RF Field Strength

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Introduction

The process of building a crystal radio begins with the transmitter. Without the transmitter there would be no point in building the radio.

AM Broadcast stations in the United States operate at 10 kHz intervals between 540 kHz and 1,700 kHz using double sideband amplitude modulation with a modulation bandwidth of 5 kHz (10 kHz total channel width) and a transmitted power ranging from around 1 kW to 50 kW. The broadcast antenna is generally some form of a one-quarter to over one-half wave vertical tower (the entire tower is the antenna) with numerous one-quarter wave ground radials. A quarter-wave antenna at 540 kHz would be around 139 meters high!

A quarter-wave antenna is attractive because it has a low resistive (i.e. no reactive component) impedance of around 35 ohms. For a 50 kW transmitter the applied voltage to the antenna would be around 1,300 volts rms! This impedance is not the resistance of the tower – that needs to be as low as possible for high efficiency. The impedance of the antenna is the result of the fact that power leaves the antenna as a result of radiated electromagnetic fields – that is the purpose of the antenna.

If the electrical length of the antenna is not a quarter wave then there is a reactive component in the antenna impedance. This reactance is in the way of coupling power to the antenna. Various tuning schemes can eliminate the net reactance. Antenna designers are interested in maximizing the strength of the electromagnetic field emitted from the antenna. They also have to deal with other limitations such as maximum allowed antenna height, electrical characteristics of the soil around the antenna, and other factors. For these reasons the electrical height of the antenna may deviate from the seemingly ideal one-quarter wave. The result is an antenna that optimizes the broadcast range of the transmitter. Tuning networks can compensate for any antenna reactance.

The signal strength some distance from the transmitting tower is commonly measured in volts per meter. There is a corresponding current measured in amperes per meter obtained by dividing volts per meter by the impedance of free space, 377 ohms. There is no power dissipated in free space as the voltage and current are physically orthogonal. The voltage per meter is a cyclic gradient and is only meaningful over distances that are short (roughly 20 electrical degrees) with respect to a wavelength. Short antenna probes can measure this voltage. Amperes per meter is also a cyclic gradient and is a bit more difficult to visualize as it represents a magnetic field that would exist in response to an actual current. There is no actual current in free space which is an electrical insulator. The magnetic field can be measured using small (with respect to a wavelength) loop antenna probes in which a current is induced.

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Thus, electromagnetic radiation is a combination of a cyclic voltage field and an orthogonal cyclic magnetic field. Either alone is just induction as opposed to radiation. As fields spread, the strength of an electromagnetic wave follows a one over distance law. Induction fields follow a one over distance cubed law. Thus, induction fields are useful only for very short distances.

In order to engineer a crystal radio we need to know the expected electromagnetic field strengths we intend to receive. Those strengths must be above some minimum or we will hear nothing in our headphones. Data is readily available that gives us a reasonable expectation of the amplitude of a radio wave in terms of volts per meter at a given distance from the broadcast antenna. We must understand not to interpret such data too literally as there are always variables related to terrain and various structures that will affect the data – mostly negatively but sometimes positively.

Figure 1 shows typical signal strengths for a 50 kW station during daylight hours. The voltages will be about one-third for a 5 kW transmitter. The increased drop-off with distance is due to the curvature of the earth and varies at night and with weather conditions so a significantly greater range is possible at times. The typical atmospheric noise level for a 10 kHz bandwidth is also shown although this can vary significantly with location and season. Excellent reception is when the signal strength is 100 times the noise level. Poor, but usable, reception is when the signal strength is around 5 times the noise level. The noise floor is only shown for reference. Crystal radios are typically so insensitive that the minimum usable signal is around 1000 times the noise floor.

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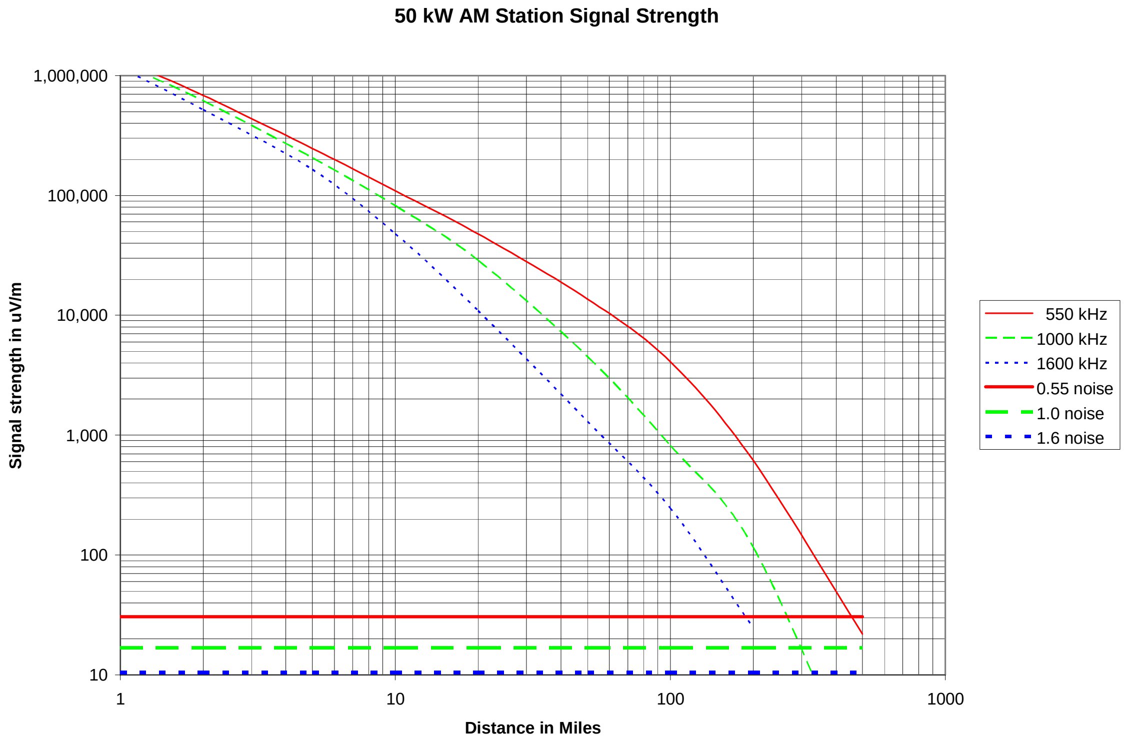

Figure 1: Signal strength with distance adapted from Reference Data for Radio Engineers, Howard W. Sams, Inc. sixth edition, pages 30-3 to 30-5