, this may seem counter-intuitive until one realises that the lowest frequency (and hence the longest wavelength) that will penetrate a rectangular aperture cut in a large conducting sheet is, in waveguide parlance, the TE10 mode which has its electric field component aligned at right angles to the longer side of the aperture. Thus, in a dense forest, that longer side corresponds to the vertically aligned trees with rather narrow gaps between trees. Therefore it's the horizontal electric field component that will pass through, whereas any vertically aligned component will not (or, at least, less of it will).

So, the Ikrath model, based as it is on well-known microwave principles, seems quite appropriate within the forest environment at HF. At least it offers an explanation for what might otherwise have seemed a very strange effect.

What Next?

Kurt Ikrath died suddenly in 1976 and with him, seemingly, went the enthusiasm to explore his fascinating ideas further. However, this story would not be complete if it did not include a mention of what had happened many years before when the idea of using trees as antennas was actually first conceived. In July 1919, the popular science magazine *Scientific American* published an article [7] entitled *With Trees For Ears*. It described, in very enthusiastic terms, how the Signal Corps of the US Army in the person of Maj. Gen. George O.Squier (1865 – 1934), had discovered

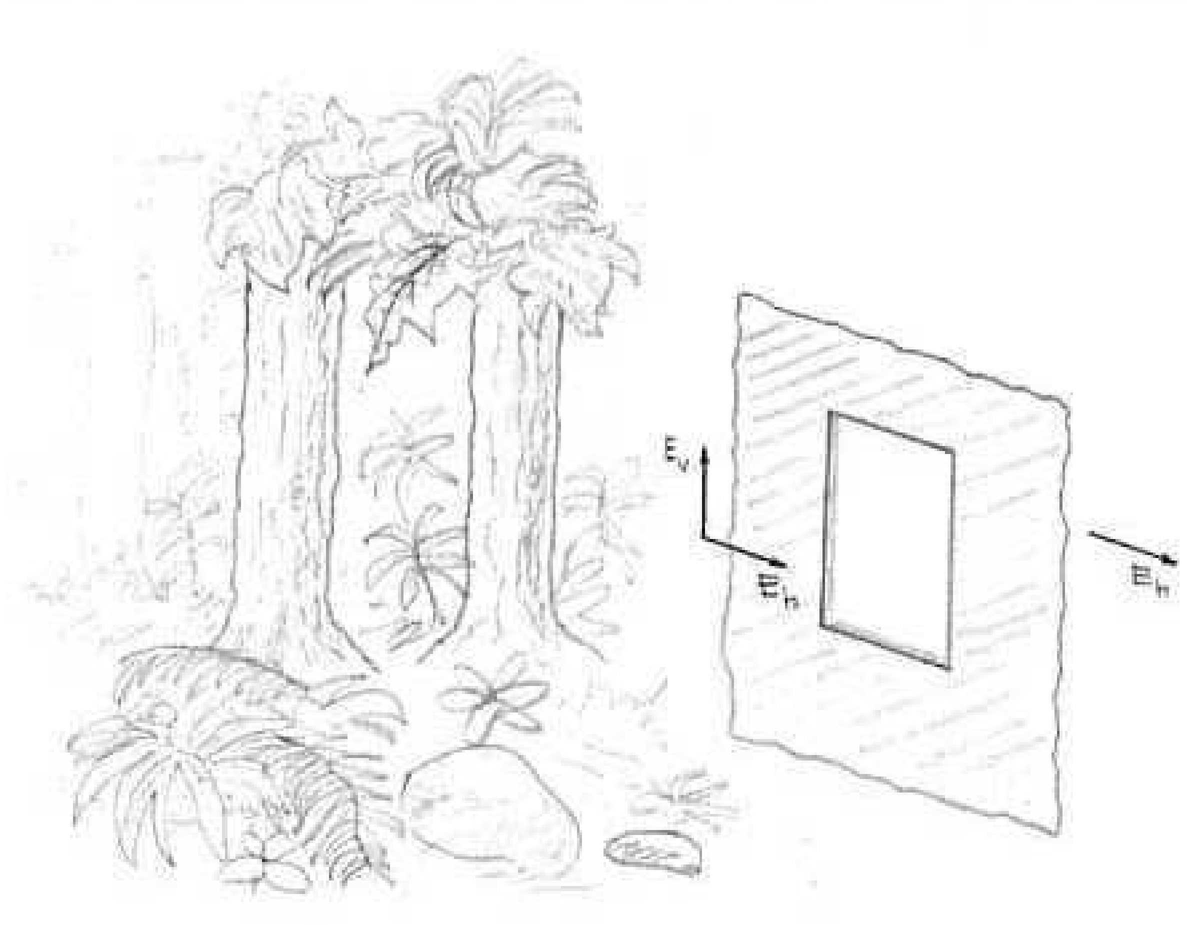


Fig.6. A resonant slot analogy to trees in the jungle

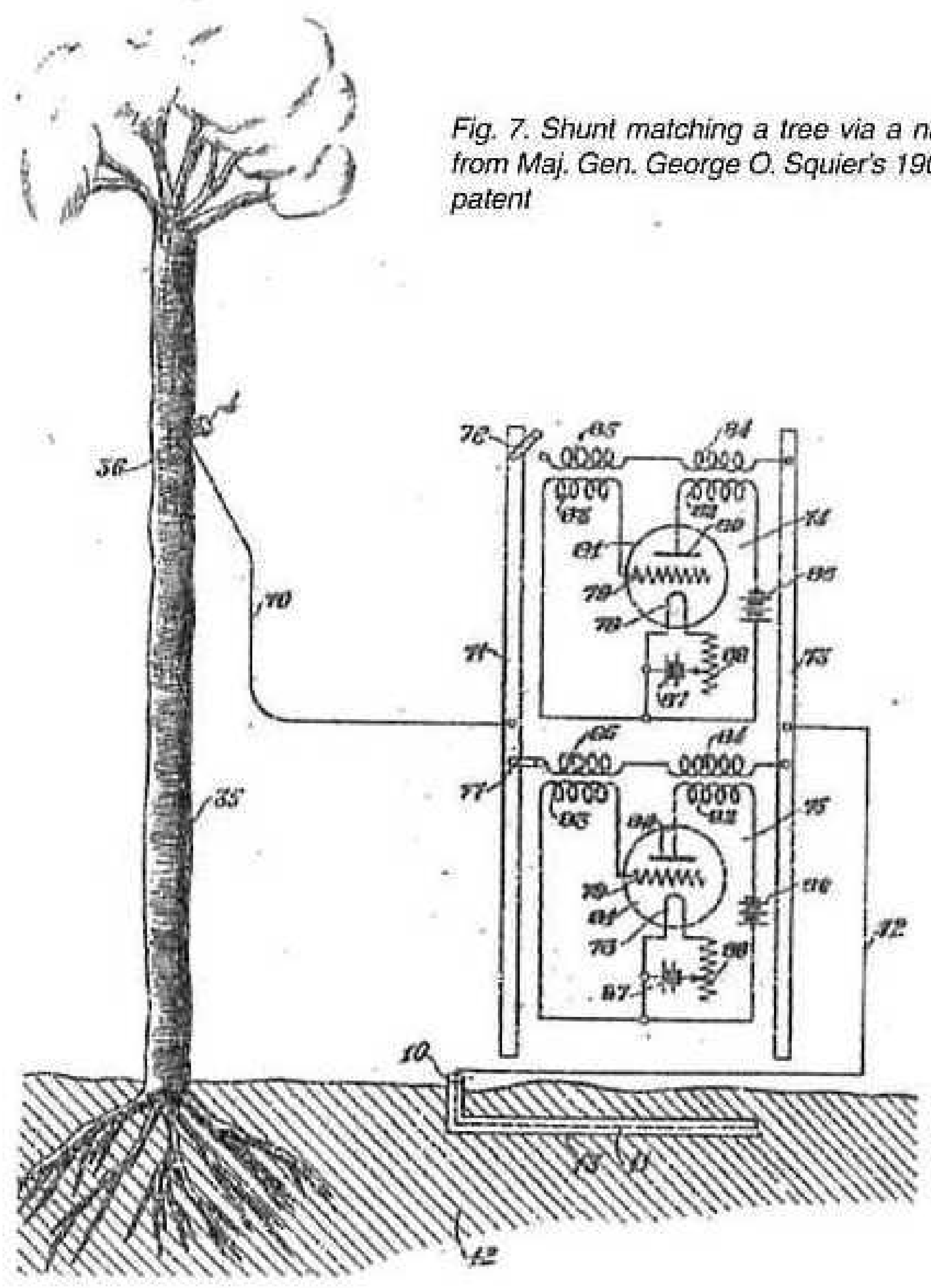


Fig. 7. Shunt matching a tree via a nail from Maj. Gen. George O. Squier's 1905 patent

how effective trees were as antennas. In fact, Squier had patented the idea as long ago as 1905 when wireless was very much in its infancy and the technology was still that of the spark transmitter with receivers that used the coherer as the detector [8]. Thermionic valves, and hence amplifiers and oscillators, were still some years away.

Squier, just like Ikrath many years later, was an inveterate experimenter and he took out many patents involving improvements in wireless telegraphy. Amongst them was at least one that showed in clear diagrammatic detail the use of a tree as an antenna, but it was connected not to one but two transmitters, with each consisting of a single oscillating valve. According to the patent these can be connected to the tree either separately or together, as required.

