LOW SIGNAL STRENGTH A PROBLEM RECEIVING WWV?
TRY AN ALL-WAVE ANTENNA FROM 1936!

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Abstract

The WWV time and frequency broadcasts are sufficiently accurate for many needs. To be able to be used, however, they must be received and some locations have very low signal strength. Faced with this situation, an analysis of the factors affecting reception was performed and a 1936 antenna design was identified as a potential solution. Presented are highlights of the analysis, the antenna system employed and details of an improved antenna-to-receiver coupling network that enhances and extends performance over the original. Also included from the analysis are factors that have been forgotten over time.

Introduction

Many applications require a known frequency source or a counter calibrated against such a source. The "Atomic Clock" sources, Cesium and Rubidium, provide exceptional stability and can be tracked using signals from the GPS (Global Positioning System) or by other means. Indeed, the ease with which the GPS signals can be employed is steadily improving. The carriers of the time signals broadcast by WWV, or equivalent, are locked to such frequency standards but there is some degradation because of propagation effects. WWV signals, however, are quite sufficient for many requirements, especially when the accuracy need is only moderate. The carrier frequencies from WWV are in the High Frequency, HF or Short Wave range (3 to 30 MHz) except for the 2.5MHz frequency.

A need arose some years ago for a traceable frequency source known to only a part in 10^7. It was found that, even though the distance to the WWV transmitter in Fort Collins, Colorado was less than 800 kM (500 miles), the preferred 10 MHz signal could not be reliably received using a high-sensitivity (<1μV at 10 MHz) communications receiver with a simple antenna. Unfortunately, the other WWV frequencies were not stronger or more reliable. An improved antenna seemed the solution but needed to be wide-band so that the stronger of the several HF signals broadcast by WWV might be used without the need to match the antenna to the receiver at each frequency. After consideration of a number of possibilities, the problem was solved by use of an all-wave antenna system from 1936 but the antenna itself and other parts of the story are in the category of lessons forgotten over time. This paper has been developed from a short newsletter article[1] for the IEEE, I&M Society. Included are the answers to several questions asked in response to the article.

Basic Antenna Characteristics

A first thought many of us have on the topics of reception and antennas is to refer to the Radio Amateur's Handbook. By the 1940's, a time when the HF range was of great interest to amateurs, the basic characteristics of antennas had been thoroughly studied and were available in various handbooks even though some lessons in propagation were yet to be mastered. The Radio Amateur's Handbook[2A 2B] shows the half-wave dipole (widely called a doublet in the 1930's and 1940's) and methods of coupling the antenna to a transmitter for optimum radiated power. Above 100 MHz (called Mc or Megacycles then) the term dipole was coming into use and, at these frequencies, the need for a matched transmission line was recognized. The effects of capacitance at the ends of the dipole, diameter of the antenna conductor to length of the antenna, height above ground, and imperfectly conducting earth are also discussed. These are all concepts very important for transmitter applications but which also have application to receivers.

However, very little information is given concerning HF receiving antennas in the listed references. Early handbooks[2A, 2B] note that receivers have very high sensitivity and that, for this frequency range "a wire of 15 or 20 feet is usually sufficient." Later handbooks[2C, 2D] refer only to "a wire of random length." All note that a longer wire outside gives better results and a matched antenna is the best; however, the common short vertical whip antenna is not mentioned for the HF range. All of these references are primarily directed to transmitter applications and those later in time give increasing information on the Very High Frequency (VHF) range. The limited information on HF receiver matching implies that it is not critical but does not give the rationale.

Amplified Antenna/Signal Booster

One possible solution for low signal strength is to use an amplified antenna. This approach has been made attractive by constraints on outdoor antennas, especially those long or high. It is used with television (TV) and other low sensitivity receivers. A simple solid state amplifier can supply 20 db or more of voltage gain over very broad bandwidth and requires little power. Both signal and noise are amplified and the input is a whip or similar antenna that is fairly insensitive because it has a very short length in the HF range. If a reasonable signal level is available, the amplified antenna can aid a low sensitivity receiver. However, a receiver with a large ferrite rod in the antenna tuning circuit will often give better results without amplification.

Amplifiers are also available in the form of a signal booster; these have one or two gain stages and are tuned so that signal strength, selectivity and noise rejection are all improved. Signal boosters are intended to improve coupling of a low sensitivity receiver to an appropriate antenna and are somewhat difficult to use since the receiver and the booster require separate tuning.

Neither an amplified antenna nor a signal booster offers a significant advantage when a high sensitivity receiver is available but the signal is low; for this combination only a better antenna will help.

