The Corona Wind Loudspeaker*

GERALD SHIRLEY†

Televex Co., Yonkers, N. Y.

The discovery in England of a method of controlling the wind produced by a corona discharge provides the basis for a new loudspeaker design having no moving parts and offering other potential advantages over conventional speakers. The inventor of the Corona Wind Loudspeaker is Dr. David M. Tombs.‡

The author first describes the construction of a corona triode in which a ring mounted coaxially about one electrode and given suitable potentials is found to control the discharge and hence the magnitude of the wind. Characteristic curves indicating triode-like behavior for various electrode spacings are presented.

By applying an af voltage to the ring, a sound source results. An early experimental model of such a loudspeaker is described and illustrated, together with its observed frequency response. Comparisons with the Ionophone and the electrostatic loudspeaker are made, which indicate its potential superiority in wide range reproduction. The author discusses the acoustical and electrical problems that arise in the construction of a practical loudspeaker, and concludes with details of the research and development program necessary for its commercial realization.

BACKGROUND

UNTIL RECENTLY corona has been regarded almost universally as an undesirable phenomenon, and such studies of it as have been made were usually undertaken with a view to suppressing it. Most engineers in the communications field are aware that it is a source of hf noise and interference, and that countermeasures are regularly applied to aircraft and high voltage power lines. In the latter case the need to control power losses is a primary concern.

Since so little is known about corona on the positive side, it was necessary to make some rather fundamental tests and observations of the phenomenon, and in particular on the wind that accompanies a corona discharge. A convenient method of observing the properties of these winds—direction, strength and pattern—consists of injecting a smoke stream at low velocity into the corona field.

Starting with the simplest case, a pair of electrodes, one of which was sharply pointed and the other blunt, it was found that only the sharp electrode produces a wind. Further, the wind is stronger when the needle (i.e., the sharp electrode) has a positive potential on it than when it bears a negative sign.

In order to control this wind, it was thought that a smooth ring mounted coaxially around the needle might provide a valve action in the same manner as the grid in a triode vacuum tube. It was found that the corona current could be controlled by changing the potential on the ring, and was also affected by the diameter of the ring as well as by its position with respect to the tip of the needle. In order to measure these several parameters so that the "plate characteristics" of the corona triode could be graphed, special laboratory apparatus with micrometer controls and a series of rings of different diameters was constructed. This apparatus is shown in Fig. 1.§ The triode section is on the left. (The two long needles on the right side were used to measure and plot the resistance characteristics of corona diodes, which could be used as 'loads' for corona triodes. These diode characteristics are shown in Fig. 2.) The E_g–I_p–E_p characteristics of the corona triode for several varying geometries are shown in Figs. 3 and 4. The very interesting similarity of these curves to the plate curves for certain triode vacuum tubes is immediately apparent.

In this form—i.e., with one sharp and one dull electrode plus a ring or grid—the corona triode can act as a "uni-

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† President.

‡ D. M. Tombs, *Nature,* **176**, 923 (1955).

§ Figures 1 to 5 have been furnished through courtesy of Dr. Tombs.

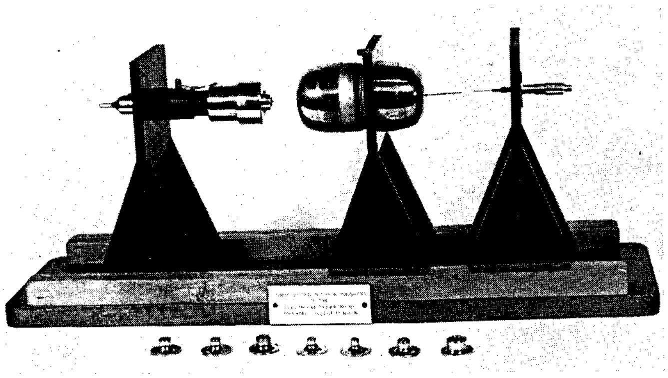

FIG. 1. Laboratory model of the corona triode. The needle and ring-like grid is seen at the left, with the blunt electrode at the center. Grids of various sizes are shown in the foreground.

directional" loudspeaker if an audio signal is applied between grid and the sharp electrode. This is shown diagrammatically in Fig. 5a. The sound output can be described as "modulated dc." In other words, there is a steady (dc, uni-directional) wind accompanying the (ac) sound.

If two sharp electrodes are used in constructing the triode, two opposed winds are created, the positive wind being the stronger of the two, and also having a narrower "beam" as shown by the smoke patterns. By suitable positioning of the grid (and adjustment of its voltage) with respect to the positive needle, it is possible to balance the two winds so that with no signal present there is no "net" wind. This is shown diagrammatically in Fig. 5b.

The amount of sound produced by a single corona triode is very faint, and in order to get sufficient volume a large number of them must be operated in parallel. The first stacked triode speaker which was built utilizes 144 pairs of needles spaced one-half inch apart, giving an outside dimension of 6″ × 6″, or one-quarter square foot. This is shown in Fig. 6. The grid was constructed in the form of a screen made up of interlaced wires spaced one-half inch apart. Thus there is a square hole for each pair of needles, and when properly aligned the axes of the needle pairs intersect the centers of the square holes. The supporting structures for the grid and needle matrices shown in the photograph are not the original ones but were hastily improvised by the author, since Dr. Tombs was able to bring only the grid and matrices when he came to the U. S. A. Because of the time element it was not possible to construct a highly accurate structure with guide rails or other similar means to ensure exact mechanical parallelism at all settings, and adjustments have to be made by looking and listening.

