A METHOD FOR INCREASING THE ACCURACY OF INTENSITY MEASUREMENTS OF LIGHT DIFFRACTED BY ULTRASONIC WAVES

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John Wente Nagle

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By

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A THESIS

Submitted to the College of Science and Arts of
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A Method for Increasing the Accuracy of Intensity Measurements of Light Diffracted by Ultrasonic Waves.

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Abstract

Optical methods based on ultrasonic effects may be used to make quantitative measurements of elastic constants and losses for transparent materials.

Light passing through ultrasonic sound fields set up within the material under investigation will undergo diffraction. Intensity and position measurements of the resulting diffraction pattern will yield information which makes it possible to determine the properties mentioned above. Errors caused by light scattered or refracted into the intensity measuring device are avoided by modulating the ultrasonic wave within the material, and then receiving selectively by means of a photo multiplier, only the component of the diffraction pattern which is modulated.

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INTRODUCTION

In transparent materials, optical methods based on ultrasonic effects may be used to make quantitative measurements of such properties as elastic constants and losses.

By means of an ultrasonic generator, standing or progressive waves of sound may be produced in a substance under investigation. Light passing through these sound fields will suffer diffraction in a manner similar to light diffracted by an optical grating. Measurements of the intensities and positions of the resulting diffraction patterns will yield information which will lead to the determination of the propertitles mentioned previously.

For measurements of the intensity of the light diffracted by ultrasonic waves, one must avoid errors caused by light scattered or refracted into the light measuring device.

An effective way to exclude all other effects than those produced by the ultrasonic waves is to modulate the ultrasonic frequency and to receive selectively only the output of the photocell detector which is at the frequency of modulation.

The development of an experimental set-up appropriate for such measurements is the object of this thesis.

By means of an amplitude modulated ultrasonic generator, the amplitude of the sound field within the material under investigation is varied between zero intensity and a maximum intensity at a frequency in the audio range. This in turn modulates the light intensity in the resulting diffraction pattern with the same frequency. The portion of the diffraction pattern which is to be measured is then allowed to fall upon the face of a photomultiplier which will convert the light signal into an electrical signal, for which the voltage output will be proportional to the light intensity incident upon the photomultiplier tube. At this stage, the signal will have a component modulated with the frequency of modulation, this being the desired signal. In addition, the signal may have other components which correspond to the optical background.

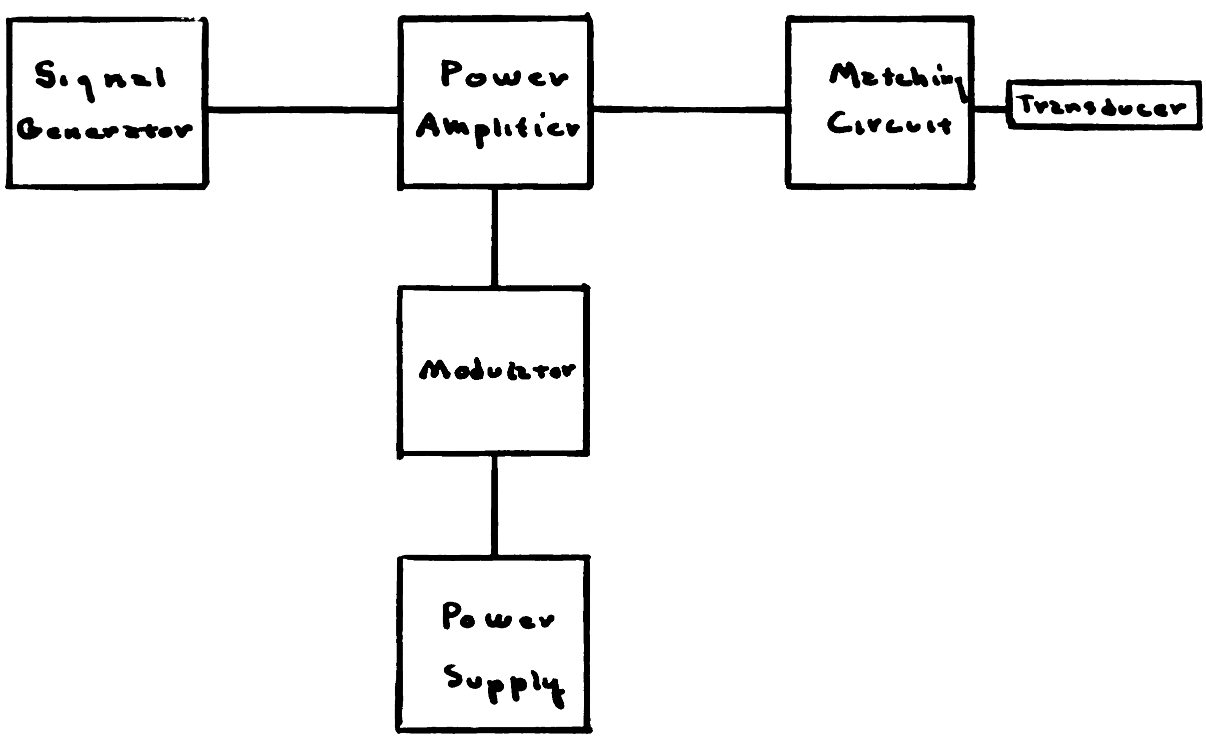
This composite signal is then fed through an amplifier which is tuned to pass only frequencies in the immediate neighborhood of the original modulation frequency and to reject all other frequencies. Thus, only the signal produced by the modulated ultrasonic wave field will be passed and those frequencies caused by the various forms of noise will be rejected.

