

Designing at Frequencies Below 100 MHz

By Gary Breed
Editorial Director

This tutorial note reviews the unique characteristics of electronic components and design methods for the lowest region of the “high frequency” spectrum

Depending on what reference’s definition you choose, the “radio frequency” or “high frequency” part of the electromagnetic spectrum may begin as low as 10 kHz. (And there are

applications of radio communications below 10 kHz.) From these lowest frequencies up to approximately 100 MHz, similar design techniques are used, which are much different than those used for design above this frequency range. In this frequency range, component behavior is predictable, and at the lower range may often be assumed to be ideal, since parasitic reactances, losses and other frequency-dependent effects are small.

There are many applications in the under-

100 MHz range—radio broadcasting, RF heating, plasma generation, RFID, ultrasonics, digital subscriber line (DSL, ADSL), CATV return path systems, amateur, marine and point-to-point radio communications, military communications, sensors, and many others.

In addition to design for specific applications, this lower frequency range may be used for proof-of-concept prototypes—as was done in another article in this issue that describes the development of an outphasing transmitter [1]. That author notes that a lower-frequency prototype can use lumped element components and lower cost active devices. Observation of circuit behavior is much easier, as well. Table 1 lists the major factors that affect design at the lower range of “high frequency.” It is easy to see how some of those factors make design and implementation of a circuit faster and easier.

- | | |
|--|---|
| <ul style="list-style-type: none"> · Passive components (capacitors, inductors, resistors) behave much like ideal devices. · Active components are less costly than higher-frequency devices with the same functions. They will also be available in standard packages, and most will also have higher gain. (Which may require extra caution!) · Parasitic capacitance and inductance are very small, making as-built circuit behavior more predictable than at higher frequencies. · Long wavelengths means that interconnecting wires and p.c. board traces are very short relative to wavelength, reducing the inductive reactance, loss and radiation. · Coaxial cable loss per unit length is much lower at these frequencies. · Ferrite or iron powder magnetic materials may be used to construct transformers, couplers, RF | <ul style="list-style-type: none"> chokes, etc., dramatically reducing the size compared to transmission line implementation. · Due to the factors noted above, circuit construction is much less critical than at higher frequencies. Prototype and evaluation circuits can be assembled quickly in inexpensively. · Circuit synthesis and simulation can use common “non-microwave” software such as SPICE, while maintaining accurate results. · Time domain (cause-effect, stimulus-response) circuit behavior is easily observed with an oscilloscope, with the caution to use high quality probes. · Other general purpose test instruments may be used for many measurements. · The lowest cost models of RF test instruments may be used instead of those with coverage into the microwave range. |
|--|---|

Table 1 · Important characteristics of design at lower frequencies.

A Closer Look

Let's examine some of the reasons behind the behaviors included on the above list. First is parasitic inductance and capacitance, key frequency-dependent characteristics. Figure 1 shows the capacitance of a wire above ground. A one inch long #18 AWG wire (0.04 in. dia.) placed 0.05 inch above ground will exhibit approximately 1 pF. At 100 MHz, this capacitor will have reactance of 1,591 ohms. This certainly not negligible, but will have little effect in a 50 ohm circuit. At 1 GHz, its 159 ohm reactance would have a major effect on almost any circuit.

Figure 2 shows the inductance per unit length of a wire. The same one-inch #18 AWG wire will have an inductance of approximately 0.018 μ H, or 18 nH. This is 11 ohms reactance at 100 MHz, which is quite significant, although its 1.1 ohm reactance at 10 MHz may be acceptable for circuits operating at that frequency.

A one-inch interconnection is considered quite long for any RF circuit. What this example demonstrates is that such "large" construction may be acceptable in the lower frequency range.

Another frequency dependent effect is *skin effect*, the bunching of current flow at the outside of a conductor, e.g., the surface of a round wire, or the most widely separated edges of a flat conductor. This has the effect of using only a portion of the conductor to carry the current, which increases the effective resistance. Figure 3 shows a plot of skin depth and loss versus frequency. The actual values are not so important, but all readers should note that the plot show resistance increasing linearly with frequency. Thus, for any conductor, the effective resistance due to skin effect will be ten times higher at 10 MHz vs. 1 MHz, or 100 MHz vs. 10 MHz, etc. Conductors with the lowest

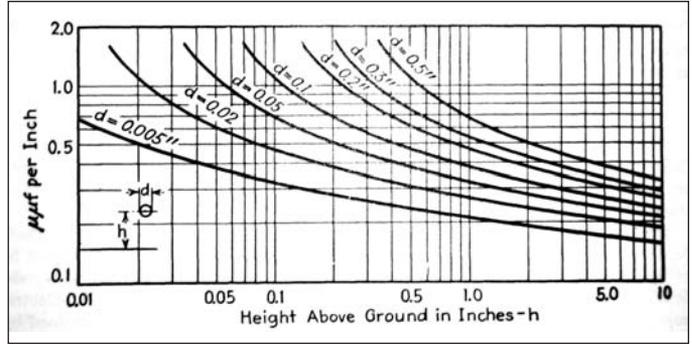


Figure 1 · Capacitance per inch for wires of various diameters vs. height above ground (2).

