much better than those obtained on the physical circuits.

Set up as a ground-return circuit, the carrier noise level ranges from 30 to 40 decibels below the received signal at Havana, and 20 to 30 decibels below the received signal at Key West. Compared with Havana, the received signal level is low at Key West, since the northbound channels utilize the top frequencies and are more heavily attenuated; also noise from extraneous sources is higher because the cables are in shallow water for a greater distance at the Key West end of the route. The noise measurements were made during the month of February; somewhat higher levels of natural disturbances, such as lightning, may be expected in the summer months.

For the greater part of the year, ground-return operation on *3 KZ-HVA* and *4 KZ-HVA* provides excellent transmission quality on both carrier channels for teleprinter, ticker, or 3-channel multiplex. Under similar conditions, *2 KZ-HVA* is less effective by reason of its higher attenuation. Some deterioration of ground-return operation during the summer is caused by lightning disturbances.

The performance of the new system in traffic service has amply confirmed the excellent test results. Since completion of the installation, there have been several cable interruptions. During one period, two of the cables were out of service. Through use of the new carrier, all essential services to Cuba were maintained on the single remaining cable. On another occasion with one cable interrupted, the new system was superposed on one cable while an old-type 300-cycle channel was operated southbound on the second cable, with excellent performance.

Traffic experience with ground-return operation of the new system has developed a special circuit arrangement of some practical importance. When a cable is out of service because of an interruption or fault, that cable, under favorable conditions, may be utilized with an operating cable to provide a regular metallic circuit connection for the carrier, thus retaining the low interference levels normal with metallic operation. The nature and location of the fault and its effect on the duplex balance of the faulty cable determine the suitability of this arrangement in specific situations. If the fault is so near to one terminal that the carrier duplex balance cannot be restored readily, the ground-return connection would be used for the carrier at that terminal while the metallic connection could be used at the distant terminal. If the fault is in the midsection of the cable, the metallic connection can be utilized at both terminals.

Operation of the polar differential duplex physical circuits is not affected appreciably by the new carrier equipment. The field tests indicate that 4-channel 66-cycle multiplex operation will be feasible as a resistance-bridge duplex with signal-shaping amplifiers.

The Key West–Havana cables utilize core types (Table I) typical in general of short submarine telegraph cables. Although the *C-3* carrier system was developed for specific conditions it is applicable to similar cables for distances not exceeding about 100 nautical miles or attenuations not greater than 80 decibels at 1,000 cycles per second. Modified systems such as one 2-way channel or one to four 1-way channels would be suitable for cables of somewhat greater attenuation.

REFERENCE

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Electrical Essay

Half and Whole Solution for Commutatorless D-C Machine

Perhaps I was getting over my head in my inventions on electrostatics made while I was doing that repair job on the Van de Graaff generator at the Research Laboratory. I am glad to be back down here on the test floor again where I work with motors and generators which I fully understand. However, I still have my inventive ability tuned to the stars, and I am working on nothing less than the problem of getting rid of the commutators on d-c machines. Needless to say if I get rid of the commutator, I'll also get rid of the brushes and brush-rigging since I am not going to have the brushes ride on empty air, ha! ha! Also, needless to say that will be a wonderful advance in the art of d-c machines.

While I haven't completely solved the problem yet, I have made such great progress these last few days I am sure that the people who have taken such an intense interest in my inventions will want to hear about it.

There appeared yesterday on the test floor a very curious hybrid sort of machine. On one side, it was direct current with full-fledged commutator with complete rigging for two separate sets of brushes. I hooked my voltmeter and oscilloscope to the brushes and found top-quality direct current. However, I was amazed when my prying eyes discovered that the back side of the machine was alternating current. There, there were two slip rings with brushes riding on them, and my trusty oscilloscope showed that the slip rings were giving top-quality alternating current. Naturally, I was much intrigued.

Connected across the brushes on the slip rings was some sort of coil, with a center tap coming out of the case. So I began to test this center tap. When I put my oscilloscope across it and one of the sets of brushes on the commutator, I found top-quality direct current. Then the significance of my discovery hit me hard. I was getting direct current using only one of the two sets of brushes. The other brush set was completely idle, and could just as well be stripped from the machine. To get a commutatorless d-c machine, of course, I would need to get rid of both sets of brushes. I had now got rid of one set. The problem is now half-solved. All we have to do is get rid of the other set.

Will some reader contribute his half of the invention by getting rid of that other set of brushes?