The amount of sound produced by this first crude model is still rather small, though it can be reported that AES members sitting in the back row during the demonstration given by the author (June 12, 1956) at a New York Section meeting of the Society in a fairly large room were able to hear what was being reproduced fairly well. It is obvious that a commercially acceptable Corona Wind Loudspeaker (hereafter referred to as CWLS) will have to be considerably larger. Dr. Tombs estimates that four or five square feet may produce adequate volume for home use, though for hi-fi enthusiasts the figure would probably have to be increased. Obviously, too, the ultimate size will be affected not only by the acoustic power output requirements but also by the ultimate efficiency of the device. It is believed that this is one of several factors which can be improved by further research.

CHARACTERISTICS OF THE CORONA WIND LOUDSPEAKER

To any audio engineer, and particularly to any loudspeaker designer, the most significant thing about the CWLS is the absence of any moving parts. Actually this is not the first transducer to convert electrical energy directly into sound. Several years ago the French inventor Klein

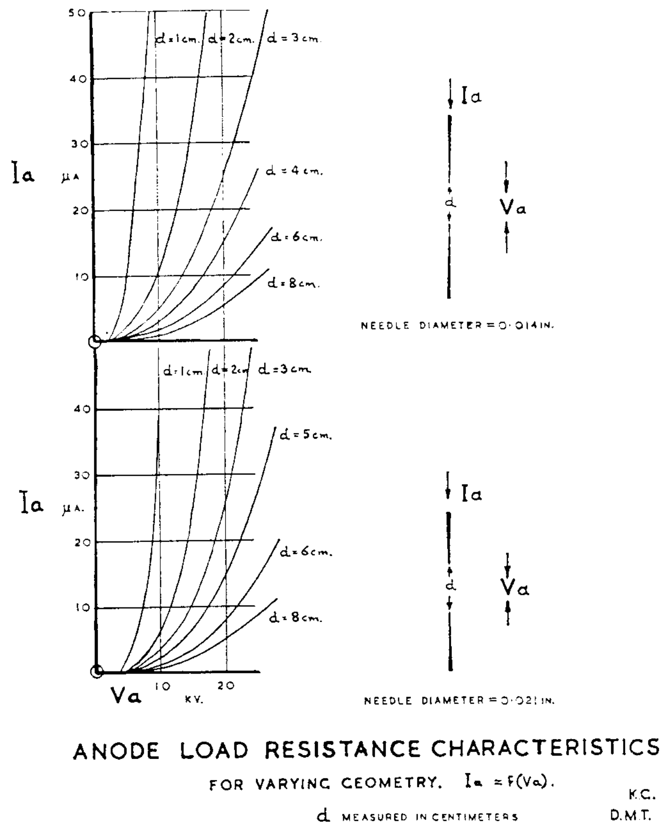

FIG. 2. Corona diode characteristics. The corona current I_a depends upon the electrode potential difference V_a, and the separation d. The effect of the needle diameter, 14 mils (above) and 21 mils (below), is not apparent until d is less than 2 cm.

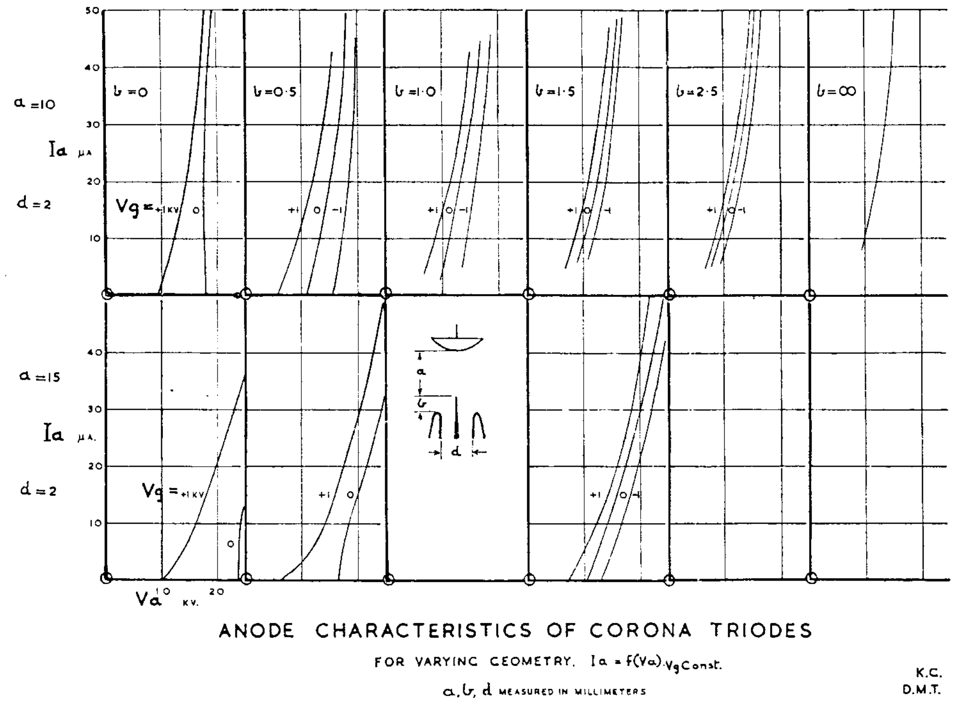

FIG. 3. Corona triode characteristics. The corona current I_a is shown as a function of the electrode potential difference V_a for various electrode spacings and three different grid voltages. At the top, the needle-to-blunt electrode spacing, a, is held at 10 mm, but the needle tip-to-grid distance, b, is varied. Below, a has been increased to 15 mm. In both cases, the needle remains 1 mm away from the grid.

