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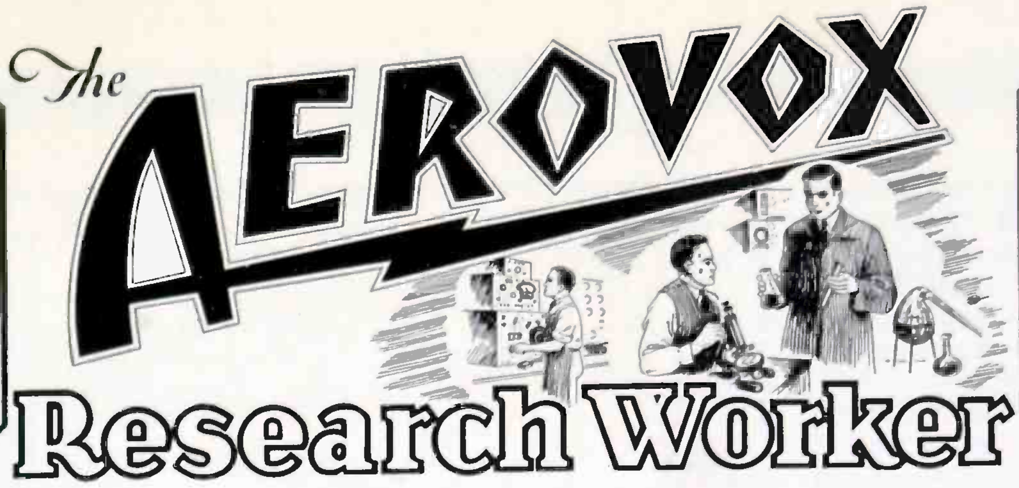

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Millimeter Waves

The New Frontier in Radio

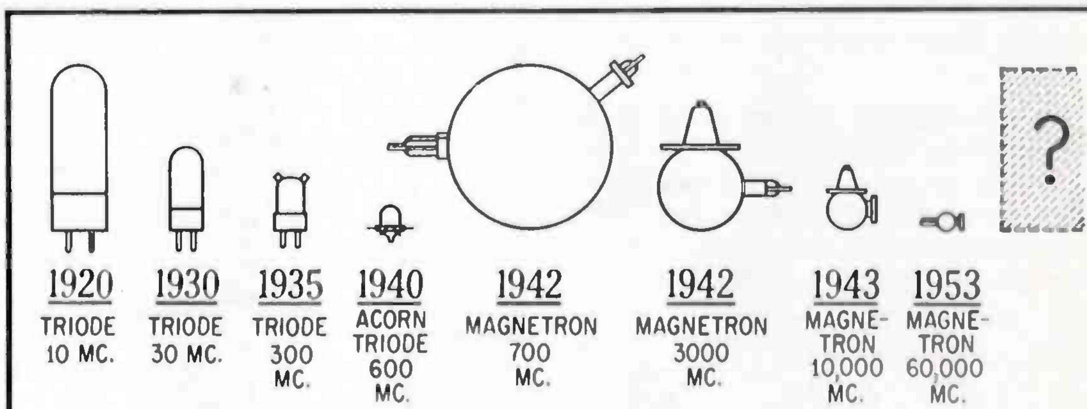
By the Engineering Department, Aerovox Corporation

SINCE the earliest days of radio, the exploration of frequencies higher than those in common use at the time has provided an exciting field of endeavor for the scientist and experimenter with pioneering instincts. Strangely enough, such efforts have almost invariably been ridiculed and condemned to failure by the contemporaries of such "explorers". And, just as unfailingly, the ultimate results have usually proven the skeptics to be wrong and the new portion of the radio frequency spectrum has always turned out to be of extreme value in extending the art of radio communication.

Even before World War I, in the days of spark transmission, the radio amateur fraternity were relegated to the region *"200 meters and down"* because this portion of the spectrum was considered virtually worthless for communication purposes by the professional engineering world. However, when the "hams" demonstrated that trans-oceanic contacts were easily accomplished on the unheard-of wave-length of 100 meters, these same commercial interests flocked to use the new "short waves". Needless to say, this region now contains almost all of the valuable communications channels now in use.

