H O M E   R A D I O

THESIS IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE PROFESSIONAL DEGREE OF INDUSTRIAL DESIGNER AT THE CALIFORNIA INSTITUTE OF TECHNOLOGY PASADENA CALIFORNIA

H E N R Y   K E C K

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O R D E R   O F   C O N T E N T S

I N T R O D U C T I O N

REQUIREMENT

To design a radio, table or floor model, which has increased utility over existing radios.

CHOICE OF REQUIREMENT

After careful study of the radio field it was found that little attention had been directed to radios small enough for the small home, yet fine enough in design and tonal quality to be used as the main family radio. For this reason it was felt that an engineering and design contribution could be made on a radio of this type.

CONSECUTION

Market research was carried on to determine the probable extent of the radio market. In conjunction with this consumer research was done to ascertain the needs and desires of consumers in radio buying.

Engineering research was done in acoustics to determine what had been done and what could be done in the field of improving the acoustic qualities of a small set. In conjunction with this a study of the human ear was made to determine its peculiarities in translating air wave motion into sound.

Production facilities of the company with which the work was carried on were studied. They were considered as one of the basic challenges of the design.

The extent of the change from existing models that would be immediately practicable for the company was discussed at length with company executives and engineers.

A working model of the proposed radio was made. Its acoustic properties were tested and recorded according to recognized standards.

Suggested changes on the working model were made in accordance with facts found. A program of additional design and acoustic research was suggested.

RESULTS OF THESIS WORK

I A comprehensive market and consumer survey of the radio field was made which is of value to the radio industry and to radio designers in building sets that are more utilitarian than those available at the present time.

II A radio different in conception and design than anything previously done was developed using a standard superheterodyne circuit.

III An acoustical system was developed for this radio which it is believed is superior to any system existing at the present time in its size class.

IV A radio easily adaptable to the mass production techniques of a particular company of medium production capacity was designed. This is of particular worth in a product design since it brings the design closer to the pragmatic test of industrial design: to give the ultimate consumer a higher living standard as expeditiously as possible.

V A direction for future fruitful research was indicated.

MARKET AND CONSUMER RESEARCH CONTENTS

MARKET RESEARCH SUMMARY

OBJECT OF RESEARCH

To determine the number of radios and the type of radios that can be sold in the United States in 1947.

PROCEDURE

Sales history of the radio market was checked as far back as 1922 for total number of sales and for total retail value of sales. Two economists were consulted to help in determining the trend of sales of the radio industry as a whole. The percentage of electric consumers in the Mountain and Pacific States as compared to the country as a whole was determined to be used as a basis for determining the approximate potential market of companies distributing in those areas. Purchasing power of the dollar, Total income payments and other government indices were checked to help determine the relative ability of families to buy as compared to pre-war standards.

RESULTS

1. 6,141,000 radio sets will be sold in the United States in 1947.

This is the estimate of the Research Department of Electrical Merchandising. It has been made by projecting the combined predictions of 82 major utilities in the U.S. to the total number of electric customers in the U.S.

2. 655,000 radio sets will be sold in the Pacific States in 1947.
   184,000 radio sets will be sold in the Mountain States in 1947.

These estimates are based upon the percentage of the total number of electrical customers in the United States that these areas represent. Regional variations have been neglected.

3. Straight table sets, console combination sets and table combination sets will sell best in 1947 in that order by dollar volume. This estimate is based upon sales histories of these types in 1940, 1941,1942 and 1946. Only 79,047 straight consoles were sold in 1946. This compared to the 714,324 console combination sets sold in the same period (despite acute cabinet shortages) shows the undesireability of producing that type of set.

RESULTS (continued)

4. The radio industry is selling to a practically saturated market in this country. New sets sold are almost entirely replacements or additional radios in the home.

DISCUSSION OF RESULTS

Caution should be used in utilizing the statistics mentioned. Predictions of the type made in statements 1 and 2 are at best approximate even though they represent an almost complete coverage of the market. Too many variables are involved, however, to use the figures as more than rough gauges as to production.

Many families in this country are in a position to spend more money on consumer goods than before the war for two reasons:

1. Total income payments in the U.S. have risen to such an extent that they more than offset the decreased purchasing power of the dollar.
2. The number of persons employed per family has increased giving the family unit greater buying power.