demonstrated his Ionophone[1] which also has no moving parts. On theoretical grounds, at least, the CWLS appears to have certain important advantages over the Ionophone, not the least of which is its wide range, whereas the Ionophone is evidently limited to tweeter applications. Other comparisons which can be made are:

1) the Ionophone is a point source of sound (and a very small point at that) whereas the CWLS is an extended source;
2) the Ionophone functions as a power diode, whereas the CWLS is apparently a triode device, which is more efficient than a diode.

In comparing the CWLS to electrostatic speakers the following points can be made:

1) both are extended rather than point sources of sound, and both are adaptable to push-pull operation;
2) the CWLS can reproduce a wider frequency range, and should be able to create a greater amplitude of air motion at any frequency, both of these advantages deriving from the absence of any diaphragm. (The excursion of the diaphragm in an electrostatic speaker is severely limited);
3) for electrostatic speakers actual watts of audio power are required (to drive an essentially capacitive load) as well as polarizing voltages (these voltages, however, are not high enough to cause ionization).

The requirements for the CWLS, to be discussed in detail further on in this paper, will be seen to be quite different.

Having made these brief comparisons, the discussion will now revert to the characteristics of the CWLS itself, the first of which is its frequency response. The CWLS appears to be capable of covering the entire audio spectrum from zero on up. The very fact that it can produce a wind is prima facie evidence of its low frequency capabilities. However, actual measurements in the range from zero to 20 cycles will present some interesting problems. First of all, to provide an ultra-low frequency signal it is necessary to use a beat-frequency oscillator, since conventional audio oscillators normally extend down to only 20 cycles. Secondly, a microphone which responds all the way down to zero, and is accurately calibrated, is not easily come by—if indeed it exists at all. Subjective judgments are not likely to be of much help considering that the crossover point between hearing and feeling is in the vicinity of 20 cycles. Perhaps a more promising approach would be the observation of the movement of a flame (as from a candle) held in front of the CWLS. This method has been used

[1] S. Klein, *Comptes Rendues,* **222,** 1282 (1946), **233,** 143 (1951), *L'Onde Electrique,* **32,** 314 (1952).

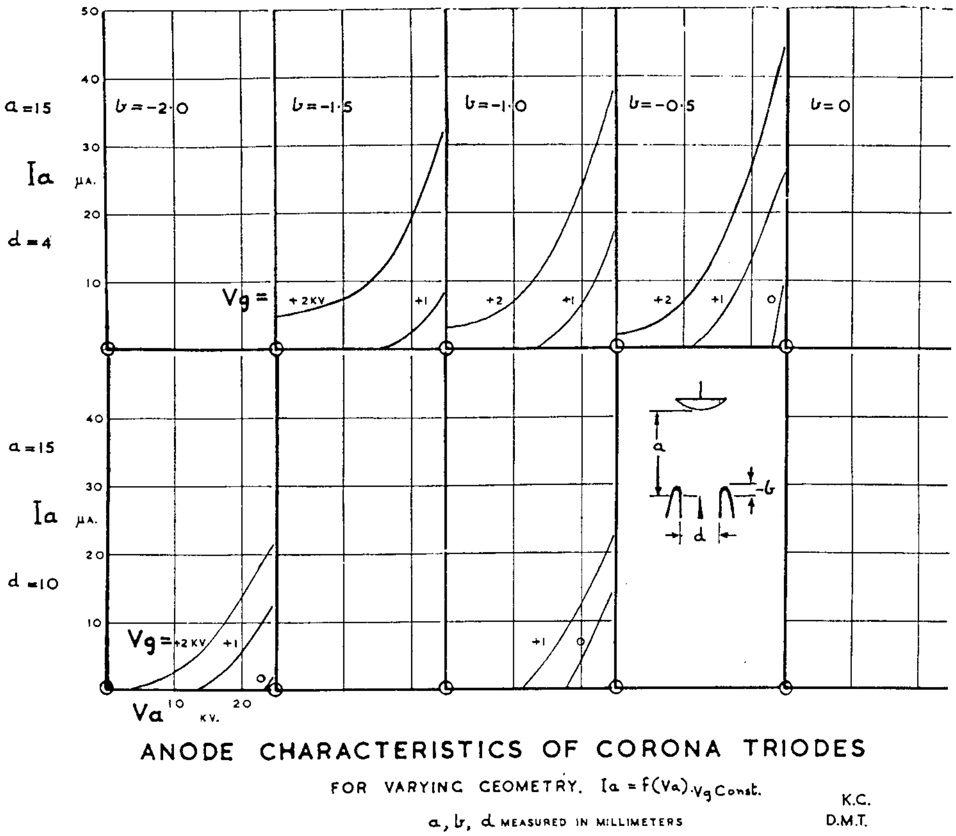

FIG. 4. Corona triode characteristics (cont'd). In this series, the needle is located at varying distances within the grid. The anode-to-cathode distance, a, is maintained at 15 mm in both cases, but the relative position of the needle within the grid is varied, as shown. A 4 mm ring is used in the series at the top, and a 10 mm ring below.

by Dr. Tombs to demonstrate the response at around four or five cycles. It seems likely that a fair degree of accuracy could be achieved in measuring the amplitude of a flame movement by using a specially constructed sighting—or optical projection—device.