The adventurous experimenters didn't stop at 100 meters, or even 50 meters, however. They pushed the revolutionary new vacuum tube oscillators and receivers all the way down to about 20 meters. Again, this "radio no-mans-land", which had been thought to be worthless, had, in a short time, demonstrated a new phenomonen in communication — long distance signals over a daylight path. This started another rush for new channels, and today these frequencies are highly prized for international broadcasting and communication.

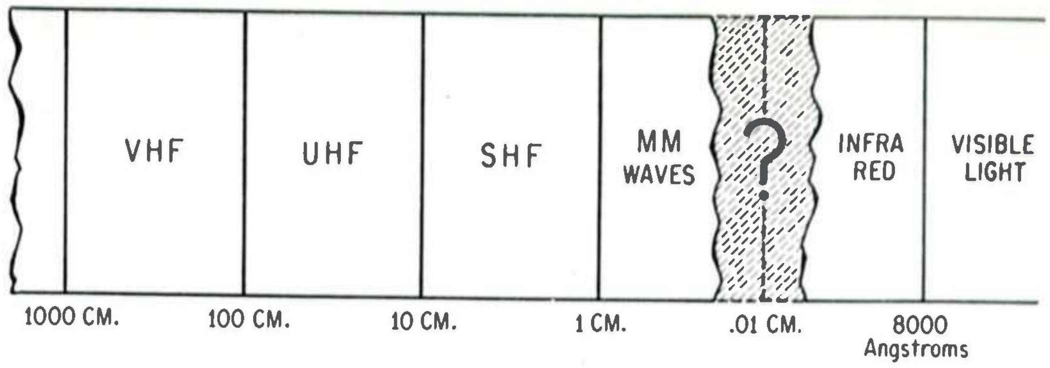
This downward migration, spearheaded by the amateur and experimenter, ground to a halt below 10 meters, where it was found that radio signals were not reflected back to the earth by the ionosphere much of the time, making communications beyond the horizon doubtful. For a long while these line-of-sight VHF frequencies remained unexploited because of these limited propagation



ILLUSTRATING EVOLUTION OF COHERENT OSCILLATORS

FIG. 1

characteristics and the fact that conventional vacuum tubes of that era would not operate efficiently at such elevated frequencies. Transit-time effects, excessive lead inductance, and high losses in the base materials used limited their performance. Little effort was expended in developing improved tubes and circuits since few people had enough vision to see that such short-haul radio might be extremely valuable for local services like police radio, where the line-of-sight characteristic would give freedom from interference by similar services in distant cities.



THE MILLIMETER WAVE SPECTRUM GAP

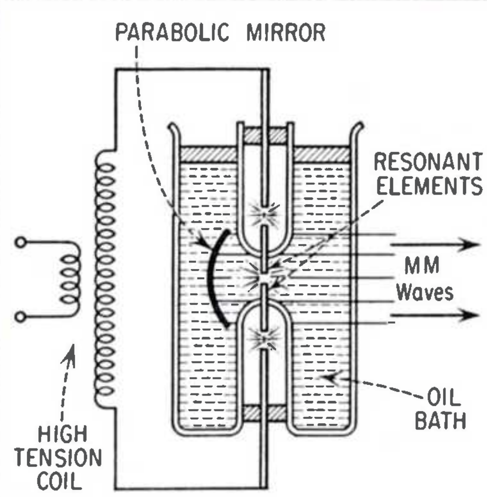
FIG. 2

Here again, however, a few intrepid experimenters, with an eye on the vast reaches of unused megacycles stretching into the VHF region, perservered. They removed the lossy bakelite bases from the available tubes, and developed "long-lines" circuits to minimize the effects of tube element loading. They spent long hours policing unused frequencies looking for someone with whom to communicate. They learned to make multi-element, high-gain antenna arrays compensate for the low powers available from the tubes at hand. Even as late as 1940, a "ham" experimenter engaged in such pursuits was likely to be considered more than slightly demented by his fellow amateurs, who maintained that he was wasting his time with "back-yard" radio when he could communicate across the world by going a few megacycles lower.