Direct measurements of the signal passed are then made with the aid of an alternating current vacuum tube voltmeter.

EXPERIMENTAL APPARATUS

In the following discussion, the equipment used in the unit mentioned in the introduction will be described in detail after a discussion of the more important factors which had to be taken into consideration in the design and construction of the apparatus.

The block diagram shown below is presented to help illustrate the relationship between the respective components as they are incorporated in the production of a signal produced by the low frequency modulation of a high frequency generator.



The High Frequency Power Amplifier.

A very important part of the apparatus is the high frequency power amplifier which, in conjunction with an impedance matching device, delivers an alternating current signal to the transducer.

The power amplifier used in this circuit consists of two stages: a buffer stage, followed by a power amplification stage. The buffer stage is excited at the desired frequency by means of a Heathkit Radio Frequency Signal Generator which has a frequency range of from .160 to 220 megacycles. The buffer stage itself is a plate tuned voltage amplifier which incorporates a 6V6 pentode vacuum tube. This stage is coupled to the power amplification stage by means of a coupling condenser connecting the plate tank circuit of the 6V6 to the grid circuit of the power amplifier stage. The power amplification stage incorporates a single 6146[1] power pentode vacuum tube which is likewise tuned in the plate circuit by means of a L/C tank circuit. The inductance coils used in both tank circuits are of the plug-in type which are used in most amateur radio transmitters and their values may be interchanged in order that the proper frequencies of oscillation may be secured.