The upper limit of frequency response of the CWLS would appear on theoretical grounds to be well up in the ultrasonic region, depending in large measure on the recombination time of an ionized gas. It therefore seems reasonable to anticipate that response to a minimum of 20 kc will be readily obtained.

Due to the absence of moving mechanical parts (and associated suspensions) the overall response curve is in general much smoother than that obtained from a typical cone-type speaker. In Fig. 7 there is shown a curve taken on the first model. The measurements were made with a calibrated microphone over the range shown. This is obviously not yet a "flat" response, and indeed it would have been surprising if perfection had been obtained on the first try. Even so, this curve represents a deviation from flat response of only 3.5 db, assuming a reference frequency of 1500 cycles. The dip at 8000 cycles, which is the only pronounced irregularity in the curve, is apparently related to the physical spacing between the tips of the two sets of needles and corresponds to a half-wavelength at the indicated frequency. Since the spacing can be varied, the position of the dip can be moved up or down, though it is unlikely that this would be the decisive factor in establishing an optimum spacing. More important, it is believed that there are several approaches which could succeed in minimizing the amplitude of the dip, if not in eliminating it completely.

The CWLS is not immune from the degradation of low frequency performance which results from cancellation effects between front and back radiation. In other words baffling is necessary. Depending on the application and the desired low-end response, either a bass reflex or an infinite baffle type enclosure could be used.

No measurements have been made on the polar dispersion pattern as a function of frequency. Theoretically the CWLS should show an increasing tendency towards beaming as the frequency is increased, and subjective judgments based on listening to an audio oscillator indicate that this is so. (In this respect the CWLS is similar to electrostatic

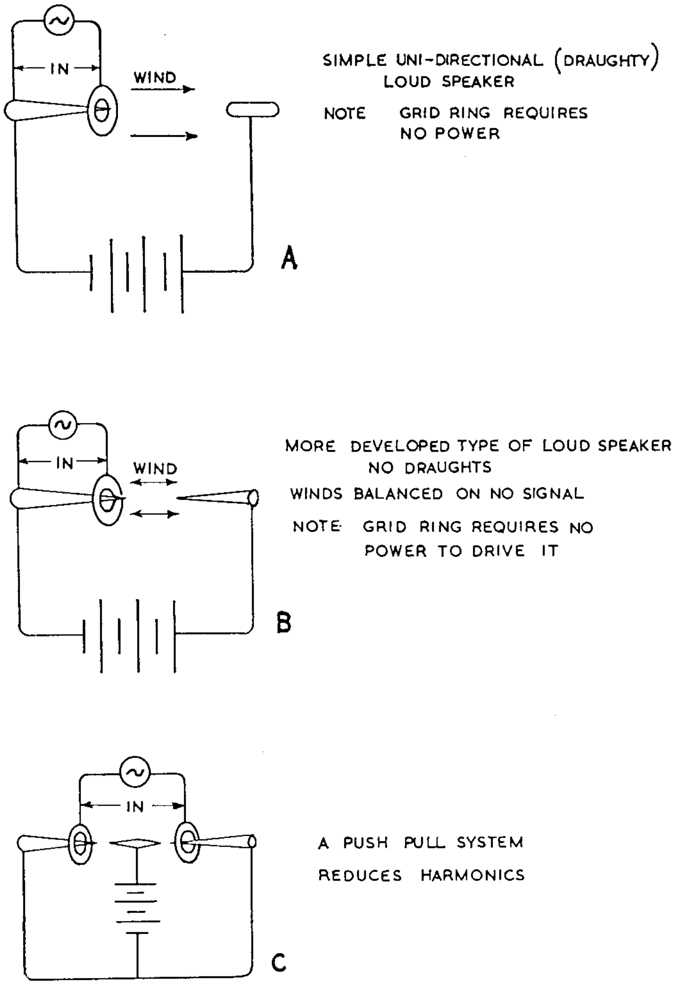

FIG. 5. Schematic diagram of triode as loudspeaker. A. With the polarities shown, an audio signal applied to the grid produces a wind in the anode direction. B. Replacing the blunt anode with a needle causes winds in both directions. C. Push-pull arrangement.