Since radios are on the borderline between luxury and necessity these two facts should have a healthy effect on the radio industry. Reference to the graph on page 7 shows this borderline situation clearly since in almost every instance when Total Income Payments go up, radio sales go up proportionately. On the other hand when Total Income Payments go down radio sales go down faster proportionately.

A relatively unexploited market that may prove fruitful is the market represented by the constant demand of hotels and restaurants for radios. The annual sale of radios to these sources amounts to $4,000,000 in the Unites States in a normal year. 28% of the country's hotel business is concentrated in the Mountain and Pacific states (17.04% in the Pacific States and 10.96% in the Mountain States.) Orders from chain hotels and restaurants are of course particularly helpful.

The pages following present the detailed information from which the "results" were deduced.

ESTIMATED POSTWAR RADIO SALES IN DOLLARS IN THE MOUNTAIN AND PACIFIC STATES

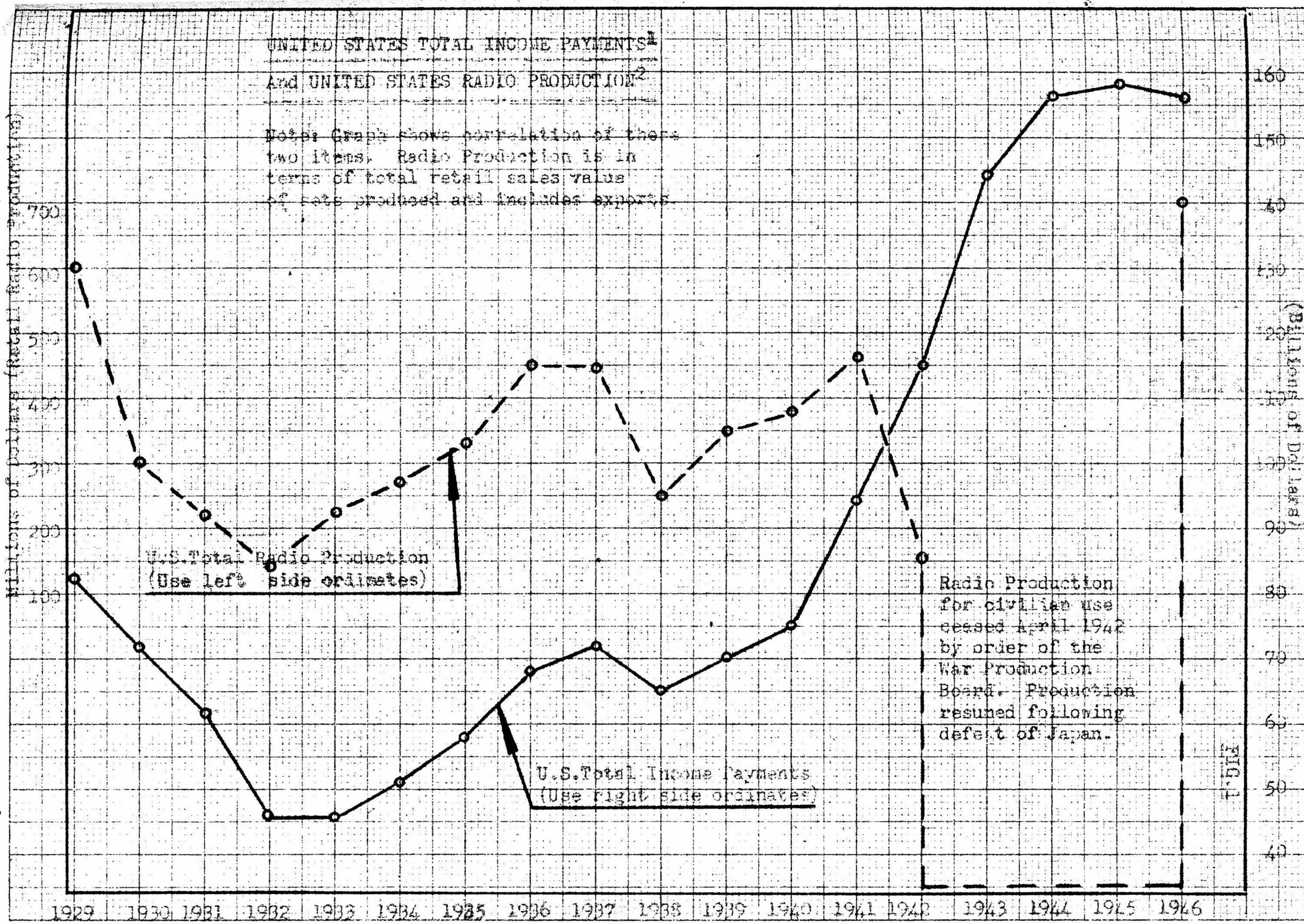
Furniture Store Radio Sales

State	No. of Stores	Postwar Sales in Dollars
Montana	76	$ 405,000
Colorado	176	540,000
Wyoming	46	135,000
New Mexico	78	135,000
Arizona	79	405,000
Utah	81	540,000
Nevada	16	not available
Washington	294	1,755,000
Oregon	182	1,080,000
California	1,413	7,560,000

Department Store Radio Sales

State	No. of Stores	Postwar Sales in Dollars
Montana	45	460,000
Colorado	56	805,000
Wyoming	15	1,035,000
New Mexico	24	1,955,000
Arizona	29	4,025,000
Utah	36	690,000
Nevada	9	805,000
Washington	88	3,220,000
Oregon	56	2,185,000
California	284	2,875,000

Note: These figures are part of the results of the Radio and Television Survey published in 1946, which was made by the magazine Home Furnishings. Although they were not directly mentioned in the results of the Market Research they are included since it is felt that the breakdowns indicated are valuable to manufacturers distributing in these areas.