Receiver Characteristics

Television (TV) and FM Broadcast have made everyone aware of the need for matched impedance antenna coupling to the receiver but this is not the case for HF receivers. General coverage HF receivers often cover a 3:1 frequency range on each receiving band and, more than 60 years ago, the input coupling problem had been investigated and some practical compromises had been established. The Radiotron Designers Handbook[3] gives a complete mathematical analysis of antenna input systems, both with inductive and capacitive antenna coupling. This reference also covers the standard, 48 I.R.E. 17S1, on the testing of AM receivers (1948) and gives the standard input impedance of 200 ρF for broadcast band frequencies changing to 400 Ω resistive above 1.8 MHz. A more easily understood explanation[4A, 4B] covers the basic circuits, circuit limitations and gives practical values adequate for design using coupled inductor mathematics. While the listed references refer to vacuum tube equipment, the same constraints apply for transistor equipment and manufacturers of today's highest quality communication receivers follow the same rules.

The 400 Ω input resistance in the HF range means that the receiver is not matched to the impedance of the antenna and can perform well for frequencies above and below the half-wave length where the antenna reactance causes only a small but acceptable reduction of sensitivity. Such receivers are voltage sensitive rather than power sensitive and a broadband effect is thus achieved. Curiously, some receivers are marked for 50 Ω antenna but do not have that impedance.

Broadband or "All Wave" Antenna

TV brought changes not only in the frequencies received but also in watching and in listening habits. Parts of the United States did not get TV reception until the late 1950's (such as western Nebraska where the author misspent his youth repairing radios). FM aided in this revolution, although the early frequency band was 40-50 MHz rather than the 88-108 MHz well known today. Before one could "watch" the show, one could listen to broadcasts from all over the world through the HF range and there was strong interest in such reception. Needed were a sensitive receiver and a "proper" antenna to get all those stations; often an outdoor doublet was used with a twisted, rubber-covered feed of a popular power cable (about 113 Ω impedance but impedance is not overly important in the HF range). In 1936, the analysis and design of an all-wave antenna with optimized receiver coupling was published[5, 6]. The usable range of this design was from the Broadcast band through 18 MHz. This antenna configuration appeared attractive as a solution to the WWV reception problem.

The antenna system is shown in Figure 1. The antenna itself is composed of two dipoles each 15 m long with a 2 m separation at the ends and the centers connected to form a pair of opposite horizontal V's. The advantage of this is that the resistive component does not change significantly from that of a single dipole but the maximum reactive component is reduced to half that of a regular dipole (2000 Ω compared to 4000 Ω). The 400 Ω receiver input resistance is at the geometric center of the antenna minimum/maximum impedance range (80 Ω to 2000 Ω). From this input, the receiver shows a surprisingly uniform response throughout the frequency range and an excellent wide-band match to the receiver is obtained. The resonant frequency of a half-wave dipole, 15 m long, is 9.2 MHz; however, the horizontal doublet V with the same length drops this frequency to 8.6 MHz.