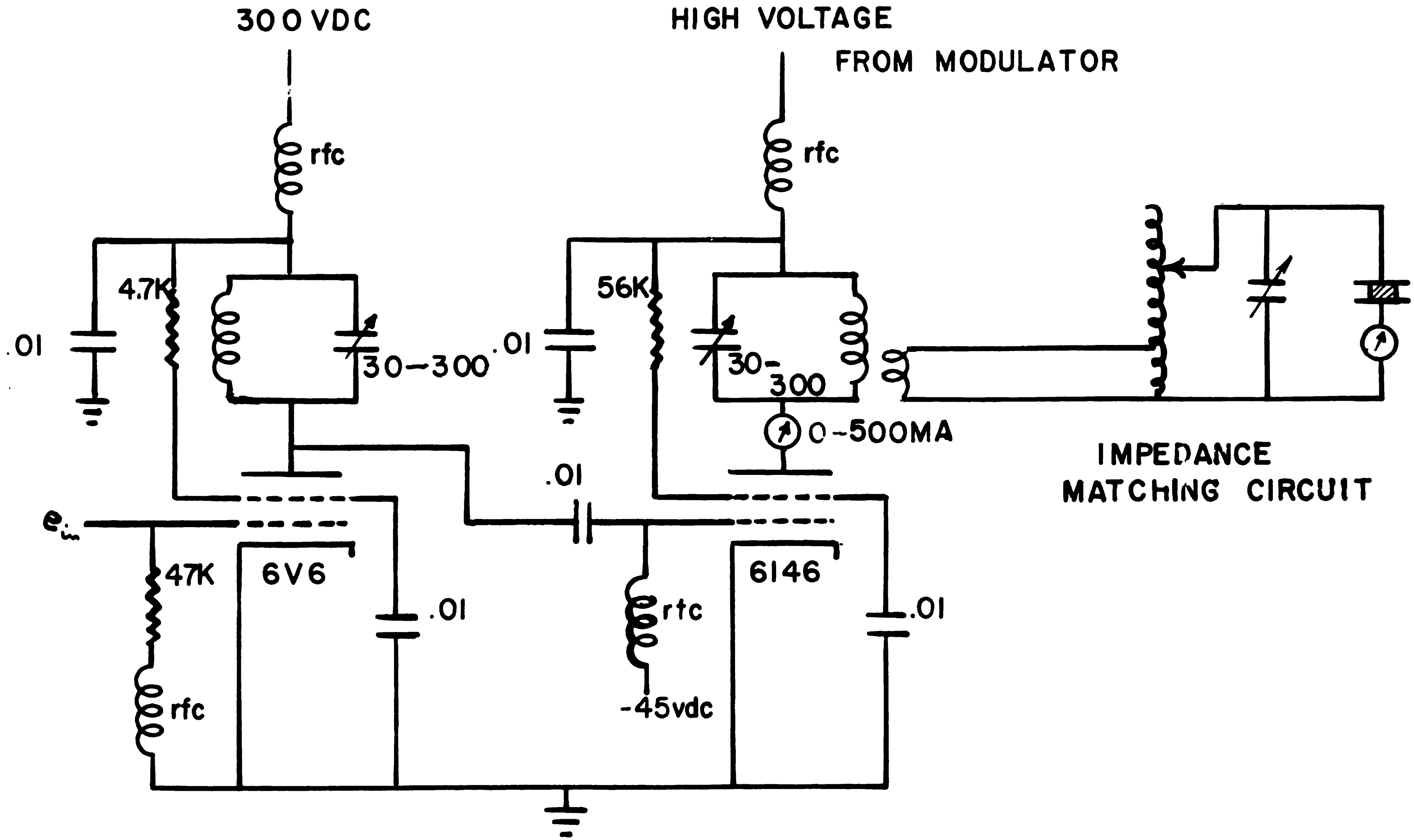
The 6146, when used in such an application as mentioned above, is found to have the following recommended zero excitation voltages and currents: for a plate voltage of 750 volts, screen voltage of 120 volts and a grid bias voltage of - 45 volts, the plate current should be of the order of 120 milliamperes. Operating at this plate voltage the amplifier may be operated for intermittent periods only. When operated continuously or when it is plate modulated, which it is in its present application, the plate voltage must be reduced to a minimum of 600 volts under which condition the plate current will be reduced to 110 milliamperes.

The impedance matching circuit which is used in conjunction with the power amplifier is typical of those used in such matching applications.[2] By varying the inductance and capacitance of the matching circuit, the output impedance of the power amplifier may be matched to the input impedance of the transducer and hence a maximum of power transmission to the transducer is accomplished.