Source: 1. U.S. Dept. of Commerce 2. Radio Today, Compiled for 1943 Broadcasting Yearbook

R A D I O S A T U R A T I O N
January 1947

States	Total families	% Radio Owners	Radio Families
Mountain States	1,211,000	88.9	1,077,000
Montana	148,400	92.3	137,000
Idaho	141,700	92.4	131,000
Wyoming	73,100	91.4	66,800
Colorado	332,100	91.4	303,600
New Mexico	133,400	73.5	98,000
Arizona	169,800	82.4	139,900
Utah	166,700	95.9	159,800
Nevada	45,800	89.3	40,900
Pacific States	3,863,000	95.5	3,689,000
Washington	667,000	94.5	630,000
Oregon	412,000	93.7	386,000
California	2,784,000	96.0	2,673,000
U.S. TOTAL FIGURES	37,600,000	90.4	33,998,000

The above figures are broken down in subtotals for Urban, Rural-Nonfarm and Rural-Farm as follows:

Mountain States			
Urban	606,000	93.9	569,000
Rural-Nonfarm	362,000	85.6	310,000
Rural-Farm	243,000	81.5	198,000
Pacific States			
Urban	2,711,000	96.9	2,628,000
Rural-Nonfarm	787,000	92.9	731,000
Rural-Farm	365,000	90.4	330,000
U.S. Total			
Urban	23,748,000	95.2	22,597,000
Rural-Nonfarm	7,733,000	87.4	6,586,000
Rural-Farm	6,319,000	76.2	4,815,000

Source: Radio Families USA 1946, published by Broadcast Measurement Bureau, Inc., New York, New York

HOW THE MARKET IS DIVIDED
January 1947

	Residential and Rural Electric Customers	Percentage of U.S. Total
Mountain States	927,349	2.99
Montana	111,654	.36
Idaho	130,263	.42
Wyoming	49,624	.16
Colorado	263,628	.85
New Mexico	77,538	.25
Arizona	114,755	.37
Utah	148,872	.48
Nevada	31,015	.10
Pacific States	3,293,793	10.62
Washington	558,270	1.80
Oregon	331,860	1.07
California	2,403,663	7.75

Note: These figures show the relative importance of the Mountain States and the Pacific States, as compared to each other and as compared to the United States as a whole, as a potential radio market. The importance of the single state California in this market is of particular interest to manufacturers in this area.

