A Brief History of UWB Antennas

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ABSTRACT

This paper provides an historical overview of ultra-wideband antennas presenting key advances at the root of modern designs.

INTRODUCTION

"Ultra-wideband" has its roots in the original "spark-gap" transmitters that pioneered radio technology. This history is well-known and has been well documented in both professional histories [1-2] and in popular treatments [3]. The development of UWB antennas has not been subjected to similar scrutiny. As a consequence, designs have been forgotten and then re-discovered by later investigators. This paper aims to fill this void by offering a brief history of UWB antennas.

SPARK GAP DAYS

Ironically, the very patent which inaugurated the concept of narrowband frequency domain radio also disclosed some of the first ultra-wideband antennas. In 1898, Oliver Lodge introduced the concept of "syntony," the idea that a transmitter and a receiver should be tuned to the same frequency so as to maximize the received signal [4]. In this same patent, Lodge discussed a variety of "capacity areas," or antennas, that will be quite familiar to modern eyes:

> *"As charged surfaces or capacity areas, spheres or square plates or any other metal surfaces may be employed; but I prefer, for the purpose of combining low resistance with great electrostatic capacity, cones or triangles or other such diverging surfaces with the vertices adjoining and their larger areas spreading out into space; or a single insulated surface may be used in conjunction with the earth, the earth or conductors embedded in the earth constituting the other oppositely-charged surface" [5].*

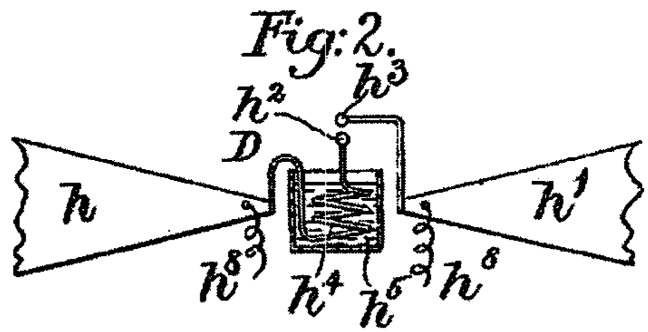

Fig. 1. Lodge preferred antennas consisting of triangular "capacity areas," a clear precursor to the "bow-tie" antenna (1898)

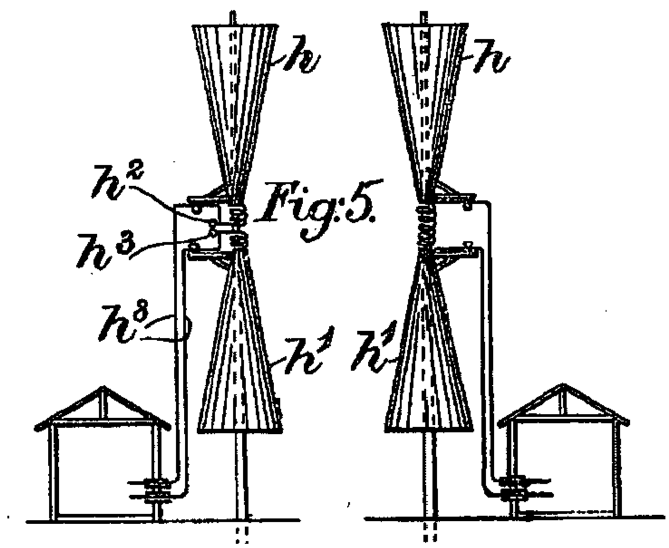

Fig. 2. Lodge's biconical antennas (1898)

In what is likely the most profound and sweeping sentence in the history of antenna technology, Lodge disclosed spherical dipoles, square plate dipoles, biconical dipoles, and triangular

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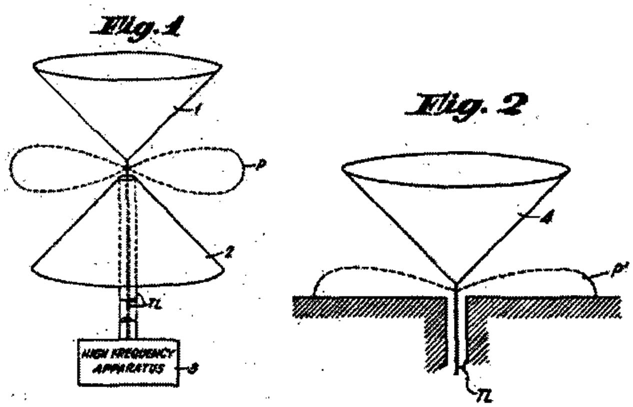


Figure 3A. (l): Carter's biconical antenna (1939)
Figure 3B. ®): Carter's conical monopole (1939)

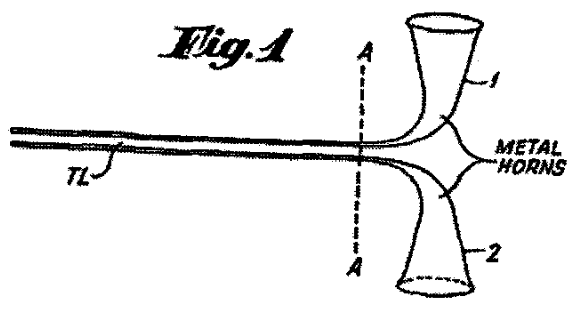


Fig. 4. Carter's improved match biconical (1939)

or "bow-tie" dipoles. He also introduced the concept of a monopole antenna using the earth as a ground.