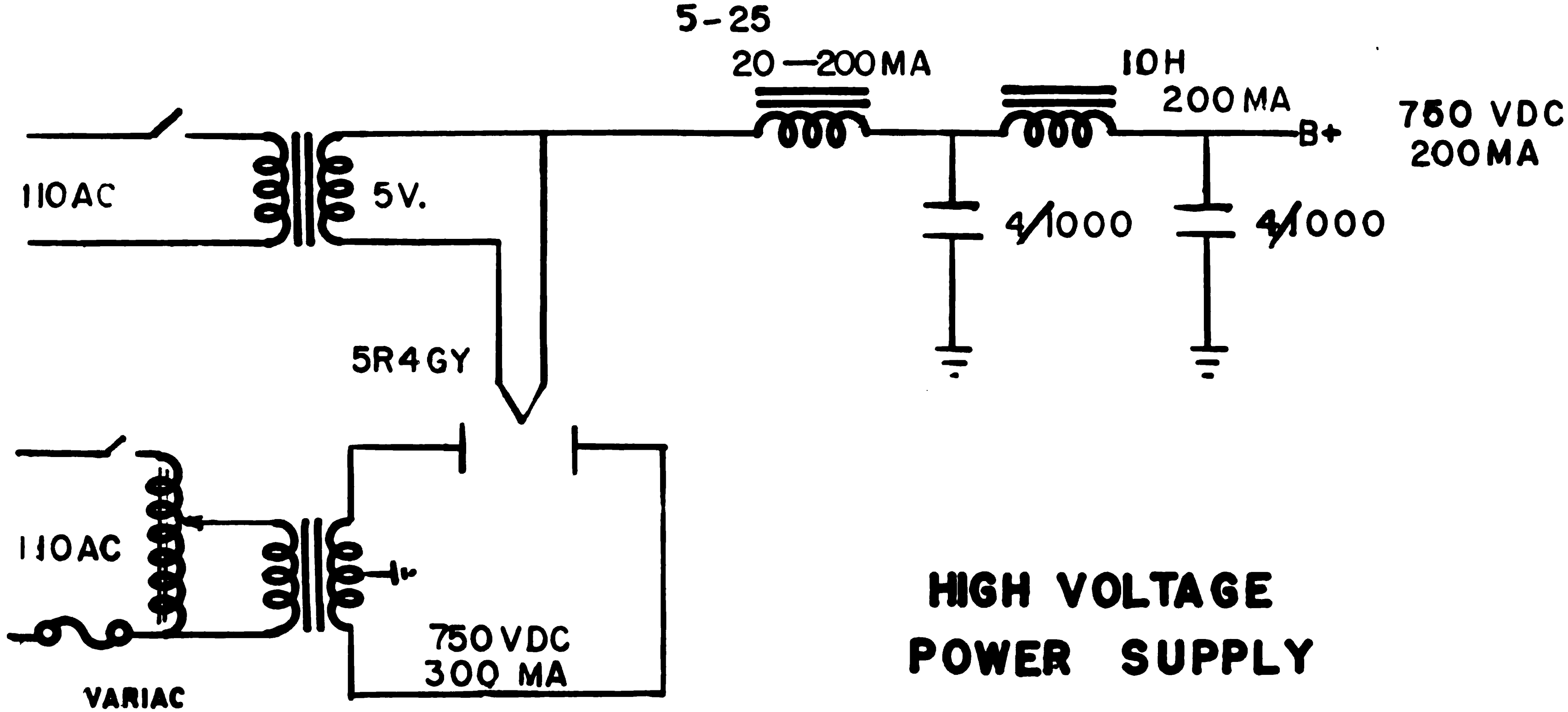
Filtered voltage is supplied to the amplifier by means of a direct current power supply which is capable of developing a peak voltage of 750 volts with a current rating of 200 milliamperes. Output voltage is controlled by means of a V-2 Variac in the primary circuit of the power transformer. Plate voltage for the buffer stage is regulated at 300 volts by means of two voltage regulator tubes.

Amplitude Modulation and the Modulator.

Amplitude modulation[3] is produced by varying the ampli-



POWER AMPLIFIER



HIGH VOLTAGE
POWER SUPPLY

tude of the high frequency carrier wave in accordance with the amplitude and frequency of the modulating source.

If $e_m = E \cos_m \omega_m t$ represents the modulator signal voltage and $e_c = E_c \cos \omega_c t$ represents the unmodulated high frequency carrier wave, the composite wave has the form:

$$e = (E_c + E_m \cos \omega_m t) \cos \omega_c t$$

or,

$$e = E_c (1 + k \cos \omega_m t) \cos \omega_c t$$

where k is the ratio of maximum modulation signal voltage to the maximum carrier voltage.

If this expression is expanded, it will take the form:

$$e = E_c \cos \omega_c t + \frac{kE_c}{2} \cos (\omega_c + \omega_m) t + \frac{kE_c}{2} \cos (\omega_c - \omega_m) t.$$

It can be seen at once upon examination of this expansion that amplitude modulation gives rise to a composite signal consisting of the high frequency carrier with the addition of two side bands of frequency $(\omega_c + \omega_m)$ and $(\omega_c - \omega_m)$, each of which exhibits a constant amplitude. It is the resultant of these three wave forms which is characterized by the amplitude modulation at a frequency ω_m.

