A RADIO-FREQUENCY PULSE GENERATOR
FOR ULTRASONIC STUDIES

Thesis for the Degree of M. S.
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Walter Georg Mayer
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This is to certify that the

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A Radio-Frequency Pulse Generator for

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presented by

Walter G. Mayer

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of the requirements for

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E. A. Hiedemann

Major professor

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A RADIO—FREQUENCY PULSE GENERATOR

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By

Walter Georg Mayer

A THESIS

Submitted to the School of Graduate Studies of Michigan
State University of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

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Department of Physics

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W. Mayer

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AN ABSTRACT

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This work describes the design and construction of a r-f pulse generator which can be used with either one or two transducers to measure primarily sound velocities and absorptions in liquids and solids. The pulse length, repetition rate, frequency, and amplitude are variable. Circuit diagrams and operational details are included.

A discussion of operation principles is followed by a report on velocity measurements made in three fatty acids which were suspected of showing a dispersion of sound velocity as a function of frequency and sound intensity.

Experimental evidence is offered indicating that lauric, palmitic, and stearic acid show a velocity dispersion as a function of sound intensity but not as a function of total energy radiated into the liquid acid. The dispersion occurs only within a range of about 15° above the respective melting points.

I. INTRODUCTION

The measurement of physical properties of materials by ultrasonic waves has become a valuable tool in the study of matter. There exists a number of techniques by which ultrasonic waves can be generated and detected; however, the desired information concerning the material under investigation determines to a large extent the usefulness of one or the other method.

The present work concerns itself only with a technique by which sound energy is propagated in pulses of a few microseconds duration.

Progress in electronics made it possible to adapt principles of pulse circuits to ultrasonics, and in 1940 E. Hiedemann and H. Freund[1] suggested an arrangement in which a transducer was to be driven by a short, strong electrical pulse. This pulse, transformed into ultrasonic energy, was to be received by another crystal, amplified, and used to activate the first transducer again. The time lag, introduced by the medium between the two crystals, could be measured, and the "apparent" sound velocity could be computed from it. If the ultrasonic pulse did not meet any obstacles, flaws, cracks, etc., in the material, the "apparent" sound velocity was identical with the actual sound velocity in the material. If the pulse was disturbed by a flaw, the "apparent" sound velocity was lower than the velocity characteristic for the material. This allowed ultrasonic testing of materials.

A different procedure was patented by Firestone[2] in 1942. It proved to be highly efficient and could later be developed into the well known "Reflectoscope". In Firestone's method a pulse travels through the sample to be tested and is reflected by a flaw. The initial and the reflected pulse are observed on a CRO. From the distance on the screen between the two signals and from the time scale the location of the flaw can be found.

Extensive work on Radar and Sonar during World War II produced more refined circuits and more accurate timing devices which were used to some extent for ultrasonic investigations at the time of their development. Teeter[3] points out the various possibilities of such instruments, and his findings are in good agreement with results obtained by other methods; Ivey et al describe similar equipment for various measurements[4].

After the war a great number of electronic improvements were made available so that it became possible to even manufacture small ultrasonic pulse generators for commercial purposes. Those are mainly used for testing materials for flaws, alloys for grain size, boilers and metal pipes for weak spots, and for similar tests[5,6].

Since the pulse technique presents a convenient way to make velocity and absorption measurements in liquids and solids in a very simple and accurate manner[7], the design and construction of the present instrument was undertaken, and an attempt was made to include as many features as possible.

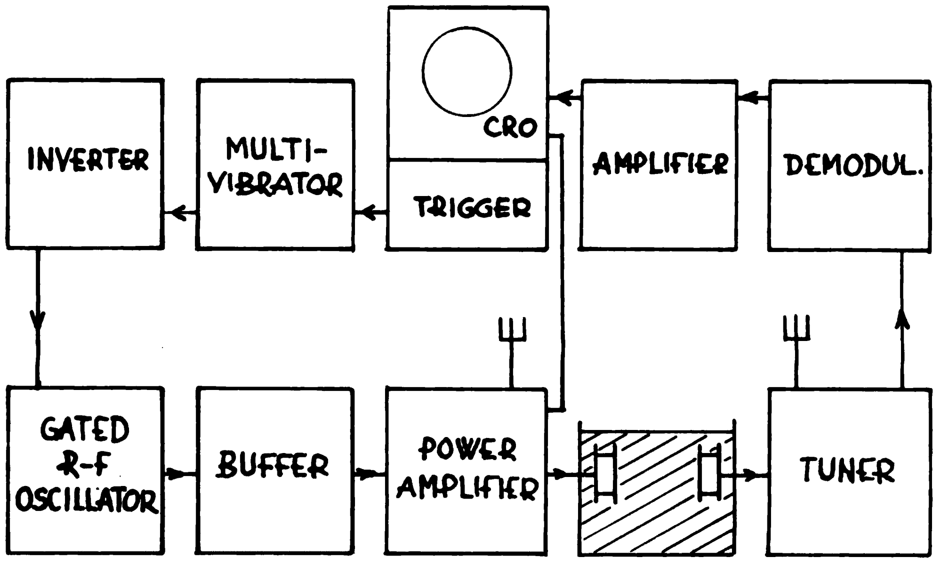
II. PRINCIPLES OF OPERATION

In Fig. 1 a block diagram indicates the methods employed in producing and receiving the electric pulses driving the transducer and emitted by the receiving crystal.

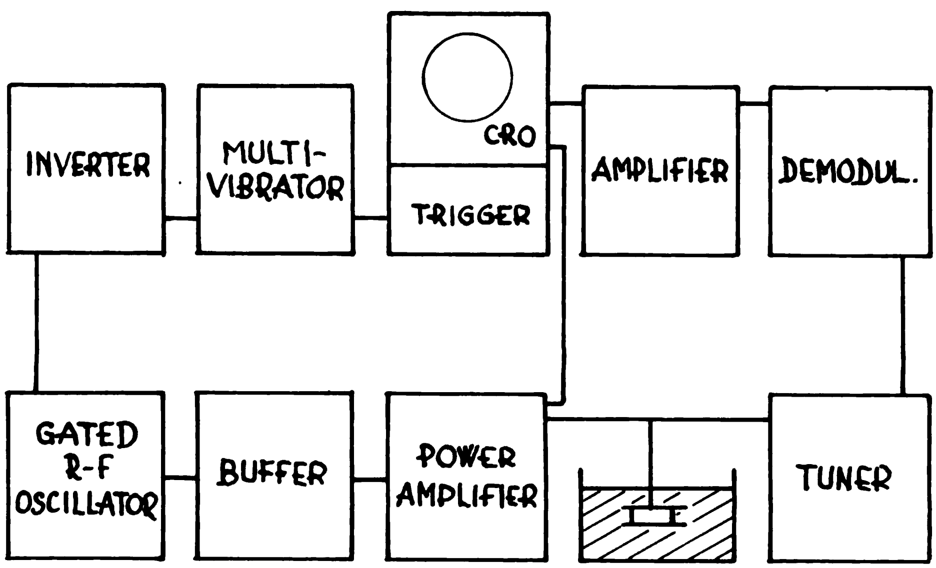
A sharp positive pulse from the trigger circuit of the DuMont Type 256-F Oscilloscope activates the sweep of the CRO and fires the multivibrator. The beginning of a rectangular pulse, given off by the multivibrator as the result of the trigger pulse, is set by the repetition rate of the CRO; its duration is adjusted within the multivibrator. The positive-going signal from the multivibrator is inverted and used to gate a variable frequency oscillator which in turn emits r-f oscillations as long as the gate is present. This amounts to a modulation of the rectangular pulse by a frequency, set to coincide with that of the crystal in use. A buffer stage couples the gated v.f.o. to the power amplifier which increases the amplitude of the signal and can be used to multiply the frequency by one, two or three. Through a coupling device the r-f pulse is transmitted to the transducer.

By disconnecting the gated v.f.o. and placing a c.w. v.f.o. ahead of the buffer, the unit can be used as a continuous wave generator.

In the case of transmission operation two antennae couple the transmitter to the receiver, in case of reflec-



a. Transmission Method.



b. Reflection Method.

Fig. 1. Block Diagrams

tion operation transmitter and receiver are connected directly.

The tuner of the receiver is set to the frequency of the receiving crystal which is the same as the frequency of the transmitting transducer. After the signal is detected by the tuner the carrier frequency is taken out of the signal in the demodulating section, and only the amplitude and general shape of the signal, its envelope, reaches the final amplification stage. From there the signal is fed into the "Video Input" of the CRO.

Depending on the velocity of sound in the medium between the crystals and their seperation, the time elapsed between the departure of the sound pulse from the transmitting transducer and the arrival at the second crystal is indicated on the screen of the CRO as a vertical deflection of the trace. The travel time of the sound through the medium can be read on a calibrated scale of the CRO, and depending on the choice of sweep length, this calibration is accurate to 10^{-6} or 10^{-7} second, respectively. It is possible to estimate to the nearest 10^{-7} or 10^{-8} second, respectively.

The amplitude of deflections gives an indication of losses the sound experiences in the medium.

For applications of reflection operations the receiving transducer is replaced by a reflecting surface; the remaining crystal serves as transmitting and receiving transducer, the sound traveling twice the distance. For accurate absorption measurements the transmitter has to be disconnected from both the transducer and receiver immediately after the end of the activating r-f pulse. The reasons for such a switching arrangement will be pointed out in Section V.

III. ELECTRONIC EQUIPMENT

The functions of the various stages in the operation of the apparatus have been pointed out in Section II. The arrangement of the components is shown in Fig. 2, the complete circuit diagrams in Fig. 9 - 12.

A. Power Supplies

The power supply for the pulse generator and the transmitter consists of two sections, one for high voltage, and one for B plus together with 6.3 volts for filament supply, all of which is mounted on one chassis and constructed according to conventional methods. Choke inputs are employed, a swinging choke stabilizes the high voltage, and a variac is used to adjust the potential of the high voltage supply.

A separate power supply for the receiver is mounted on the receiver chassis, its construction also follows standard methods.

Negative biasing voltage is obtained by tapping a bleeder connected across the last of three RC filters which are operated from a half wave selenium rectifier.