In the end, however, these "die-hard" experimenters had pioneered the VHF bands and had laid the groundwork for the techniques now employed in the transmission and reception of television, FM, police radio and many other services. These frequencies now include the most commercially important megacycles in the entire radio frequency spectrum.

Unquestionably, the most rapid advance in the exploration of the spectrum was made during the period of World War II, when the upper limit of efficient radio frequency generation was extended at least *100 times* in a few short years. The impetus, of course, was the development of radar. At the start of this period, the conventional triode had reached its limit of practicality at about 600 megacycles. From the early "audion" it had been "scaled down" to the size of the familiar acorn tube. This reduction in size was necessary to keep interelectrode capacitances small so that the external circuit would not be reduced to a short between the grid and plate. It was also necessary to space the tube elements extremely close to reduce transit time effects. The result of this size scaling is to greatly reduce the power generating capabilities of the tube, since the small electrodes can only dissipate a small amount of heat.

The need for a source of powerful centimeter waves for radar led to the development of the microwave magnetron and klystron tubes. These made the extension of the state of the art mentioned above possible because, unlike the triode, their dimensions are comparable to the wavelengths generated. Thus, a magnetron for 600 megacycles was many times larger than a triode for the same frequency and could dissipate proportionally more power. However, as the microwave tubes have been scaled to progressively higher frequencies, the size of their critical elements have decreased accordingly. The result is that the magnetron and klystron have encountered, at around 60,000 megacycles, the same kind of limitations reached by the triode in the thirties. Their size and element tolerances and spacings have become comparable to the acorn tube — and their power handling capabilities not much better.



LEBEDEW'S MILLIMETER GENERATOR (1895)

FIG. 4

The evolution of radio frequency generators discussed above is illustrated in Fig. 1, which shows relative size comparisons. It is obvious from this presentation that a new principle is needed to extend the useful limit of generation further into the millimeter wave region. Scientists and physicists interested in spanning the gap which exists between the long infra-red part of the spectrum and the radio frequency portion (See Fig. 2) have long sought this new principle. Figure 1 indicates that a successful generator for the millimeter wavelengths will probably have to be much larger in dimensions, compared with the waves generated, than the magnetron and klystron are. To date, the approaches used in the generation of such extremely short waves have had this property. We will now discuss some of these.

Incoherent Generators

Most of the radio frequency sources, except the early spark transmitters, are *coherent* generators. A coherent generator is one which emits a wave train having a single (or *monochromatic*) frequency of a single and sinusoidally varying phase. An *incoherent* source, on the other hand, is one which emits energy over a band of frequencies consisting of numerous wave trains of various phases and amplitudes. Wave trains of these two types are compared in Fig. 3. Examples of incoherent sources are hot bodies which emit visable light or infra-red waves, and the spark transmitters mentioned above.

The type of generator employed in attempts to span the gap between light waves and radio waves in the past has usually depended upon the background of the researcher. Physicists, trying to extend the long wavelength limits of their light