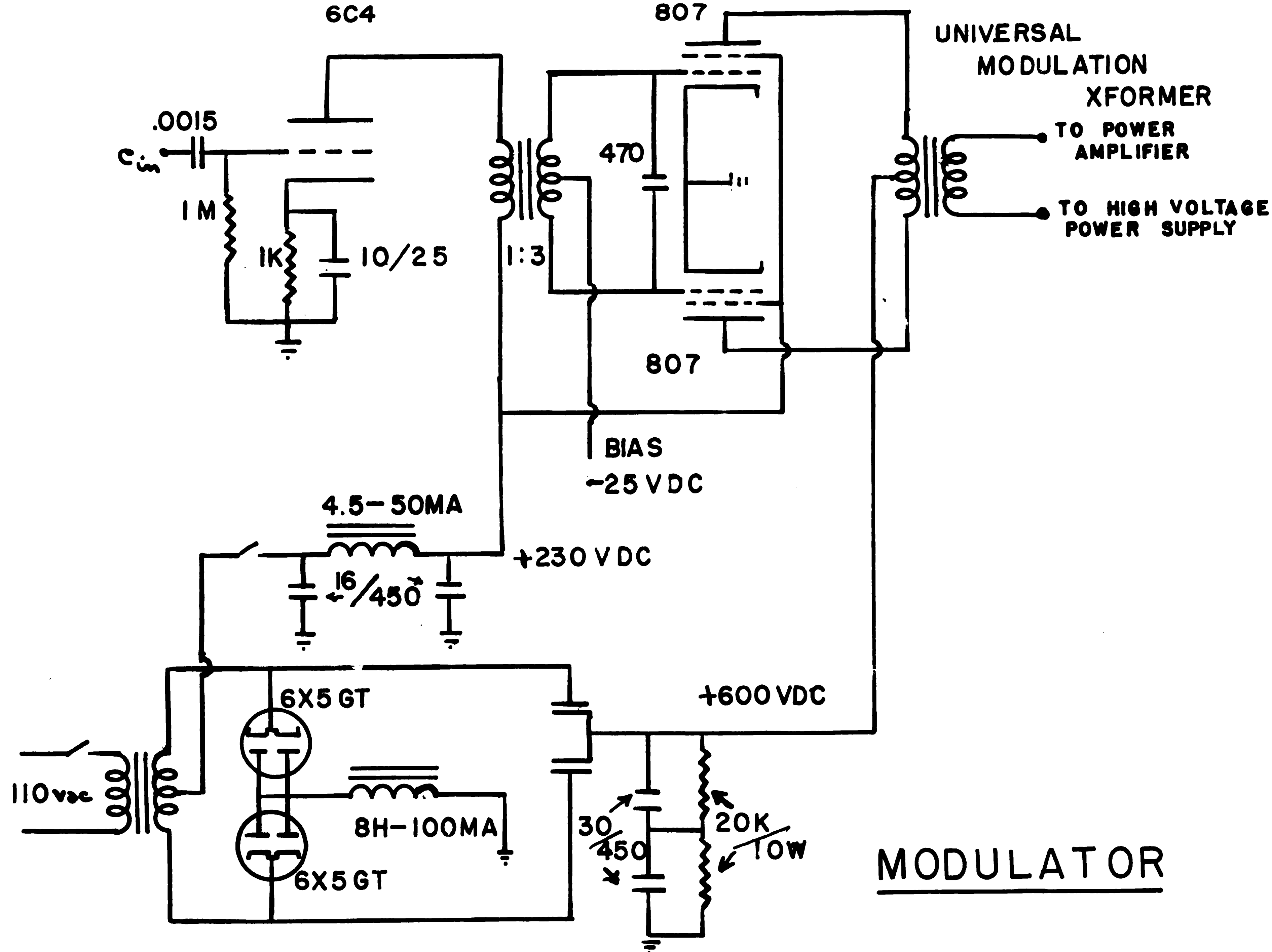
For 100 percent modulation, k is equal to unity, and the voltage amplitudes of the side bands are one-half that of the high frequency carrier, so that, since power is proportional to the square of the applied voltage, each side band transmits one-sixth of the power and the carrier transmits two-thirds of the power. Thus for 100 percent modulation, the modulator must be capable of supplying one-third of the power in the composite signal, or an amount which is equal to one-half of that supplied by the power amplifier.

From a consideration of the side band frequencies, it is apparent that the transducer used in conjunction with amplitude modulation must have a band width of sufficient magnitude so that the side bands are not attenuated, if one hundred percent modulation is to be approached.

In the case of barium titanate crystal transducers and quartz crystal transducers radiating into liquids or solids, such a wide band width is present and little difficulty should be met in producing a well modulated signal.

For this particular application, amplitude modulation was obtained by means of plate modulation, since this mode gives the highest efficiency in the modulated power amplifier and is the easiest to adjust for proper operation.

Plate modulation is achieved by transformer coupling a push-pull audio frequency power amplifier to the plate circuit of the power amplifier.[4] Since the 6146 power tube is a screen grid amplifier, it is also necessary to couple the modulator to the screen grid, for the screen voltage has a greater effect on the plate current than does the plate voltage. Hence, the modulator's output transformer secondary was connected directly between the high voltage power supply and the high voltage input of the power amplifier. As mentioned before, the modulator is a push-pull power amplifier.