B. Triggered Multivibrator

In principle the pulse generator is a one-shot-multivibrator activated by a positive trigger pulse from the DuMont Type 256-F Range Oscilloscope whose variable repet-

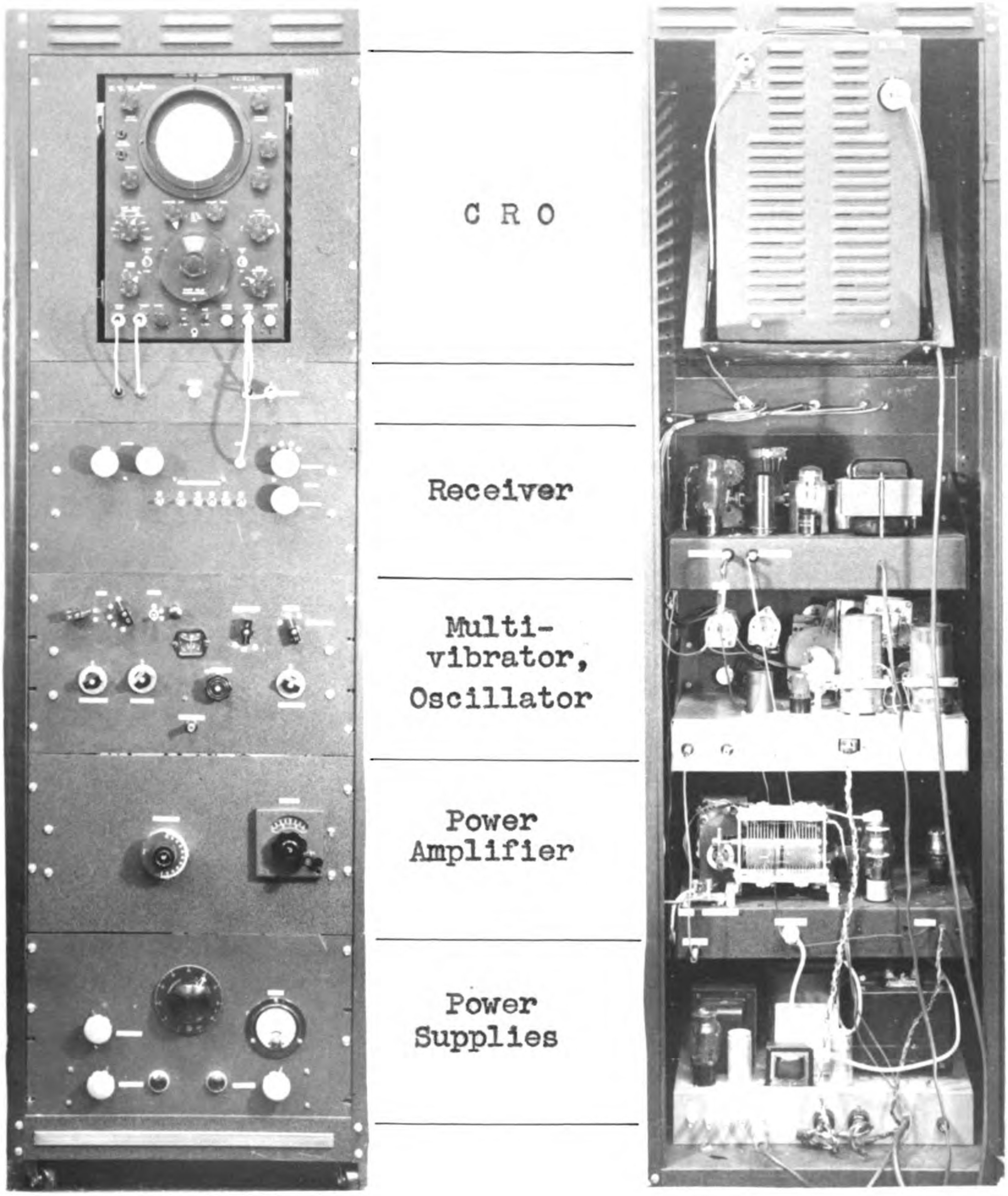


Fig. 2. Electronic Equipment

ition rate determines the frequency with which rectangular pulses are emitted by the multivibrator. The somewhat involved circuit of the oscilloscope is described in the operation manual supplied with the instrument.

The duration of the rectangular positive pulses from the multivibrator is fixed by the RC-time of the grid bias resistor and C9 and C10. Contrary to ordinary multivibrators[8] the duration of the negative part of the wave train can not be changed by adjusting the grid resistor or the coupling capacitors of the second half of V4 since this portion of the cycle ends only with the arrival of a trigger pulse from the oscilloscope. Thus C7, C8, and R9 provide the proper bias on the grid of the second half of V4, causing the rectangular pulses to have a flat top and a steep leading edge (Fig. 4).

R3 to R6 act as biasing resistors for the grid of the first half of V4, keeping it below cut-off for the plate potential employed, until a sufficiently positive trigger pulse is applied, allowing the first half of V4 to conduct and the same set of resistors to be used in determining the duration of the rectangular pulse, which is applied to the next stage by a cathode follower. This method of coupling, whereby placing the two cathodes of V4 at different operating potentials does not affect the performance of the multivibrator, provides an additional amount of stability which is desirable since the ratio of conducting to quiescent periods within one cycle is to be variable from about 1:10 to less than 1:1000 (Fig. 6).

Since it is required to supply to the transducer short electrical pulses of controllable duration and energy level, a number of methods for further modulation of the rectangular pulse from the multivibrator are available. Probably the simplest way of exciting the transducer is to supply a sufficiently high DC pulse to the crystal. If the rise and fall times of such a rectangular pulse are of the order of 10^{-7} second or less, the crystal will vibrate at its resonant frequency. This is due to the fact that such a pulse contains an infinite number of frequencies, but Fourier Analysis indicates that any one frequency contributes only a fraction of the total energy present. Since the transducer will be activated only in its principal mode of vibrations, a large part of the electrical energy applied to the crystal by a rectangular DC pulse will not be used for the production of an ultrasonic wave. It can be seen that this method is not extremely efficient, although its application has yielded good results[9].

C. R-F Generator

A much higher sound level can be obtained with the same electrical input if the electrical energy is propagated at the frequency corresponding to the principal mode of vibrations of the crystal used for the production of ultrasonic energy. There are two general approaches; either the required frequency is generated continuously and the output of the generator connected to the transducer by means of an electronic switch synchronized by pulses of desired length; or the pulses are employed to regulate the time of operation of the frequency generator, which, in this case, is connected to the transducer without an electronic switch. In both cases the transducer receives predetermined pulses of one specific frequency (Fig. 3).

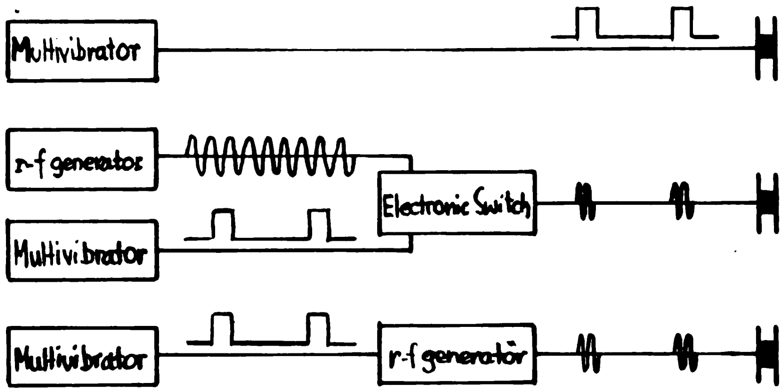


Fig. 3. Methods of Pulse Generation

Since for purposes of measurements the ultrasonic pulse has to be transformed into electrical energy by means of a crystal whose electrical output is of the same frequency as that of the incident pulse, the process of amplification of only the electrical crystal output becomes difficult. With the frequency generator operating on c.w. of about 100 watt there is enough radiation reaching the receiver at all times to drown the incoming pulse in a high signal-to-noise ratio. Proper shielding of the receiver and the transmitter becomes involved and the approach of an intermittently operating r-f generator is preferable.

Oscillations can be produced in a number of ways, commonly by placing an inductance-capacitance network either in the plate circuit or between cathode and ground of the oscillator tube. Other forms of oscillators (phase shift, grid-tuned, etc.) are not conveniently adaptable to modulation of pulses of short duration. A shock-excited (ringing) oscillator was selected since this form is now generally used in radar and similar applications involving pulse techniques[10]. However, it was found that applying the gate pulse, which is a rectangular positive-going pulse from the multivibrator (Fig. 4) inverted by V5 into a negative-going pulse (Fig. 5), to a simple one-tube ringing oscillator

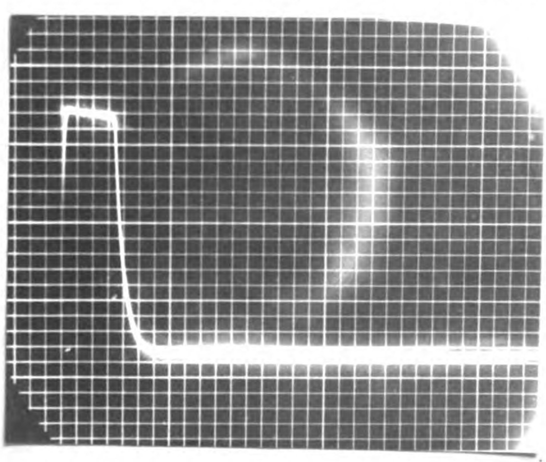


Fig. 4. Positive Gate

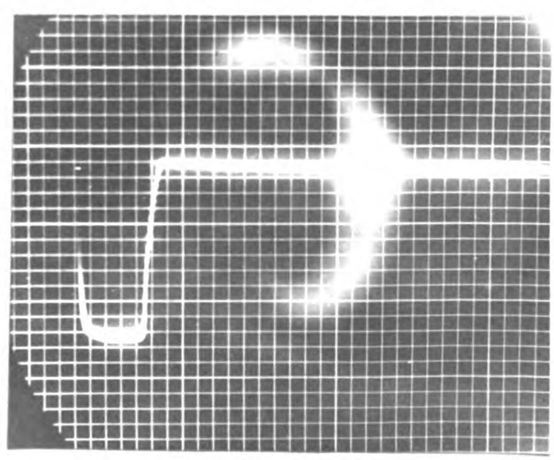


Fig. 5. Inverted Gate

results in a distorted signal with an extremely long rise time as its main undesirable characteristic. As pointed out by Elmore and Sands[11], this difficulty is bound to arise in such an arrangement when frequencies higher than 2 Mc are required. The problem of maintaining a fairly stable voltage level of the oscillator output presents itself, and no solution to it can be found within the circuit of the oscillator if one considers that the voltage level is the product of frequency, current, and inductance of the oscillator. Although the frequency is inversely proportional to the square root of the inductance, and the current can be varied within limits, it becomes difficult to keep the voltage reasonably constant through an extended range of frequencies.