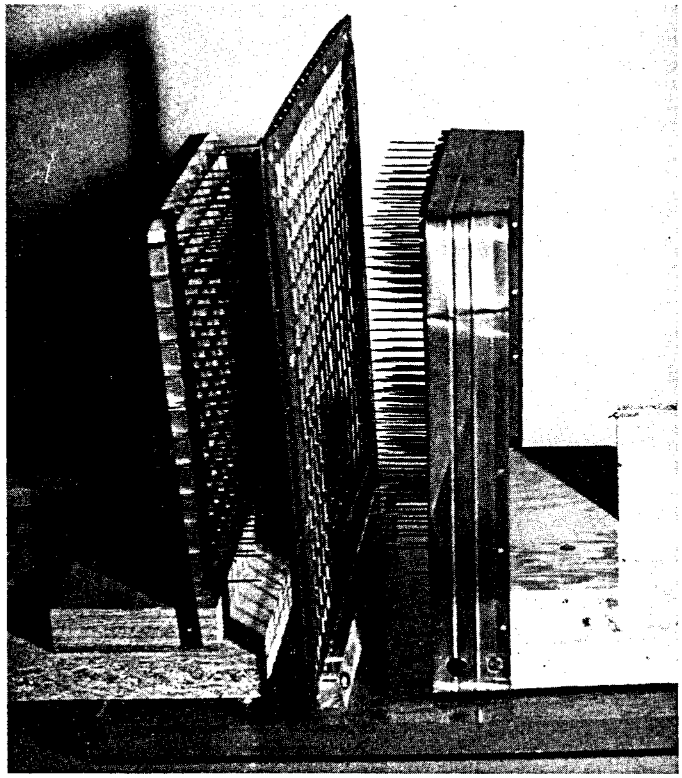

FIG. 6. Experimental form of loudspeaker as an extended source. The grid is a screen with square holes, one-half inch wide. The axes of each electrode pair pass through the center of the corresponding hole.

speakers.) In production models uniform sound dispersion through any desired angle could be obtained by constructing the needle matrices and grids in a curved section rather than in a flat plane. Since these members have to be made rigid anyway, it is thought that there should be no great difficulties in constructing the speaker with a curved cross-section. Alternatively it could be made in narrow planar segments joined together so as to approximate a curved section of any desired arc. Inasmuch as satisfactory vertical dispersion patterns are (evidently) obtained in electrostatic speakers without curving them in two planes, the chances are that double curvature would not be necessary in the CWLS either.

Measurements on distortion have not yet been undertaken. These will be part of the program of research and development on the CWLS, one of whose aims, of course, will be to chart all the relationships between distortion and the various electrical and mechanical parameters. With the first model which is in the author's possession, some distortion is definitely audible, and seems to vary with the mechanical "settings" of the matrices and grid (which are

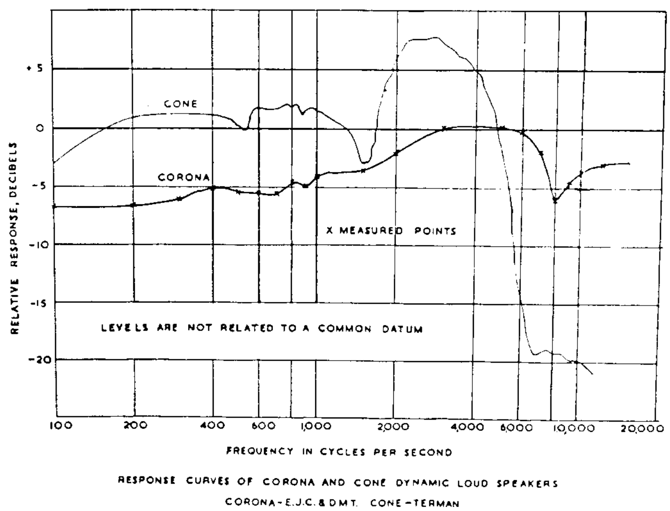

FIG. 7. Frequency response of the experimental loudspeaker. The dip at 8 kc results when the electrode separation is $\lambda/2$ of the applied signal (see text).

not highly accurate, as previously explained), and also on the amount of drive voltage fed into it. The CWLS can be overdriven like any other transducer (despite the absence of a diaphragm), and in playing around with the small model there is always the desire to crank up the volume in order to hear it better. It is interesting to speculate on whether the CWLS may not be inherently less susceptible to intermodulation distortion by virtue of its weightless "invisible diaphragm."

Still on the subject of distortion, a very important point to consider is that the configuration which has been discussed thus far is single-ended—both the speaker and the driver amplifier. It is very easy to construct the CWLS in a symmetrical, push-pull form, one version of which is shown schematically in Fig. 5c. Dr. Tombs has since constructed a push-pull model and reports that the performance is definitely superior to that of the first (single-ended) model. It is driven by a push-pull amplifier with negative feedback over the output (driver) stage only. The possibility of applying *over-all* feedback—with all of its well-known benefits—is one that will naturally occur to most readers, and there are several methods whereby this could be accomplished.

Measurements on the acoustic output of the first model show that for minimum audible distortion a figure of about 0.1 mw/sq. cm. is attained, and it is believed that this is roughly comparable to the output of electrostatic speakers. The electrical power input (dc) is about 50 mw/sq. cm. at 12 kv. A quick calculation shows that the efficiency is quite low, but as mentioned earlier, this factor may be susceptible of improvement. Whether such improvement would be nominal or considerable only time and further research will tell. Direct comparisons of efficiency with cone-type speakers are not completely relevant, since with these the lowest level of efficiency which can be tolerated is in part dictated by the economics of providing sufficient watts of audio power to drive them. This is not a desideratum in the case of the CWLS, since only an audio *voltage* is required to drive it, regardless of its physical size and acoustic output. There remains, of course, the economics of the high voltage supply for the corona field, and from this standpoint it is obvious that the goal of improved efficiency will have a priority second only to the goals of linear response and elimination of all distortion.