6C4
807
UNIVERSAL
MODULATION
XFORMER
TO POWER
AMPLIFIER
TO HIGH VOLTAGE
POWER SUPPLY
.0015
e_{in}
1M
1K
10/25
1:3
470
807
BIAS
-25 VDC
4.5-50MA
+230 VDC
16/450
+600 VDC
6X5 GT
6X5 GT
8H-100MA
110vac
30/450
20K/10W

MODULATOR

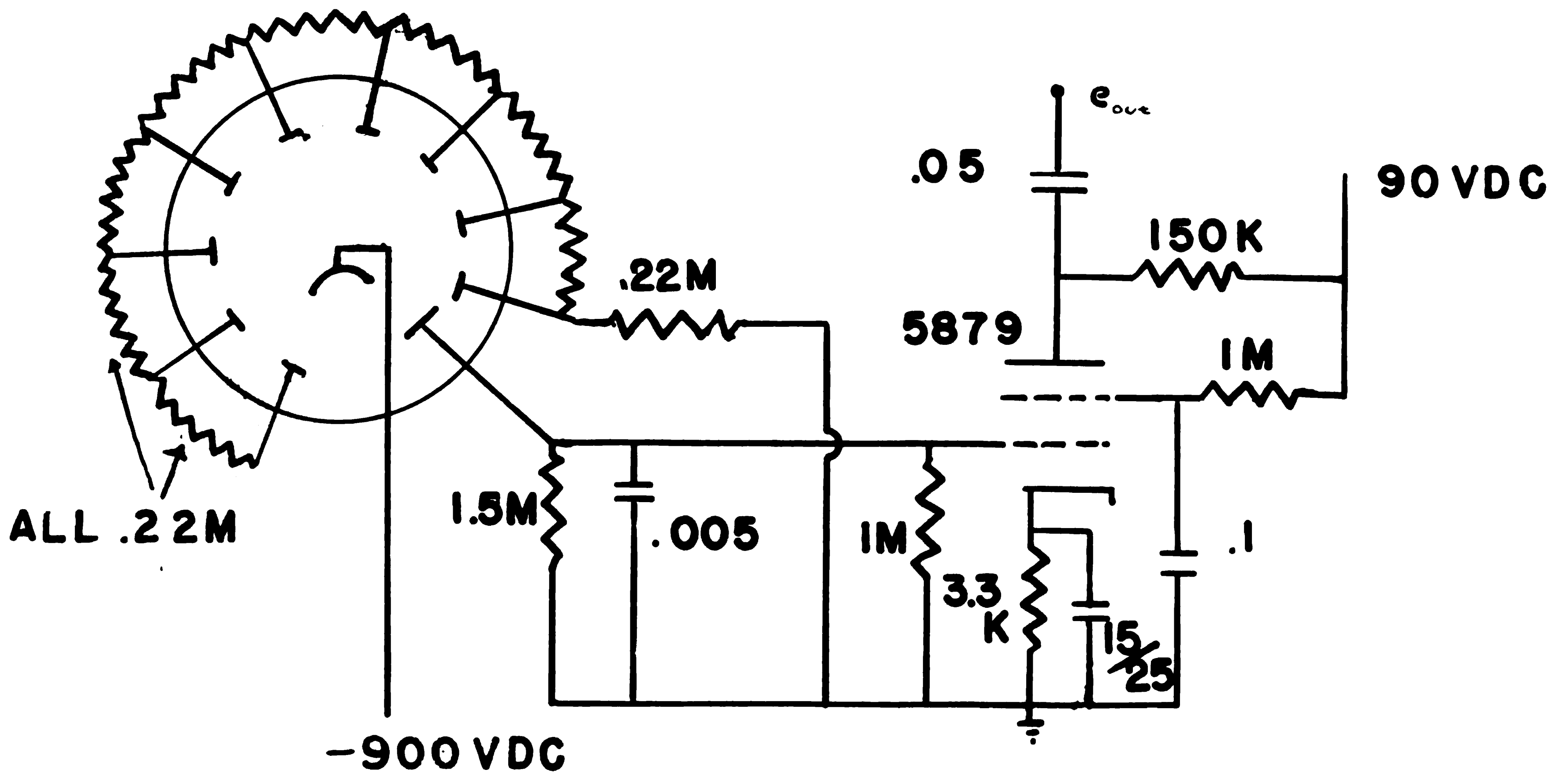
It incorporates two 807 pentode power amplifier tubes operating in class AB_1. A 6C4 driver stage is excited by means of an audio frequency oscillator, and it is coupled to the negatively biased grids of the 807's by means of an interstage audio transformer of turns ratio 3:1, total secondary to primary.