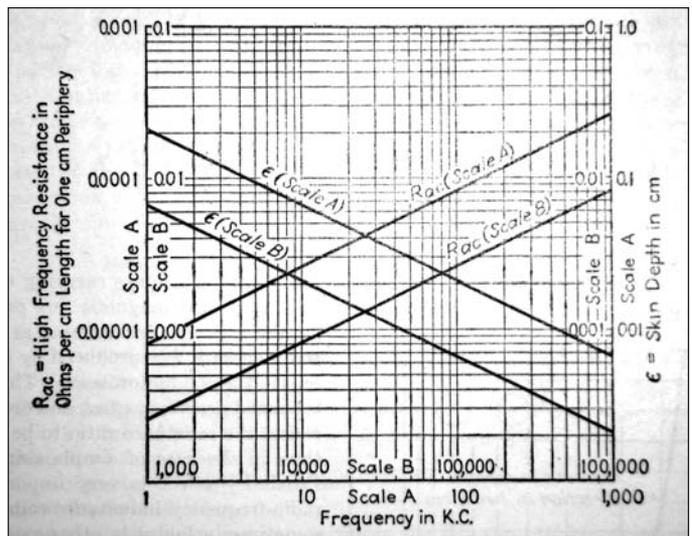


Figure 3 · Skin depth and resistance of copper vs. frequency (2).

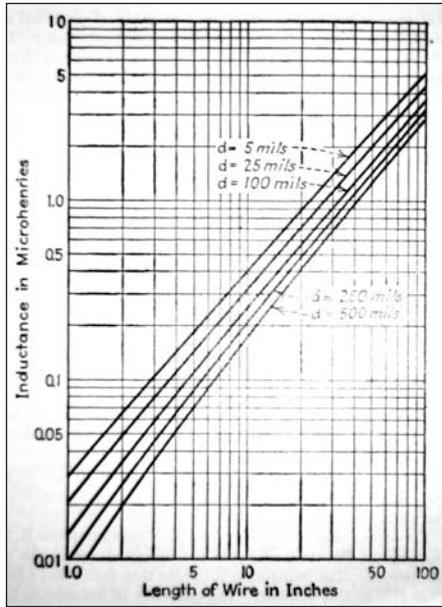


Figure 2 . Inductance per unit length for a straight wire of different diameters (2).

resistance (silver, gold, platinum) are often used at microwave frequencies—although a thin plating layer is sufficient. At low frequencies, inexpensive copper, aluminum and brass have acceptable resistance.

Transmission Lines

There are few significant drawbacks of operation at low frequencies. One is the difficulty of implementing transmission line elements. In most cases, a lumped element equivalent circuit must be designed to provide the desired phase shift.

Fortunately, these lumped element networks are much smaller than the transmission lines they replace—90° in free space is nearly 25 feet (7.5 m) at 10 MHz. Also, the design procedures for such networks are well documented, so the task is not difficult. Simple networks of inductors and capacitors can accurately mimic transmission lines.

Magnetic Materials

The under-100 MHz range is (nearly) the exclusive territory of broadband ferrite or iron powder

transformers and related coupler designs. Depending on the bandwidth, loss and impedance transformation requirements of a circuit, either conventional primary-secondary transformers or transmission line type transformers may be used.

With mutual coupling of near-unity, transformers and couplers using these materials and techniques can have very low loss and extremely wide bandwidth. As an example, it is not a particularly difficult task to design and build a power amplifier with two decades of bandwidth, e.g., 1-100 MHz. A similar span at microwave frequencies is a daunting challenge, e.g., 1-100 GHz!

Summary

Today, most commercial wireless design and university research focuses on microwave frequencies. But as noted earlier, there are many applications and products operating in the lower frequency range.

Design and construction of circuits operating at the lowest range of “high frequency” design has differences from design at microwave frequencies. Many things are easier or less critical, but there are some unique circuits and methods that should be learned and understood.

The ease of implementing most circuits makes the under-100 MHz frequency range valuable for proof-of-concept circuits, as well as for teaching RF/high frequency design concepts. Some universities include circuits at these frequencies in their undergraduate laboratory curricula.

References

1. R. Beltran, F. Raab, A. Velazquez, “An Outphasing Transmitter Using Class-E PAs and Asymmetric Combining: Part 1,” beginning on p. 18 of this issue.
2. F. E. Terman, *Radio Engineers' Handbook*, 1st edition, McGraw-Hill 1943.