In fact, Lodge's patent drawings make very clear his preferred embodiments. Figure 1 shows Lodge's second figure in which triangular or bow-tie elements are clearly indicated. Figure 2 depicts Lodge's fifth figure in which biconical antennas are unmistakenly used in a transmit-receive link.

ANTENNAS FOR SHORT WAVES

As frequencies increased and waves became shorter, the economic advantages of a "thin-wire" quarter wave antenna overrode any performance advantages of Lodge's original designs. With the advent of research into television however, interest in antennas that could handle the much wider bandwidths associated with video signals increased.

This renewed interest in wideband antennas led to the rediscovery of the biconical antenna and conical monopole by Carter in 1939 (see Figures 3A and 3B) [6]. Carter improved upon Lodge's original design by incorporating a tapered feed (see Figure 4) [7]. Carter was among the first to take the key step of incorporating a broadband transition between a feed line and radiating elements.

Schelkunoff proposed elaborate conical waveguides and feed structures in conjunction with his spherical dipole (see

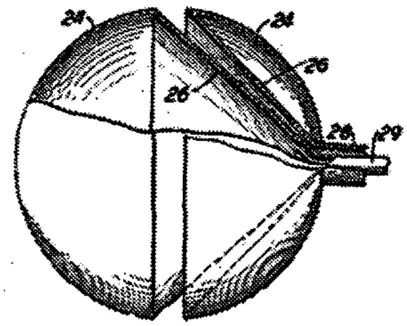


Fig. 5. Schelkunoff's spherical dipole (1940)

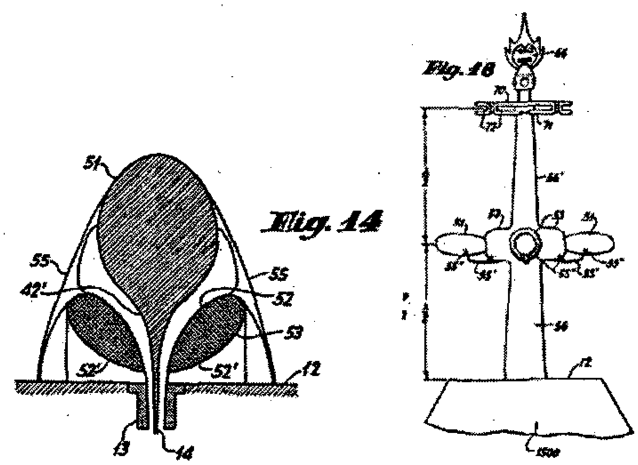


Fig. 6A. (l) Lindenblad's element in cross-section (1941)
Fig. 6B. ®) A turnstile array of Lindenblad elements for television transmission (1941)

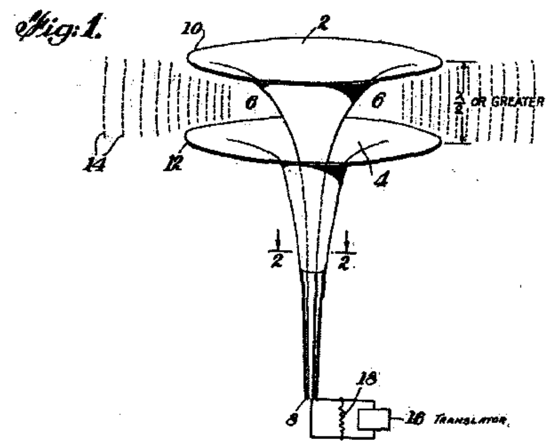


Fig. 7. Brillouin's omni-directional coaxial horn (1948)

Figure 5) [8-9]. Unfortunately, Schelkunoff's spherical dipole antenna does not appear to have seen much use.