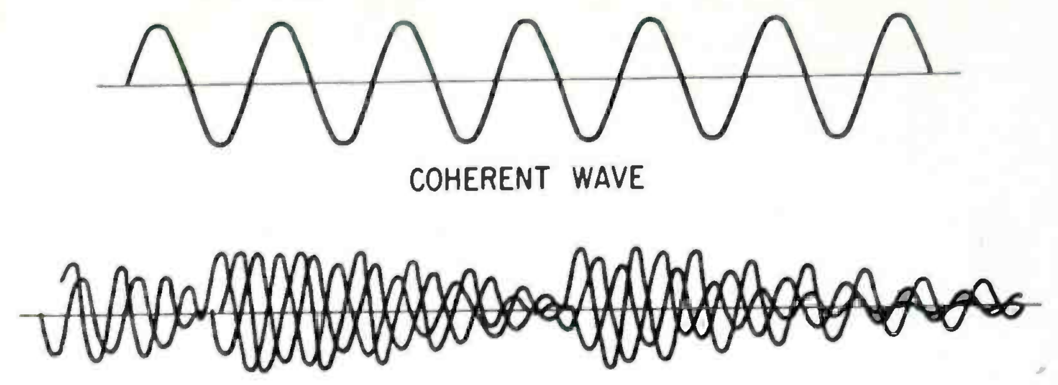
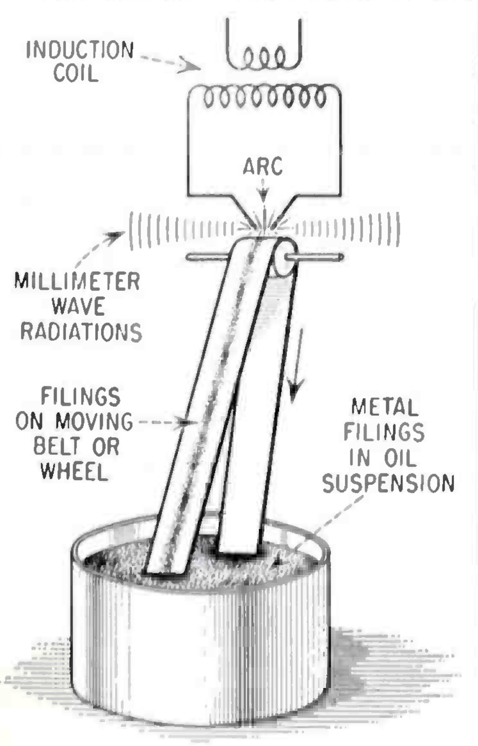


FIG. 3

sources for spectroscopy, have pushed into the long infra-red region with incoherent generators, while engineers have scaled coherent oscillators down to a few millimeters from the radio side.

The first successful millimeter generators were incoherent sources utilizing the spark discharge principle. There were essentially scaled-down versions of the early long-wave spark transmitters, which consisted of a resonant circuit excited by a spark discharge. It will be recalled that a circuit of this kind generates a "damped" wave because the spark *shock-excites* the resonant circuit which then oscillates until the circuit losses cause the oscillator to die out, or *decay*. A good example of a millimeter source using this principle is *Lebedew's* generator, built in 1895. See Fig. 4. In this simple arrangement, a spark discharge produced by a high-tension induction coil is passed through a gap between two resonant elements immersed in an oil bath. A parabolic mirror focusses the oscillatory energy thus produced in the desired direction. The oil bath serves to cool the resonant elements. The wavelength generated is determined by the physical size of the spark-gap elements; incoherent waves as short as .22 millimeter have been generated by this method.



MILLIMETER GENERATOR OF MASS RADIATOR TYPE
FIG. 5

A similar form of incoherent millimeter wave generator has been known since the early 1920's. This machine, classified as a *mass radiator*, is illustrated in Fig. 5. It consists of a sort of conveyor belt which carries metal filings suspended in oil from a reservoir up through a spark gap where a high-tension spark is passed through them. Here again, the mechanism is similar to that of the old spark transmitter and is closely related to Lebedew's generator, except that the spark is passed through a large number of metallic particles which radiate at the same time. The radiations produced are far from monochromatic because of differing metallic particle sizes and the inherently low "Q" of the radiators. This renders the mass radiator inadequate for the purposes of spectroscopy required by physicists since the large spread in frequency reduces the resolving power of the instrument.

More recent attempts to generate millimeter waves by incoherent means have consisted of impinging charged ball-bearings or atomized mercury droplets on a metal plate, and similar schemes. All such methods suffer from low power generating ability, frequency dispersion, and difficulty in utilizing the energy because it is radiated in all directions.