It is frequently asked whether the background hiss of the corona discharge is objectionably audible. No quantitative measurements have been made, but those who have heard the first model would generally agree that with proper adjustment the hiss is practically inaudible. Starr[2] has shown that radio interference and acoustic hiss can be greatly reduced by using a slender needle. Though the needles used to construct the first model are of small diameter, it is by no means certain that they represent an optimum selection from the viewpoint of hiss-suppression. At close settings of the needle matrices it is necessary that all the tips of each set of needles lie exactly in a plane, and that the two planes be exactly parallel to each other. If this condition is not met, then as the matrices are brought closer together whichever pair of needles has the smallest inter-tip spacing will pass a higher than average corona current and this will be accompanied by audible hissing. As the matrices are moved still closer, at some point arc-over will occur as the dielectric strength of the air is exceeded. In a darkened room one can see the corona discharge, which takes the form of a tiny blue glow at the tip of each needle.

DRIVE REQUIREMENTS FOR THE CWLS

The required amplitude of the audio driving voltage is in the neighborhood of one to two kv peak to peak. At first glance this may seem like a serious and costly obstacle, but in reality it is quite simple to achieve, inasmuch as a high voltage supply (at least 8 kv) is already required for the corona field. The only other elements needed are a suitable voltage amplifier tube and a load resistor. There are currently available special purpose tubes such as the 6BK4 and 6BD4A originally designed for regulator use in high voltage power supplies, which perform very satisfactorily in this application. These tubes draw very little current and have an amplification factor of 2000. Thus it is necessary to apply only a few volts to the grid in order to get the required 1 to 2 kv swing at the plate which is directly coupled to the grid of the CWLS. The circuit employed in the experimental model is given in Fig. 8.

POWER REQUIREMENTS

The power requirements for the corona field vary proportionately with the number of needle pairs and in inverse ratio to the distance between the opposed tips. The effect of increasing or decreasing the spacing between (adjacent) needles is not yet known. The amount of current drawn is also influenced by the mechanical configuration of the grid structure, its position relative to the needles, and the voltage on it. According to Dr. Tombs' measurements on the first model, each needle pair passes "some tens of microamperes" of current. No precise figure can be given, of course, without defining all the electrical and mechanical conditions.

The minimum voltage required is one that will cause a corona discharge, and maintain it with an adequate margin of reserve to overcome any conditions which might tend to "quench" it. The maximum—tolerable—voltage will be defined by considerations of efficiency, performance, cost, hiss, safety, and so on. There is evidently a wide range

[2] E. C. Starr, A.I.E.E. Technical Paper 40-118 (May 1940).

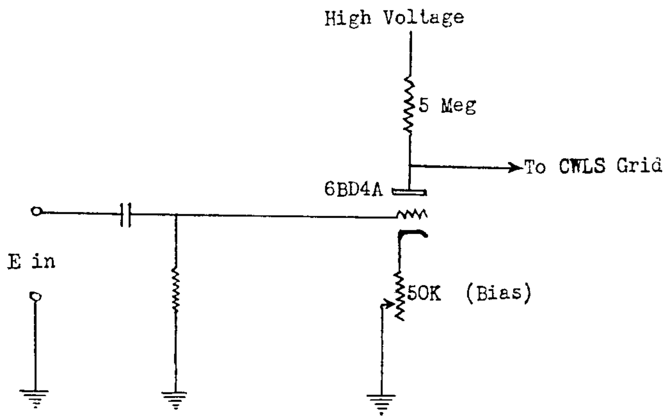

FIG. 8. Schematic diagram of high voltage af driver. With a voltage gain of about 60 db, and an anode supply voltage of from 10 to 20 kv, an audio signal of 1 to 2 kv appears at the anode.

of usable voltages, and one of the goals of the R and D program will be to determine the optimum value.

NON-ACOUSTIC OUTPUTS OF CORONA TRIODES

As an electronic amplifier, the corona triode has a voltage gain of about 3. No especially useful application comes to mind for this, and any suggestions would be welcome. Someone has pointed out that a corona triode—or several in cascade—could be used to obtain the high driving voltage required for a CWLS. This is an intriguing idea, but is probably doing it "the hard way".

The other non-acoustic output of corona triodes is ozone and nitrous oxide, which are by-products of the corona discharge. This will have to be studied carefully to determine whether it presents a health hazard.

RESEARCH AND DEVELOPMENT PROGRAM FOR THE CORONA WIND LOUDSPEAKER

A program of research and development aimed at bringing the CWLS to a point where it can be commercially produced could logically start with a careful investigation of the corona wind phenomenon itself. There are certain fundamental questions whose answers might well save time during later phases of the program. For example: What actually causes the winds? Is the relationship between wind velocity or volume and corona current linear? A search of the literature might uncover earlier studies which could reveal useful information, but it is thought likely that the bulk of references will concern various (usually harmful) effects of corona and methods of suppressing it. In the present instance the goal is to encourage corona—not to discourage it.

The first phase of the R and D program will undoubtedly consider the CWLS only as a wind producing mechanism (corona diode), and will be concerned with investigating and measuring the effects of the various mechanical and electrical parameters on efficiency and hiss. Efficiency would be defined, of course, as the ratio of wind out to power in.