Perhaps the most prominent UWB antenna of the period was Lindenblad's coaxial horn element [10-11]. Lindenblad

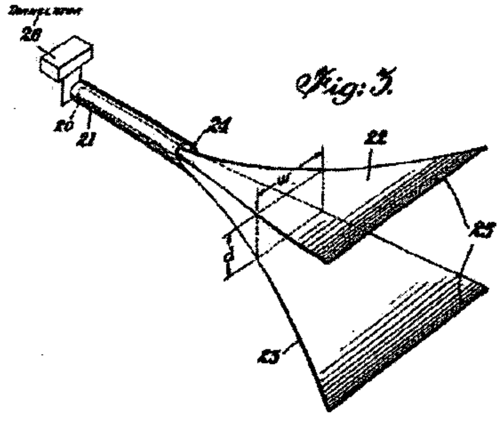


Fig. 8. Brillouin's directional coaxial horn (1948)

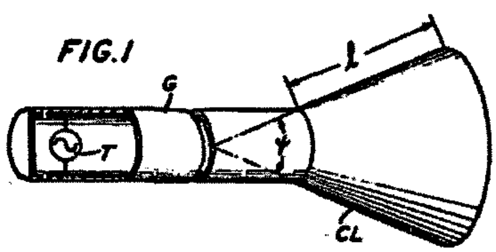


Fig. 9. King's conical horn (1942)

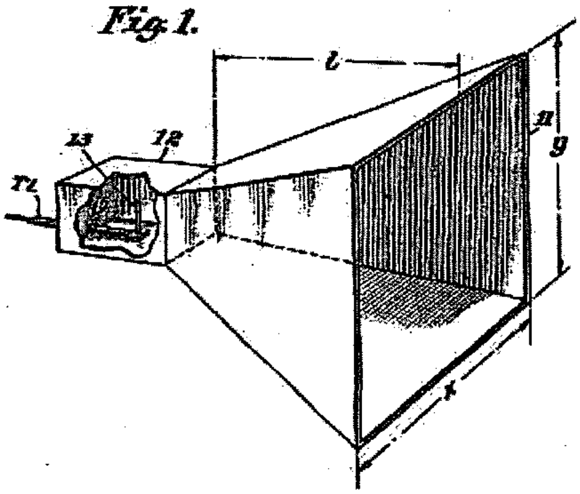


Fig. 10. Katzin's rectangular horn (1946)

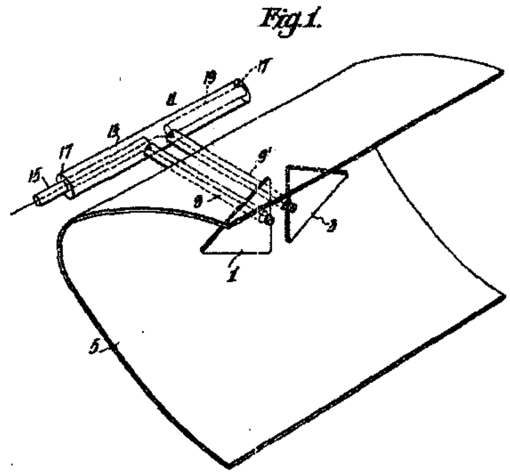


Fig. 11. Master's diamond dipole (1947)

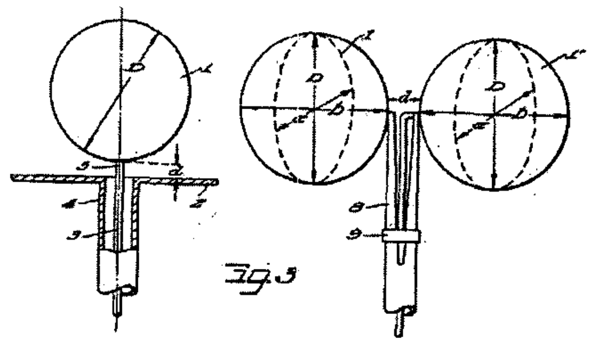
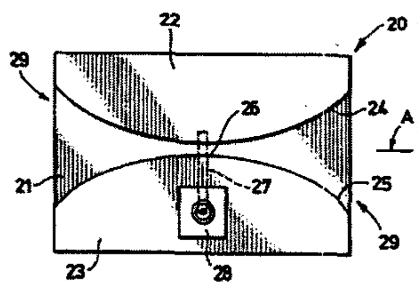


Fig. 12A. (l): Stohr's ellipsoidal monopole (1968)
Fig. 12B. (r): Stohr's ellipsoidal dipole (1968)



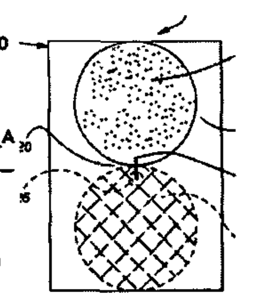


Fig. 13A. (l): Lalezari et al's broadband notch antenna (1989)
Fig. 13B. ®): Thomas et al's circular element dipole (1994)

improved on the idea of a sleeve dipole element, adding a gradual impedance transformation to make it more broad banded. RCA chose Lindenblad's element (seen in cross-section in Figure 6A) for experimental use in television transmission. RCA envisioned multiple channels being broadcast from the same central location, thus a wideband antenna was essential. For several years during the 1930s, a turnstile array of Lindenblad's coaxial horn elements graced the top of the Empire State Building in New York City where RCA located its experimental television transmitter. Figure 6B displays a patent drawing of this array. The antennas at the top of the tower in Figure 6B (items 70-72) are folded dipoles used to transmit the audio portion of the television signal. Kraus developed a design similar to Lindenblad's coaxial horn element and dubbed it a "volcano smoke antenna" [12].

