Breaking Through the Mental Barrier

SEYMOUR B. COHN†

ANY of us whose work requires thinking will realize that the brain was not really meant for scientific effort. As to whether it is better suited to its more basic functions of guiding the individual is another fascinating subject that I will not consider here. Instead, I choose to pinpoint and attack a major inadequacy of the mind that interferes with our professional labors, and hope thereby, in some degree, to assist progress in our field.

We all know that for routine tasks an electronic computer is often far superior to the human mind. However, as a generator of new ideas the mind despite its inefficiency will probably never be replaced. Our best hope for scientific advance is to improve our use of the mind by understanding its built-in faults and by struggling constantly against them.

One does not have to be a psychologist to know that the mind tends to form easy paths of thought, with access to new ideas blocked by over-generalized beliefs and over-extended assumptions. Scientific principles, whether called laws, rules, theorems, or common knowledge, are invaluable aids when properly used, but when blindly accepted they can guide us to error and wall us from discovery. In effect, misused principles are barriers to creative thought. To break through these barriers we must completely understand the range of validity of each principle, and realize that outside this range any principle may be as unreliable and treacherous as prejudice and superstition.

The history of science is rich in examples of knowledge that served us well, but eventually proved to be barriers to further advance. Around the end of the last century many physical "certainties" were impeding progress until they were suddenly broken through, permitting entry into our current era of "modern" physics. Thus Newton's laws, believed for several hundred years to be the absolute regulators of the motion of matter, were found inadequate for particles approaching the velocity of light. Similarly, energy and mass were each considered to be constants in any given system, until an accumulation of perverse data made necessary the bold step of linking energy and mass together in a composite law of energy-mass conservation.

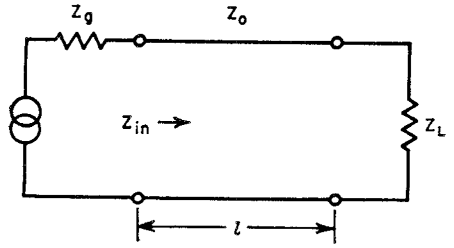
We can cite in our own field of microwaves many cases of beliefs proved wrong. It was once common knowledge that the transmission of electricity must require at least two conductors. Then in the 1930's several audacious men showed how to send high-frequency electrical waves with almost no loss down hollow conducting tubes. It still remained common knowledge that a wave could not be transmitted on the outside of a single conductor without radiation loss. Then, about a decade ago, a dielectric-coated wire was made to serve as an efficient transmission line. "Everyone" knew that passive microwave circuits had to obey the law of reciprocity, until it was shown how to circumvent this law by converting RF energy into kinetic energy of precessional motion of electrons spinning in a magnetized ferrite medium. Crystal mixers were known to introduce conversion loss until someone used nonlinear capacitance as the mixing agent, rather than nonlinear resistance, thereby obtaining conversion gain from a supposedly passive element.

I could easily continue with other examples of principles and beliefs found wrong, and important fields thereby created. However, this editorial would serve a more useful purpose if I could succeed in pointing out possible loopholes in our common knowledge through which future discoveries may be made. The best example would be the revelation of a new major breakthrough, which obviously won't be found here. Nonetheless, I will suggest a few weak points in microwave knowledge, and will hope that some far-seeing person will be able to exploit at least one of these into a practical application.

We have all proved as students that a generator emits its full available energy only when the load impedance is the conjugate of the generator impedance. I will now show how one of the postulates in the proof may be evaded in a practical way to allow a generator to put forth its complete available power into any impedance. In Fig. 1, a magnetron with internal impedance $Z_g = R_g$ is connected to a waveguide of characteristic impedance $Z_0 = R_g$ and input impedance $Z_{in} \neq R_g$. If the magnetron produces a pulsed signal of duration $\tau = 2l/v_g$ (where l is the waveguide length and v_g is the group velocity) the entire available energy will enter the waveguide. Before the reflected wave can return, the magnetron will have become inactive. Thus there will be no pulling effect on the magnetron. Also, the reflected wave will be re-reflected by the magnetron, since Z_g will have changed from a resistance into a reactance. Of course this scheme would have disadvantages in a practical system, but it illustrates, nevertheless, that the conjugate-match principle is valid only when steady-state conditions hold, and may be evaded easily when time-varying signals and elements are considered.