Experiments with a slightly altered form of the ringing oscillator described by Elmore and Sands in combination with a thyratron circuit used by Easton[12], also slightly changed to be useful in this application, have proved to be so much more suitable than other circuits tested that this combination was incorporated in the apparatus.

Two sets of oscillator coils can be placed in the circuit by a switching arrangement which also varies the inductance in steps of convenient values. Two other inductances can be coupled to the oscillator coils by the same switch in such a manner that either L5 and L6 or L7 and L8 are in the circuit. The thyratron fires after the trigger pulse from the CRO arrives at its grid which happens before the negative gate pulse arrives at the oscillator; this difference is due to the delay the gating pulse experiences through the preceding circuit components. Thus when the ringing oscillator is shocked into operation the damping of its sinusoidal output is essentially prevented by a transfer of discharge current through the cathode coil of the thyratron to the oscillator tank circuit. With the proper values of the cathode resistors of V6 and V8 it is possible to obtain r-f pulses with flat tops and rise and fall times of less than 1 microsecond. The voltage level of these pulses is about 60 volts maximum, decreasing slightly with a decrease in pulse length. The energy delivered by the oscillator is sufficient to drive a transducer directly.

D. Buffer and Power Amplifier

In order to expand the apparatus so that it can be used easily for a one crystal reflection instrument it was felt that a buffer stage and a power amplifier should be added. The circuit used is similar to a transmitter design[13] which also allows installment of a variable frequency oscillator preceding the buffer and power amplification stages, enabling the operator to use the apparatus as a standard high frequency generator (c.w.)

Operating the crystal from the modulating oscillator yields a sound intensity great enough to make measurements in liquids which present absorptions of relatively small magnitudes, and in which the path of the sound is not too long. The addition of a power amplification stage makes it possible to overcome these limitations to some extent. Furthermore, the correct choice of the output tank circuit results in a frequency multiplier with which the frequency modulating the output pulse can be increased by a factor of two or three without decreasing the amplitude of the pulses appreciably.

The transducer is connected to the output of the power amplifier by a coaxial transmission line terminated in a link coupling around the inductance of the output tank circuit.

Since during transmission operation of the unit there is no direct electrical connection between the transmitting and receiving stages which would indicate on the screen of the CRO the time of transmission of the pulse to the crystal, a vertical deflection of the sweep is produced by feeding a part of the signal from the transmitter into an antenna which radiates enough energy to be intercepted by another antenna leading into the receiver and to the vertical deflection of the CRO.

Fig. 6 - 8 show the modulated pulse with which the transducer is driven. The pulse repetition rate is 800/sec, modulating frequency 2.595 Mc, pulse length 30 sec^{-6}.

In Fig. 6 the trace extends over 4500 microseconds,

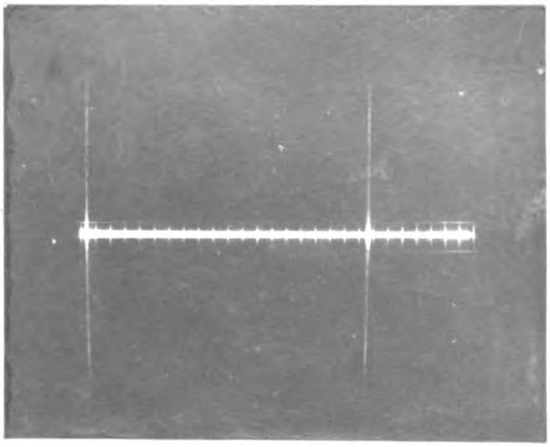


Fig. 6. Trace 4500 sec^{-6}

thus two pulses arrive at the transducer. In Fig. 7 the first 100 microseconds are shown, and in Fig. 8 the trace

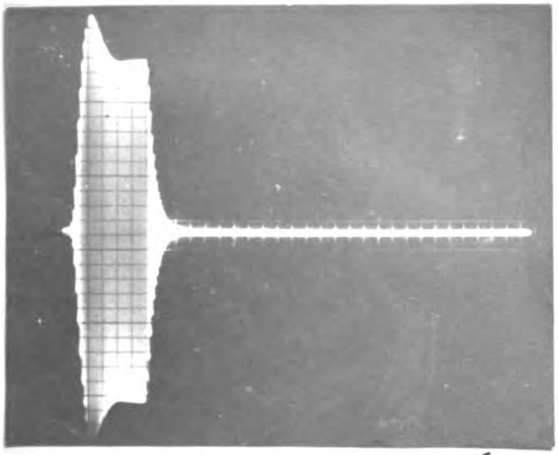


Fig. 7. Trace 100 sec^{-6}

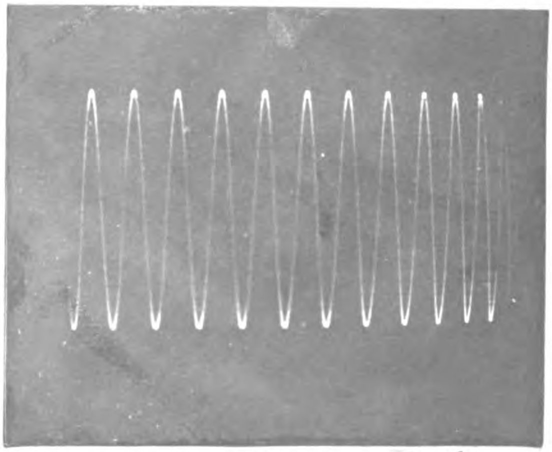


Fig. 8. Trace 4 sec^{-6}

pictured consists of the center portion of the pulse, the time elapsed from beginning to end of the trace being 4 microseconds.

E. Receiver

In principle the receiver is a stagger-tuned amplifier with two inputs, one of which is the antenna whose purpose was described in part D, the other the output of the receiving crystal. An impedance matching coaxial transmission line connects the crystal with the input of an attenuation box with an internal impedance of 70 ohms, connected by another coaxial line to a terminating resistance of the same value. From this resistor the signal is fed into the first stage of the receiver.

The attenuation box has no purpose if measurements of sound velocity are to be made, yet it is essential for calculations of sound absorption. Its operation will be described in Section V.

The first two stages of the receiver are used for detecting the signal by stepwise changing the ganged inductances L11 and L12 and tuning the ganged capacitors C41 and C49. The difference in resonant frequencies of the two tuning networks was chosen to be about 10 Kc, variable to a very limited extent by trimmer capacitors in parallel with the tuning capacitors. This narrow bandwidth, the result of stagger-tuning[14], allows an accurate tuning of the receiver, and still compensates for small variations of input frequency. The following pentode rectification stage demodulates the signal and the remaining envelope is fed into an inverter which is connected to a driver stage. Two output tubes in parallel constitute the final stage of the receiver. The output is not driven in push-pull, the parallel tubes insure merely operation below maximum rating and on the straight portion of the tube characteristic curves even with large grid voltage variations on the output stage. Two gain controls limit the amplitude of the signal between stages.

The output of the receiver is applied to the vertical deflection of the CRO, either directly, or if the signal is weak, to a video amplifier within the CRO.