Source: Market Analysis Dept. of the magazine Electrical Merchandising. Figures compiled by the Edison Electric Institute and the National Electrical Manufacturers' Association.

R A D I O S A L E S H I S T O R Y

Retail sales

Year	Number of Radios Sold	Retail Value
1929	4,428,000	$600,000,000
1930	3,827,800	300,000,000
1931	3,420,000	225,000,000
1932	3,000,000	140,000,000
1933	3,806,000	230,099,000
1934	4,084,000	270,000,000
1935	6,026,800	330,192,000
1936	8,248,000	450,000,000
1937	8,064,000	450,000,000
1938	7,100,000	250,000,000
1939	10,538,000	355,000,000
1940	11,150,000	380,000,000
1941	13,100,000	460,000,000
1942*	4,400,000	154,000,000
1943	---------	-----------
1944	---------	-----------
1945	---------	-----------
1946	14,031,000	701,000,000

Note: It is of interest to note the fluctuations in the radios sold each year compared to the U.S. Total Income Payments compiled by the Department of Commerce. The graph on page 7 shows the extreme close relationship between radio sales and U.S. Total Income Payments.

*Civilian production of radios terminated April 22, 1942 by order of the War Production Board.

All figures above are at retail value. The figures for the years 1935-1942 include the value of the tubes in the receivers. Totals shown include exports to other countries.

Source: Compiled for the 1943 Broadcasting Yearbook by Radio Today. The figures for 1946 are from Electrical Merchandising, January 1, 1947. They are compiled from sales records of association executives and leading manufacturers.

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C O N S U M E R   R E S E A R C H   S U M M A R Y

OBJECT OF RESEARCH

To find out what the public desires and what the public will buy in the radio market of 1947.

PROCEDURE

Extensive reading was done in current periodicals pertaining to the radio field. Requests were sent to the companies that had made radio surveys recently to obtain more direct information. A check was made of the leading department stores and radio stores in the Los Angeles area to ascertain opinion in this area and to check the findings of the national surveys. The response of movie audiences to various types of interiors was noted.

RESULTS

1. A console model that does not have a phonograph has practically no market.

2. Frequency Modulation or provision for its addition to the set is a very important feature and should be emphasized particularly in the larger models whose output and fidelity warrant its use.

3. Short Wave is a feature which helps to sell radios even though it is little used.

4. Push button tuning in general is unsatisfactory since too much adjustment and servicing is required.

5. In consoles a split top or a top which opens up is very undesirable due to the inconvenience occasioned when a vase or picture must be moved every time the set is used.

6. Tone, reception (sensitivity, clarity) and cabinet styling are the most important factors in deciding the purchase of a home radio in the order given. (The intelligence of this choice gives some refutation to the generally held conception that the public consists only of morons.)

RESULTS (continued)

7. Known brands of radios sell best, However, among the well known nationally advertised makes there is little brand loyalty. That is, persons buying radios seldom insist upon buying the same make that they own or previously owned.

DISCUSSION OF RESULTS

On the following pages are the sources from which the results are derived. In interpeting these results it should be constantly borne in mind that the results of any survey are based upon what people say as opposed to what they do. Therefore, complete reliance should not be placed upon statistical surveys of the public's opinion. The results should be considered more from the standpoint of indicating a trend.

It will be noted that brand name is extremely important in radio sales. When nationally advertised brands are available it is very difficult to sell lesser known brands. Therefore new names in the field should stimulate sales by:

1. Giving a better radio for the same price as nationally known brands.
2. Advertise intensively in the areas in which they distribute.
3. Design a radio which from appearance, servicing and ease of use standpoint is superior to nationally advertised makes. In conjunction with this a regional sales feature such as local stations marked on the dial would be a sales stimulant.

The reason for checking the response of movie audiences to various types of interiors is that the movie industry receives a constant flood of mail indicating audience reaction to the interiors in the movies shown. It has been found that interiors with many earmarks of familiarity (such as modified colonial style) combined with modern features such as large windows and fireplaces and simple furniture are the most popular. This reaction is an excellent means of cataloguing public taste. This means that the public is gradually being won over to greater simplicity in design. This is turn means that the potential market for radios of simple functional design will become increasingly important.