Power-breakdown ratings on waveguides and components have been arrived at experimentally and confirmed generally by theory. I will now suggest how the power-breakdown point may be increased by a few orders of magnitude. The theory of high-power break-

† Stanford Res. Inst., Menlo Park, Calif.



$$Z_{in} = Z_0 \frac{Z_L + Z_0 \tan \beta l}{Z_0 + Z_L \tan \beta l}$$

Fig. 1—Microwave circuit.

down assumes free electrons to be present in the strong-field region. Without free electrons, the breakdown process could not start until the electric field became so high as to tear electrons loose from air molecules or surrounding surfaces. I will leave to the reader the practical details of how to prevent formation of free electrons by shielding the microwave circuit from natural radiation, or of how to eliminate free electrons by sweeping them away or instantly trapping them in molecules of some yet unknown gas.

We have in the past decade become familiar with several ways of making nonreciprocal passive components. The major methods utilize spinning electrons in a ferrimagnetic medium placed in a dc magnetic field. Other methods employ a plasma medium with free electrons spiralling around a dc magnetic field. From these examples we are likely to assume that both rotational motion and a static magnetic field are necessary ingredients for passive nonreciprocal performance. But this is not true, as may be seen from the simple device sketched in Fig. 2. Microwave tube designers know that two types of space-charge waves can propagate on an electron beam. One type, used in traveling-wave amplifiers, travels slower than the beam and yields energy to the surrounding RF circuit as the wave grows in amplitude. The other space-charge wave travels faster than the beam and absorbs energy from the RF circuit as it grows. This fast wave is incapable of power amplification (unless pumped at a higher frequency in the parametric-amplifier mode of operation), but it can serve nicely as the energy storage element in a passive component. Thus in Fig. 2, the electrical energy of the input signal is transferred into energy of the fast wave by the input helix coupler, and is transferred back into very nearly the original quantity of electrical energy by the output helix coupler. If the generator and load are interchanged, however, the insertion loss will be very high since the fast wave travels only in the direction of the electrons. The exact equality of input signal power to output plus dissipated signal power justifies my calling the component "passive," and distinguishes it from "active" components, such as traveling-wave amplifier tubes and parametric amplifiers, within which signal power is created from nonsignal power. The device adds virtually no noise to the signal, since the input helix serves not only to couple the input signal onto the beam, but also removes the original fast-wave noise from the beam. Perhaps this component may be of practical value below 1000 mc, where ferrite and garnet isolators are relatively poor. In any event, the example will still serve its purpose if it encourages readers to look beyond magnets and whirling particles in seeking new schemes for nonreciprocal passive components.

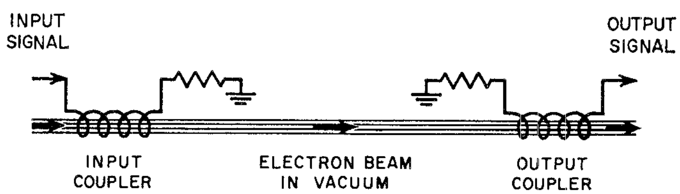


Fig. 2—Nonreciprocal device using fast space-charge wave.

It will now be obvious that I hope through this discussion to foster a critical attitude toward entrenched knowledge. Let us never forget that our most trusted beliefs may, outside their ranges of validity, be mental barriers to productive thinking. Let us arm ourselves with skepticism, combined with a firm grasp of fundamentals, and break through these mental barriers.