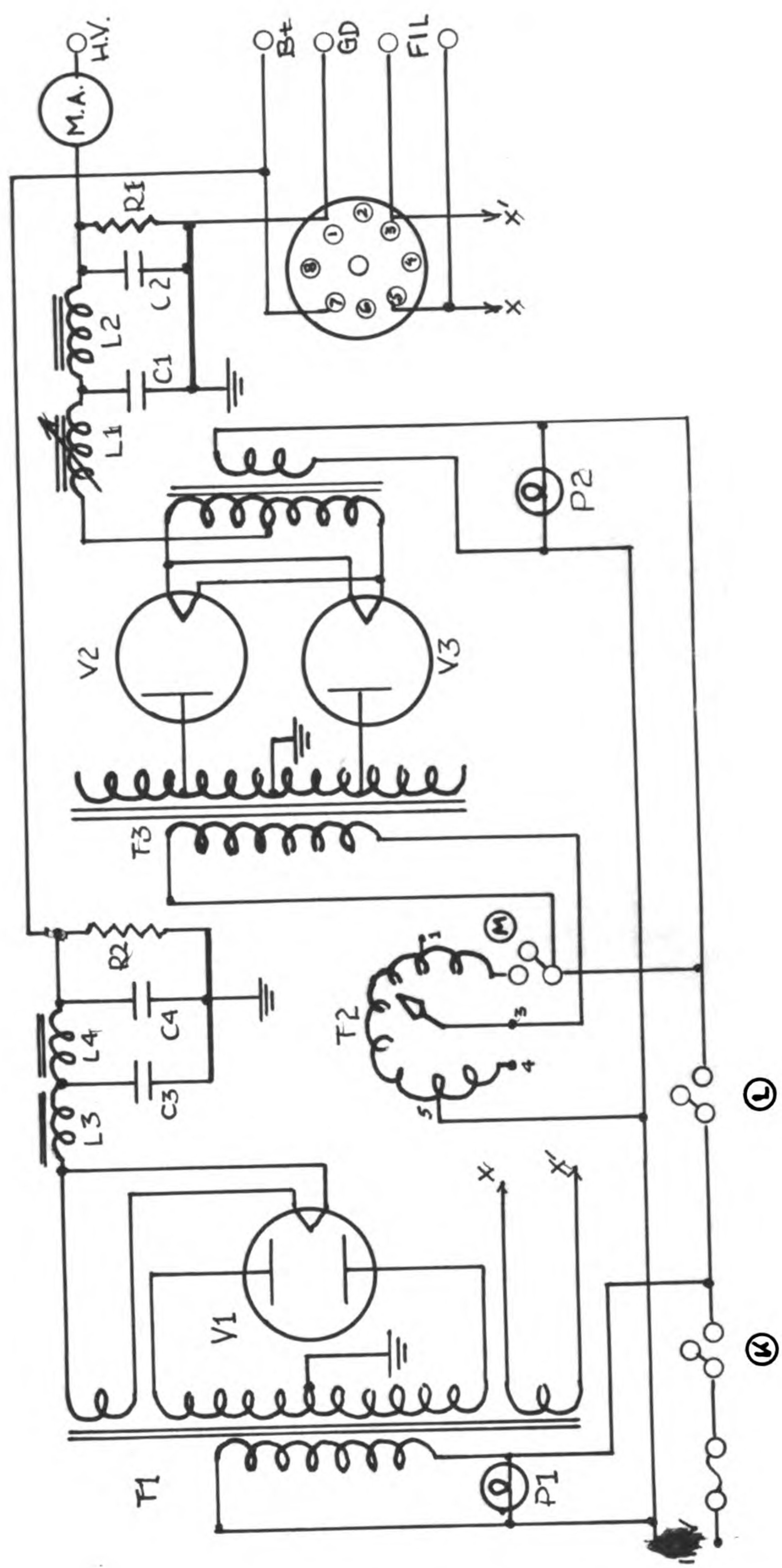


Fig. 9. Power Supplies

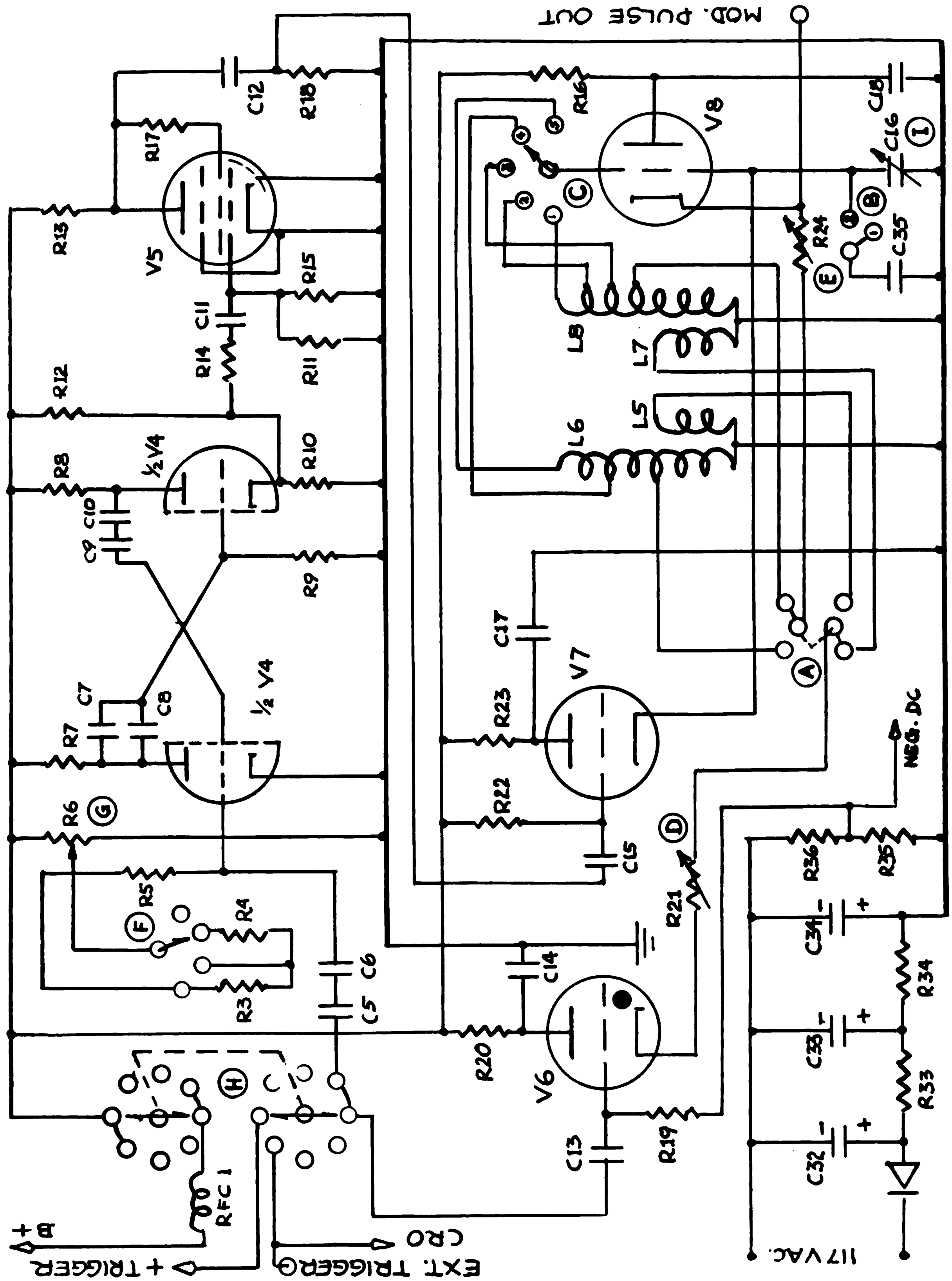


Fig. 10. Multivibrator

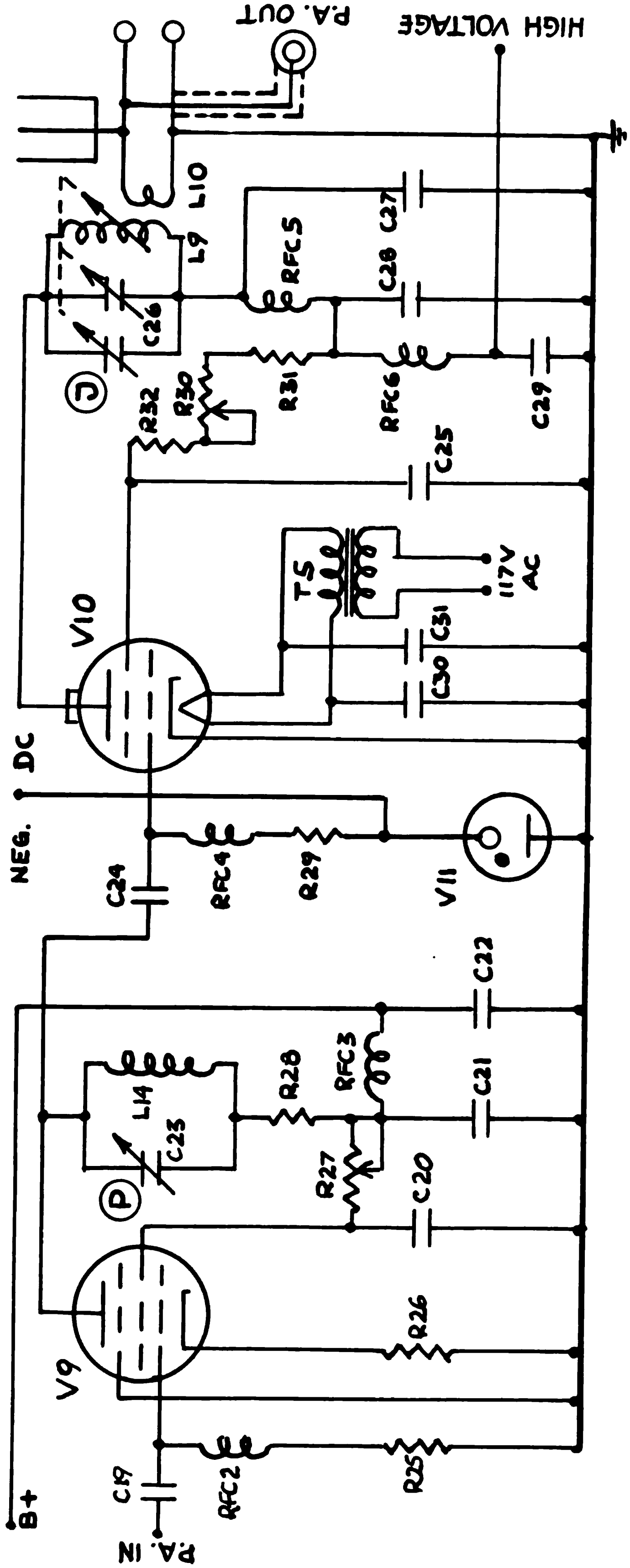


Fig. 11. Power Amplifier

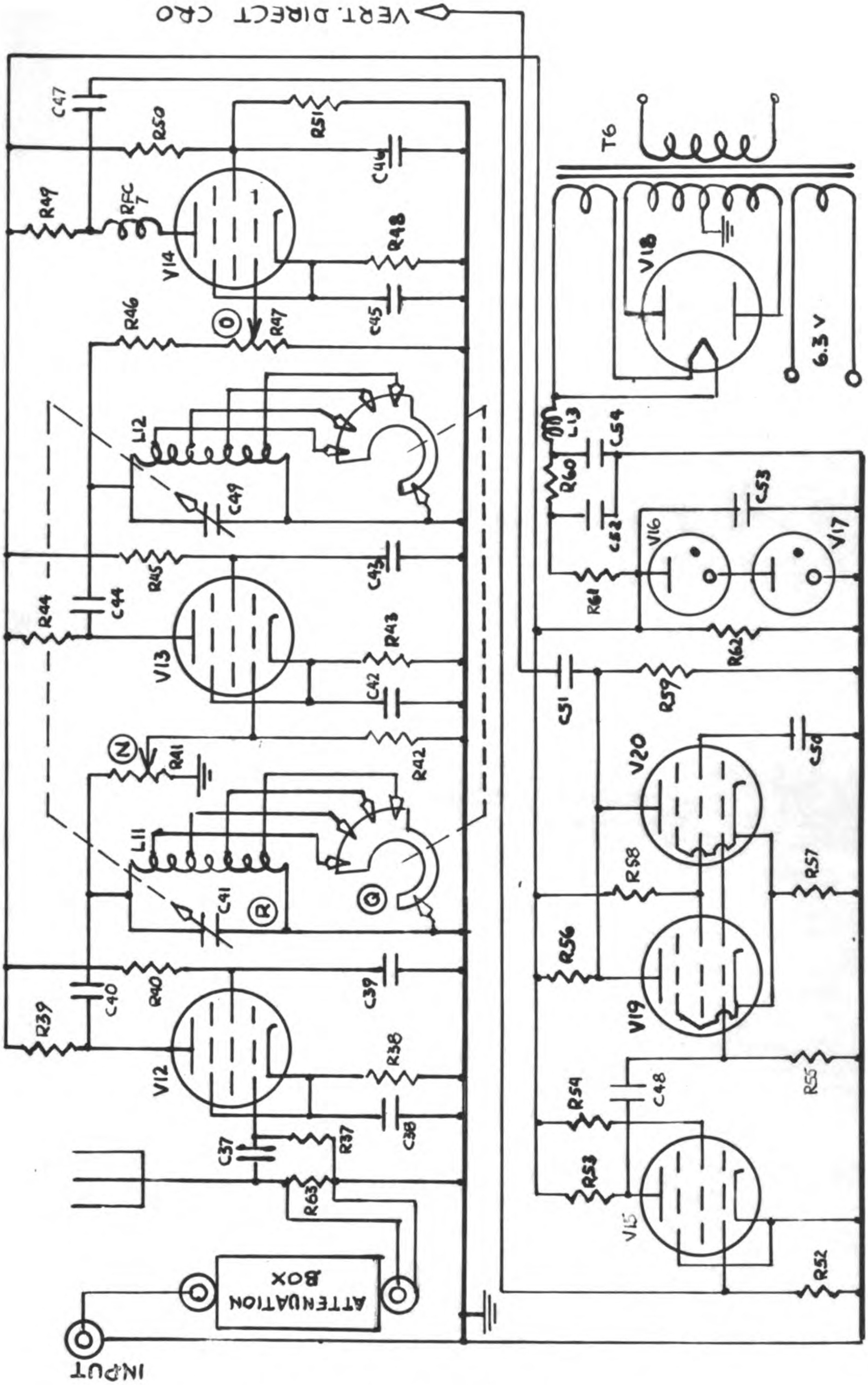


Fig. 12. Receiver

F. List of Components

Multivibrator:

Resistances (R).