Note: For further details of the consumer research work please turn to the pages following this.

R E S U L T S O F S P O T C H E C K S U R V E Y

PROCEDURE

Survey was made by personal interviews with sales managers and sales personnel in the radio departments of five major department stores in the Los Angeles area and five major radio stores in the same area.

RESULTS

1. (Question) Of the radios you sell what brand and what price in that brand do you prefer to sell the most?

60% preferred Magnavox selling at $250 to $400

40% preferred other brands

Comments: Great preference expressed for Magnavox was due mainly to excellent cabinet work, tone and styling of the Magnavox. Preferences for other brands was inconclusive. This question was asked to determine indirectly what people desire in a new radio and further to determine the dealers point of view with regard to the currently available sets.

2. (Question) In your opinion who is most important in buying or directing the decision to buy a radio, men or women?

90% said women were most important

10% didn't know

Comments: This is strong corroboration for the importance of paying attention to the desires of the women in the home in designing radios.

3. (Question) What features in order of preference are most desired in radios by women? by men?

Women
1. Styling (like furniture)
2. Tone
3. Ease of use

Men
1. Gadgets
2. Tone
3. Styling (appearance)

Comments: Overwhelming opinion of sales personnel was that women like furniture styling in their radios that will conform somewhat to their other furnishings. Hidden knobs and grilles were also preferred by women. Although price was not listed it was the opinion of those interviewed that in 1947 price would become of prime importance.

RESULTS (continued)

4. (Question) What materials are most preferred in radio cabinets in order of preference?

First choice	Wood
Second choice	Plastics
Third choice	Metal

Comments: Wood was first choice of all those interviewed because of its tonal qualities, tactile qualities and relative infrangibility. Plastic cabinets were disliked since once cracked a whole new cabinet was necessary. Also plastics connote cheapness and the tonal qualities in plastic sets were described as "tinny". Metal too was indesirable tonally.

5. (Question) What are the most popular colors in the radio sets you sell?

Wood	First choice	Mahogany
	Second choice	Walnut
	Third choice	Blonde
Plastics		
	First choice	Ivory
	Second choice	Brown
	Third choice	Black

Comments: It is of interest that even in Southern California which is noted for its advanced ideas the old standby Mahogany still ranks first. Ivory, a cream white is much preferred in comparison to dead white which looks lifeless.

6. (Question) Is there any trouble brought on in your store by problems of shipping and storage?

Comments: Majority of persons interviewed were satisfied with shipping and storage of their sets. One large department store sales manager expressed opinion that crates strong enough to be piled one on top of the other would help his storage problem. On the other hand sets too well packed were mentioned as too expensive to unpack.

Unsolicited comments of interest made by sales personnel:

1. Stromberg-Carlson 112PF console (34" high, 35" wide and 17" deep) was considered by one major department store an excellent standard console combining features everyone was looking for. It had dials hidden by door, automatic record changer that pulls out from cabinet, record cabinet, top that does not open up and is not split into two parts.

RESULTS (continued)

2. Four of the dealers interviewed felt that higher wattage output would be desirable in the radios they sold since standard test of customers seems to be to turn radio on full blast momentarily to see how it sounds. If set doesn't vibrate and the sound doesn't seem too distorted it's considered a good set.
Note: It should be mentioned at this point that the most effective way of increasing the cost of a radio chassis is to increase the wattage output it is capable of delivering.

3. Three of the persons interviewed expressed opinion that a record cabinet as optional equipment in matching style to the radio set is a very desirable selling feature.

O W N E R S H I P O F R A D I O S

Radio ownership by type	All families in U.S.	West (Mt. and Pacific States)
Without Phonograph	86.6%	83.4%
With Phonograph	19.6%	20.6%

Families planning to buy radios		
Without Phonograph	14.4%	12.5%
With Phonograph	14.5%	19.0%

RADIO WITH PHONOGRAPH

Time of Action	All families in U.S. Planning this Purchase	West
Within two years after item available	60.4%	53.2%
Within two years after war	3.5%	2.5%
More than two years	16.7%	25.3%
Indefinite(didn't know)	19.4%	19.0%
	100.0%	100.0%

Estimated Expenditure		
Less than $50	1.1%	0.0%
$50-99	11.9%	15.0%
100-149	14.9%	15.0%
150-199	14.6%	12.5%
200-299	16.7%	12.5%
300 and over	8.6%	11.2%
Don't know	32.2%	33.8%
	100.0%	100.0%
Median Price	$170.	$163.