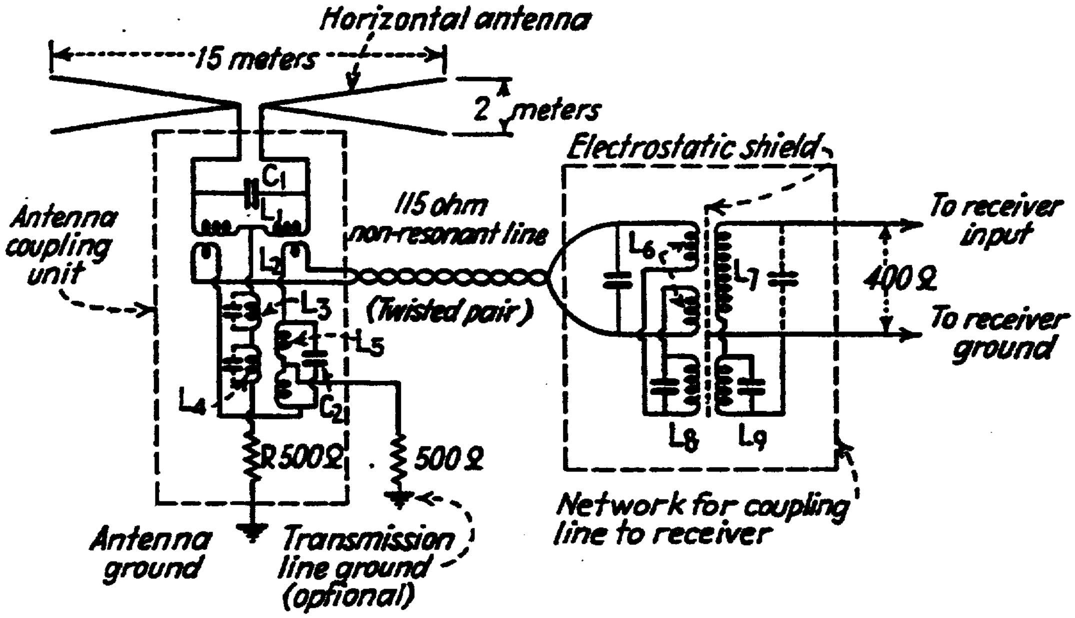

Figure 1. Actual Circuit of the Original Antenna System

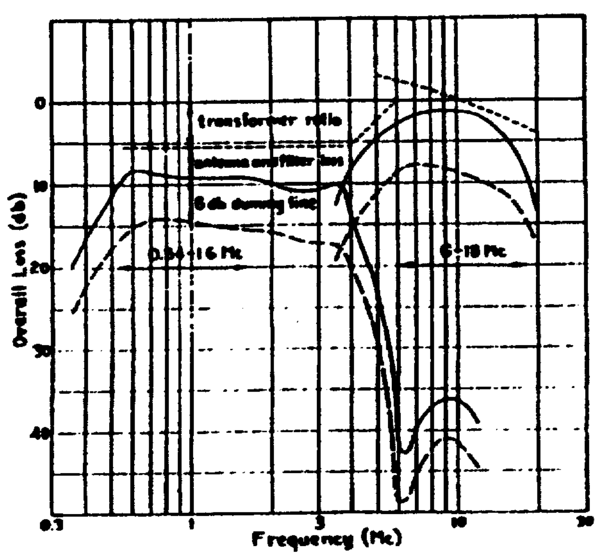

Figure 2. Overall Loss of the Original Antenna System

To provide coverage of the Broadcast band, the coupling units change the antenna configuration from the doublet to a single-wire-center-fed, "T," or "Flat-Top" antenna. The coupling circuits were designed to accomplish the change at about 4 MHz. The antenna system performance is shown in Figure 2., reproduced from original paper. In this figure, the upper dotted line gives the coupling system (transformer) performance; the solid line covers the complete system with the antenna; and the lower dashed line allows for a 6 db loss in the transmission line.

The Antenna System Actually Used

The characteristics of the 15 m horizontal doublet V antenna described above were considered very attractive as a solution to the WWV reception problem but duplicating the coupling units is a non-trivial task. On reflection, however, a simpler coupling network using a single trifilar torroidal transformer was selected. This version of the antenna system is shown in Figure 3.