3	680K
4	1.2Meg
5	120K
6	300K var.
7,13	10K 5W
8	25K 10W
9	220K
10	6.8K
11,14,18	39K
12	68K
15	25K
16,17	2.2K
19	81K
20	330K
21,24	400 var.
22	470K
23	5.1K
33,34	450 5W
35	20K 10W
36	8K 5W

Capacitors (C).

5	15mmf
6,9,10	24mmf
7,12,17,18	.01
8	.001
11	.047
13	.0015
14	920mmf
15	.02
16	300mmf var.
32-33-34	50-40-30 350V
35	250mmf

Tubes (V).

4	6SN7
5	6AC7
6	884
7,8	6J5

Inductances (L).

5	9 microh
6	5.5 microh
7	17 microh
8	5 microh
RFC 1	2.5 mh

Power Supplies:

Resistances (R).

1	43K 200W
2	130K 50W

Capacitors (C).

1,2	4	1000V ele.
3	16	450V ele.
4	20	450V ele.

Tubes (V).

1	5Y3
2,3	866A

Inductances (L).

1	5/25 hy
2	20 hy
3	5 hy
4	14 hy

Transformers (T).

1	375-0-375, 5V-3amp, 6.3V-1.8amp
2	Variac
3	2150-0-2150
4	2.5V-10amp

Power Amplifier:

Resistances (R).

25,27	25K
26	220K
28,29,32	100 5W
30	25K 100W adj.
31	20K 100W

Transformer (T).

5	6.3V-1.8amp

Capacitors (C).

19,30,31	.005
20	.05
21,22	.1
23	300mmf var.
24	.0015
25,27,28,29	.001 2000V
26	145-145 var.

Tubes (V).		Inductances (L).	
9	6AG7	9	28 microh
10	807	10	3 turns 4½" diam. 1/8" spacing
11	VR 150	14	38 microh
		RFC 2,3,4	2.5 mh
		RFC 5,6	7.0 mh

<u>Receiver:</u>

Resistances (R).		Capacitors (C).	
37,42,52,55	2.2Meg	37	100mmf
38	220	38	500mmf
39,44,58	10K	39,40,44,48	.001
40,45	81K	41,49	365mmf ganged var.
41,47	300K var.	42	.05
43	470	43	.0015
46	30K	45	24 150V electrol.
48	39K	46	1.0
49	220K	47,50	.01
50	25K	51	800mmf
51	3.1K	52,53,54	16 450V electrol.
53	500K		
54,59	470K		
56	2.5K 5W	Inductances (L).	
57,60	450 5W	11,12	38 microh
61	45K 10W	13	14 hy
62	25K 10W	RFC 7	2.5 mh
63	70		

Tubes (V).		Transformer (T).
12,13,14	6AC7	6 350-0-350, 5V-3amp, 6.3V-1.2amp
15	6SJ7	
16	VR 105	
17	VR 150	
18	80	
19,20	6L6	

All values of resistances in ohms, unless otherwise specified, all values of capacitors in microfarad, unless otherwise specified.

IV. MECHANICAL EQUIPMENT

The sound source consists of a crystal which is supported by a holder of conventional design. For maximum output the crystal is air-backed. In all experiments described here a barium titanate disk was used.

Fig. 13 shows the arrangement for the reflection method. The tank holding the liquid is stationary, the left vertical wall is parallel with the crystal face and serves as the reflecting surface. The crystal holder is supported above the tank and can be moved through the liquid by a vernier, calibrated to 0.1 mm.

If the instrument is used for transmission measurements, a second transducer, identical with the first one, is mounted on the supports on the left between the thermometer and the stirring motor.

For experiments with liquids of temperatures higher than 50^{o} a Pyrex dish replaces the glass tank, and a metal reflector is submerged in the liquid if the reflection method is employed.

The crystal holder can be turned sufficiently around its three axes to hold the crystal in any necessary position.

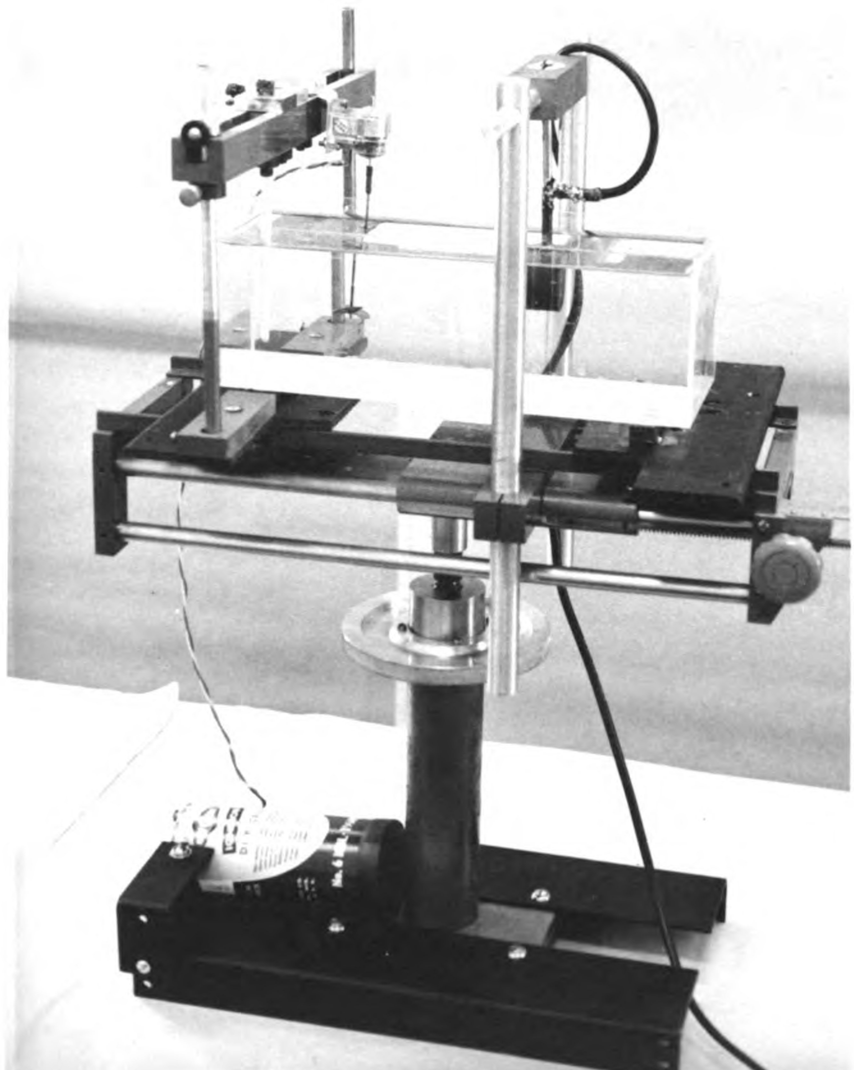


Fig. 13. Crystal Mounting

V. MEASUREMENTS

As pointed out already measurements can be made either by the transmission or the reflection method.

Ordinarily the actual distance between the crystals (or between crystal and reflector) is not known. The transducer is placed somewhere in the liquid, the reading of the mm vernier is recorded for this particular position, and the movable marker on the sweep of the CRO is placed on the beginning of the vertical deflection representing the first reflection. The time correponding to the position of the transducer is read on the sweep delay scale of the CRO. Then the crystal is moved some distance, either towards the second crystal (or reflector) or away from it. The readings are repeated for the second position, and the differences between the distances and the times are used to calculate the velocity of sound through the medium.

In order to determine the velocity in solids only one reading is taken, and the actual distance between the crystals (or crystal and reflecting surface) has to be known.

Fig. 14 and 15 show the difference for two readings in water. The crystal was moved through 50.0 mm; thus the difference between the second deflections represents the time reqired for the sound to travel 100.0 mm (reflection method). The first deflection is caused by the initial pulse activating the transducer.

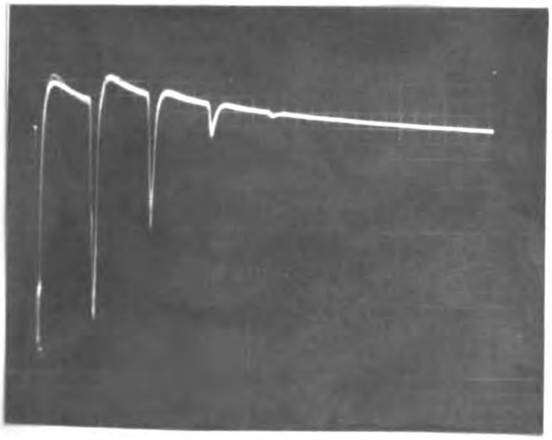


Fig. 14. Short Path Reflection

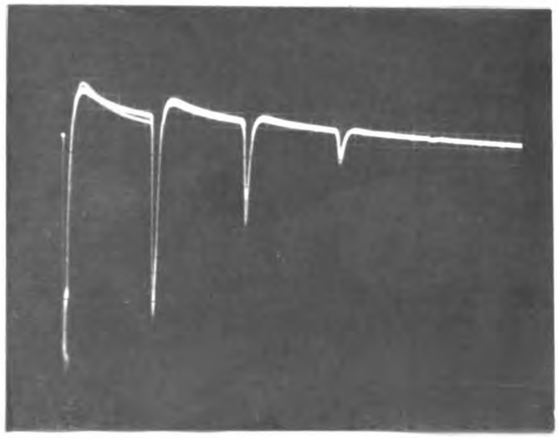


Fig. 15. Long Path Reflection

If the absorption of the medium is not too high multiple reflections become visible, and it is possible to use the second or third reflections for measurements.