P.S.: Just after writing the foregoing, I suddenly discovered how to make a commutatorless d-c machine, and completely. It is along a little different line, and I thought I had better get this postscript in before my readers spend too much time on the half-solution.

I start with an a-c machine, where a d-c winding on the rotor gives a succession of north and south poles. As the lines of force from a north pole cut the sides of a coil in the stator, it generates a certain voltage. However, the lines from the following south pole cut the coil sides and generate voltage in the opposite direction. Thus we get alternating current in the coil.

Now! After the north pole has finished cutting the coil-side and before the south pole has begun, let us reverse the direct current in the rotor. Then the following south pole changes to a north pole, and the voltage it generates by cutting the coil will have the same direction as that produced by the preceding pole. Continue this way, reversing the rotor current just after each pole has done its work on the stator coil. Then the voltage in the stator coil will always be in the same direction, and if a filter is interposed we should have top-quality direct current.

J. Slepian, Alter Ego

When the author was working on the test floor of the Westinghouse Electric Corporation many years ago, a young engineer independently made the second of the two inventions described in the foregoing, and persuaded his superior to authorize the building of a small model. The engineering report describing it, however, was entitled, "A New Method for Generating Double-Frequency Current."

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Answers to Previous Essays

Self-Running Electrostatic Motor. The following is the author's solution to a previous essay (*EE, Mar '50, p 247*).

You'll avoid getting into such fixes in the future, Alter Ego, if you'll refrain from talking about the force exerted by the electric field on charges or charged bodies placed within matter, as if the notion of such force had any uniquely verifiable meaning.

Coulomb's law and the Lorentz force equation have meaning for small enough charged bodies in empty space. For such bodies, **F**, q, **E**, and **B** may be defined operationally and uniquely. However, the definitions used for empty space cannot be carried over directly to within matter. We shall see in later essays how we may define **E**, **D**, **B**, and **H**, and even ρ, the charge density within material, but **F**, supposedly the direct action of the electric field on the charges introduced into the material, is another matter.

So far, in this discussion of this and the preceding electrical essay, "Electrostatic Space Ship," the vectors **F**, **E**, **B**, the scalar q, have meaning only for small enough bodies in empty space, and sufficiently far away from other material bodies. It is only in this domain of observable phenomena that Coulomb's law and the Lorentz force equation have verifiable meaning. If we wish to extend electromagnetic theory to the interior of extensive material bodies, new operationally meaningful definitions of the field vectors, and charge and current density must be given since the definitions given for particles or sufficiently small bodies are clearly without verifiable meaning inside of extensive matter. It is possible to give such generally uniquely meaningful definitions of the electromagnetic field and charge and current densities, and the author hopes that in future essays such definitions will be presented. However, in the author's opinion, it is not possible to define in any significantly unique way the ponderomotive force density, and again the author hopes that in future essays this will be brought out.

Going from small-charged-body electromagnetism to that for extended material bodies is similar in some ways to going from Newtonian particle dynamics to rigid body or continuous medium mechanics. In this last case Newton's laws for particles are not sufficient. We must invoke new and independent principles, such as the principle of virtual work, or D'Alembert's principle.

Similarly, in the electrical case, to systematize or put in order the electromechanical effects for extended bodies we need some additional principle over and above Coulomb's law and the Lorentz force equation. Most investigators have chosen the principle of conservation of energy for this purpose. They assume the existence of an energy function which, for the particular electromechanical system, is a function of the electrical and mechanical parameters which specify the state of the system, and which the investigator may vary at will. The change in value of this energy function as the parameters are varied is set equal to the work done by the investigator in changing the parameters, and thus an expression for the force appropriate to any particular independently variable parameter may be obtained.

Certainly no objection can be raised to this procedure. If we apply it to Alter Ego's machine, it would appear that whatever the energy function may be, it must be independent of the position of the belts along their pulleys, since shifting the belts along themselves appears in no way to change the electrical or mechanical configuration. Hence it appears that the force tending to move the belts is zero. However, many investigators have gone further. They assume (unjustifiedly) that the total energy of the system can be resolved in some significantly unique way into the sum of a purely electrical part and a purely mechanical part. Then assuming that the system changes continuously from one state to another, with great mathematical skill, they transform the rate of change of the hypothetically unique electrical part of the energy into an integral over the moving parts of the system of some vector expression multiplied scalarly into the vector velocity of the material at each point.

There is no evidence that this transformation of the rate of change of the electrical part of the energy, dU_e/dt, into an integral of the form

$$\frac{dU_e}{dt} = \int\int\int \mathbf{f}_e \mathbf{v}\, d\tau \qquad (1)$$