On the mechanical side the starting point of the investigation would be the electrodes themselves. The effects of varying the length, diameter, including angle, and tip radius will all have to be individually determined. It would probably be unwise to start out with any preconceived notions as to what the effects are going to be. In fact, it should not even be assumed that a needle shape is necessarily the best for electrode use. Other shapes and configurations should also be tested. For example, one could try thin-wall tubing of various diameters, down to hypodermic needle sizes, and with various treatments of the emitting ends, such as bevelling (to get a fine edge) or flaring.

On the electrical side, it will be necessary to determine the relationship between power in and wind out, and also whether it makes any difference if the power consists of high voltage at low current or vice versa. Of course, the voltage always has to be high enough to start and maintain the corona discharge, but from that point on there is quite a range.

Dr. Tombs has made an interesting suggestion concerning the possibility of making the tips of the needles radioactive. Ionization should thereby be aided, but whether this would increase the efficiency could only be determined by actual tests.

Not only are the velocity and volume of wind important but also its direction. Dr. Tombs' smoke experiments have shown that positive winds are more tightly 'beamed' (forward) than negative winds. The latter have an umbrella shape. Presumably a negative wind would yield less acoustic output, when modulated, than a positive one. It is possible that by suitably manipulating the dimensions and geometry of a negative electrode its wind could be made more nearly coaxial. (But it is not a foregone conclusion that this would be desirable.) Another interesting possibility is that of somehow turning the negative wind around so that it aids instead of opposes the positive wind.

During the corona diode stage of the R and D program it might be well to get started on a study of the effects of varying humidity levels. Offhand it would seem that a high humidity level might aid the flow of corona current, thus setting a limit to how close the opposed electrode tips could be. In other words, mechanical and electrical specifications might have to be chosen so that arc-over would not occur during periods of abnormally high humidity. If this limitation were found to exact too great a penalty on efficiency (during periods of normal or low humidity), then it might be worthwhile to incorporate a compensating circuit using a humidity-sensing transducer which would automatically adjust the voltage level in reference to the humidity level.

When all the facts are in on the corona diode as a wind producer, the next phase will concern itself with corona triodes. The first subject for consideration is the grid structure. The size and shape of the openings, the width of the walls, the thickness of the structure—all these will have to be individually varied to determine their effects (if any) on efficiency, frequency response and distortion. Tests should also be made with finer mesh grids to see if they offer any advantages over structures which have one hole for each pair of electrodes.

The positioning of the grid with respect to the electrodes is already known to have a significant effect on the operating characteristics, and accurate measurements to chart these relationships will be an important step. Not only does the position of the grid have an effect but also the electrical operating point—i.e., the no-signal dc voltage. If an analogy to vacuum tube operation is valid (and it certainly seems possible on the basis of the triode characteristics), then it may be possible to obtain various types of operation—i.e., Class A, Class AB[1], Class AB[2], and so on. This could be of significance in later work on the push-pull versions.

Another mechanical variable is the spacing between adjacent electrodes, and this brings up an interesting point. Though the CWLS does not have any moving parts there is a strong temptation to postulate an invisible diaphragm; this leads to some questions as to the physical properties of this diaphragm. Specifically, how porous is it? And does the porosity vary with frequency? The relationship between porosity and efficiency must be fairly obvious. It may turn out that an electrode spacing which yields maximum efficiency at low frequencies (long wavelengths) results in an intolerable attenuation of high frequencies. If such a condition is in fact found to exist, then several solutions are available, the most obvious one being a compromise spacing. Still on the subject of porosity, it may be pertinent to ask whether a negative wind may not be less porous than a positive wind. The reason for this could be that the winds from each electrode in a negative field blow not only forward but also sideways towards the other electrodes. This could perhaps have the effect of making the invisible diaphragm more impervious—i.e., less porous, hence more efficient.

When the analysis of the CWLS as a single-ended transducer is complete, and the effects of every single variable on the operating characteristics (and on each other) are thoroughly understood and measured, then the next phase —push-pull operation—can be started.

However, before too large an expenditure of time and money is made on the development of the CWLS as an air-operated device, it might be well to determine whether its production of ozone actually constitutes a health problem, and if so whether it can be overcome. If it cannot, then the CWLS will be developed for operation in an inert gas, such as argon. In this case the speaker would be mounted in an infinite baffle type of enclosure, but instead of the usual solid front panel (for mounting the speaker) there would be a thin plastic membrane, such as Mylar. (Actually both the speaker and membrane could be set in a short distance from the front edge of the cabinet so that a grill cloth could be attached in front.) In order that the usual drawbacks of diaphragms and elastic suspensions may be avoided, the membrane would probably not be fastened under tension, but would rather be loose and floppy, serving chiefly as a separator between the gas inside and the air outside. While at first glance gas operation might seem to be an undesirable complication, nevertheless it may offer some unsuspected advantages such as better efficiency, lower distortion, etc. One known advantage is that there would be no problem of metal corrosion, which does exist with air operation. The ozone and nitrous oxide which result from corona discharges in air have a corrosive effect on certain metals. Dr. Tombs has suggested that it may be possible to neutralize these chemical compounds by providing a "sacrifice" material within the speaker enclosure which the compounds could attack. (The analogy to sacrificial magnesium anodes used in water tanks and on ship hulls comes to mind.) The electrodes, or their emitting tips, could be made of stainless steel or some other corrosion-resistant metal. The grids and support structures could be made of less expensive metal and protected by a coat of suitable plastic (such as du Pont Hypalon).