Fig. 16 shows a pattern obtained by using the transmission method. The first deflection is the amplified antenna pick-up, the second is the signal caused by the sound

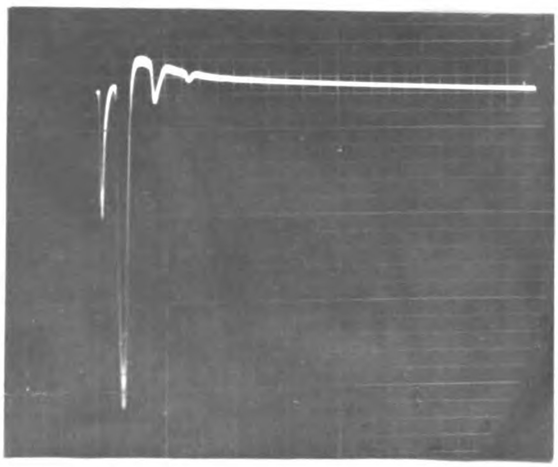


Fig. 16. Transmission Pattern

pulse reaching the receiving crystal. Some of the sound energy is reflected from the holder of the receiving transducer, travels back to the transmitting crystal, is reflected there and finally reaches the receiving crystal. Thus the third deflection is the trace of the sound pulse after it has crossed the medium between the crystals three times, the fourth deflection after five crossings etc.

As pointed out previously measurements of absorption meet a fair amount of difficulties. Yet it is not impossible to obtain results, numerically too low, yet indicative. The attenuation box is placed between the receiving transducer and the input of the receiver, thus the input can be attenuated in steps of 1 db to a total of 41 db. Measurements are made by observing the negative amplitude of one of the reflections, preferably the first one on account of its relatively high negative deflection, and by noting the position of its lowest point. Then the crystal is moved closer to the second crystal (or reflector), and the deflection of the same echo becomes more negative (longer). Attenuating the receiver input decreases the amplitude, and the amount of attenuation needed to bring the deeper deflection up to the level of the first setting gives an indication of losses due to increased distance of the sound path.

Galt[15] has used essentially the same method of obtaining absorption coefficients, yet there are three main difficulties to be considered. First, since the output of the transmitter is tuned to the crystal frequency, the output stage will resonate with the crystal if it is activated by the sound pulse reaching it from the reflector. This means that not all the electrical energy generated by the crystal reaches the receiver but part of it is consumed in the output stage of the transmitter. This loss varies with the impedance match between crystal and transmitter and between crystal and receiver input. Fig. 17 shows an extreme case where enough power reaches the output tank circuit to be

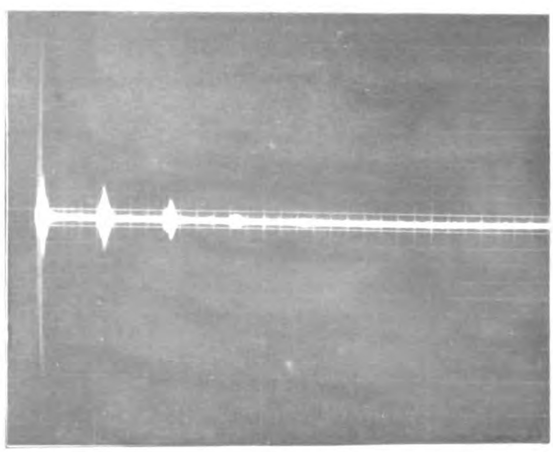


Fig. 17. Vibrations induced in Transmitter

visible on the CRO. This unwanted situation can be used for measurements of sound velocity in a very simple manner, namely by not having a receiver at all, and using the tank circuit as detecting device.

The second difficulty arises because the cross section of the wave train constituting the sound pulse varies with the distance from the source, thus not the same cross section is intercepted by the second crystal (or the first after reflection) at all distances, and as long as not the entire pulse is utilized in making absorption measurements, the measurement will be inaccurate.

The third difficulty is caused by properties of the electronic circuit. If attenuations are made to decrease the signal amplitude reaching the receiver, then the overshoot of the receiver amplifier caused by a strong initial pulse also decreases, and the base line, which is an exponentially decreasing sweep from the end of the initial pulse, approaches a more mearly horizontal position. Thus the pulse traces originating on the base line show a deflection minimum lower than they would have without attenuation and with a more curved base line. Fig. 18 illustrates this source of error.

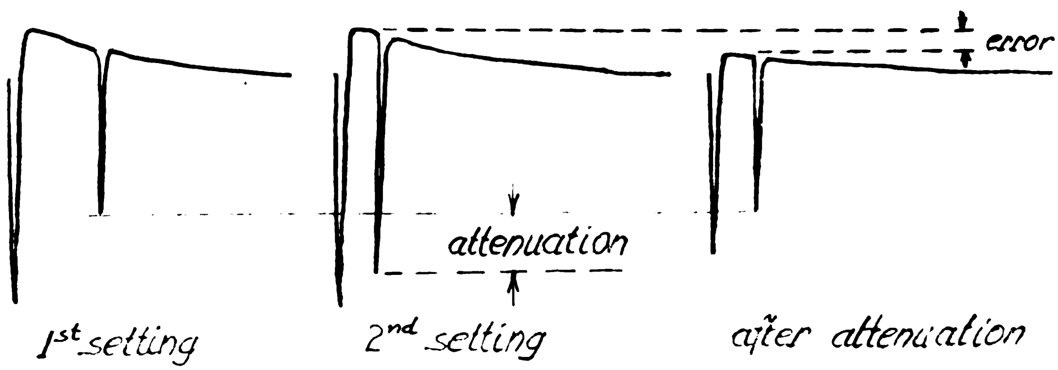


Fig. 18. Effects of Attenuation

Therefore only velocity measurements are included here since they do not depend on above mentioned phenomena.

VI. EXPERIMENTAL RESULTS

A. Calibration

Before any velocity readings of the substances to be examined could be taken the instrument had to be calibrated and checked for consistency; therefore a few preliminary measurements were made in liquids with a known change of sound velocity as a function of temperature. Then sound velocities were measured in liquids which are not suspected to exhibit any abnormal behavior, like tap water and motor oil. Fig. 19 shows some of the results, the readings ob-

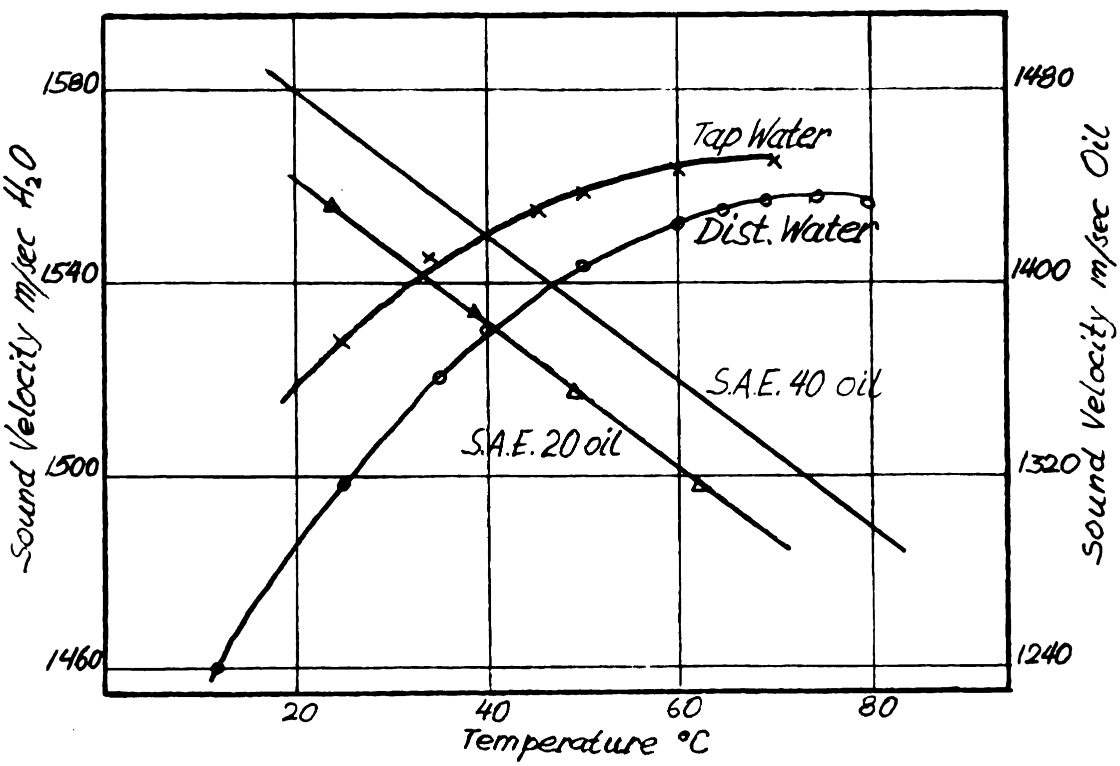


Fig. 19. Sound Velocity in Water and Oil

tained for distilled water did not differ by more than 0.1% from the values given by Mason[16]. S.A.E. 20 motor oil was compared with S.A.E. 40 oil which was examined by Melchor and Petrauskas[17].

B. Measurements

It was hoped that a pulse generator might be an instrument delicate enough to show experimentally whether some liquids cause a dispersion of sound velocity which is not due to temperature changes but to either changes of frequency or changes in sound intensity.

Bergmann[18] lists a number of researchers who conducted experiments designed to show the existence of velocity dispersion; only fractions of 0.1% dispersion could be detected. Hueter and Bolt[19] state that at attainable frequencies the dispersion is ordinarily so small that it is not measurable. Yet experimental evidence of dispersion was offered by Mason et al[20] who investigated polymers of isobutylene. Also Ghurevitch[21] mentions experiments performed in 1938 proving that acetic and formic acid show frequency-depending dispersion. Other workers found a dispersion of sound velocity in rubber[4] and a few other substances with high molecular weights[22].

However, none of the papers mentioned demonstrate any velocity dispersion as a function of sound intensity, although it was suspected[23], until Wada, Simbo, and Oda[24] published their findings of frequency dependence of sound velocity in fatty acids, including one case of intensity dependence.