RADIO WITHOUT PHONOGRAPH

Time of Action	All families in U.S. Planning this Purchase	West
Within two years after item available	60.3%	65.4%
Within two years after war	4.7%	6.1%
More than two years	10.7%	14.2%
Indefinite(don't know)	24.3%	14.3%
	100.0%	100.0%

RADIO WITHOUT PHONOGRAPH (continued)

Estimated Expenditure	All families in U.S. Planning this Purchase	West
Less than $25	5.2%	7.8%
$25-49	6.9%	3.9%
$50-74	15.0%	17.3%
$75-99	7.5%	3.9%
$100-149	17.2%	17.3%
$150 and over	13.2%	17.2%
Don't know	35.0%	32.6%
	100.0%	100.0%
Median Price	$93.	$103.

In reviewing these figures it will be noted that the median price for families planning to buy radios without phonographs and for families planning to buy radios with phonographs is very high. This is an indication of the optimism with which people announce plans to buy when the sale isn't immediate. This survey was made in 1944 when the possibility of buying a radio was remote and when incomes in general were inflated. A review of the average prices paid for radios in the past shows great divergence from these figures; a divergence much greater than would be expected by the difference between median and average methods.

Source: Research Department, The Curtis Publishing Company, Urban Housing Survey, November 1946. Survey weighted to families having incomes of $1500 to $5000. Approximately 70% of the interviews were made to families in this income spacing.

CONSUMER SURVEY

(This survey was made by the Sylvania Electric Products Company in 1945. It was made nationally by personal interviews to persons in a carefully selected cross section of the buying public.)

RESULTS

1. How much shopping does a buyer do when he buys a new radio?
   - 70.9% bought in first store
   - 15.8% shopped in two or more stores
   - 6.6% received as a gift
   - 4.2% bought second hand
   - 2.5% bought from miscellaneous sources

2. Brand loyalty
   - 15.4% purchased same brand as previous set
   - 84.6% bought brand that was different from previous set

   Of the families with three radios in their homes:
   - 5.8% had all the same brand
   - 31.2% two radios of the same brand
   - 63.0% had each radio of a different brand

3. Desirability of short wave
   - 52.0% of persons questioned had short wave in their radio sets

   Of those who have short wave:
   - 9.9% use it frequently
   - 16.9% use it occasionally
   - 73.2% use it seldom or never

   Note: On a recheck of those who have short wave it was found that the majority of people who now have short wave want it despite the fact that they don't use it.

4. Push-button tuning
   - 31% of those interviewed have it
   - 22% of those who have it report that it is unsatisfactory

5. Frequency Modulation
   - 91.3% say they will want F.M. when they buy a new set
   - 70.1% of those who want F.M. are willing to pay $5.00 extra for it.

   Note: The mere addition of Frequency Modulation circuits to a radio set means little unless the audio amplifiers and the loud-

RESULTS (continued)

speaker are improved to such an extent that they can reproduce the added fidelity afforded by F.M. reception. Therefore an additional $5.00 means little. It is not enough to cover the cost of improving the rest of the radio set.

Source: Communication from the Sylvania Electric Products Corp. 500 Fifth Avenue, New York 18, New York.

C O N S U M E R S U R V E Y

(This survey was made by the McCann-Erickson Advertising Agency for Stromberg-Carlson Radio Corp.)

RESULTS

1. 45% of those interviewed planned to buy a radio-phonograph combination

2. 27% expected to buy table models

3. 15% wanted radio consoles
   Note: Company expects this to be pared down since in actual practice it has been found that buyers paying price of console want phonograph included.

4. Portables are likely to provide strenuous competition to table models as secondary home radios.

Prices

1. 30% of those interviewed expected to pay more than $150 for model of their choice.