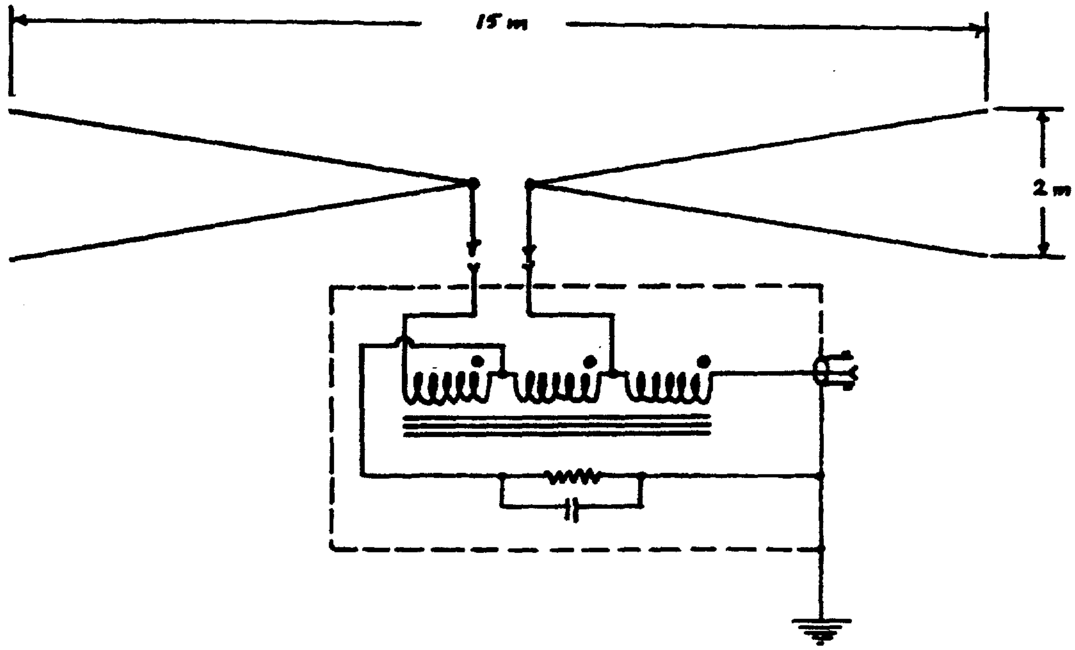

Figure 3. The New All-Wave Antenna Circuit

The actual transformer was wound on a salvaged ferrite core with a cross-section of about 1.7 cm^2. The three windings, 10 turns each of awg 24 enameled magnet wire, are connected in series aiding as shown. Test of the transformer showed a response essentially flat from 2 through 30 MHz. The purpose of the transformer is to change the antenna from a balanced doublet to an unbalanced connection for feeding a shielded transmission line to the receiver. The center connection between the doublet halves is connected to transmission line shield (ground) through the parallel Resistor/Capacitor combination shown. This connection converts the antenna to the "Flat-Top" for lower frequencies. The resistor is 4700 Ω or essentially an open circuit; a capacitor value of 100 ρF enables the "Flat-Top" at approximately 4 MHz. The resistor may be of lower value to add broadcast band attenuation but a higher capacitor value is required. In the changeover, the transformer behaves as a short circuit for frequencies below 4 MHz thus connecting the two sides of the doublet together.

Although originally located at the antenna end, the new coupling unit may be located at either end of the system, antenna or receiver. This gives wide choice over the transmission line with the possibility of a very low loss system. In the HF region, the principal loss mechanism is through capacitance loading on the system output.

Acceptable Transmission Lines

Because the new coupling unit can be located at either end of the transmission line, several different transmission line arrangeemnts are possible. If the coupling unit is located at the receiver, a two wire transmission line is appropriate; shielded 300 ohm twin lead is most suitable and is available with about 18 ρF/m to aid attaining maximum bandwidth. Also, this type of transmission line may be coupled directly to receivers with doublet and antenna terminals but these are not common. To use the full capabilities of the all-band antenna system with the new coupling unit, the doublet terminal is connected to ground and the output of the new coupling unit is connected between ground and the antenna terminal. For best results, ground should also be connected to an earth ground.

If the new coupling unit is used at the antenna end, a coaxial cable is suitable for the transmission line. Available coaxial lines vary from about 131 ρF /m (50 Ω, RG 58/U) to 43 ρF/m (93 Ω, RG 62/U). The lower capacitance of the RG 62/U makes it the preferable choice. An alternative would be to use the shielded, approximate coaxial, lead used for AM automobile radios. This lead is made somewhat similar to RG 62/U in that the outer shield is lined with a thin layer of coaxial insulation but, rather than being AWG 22 wire for the center conductor, a very fine wire is used and left loose in the assembly. This lead is difficult to obtain but essentially mates the impedance and low-capacity characteristics of shielded twin lead.

At the time the antenna was placed in service, neither shielded twin lead nor 93 Ω coaxial cable were available locally although they had been earlier and have again become available. Temporarily, 50 Ω coaxial cable, RG 58/U, was used. Even though the transmission line is relatively short, the capacitance loading of this cable (750 ρf) led to 6 db attenuation at 15 MHz and also at 28 MHz, partially because of the input characteristics of the particular receiver used. This behavior is within acceptable performance.

Antenna Performance / Conclusion

The antenna system described has been quite effective in receiving all available WWV frequencies. It is useful even during periods of high interference noise such as power-line insulator sizzle in wet/snowy conditions when HF reception can be very difficult. Although not included in the range of the 1936 design, the strength of signals to 30 MHz is also quite acceptable. For those with marginal WWV reception and with space to put a 15 m horizontal doublet V antenna, the system offers an interesting and excellent solution. Obviously, there is an attenuation of signals below the "Flat-Top" changeover frequency but the high sensitivity is not needed in the Broadcast band; signal strengths are rather high and some all-wave receivers limit gain of either the radio frequency or intermediate frequency amplifier to compensate.

Not only has the all-wave antenna system solved the WWV reception problem, it has served well in other, general listening applications. The frequency uncertainty of the WWV signals is quite sufficient for the intended application. The all-wave antenna described was installed some years ago, before GPS applications became generally available. While it has been quite satisfactory in meeting the specific need and providing a frequency stable to a few parts in 10^9, it can by no means compete with the uncertainties available using atomic clocks or other modern high accuracy frequency sources.

References

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