In fact, Lindenblad's coaxial element came to symbolize the entire television research effort. This UWB antenna has the

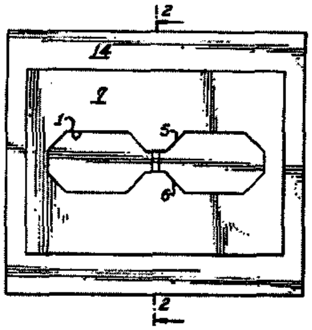


Fig. 14. Marié's wide band slot antenna (1962)

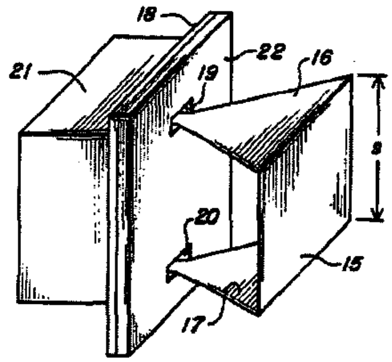


Fig. 15. Harmuth's large current radiator (1985)

distinction of being perhaps the only antenna featured prominently on the cover of a mainstream periodical [13].

Other researchers pursued the idea of constructing antennas from coaxial transitions. Brillouin introduced coaxial horns, both omni-directional (as in Figure 7) and directional (as in Figure 8) [14].

Designers also explored other more traditional horn designs during this period. Figure 9 shows one patented by King [15] and Figure 10 depicts another invented by Katzin [16].

FURTHER ADVANCES

Although existing designs offered excellent performance, other consideration became important. As broadband receivers came into common use, emphasis on inexpensive, easily manufacturable designs increased. The well-known "bow-tie" antenna originally proposed by Lodge and later re-examined by Brown and Woodward exemplifies these benefits [17]. Similarly, Masters proposed an inverted triangular dipole (see Figure 11) [18]. Later engineers rediscovered this antenna and dubbed it a "diamond dipole" [19].

More recent developments include a variety of more sophisticated electric antennas. Stohr proposed the use of ellipsoidal monopoles and dipoles as shown in Figures 12A and 12B [20].

More manufacturable antennas in this genus were pioneered by Lalezari et al who invented the broadband notch antenna depicted in Figure 13A [21]. The planar circular element

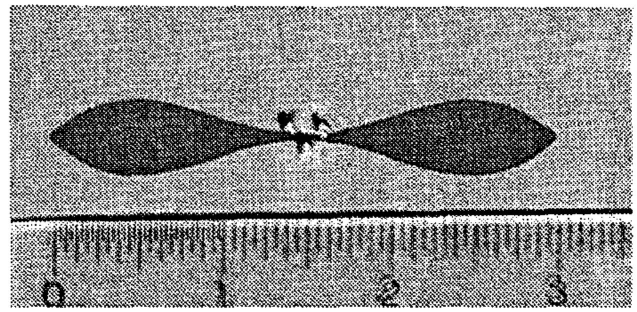


Fig. 16. Barnes' UWB slot antenna (2000)

dipole of Figure 13B put forth by Thomas et al provides still better performance [22]. This antenna is compact, readily manufacturable, and easily arrayable. Improved performance can be obtained, however, by constructing dipoles using elliptical shaped elements instead of circular ones [23]. Planar elliptical elements also work well as monopoles [24].

Significant advances have also been made in magnetic UWB antennas [25]. Marié took the concept of a slot antenna and improved its bandwidth by varying the width of the slot line [26]. Figure 14 displays Marié's antenna.

Harmuth suggested another improved magnetic antenna by introducing the concept of the large current radiator shown in Figure 15 [27]. Ideally, this magnetic antenna looks like a current sheet. Because the sheet will radiate from both sides, designers typically employ a lossy ground plane to limit undesired resonances and reflections. This tends to limit the efficiency and performance of large current radiators.

Barnes pioneered a novel UWB slot antenna [28-30]. Barnes's slot antenna (shown in Figure 16) maintains a continuous taper. The Time Domain Corporation's first generation through-wall radar, the RadarVision 1000, utilized this antenna. With proper design of the slot taper, excellent broadband matching and performance can be obtained.

CONCLUSION

The past century witnessed the development of an incredibly wide variety of UWB antennas. This paper highlights a few particularly noteworthy UWB antennas as a starting point for further explorations.

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