Since it is not my intention here to discuss the electronic circuitry involved, I'll avoid any comment about the effectiveness or otherwise of that aspect, but will just draw the readers' attention to the method of connecting the tree to the transmitter. This is done by means of a nail "affixed to and extending within the body of such tree" at a point on the trunk "substantially two-thirds of the height of the tree above the surface of the earth". That height is evidently important, as it was determined following numerous experiments. Given what we know about conventional vertical antennas with their bases electrically connected to earth, one sees evidence here of shunt matching as it came to be called some years later.

Lest anyone suggest that the single wire (marked 70 in the figure above) between the tree and the transmitter is doing all the radiating, Squier (or at least his patent attorney) commented as follows: "Some skeptiks have expressed the belief that it was not the tree, but the wire leading to the nail which was the real aerial. The absurdity of thinking a 40-foot wire could receive the widely differing wave lengths which come through the tree station is obvious, but to set any doubt to rest, the wire to the tree has been hung to the nail by means of an insulator, when the signals immediately cease, only to come in as strong as ever as soon as the connection is again established". So there!

Conclusions

The idea of using a tree as an antenna, rather than just for supporting one, may appear novel to us today. However, it is clear that it has been around for almost as long as wireless itself. Somewhat more recently it was looked at again, but with a rather different method of coupling the equipment to the tree. In both instances remarkable claims were made regarding the performance of these arboreal antennas. Given the simplicity of the HEMAC (and its undoubtedly more tree-friendly form than a nail) we could well see its revival. Any takers?

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