Thus it was considered interesting to investigate the dependence of sound velocity on sound intensity in lauric, palmitic, and stearic acid. Fig. 20 - 22 show the results of this investigation. The sound frequency used in all experiments was 2.595 Mc, the transducer a disk of $BaTiO_3$ which has the property of decreasing its output intensity at higher temperatures, yet in the range covered this decrease is small[16]. The only influence a change of $BaTiO_3$ can have on the results would show as slightly too low velocity readings in the vicinity of 81° and above.

It is possible to repeat the experiments at different frequencies without replacing the transducer since $BaTiO_3$ responds to all frequencies within a wide range[25]; however, this change to a different frequency would quite naturally involve a change in the intensity of the sound output, and since it was found that sound velocity depends on both the frequency and intensity, it would be impossible to differentiate between the additive effects of both changes. This impossibility arises from the fact that the sound pulses are so short that no instrument could be found to measure the actual intensity of a single pulse.

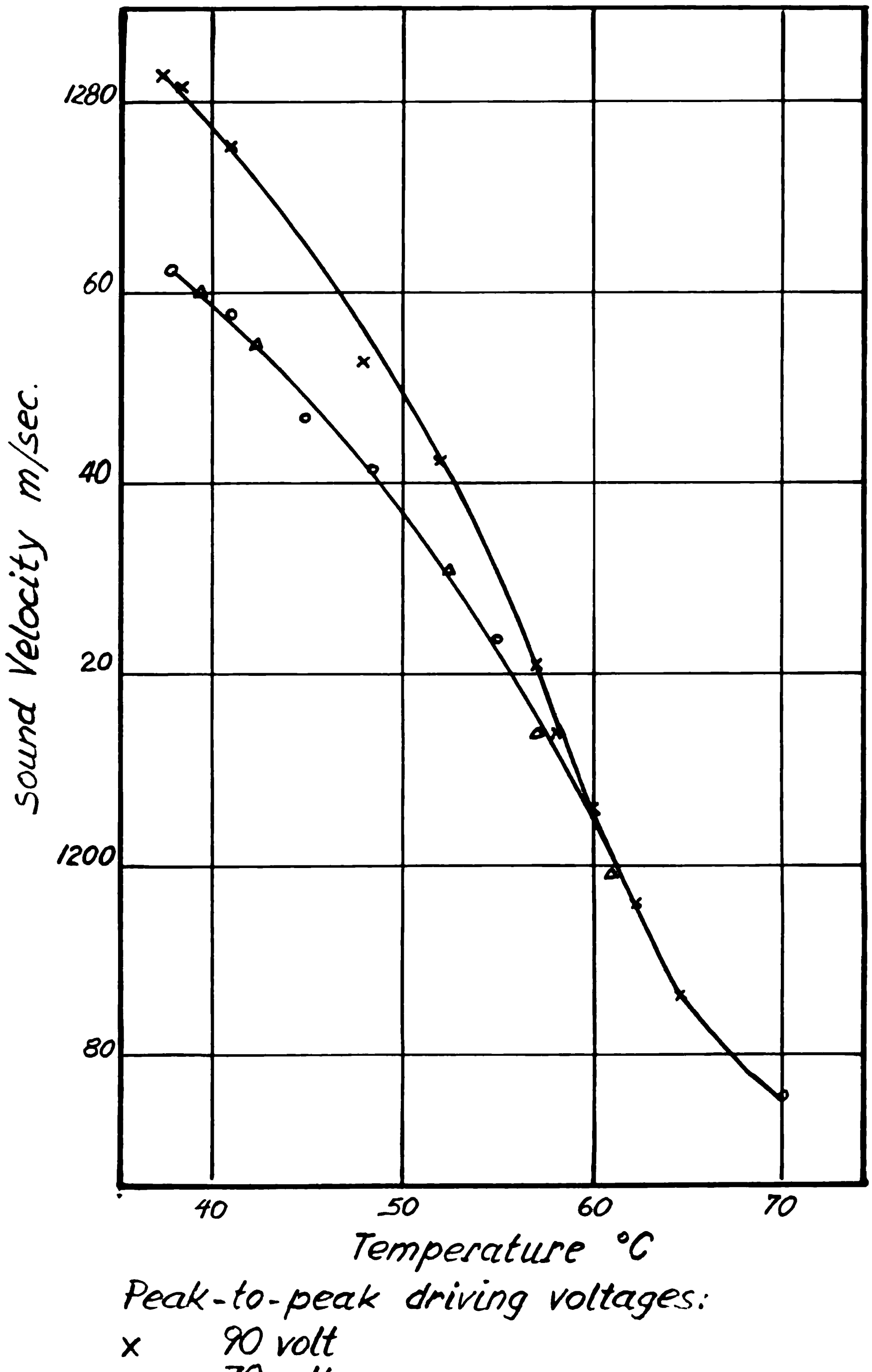


Fig. 20. Velocity Dispersion in Lauric Acid

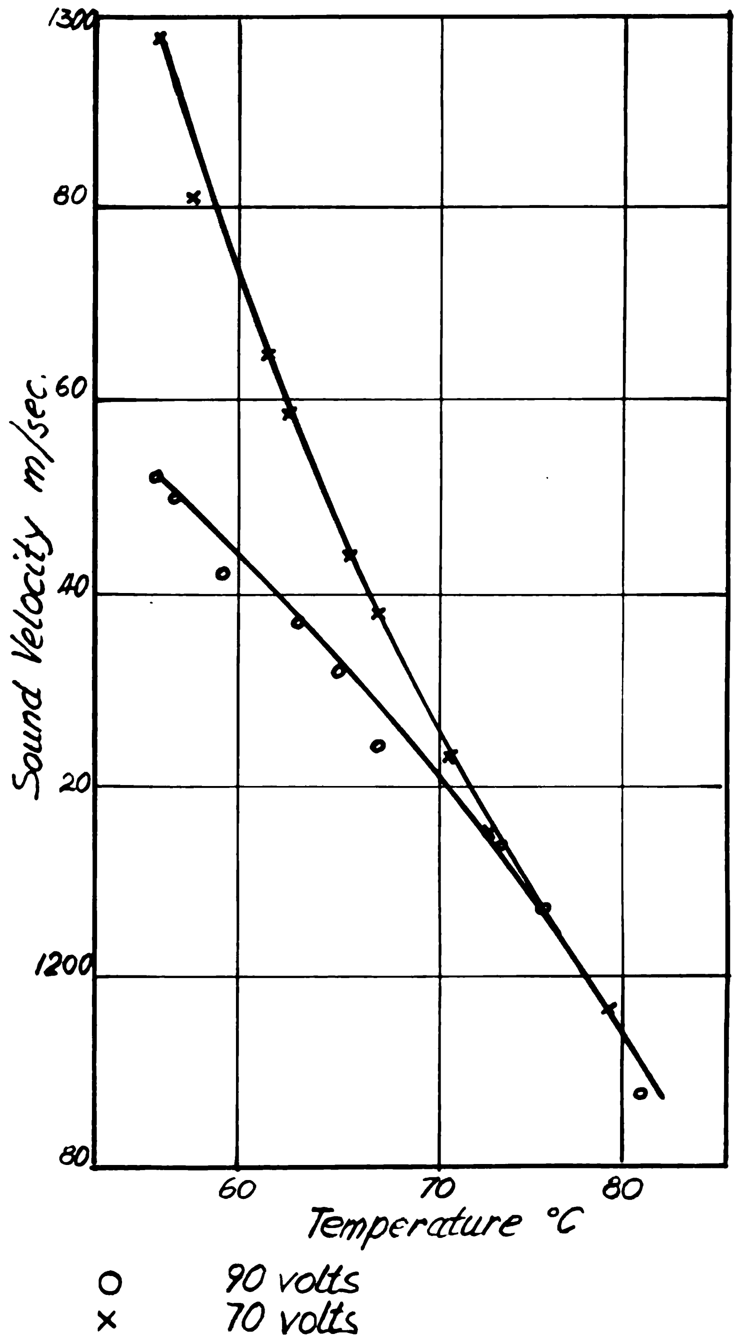


Fig. 21. Velocity Dispersion in Palmitic Acid

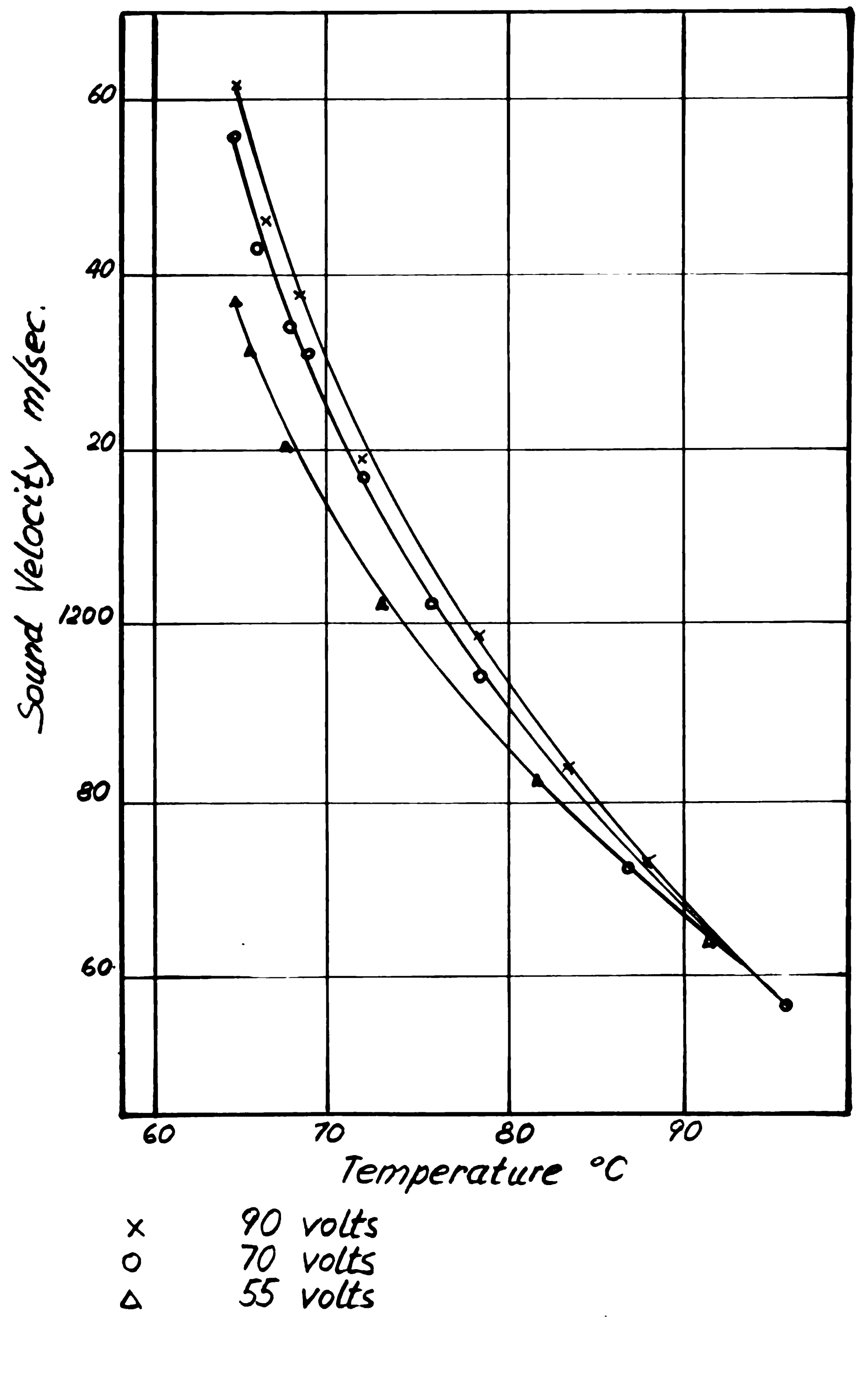


Fig. 22. Velocity Dispersion in Stearic Acid

By using the same transducer at a fixed frequency it becomes convenient to express the relative intensity changes in peak-to-peak voltages with which the crystal is driven. Different crystals will not yield the same sound intensity, even if supplied with the same voltage. Therefore no attempt was made to confirm Wada's results concerning frequency dependence.

Fig. 23 indicates the results of an investigation made to determine whether the velocity dispersion in fatty acids is due to only frequency and intensity changes. Palmitic acid was used since it shows the greatest dispersion. Points L on the curve were obtained by transmitting sound pulses of 47 microseconds duration, points S by using pulses of 19 microseconds; in both cases the driving voltage remained the same. Considering that the ratio between the pulse length is about 2.5, and comparing it with data in Fig. 22 where the intensity ratio between the two curves is about 1.65, the results seem to indicate that velocity dispersion is not due to a change in total energy (pulse length) radiated into the medium but only to amplitude variations (pulse height), the frequency remaining constant.

The dependence of sound dispersion on sound intensity does not fit into the general scheme of a linear relaxation theory. For constant temperature Wada observed a dispersion curve showing a resonance type behavior: the sound velocity

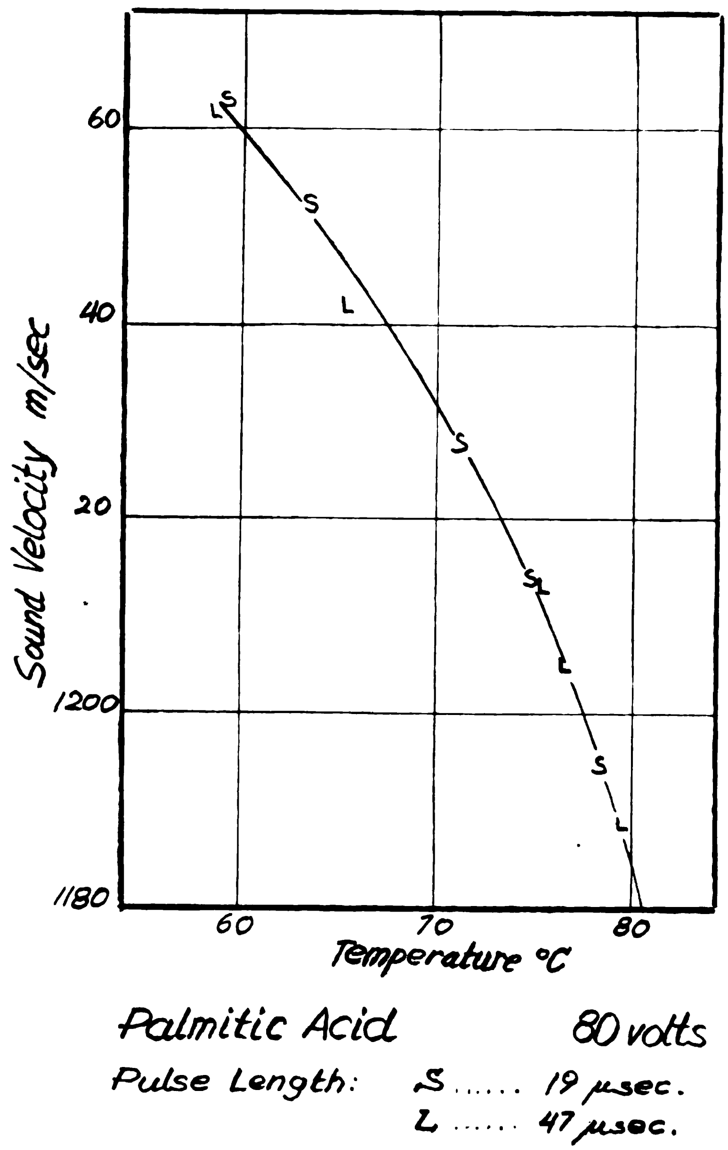


Fig. 23. Effects of Increased Pulse Length

increases with increasing frequency to a peak value and then decreases again. This special type of dispersion has been predicted in the unified relaxation theory given by Hiedemann and Spence[26] for the case that a substance is present in two different phases. This agrees with the explanation offered by Wada that near the melting point fatty acids may contain certain groups with a higher state of order than the rest. By means of a rather formal approach Wada succeeded in deriving a dispersion formula predicting a dependence of dispersion on sound intensity. Wada himself, however, pointed out that this theory does not give a physical explanation of the relaxation mechanism involved.

It may be significant that recent work[27] has proved the existence of a liquid crystal state in derivatives of the fatty acids (sodium stearate etc.). Investigations of ultrasonic dispersions in liquid crystals will show if these effects can be used as indicators for the liquid crystal state or also for a lower state of order.