Such a modulator unit is capable of delivering 40 watts of undistorted power to the high frequency power amplifier. A universal modulation output transformer was used in the circuit in order that the voltage at the plate of the modulated amplifier could be adjusted to vary between zero and twice the D.C. operating voltage.

Photomultiplier Circuit and Pre-Amplifier.

As was mentioned in the introduction, a photomultiplier circuit is used to measure the relative intensities of the diffraction patterns produced by passing light from a slit source through the ultrasonic wave field. For the circuit chosen, either a 931-a or a IP21 photomultiplier tube may be used, with the latter being the more sensitive of the two light detectors.[5]

The high voltage power supply used to supply voltage to the dynodes of the photomultiplier tube is capable of producing a potential drop across the tube of 900 volts for maximum sensitivity. By means of a one megohm variable resistance which is in series with the photomultiplier tube, the negative



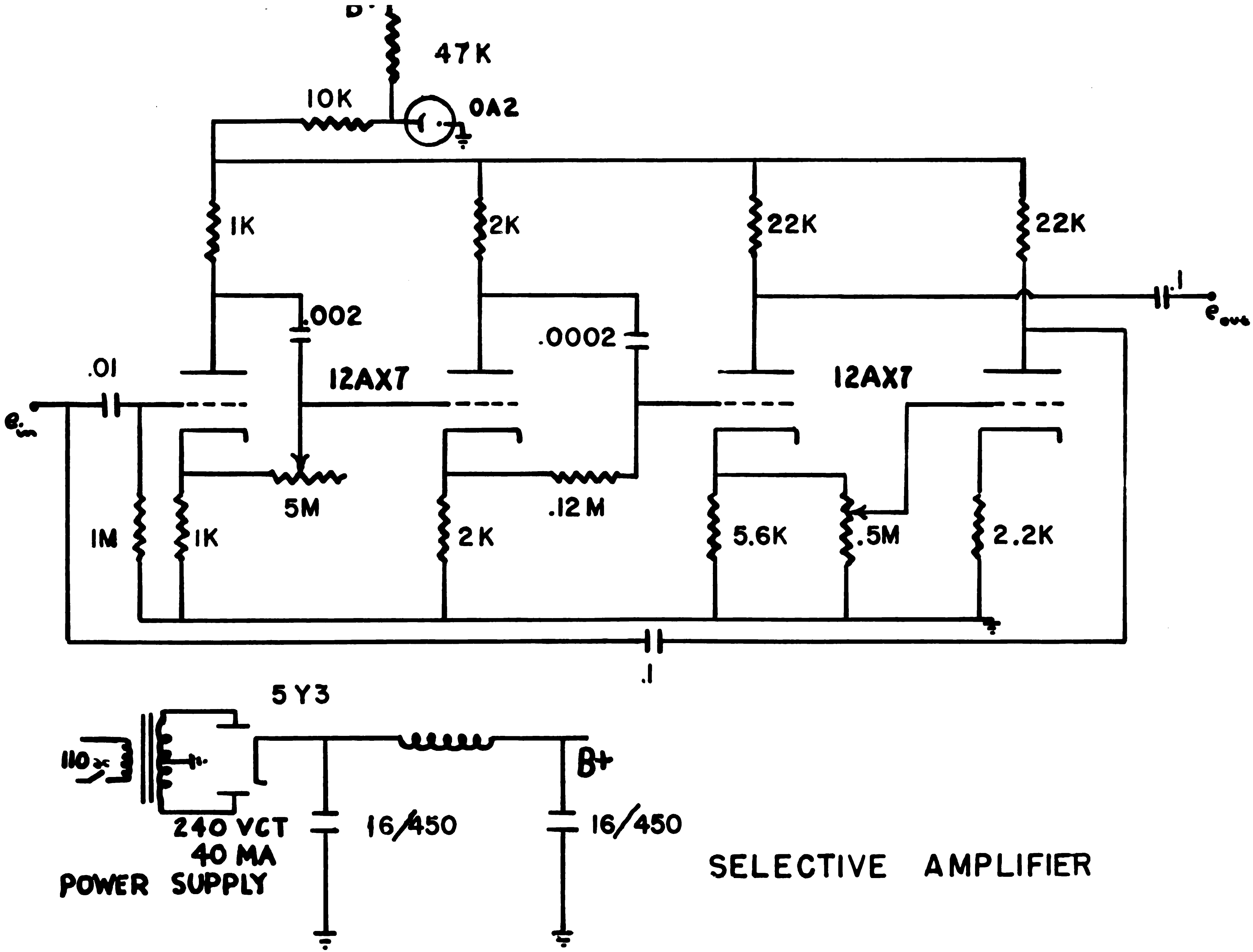
PHOTOMULTIPLIER TUBE and PREAMPLIFIER STAGE voltage across the tube may be reduced by 200 volts, thereby decreasing the sensitivity of the photomultiplier circuit.