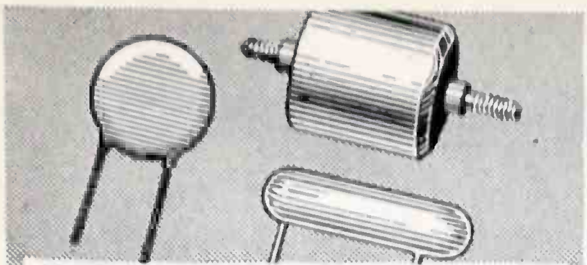
Coherent Millimeter Generators

To date, the only successful coherent millimeter wave generators are scaled-down versions of the magnetron and klystron. As discussed above, both of these are approaching their ultimate limits a little below 5 millimeters wavelength. Here the efficiency of the magnetron, normally of the order of 50% in the centimeter range, has fallen to only a few percent and that of the klystron is much lower. The powers available are only a few kilowatts pulsed or a few milliwatts continuous wave. The prospects of reaching substantially shorter wavelengths are remote. New principles will have to be evolved.

Many of the new devices which have been proposed for millimeter wave generation are cloaked in military security. Most are so large compared with the wavelength generated and so inefficient as to make practical usage outside of the laboratory highly improbable. One reason for the ponderous size of some of these schemes is the dependence upon "relativistic" electrons, i. e., electrons accelerated to velocities near that of light. Equipment to achieve such velocities is inherently complex and cumbersome.

The question naturally arises as to what possible applications millimeter waves might be put when practically achieved. *To question the ultimate utility of this portion of the spectrum is probably just as fallacious as it was in 1920 to think that all wavelengths below 200 meters are worthless.* If history again repeats, this portion of the radio frequency spectrum should become as important to the art of communication as any which preceeded it.

It is true that waves of this length are difficult to generate, transmission lines to handle them are critical, and high absorption occurs in the atmosphere to make even line-of-sight transmission marginal. However, once the first two of these shortcomings are overcome, the last may even become an advantage. The limitation to very short ranges in the free atmosphere might make highly personallized forms of radio communication possible. Also, because of the small size of the waveguides associated with millimeter waves, long distance communications through evacuated or gas-filled waveguides consisting virtually of "hollow wires" would become possible. Because of the large bandwidths carried by such transmission lines, a single one would be capable of simultaneously carrying thousands of voice communication channels or hundreds of six-megacycle television channels.



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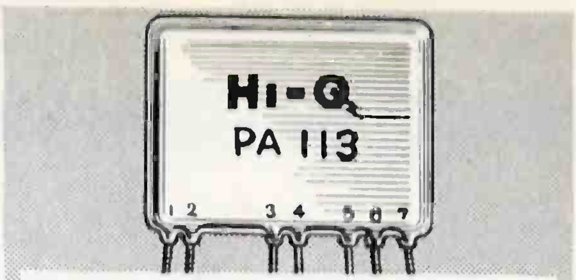

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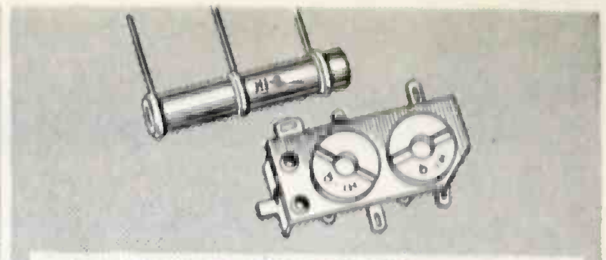

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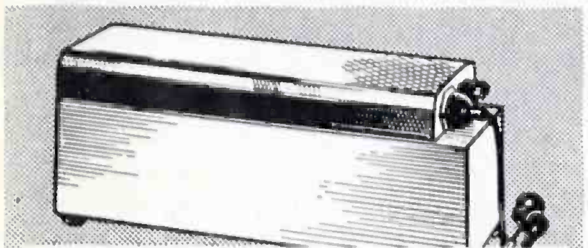