VII. SUMMARY

The usefulness of a radio-frequency pulse generator was demonstrated. The possibility to change various characteristics of sound output allows a great number of investigations to be carried out with the instrument. It was shown that the apparatus is not limited to sound velocity measurements in liquids which were described.

Dispersion of sound velocity in three fatty acids was shown to exist; it was found that this phenomenon is a function of sound intensity and not of total sound energy radiated into the medium.

VIII. BIBLIOGRAPHY

1. Hiedemann, E. "Wellenausbreitung in festen Körpern, Ultraschall", Fiat Review of German Science, Physics of Solids (1947).

2. Firestone, F. A. U.S. Patent 2,280,226 (1942).

3. Teeter, Jr., C. E. "Absorption of Supersonic Waves in Liquids", J. Acoust. Soc. Am., **18**, 488 (1947).

4. Ivey, D. G., Mrowca, B. A., Guth, E. "Propagation of Ultrasonic Bulk Waves in High Polymers", J. Appl. Phys., **20**, 486 (1949).

5. Lutsch, A. "Zerstörungsfreie Prüfung durch Überschall mit dem Laufzeit-Echoverfahren", Arch. Eisenhttw., **23**, 57 (1952).

6. Seemann, H. J., Bentz, W. "Untersuchungen über den Einfluss des Gefüges auf die Extinktion von Ultraschallwellen in metallischen Stoffen", Z. Metallk., **45**, 663 (1953).

7. Lutsch, A. "Eine einfache Methode zur Messung der elastischen Konstanten mit Hilfe von Ultraschallimpulsen", Z. ang. Phys., **4**, 166 (1952).

8. Termann, F.E., Pettit, J. M. "Electronic Measurements", McGraw-Hill, New York (1952).

9. Ficken, G. W. "A Sing-Around Circuit for the Measurement of Sound Velocity", Master's Thesis, Michigan State College (1953).

10. "Radar Electronic Fundamentals", NAVSHIPS 900,016, Navy Department, Washington, D.C. (1944).

11. Elmore, W.C., Sands, M. "Electronics", McGraw-Hill, New York (1949).

12. Easton, A. "Pulse Modulated Oscillator", Electronics, March 1947.

13. "Radio Amateur's Handbook", 32nd ed., ARRL, West Hartford, Conn. (1955).

14. Martin, Jr., T. L. "Ultrahigh Frequency Engineering", Prentice Hall, New York (1950).

15. Galt, J. K. "Mechanical Properties of Alkali-Halide Crystals", M. I. T. RLE Techn. Report 45 (1947).

16. Mason, W. P. "Piezoelectric Crystals and Their Application to Ultrasonic", Van Nostrand, New York (1950).

17. Melchor, J. L., Petrauskas, A. A. "Ultrasonic Studies of Polymethyl Methacrylate", Ind. Eng. Chem., **44**, 716 (1952).

18. Bergmann, L. "Der Ultraschall und seine Anwendung in Wissenschaft und Technik", Hirzel, Zürich (1949).

19. Hueter, F., Bolt, R. H. "Sonics", John Wiley & Sons, New York (1955).

20. Mason, W. P., Baker, W. O., McSkimin, H. J., Heiss, J. H. "Mechanical Properties of Long Chain Molecule Liquids at Ultrasonic Frequencies", Phys. Rev., **73**, 1074 (1948).

21. Ghurevitch, S. B. "Absorption of Ultra-Acoustic Waves in Liquids", C. R. (Doklady) Acad. Sci. URSS, **LV**, 17 (1947).

22. Ballou, J. W., Smith, J. C. "Dynamic Measurements of Polymer Physical Properties", J. Appl. Phys., **20**, 493 (1949).

23. Seidl, F. "Schallabsorption in beschalltem Transformatorenöl", Colloquium Over Ultrasonore Trillingen, Koninklijke Vlaamse Acad. voor Wetenschappen van België (1951).

24. Wada, Y., Simbo, S., Oda, M. "Dispersion of Ultrasonic Velocity in the Liquid Fatty Acids", J. Phys. Soc. Japan, **5**, 345 (1950).

25. Schaaffs, W. "Schallgeschwindigkeit und Molekülstruktur in Flüssigkeiten", Erg. ex. Naturw., **XXV**, 109 (1951).

26. Hiedemann, E., Spence, R. D. "Zu einer einheitlichen Theorie der Relaxationserscheinungen", Z. f. Phys., **133**, 109 (1952).

27. Moses, H. A. "The Proton Resonance Absorption in Liquid Crystals", Master's Thesis, Michigan State College (1953).