In experimenting with push-pull configurations different combinations of electrodes—positive, negative, sharp, blunt —can be tried, as well as various classes of operation (Class A. Class AB[1], etc.). As mentioned earlier, it may be worthwhile to try to turn the negative winds around so that they aid their respective positive winds. In this way each half of the speaker would produce one wind instead of a pair, and this might improve certain of the operating characteristics.

With push-pull operation, excitation of the corona field by rf power (instead of dc) may be feasible, and this presents a number of interesting possibilities which should be looked into. (The analogy to high frequency bias in tape recording comes to mind, though it may not be a valid analogy.)

Still on the subject of power supplies, the subject of regulation is one that would probably be started on during the earlier single-ended phase of the program and would of course continue on through into the push-pull phase. Since the cost of power supplies bears a direct relation to the degree of built-in regulation, it is clear that one of the goals of the program will be to find a combination of mechanical and electrical parameters which will yield optimum acoustic performance and at the same time require as little regulation as possible in the power supply.

The last important project will be the development of an over-all feedback system so that any residual distortion or irregularity in the response curve will be eliminated, or at least reduced to insignificant proportions. This boils down to finding a suitable transducer to sample the acoustic output and provide a corresponding voltage which can be fed back into the driver amplifier. A microphone comes to mind immediately, of course, but it must be remembered that ordinary microphones are neither wide-ranged (compared to the CWLS) nor particularly flat. It might be possible to make a very simple condenser type of microphone at low cost which would be incorporated right in the speaker.

In summary, one can fairly say that the complete R and D program for the CWLS will represent a rather extensive undertaking. However, there appear to be good reasons for believing that the final results should fully justify the costs of the program.

Note Added in Proof

After completing this paper, the author sent a copy to Dr. Tombs for his comments. In his reply, Dr. Tombs calls attention to an error in the description of the corona wind:

"It is obvious that I have not made myself clear about the shape of the negative corona wind. This is not umbrella-shaped in the absence of a positive wind. Positive and negative winds separately are similar in shape, the positive being rather stronger than the negative, and it is the interaction of these two blowing simultaneously which appears to give the umbrella shape in the proximity of the negative electrode."

He also comments on the drive requirements and the efficiency comparisons:

" . . . I suggest . . . that you should mention that only very small power is required to drive the Corona Loudspeaker, the power being primarily to make good the losses in . . . the way . . . the driving power of the grid of a valve . . . has to make good the losses . . . It might be worthwhile pointing out that the efficiency of ordinary loudspeakers is very low and the power required to drive them is not a measure of the acoustic power generated. The CWLS requires negligible power. The loudspeaker is in fact a control device like a valve, in which the power is supplied by the polarizing high voltage source."

Editor's Note: Additional photographs and description of the CWLS may be found in the recent paper: D. M. Tombs, E. J. Chatterton, and K. Galpin, *Electronics*, **30**, No. 7, p. 198 (July 1, 1957).

Gallina

(*Continued from page 10*)

"16mm Projector" lever switch to "Meter" position. By flipping to "Monitor Speaker" position, he can listen to the quality of the sound as it is heard by the audience. The "P.A. System" switch likewise performs the same function for the public address system amplifier.

The "Adjust Monitor Speaker" and "Adjust Meter" controls are used to adjust the setting of the meter and the volume of sound heard over the monitor loudspeaker without affecting the sound directed to the listening audience. The sound level meter and the monitor loudspeaker can be disconnected by setting both lever switches at their center position.

Equipment

1. Ampro optical and magnetic model #477 motion picture projector, equipped with a dynamic microphone and head phone and mixer.
2. Viewlex 500-watt filmstrip (single and double frame) and 2 × 2 slide projector model V25C.
3. Bogen amplifier with 3-speed turntable model J330—2 microphone low impedance channels, 1 high impedance phonograph channel, 1 high impedance tape recorder input.
4. (2) University type BLC weatherproof wide range loudspeakers.
5. Pentron 2-speed tape recorder model T90.
6. (2) clusters of weatherproof floodlight sockets, each supplied with 25 feet of power cord, having a 2-pole, twist-lock male plug.
7. (4) Atlas model SS-2 collapsible weatherproof heavy duty stands: (2) for the University BLC loudspeakers, (2) for floodlights, adjustable from 5 to 10 feet.
8. (2) Shure 55S "Unidyn" multi-impedance microphones equipped with 50 feet of shielded 2-conductor cable fitted with matched 3-pole XL-3-11 microphone connectors.
9. (2) Atlas type MS-11c adjustable microphone floor stands.
10. (2) Heavy duty American Television and Radio dc to 115-volt 60 cycle ac inverters: (1) Model 12T-HSH 12-volt dc to 115-volt 60 cycle at 200 watts. (1) Model 110T-HSH 110-volt dc to 115-volt 60 cycle at 400 watts, with extra replacement vibrators.
11. (6) General Electric 150-watt 115-volt floodlights (reflector type).
12. (1) 75-foot extension cord for the 16mm motion picture projector speaker, equipped with a 2-pole phone plug.
13. Fold Fast 7½ × 10 ft. collapsible mildew-proof screen with aluminum frame.

CONCLUSION

In summary, we can say that from the technical point of view the task of the overseas audio-visual worker is not an easy one. It offers a major challenge to his patience, to his persistence, and to his mechanical ingenuity.