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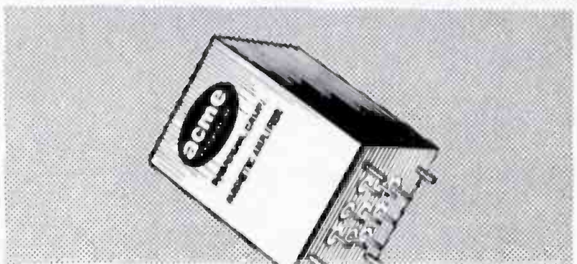

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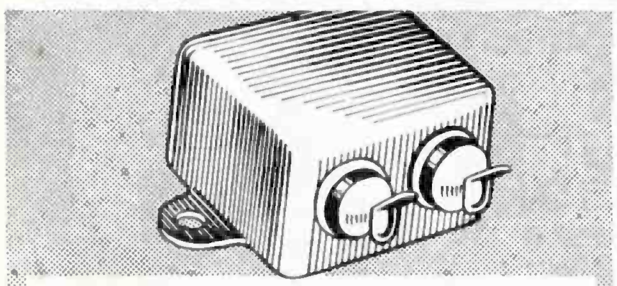

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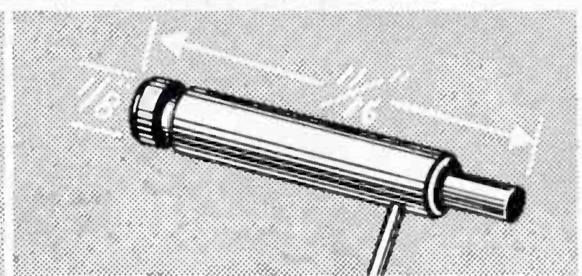

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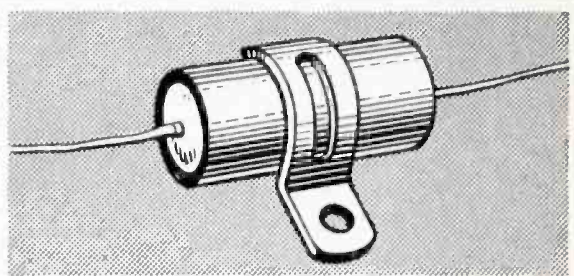

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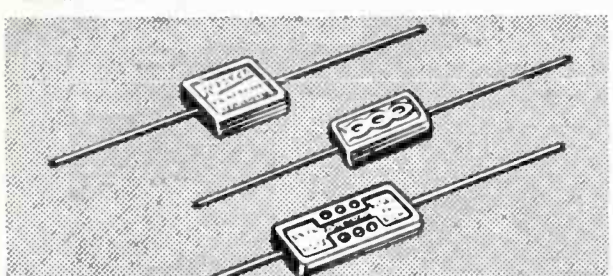

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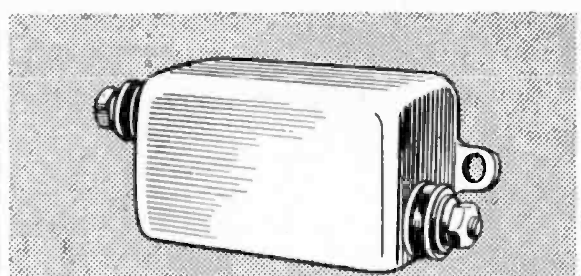

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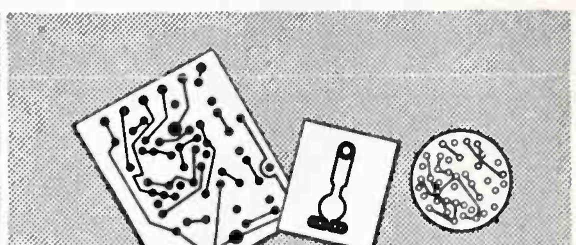

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