A Plea for Simplification

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HANDBOOK engineering is becoming more and more common in our laboratories and the distance is increasing between the engineer faced with the practical problem and the professional theoretical man. The widening of the practice-theory gap seems to be universal throughout our industry: our efficiency is reduced and progress made more difficult. The people who are compelled to the steady use of handbook formulas regret this fact and have an intense thirst for knowledge.

A drive toward a middle ground between complicated theory and practice is needed intensively in our field, and such a middle ground does exist. History shows that problems are solved in ways which appear esoteric at the time they are introduced and then drift down the scale of difficulties, appearing to become in a mysterious way easier and easier to understand. It was not so long ago when Boolean algebra, Fourier series, operational calculus were at the frontiers of mathematical knowledge. Even such abstruse concepts as those of general relativity are beginning to be understood by thousands of people when just about forty years ago they appeared comprehensible by only a few outstanding brains.

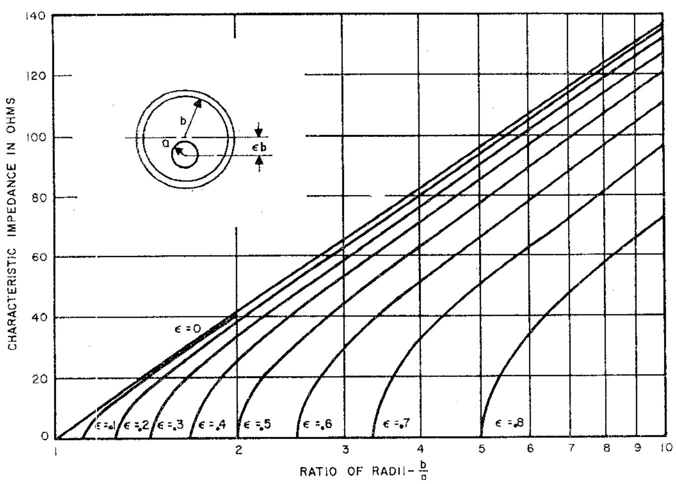

Fig. 1—Characteristic impedance of an eccentric coaxial line (from an exact computation).

This is a plea for a determined effort toward simplification of concepts, to reach a middle ground between abstract mathematical theory and the blind use of someone else's formulas. Poincaré, a great mathematician, used to say that there are two ways of understanding a concept. The first way, through mathematics, is the easier but not the more useful; the second way is that of understanding without resorting to mathematical crutches. The latter is more difficult, but it is the only real way of understanding the concept.

As a corollary to the above, we should strive toward simpler, even if not accurate, methods of analysis. We should have papers listing rough approximations to complicated problems, and simple theoretical limitations on the optimum possible performance of different devices.

As an example consider Fig. 1: it gives the characteristic impedance Z_0 of an eccentric coaxial line. The formula from which the curves of Fig. 1 have been computed can be obtained from a solution of a boundary-value problem of a well-known type. It is interesting, however, to show that the results of Fig. 1 can be obtained purely from an intuitive basis and with a surprising degree of accuracy.[1] In Fig. 2, the ordinate and abscissa axes are the normalized characteristic impedance $Z(\epsilon)/Z_0$ and ϵ/ϵ_{max}, respectively. $Z(\epsilon)$ is the characteristic impedance of an eccentric line and Z_0 is the characteristic impedance of a concentric line having the same conductors. ϵ/ϵ_{max} is the ratio between the ec-

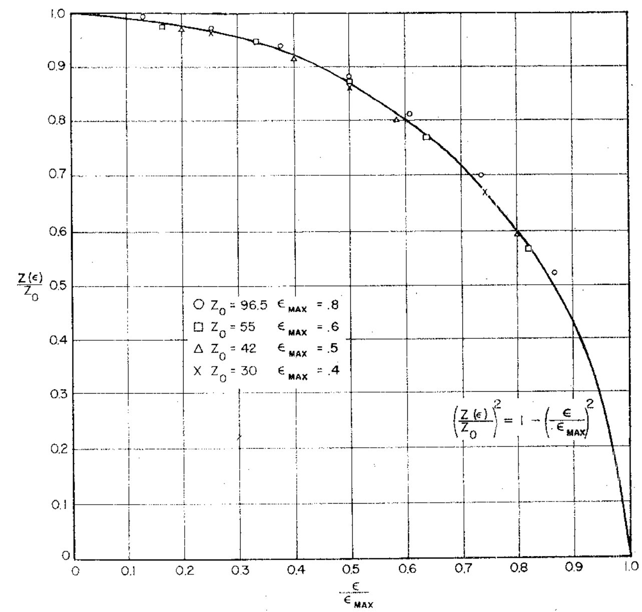

Fig. 2—Normalized characteristic impedance of an eccentric coaxial line. Comparison between approximation (solid curve) and exact theory.

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[1] I am deeply indebted to Harold A. Wheeler for having inspired this desire for semirigorous considerations and for having, in many years of mutual discussions, supplied me with innumerable examples of this approach.

centricity ϵ, defined in Fig. 1, and the maximum eccentricity ϵ_{max}.

We could now plot in Fig. 2 a set of curves which would correspond to the set shown in Fig. 1. Before doing this, however, we should point out that, due to the choice of the coordinate system, all of the curves must pass through the unity points on the ordinate and abscissa axes, since for $\epsilon = 0$ the characteristic impedance of all the lines is equal to that of the concentric line and for $\epsilon = \epsilon_{max}$ the inner and outer conductors are shorted and the characteristic impedances are zero. Furthermore, since the impedance must be an even function of the eccentricity, the impedance curve for small eccentricity must be of the type $1 - K\epsilon^2$. For large eccentricities the capacitance near the point where the two conductors almost touch must change roughly with the square root of the distance, because the "useful" area of the conductors decreases while the distance decreases. The following equation which yields a circle of unity radius,

$$\left(\frac{Z(\epsilon)}{Z_0}\right)^2 = 1 - \left(\frac{\epsilon}{\epsilon_{max}}\right)^2$$

meets these requirements and this is plotted in Fig. 2. According to this process, we should expect the family of curves of Fig. 1 to coalesce roughly into a single curve, at least near the vertical axis. The points marked in Fig. 2 are those computed by the correct formula and the curve drawn is the circle of unity radius. The accuracy of this rough computation was unexpectedly good, but the reader should not expect such good results every time!

Consider as another example the effect of losses in a waveguide. The problem can be solved by using boundary value concepts or by applying elementary impedance methods to the zig-zag concept of wave propagation.

Almost as powerful as the simplified treatment of important phenomena is the establishment of upper and lower limits to design capabilities. To know how close one is to a theoretical optimum is essential information for a designer. A few years ago the author spent several months trying in vain to improve a filter which was, without his knowledge, within a few per cent of the theoretical optimum.

Unfortunately, not all these limits have found a place in the minds of the engineers. Take the cases of the minimum delay in an amplifier of a given gain, the maximum sensitivity in a receiver whose antenna partially sees the earth, the fastest rise time for a given bandwidth, the minimum Q for a given amount of supergain, the minimum phase shift required by a given amplitude response, the maximum bandwidth over which a particular impedance can be matched, the maximum possible sensitivity of a direct detection receiver—all of these limitations and many others could be usefully and interestingly presented.

In conclusion, let special credit and glory go to those who not only solve difficult problems but also know how to make difficult solutions appear easy.