The signal from the photomultiplier circuit is fed directly through a coupling condenser to a high gain pre-amplifier stage. A 5879 pentode voltage amplifier vacuum tube was used in this stage because of its low noise characteristics and its capacity for high gain amplification with a minimum of distortion.

Selective Amplifier.

The amplified signal from the 5879 pre-amplifier tube is fed directly into a selective amplifier which has the characteristic of passing only a narrow band of frequencies in the neighborhood of the modulation frequency. Frequencies resulting from background optical ''noise'' in the ultrasonic sound field and from noise in the electronic components are thus rejected. The circuit used in this application is quite similar to what is known as the ''Selectoject.''[4] Although this amplifier does not have as narrow a band pass (it has a band width of approximately 50 cycles for a resonant frequency of 1000 cycles) as does a narrow band amplifier using a twin T network, it does have the great advantage of being capable of being tuned to any desired frequency between 80 and 10,000 cps.

The output of the selective amplifier is fed directly into an A.C. vacuum tube voltmeter with which measurements of the output voltage can be made and hence magnitudes of the light intensities of the diffraction determined with respect to a standard.



SELECTIVE AMPLIFIER

CONCLUSION

The apparatus discussed in the previous section was used in the investigation of diffraction patterns resulting from ultrasonic waves in a liquid and in a solid medium.

Working with a liquid, Xylene, it was found that the modulation of the ultrasonic waves could be produced with little difficulty, and that as many as ten diffraction orders of good intensity could be observed when working with waves of three megacycle frequency. When the modulated signal from the photomultiplier was passed through the narrow band amplifier, it was found that the amplifier essentially passed only the component of the signal at the modulation frequency. Also, it was found that there was a 120 cycle component of a lesser magnitude which was also passed. The presence of this 120 cycle component is attributed to the Mercury Vapor light source which was being operated on 110 volts alternating current. Hence, the light source was in effect being modulated at 120 cycles. Although the narrow band amplifier was tuned at 1000 cps, it was found that the 120 cps modulation of the light source was too great to be completely blocked by the amplifier and thus part of it was passed, with the result that a signal to noise ratio of the order of ten to one was present.

Working with glass, it was found that a modulated diffraction pattern could again be produced with standing waves of ten megacycle frequency, although only two diffraction orders of very low intensity could be observed. This may be partially attributed to the use of a much weaker light source than had been used with the liquid. In an effort to eliminate the 120 cycle component which was encountered in the observation on a liquid, a 500 watt filament projection lamp operating on 110 volts direct current was used as a light source. Upon filtering this light to pass a single frequency, it was found that the intensity transmitted was extremely low. This resulted, in turn, in a very low level signal output from the photomultiplier and once again the signal to noise ratio from the amplifier was not as good as could be desired.

In an effort to produce a better signal to noise ratio in the measurements, the following additions to the present experimental apparatus will be incorporated: A direct current Mercury Vapor lamp will be used instead of the present light source. If power is supplied to this lamp from a battery, an intense monochromatic light source of constant intensity will be available with the result that there will no longer be a noise component due to the modulated light source, which caused the reported difficulties. In addition, it will be necessary to replace the narrow band amplifier now being used in the detection circuit by another which will be tuned to a single frequency and which will have a much narrower frequency band pass than that exhibited by the present amplifier.

With the addition of these two pieces of equipment to the present experimental apparatus, the signal to noise ratio should be improved so much that a higher accuracy in the measurements of the intensity of light diffracted by ultrasonic waves will be obtained.

It is expected that this gain in accuracy will make it possible to study such problems of the theory of the diffraction of light by ultrasonic waves, for which the previous methods were insufficient.

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