2. 35% expected to pay $75-$150

3. 35% expected to pay less than $75

4. 2% of those interviewed owned Stromberg-Carlson radios but 6% expressed preference for it due to advertising and quality reputation of the company.

NEW COMPANY POLICY

1. New nationwide distributorship set-up of 6000 incorporated as opposed to the prewar twenty state distributorship of 2000 dealers.

2. New emphasis on lower priced models. Five sets will now be sold at prices ranging from $32.50 to $60.00 with next set at $120. Prewar price scale was one set at $25, one at $35 and next set at $150. Top price now is $750.

Source: Magazine Business Week, September 7, 1946

This survey is included specifically since it shows the direction one major company is taking. It is of interest to check the prices people will pay for radios as compared to the prices mentioned by the survey of the Crowell Publishing Company.

CONSUMER SURVEY

(This survey was made by the Electronic Corp. of America. The results are based on returns from a questionaire directed at 3000 recent* small set buyers.)

RESULTS

1. Majority of persons questioned did not feel that small set was the ultimate set they would buy.
Note: Electronic Corp. of America feels this presages growth in larger more expensive set business. However, this investigator feels that this isn't necessarily the case since almost any person buying a radio would prefer to buy a larger and better one, but cannot for reasons of price.

2. 900 of the 3000 questioned indicated intention of buying another small set within a year for another room in the house.

3. 1800 of those questioned did not consider their table model set their ultimate buy for the next two years.

4. The small sets were bought for the most part for rooms other than the living room.

5. Less than 100 of the persons questioned expressed any intention of buying a television set at the present time.

6. Frequency Modulation was desired by 32% of the persons questioned for their large living room sets.

*Note: Survey was made in 1946.

Source: The magazine Electrical Merchandising, December 15, 1946.

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II ENGINEERING RESEARCH SECTION

THE ACOUSTIC PROBLEM

The faithful reproduction of music and speech by a radio is a question of integrating many variables in a judicious way. The most important factors controlling the sound which is eventually heard from amplitude modulated wave forms* are the following:

1. The fidelity of the microphone and the transmitting circuits of the broadcasting station. In general the fidelity of the frequencies broadcast is high.
2. The band spread of the radio station. In the broadcast band of 550 to 1550 kilocycles the band spread allotted to each radio station is (with certain exceptions) 10 kilocycles. Thus, as has been shown by Fourier, any modulation about the median radio frequency of the station greater than 5 kilocycles will interfere with the radio stations which are 10 kilocycles above and 10 kilocycles below the station in question. In order to give a margin of safety to this limitation the Federal Communications Commission has specified that broadcasting station may not

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*Amplitude modulated wave forms are mentioned as distinct from frequency modulated waves since in the latter case there is no reason for imperfectly transmitted audio modulation due to station overlap. On frequency modulation the Federal Communications Commission has provided a band spread wide enough to cover the entire audio spectrum.

modulate their radio frequencies more than 4.9 kilocycles. With express permission of the F.C.C. a modulation of 7.5 kilocycles is sometimes permitted but this is the exception not the rule.

The point of this is that 4.9 kilocycles is approximately one third of the audio spectrum. Thus automatically two thirds of the range of sounds the ear is capable of hearing are cut off. In practical terms this means that most of the overtones that give distinctness to musical instruments will be cut out and that the overtones in the human voice that give each voice its particular quality are cut out to a large extent. However, despite this great handicap the fact that the one third of the audio spectrum that is broadcast lies in the region where most of the energy of music and the human voice is concentrated makes it possible to have reasonably faithful radio reception.

3. Atmospheric conditions caused by sun spots and lightning. The phenomenon known as "fading" is mainly due to the disturbances in the ionosphere which it is believed are caused by sunspots. Lightning of course results in severe static for stations in the broadcast band. Frequency modulation reception is not effected by atmospheric static of this type.

Manmade conditions such as power stations nearby, X-ray machines diathermy machines, electric motors and fluorescent lamps turning on cause disturbance to radio reception.

4. The radio receiver is the next source of distortion. It is possible to achieve nearly linear amplification in modern radio sets. However, this is an expensive achievement and is seldom attained even on costly sets. On cheaper sets the main reason for distortion is cheap intermediate frequency coils and output transformer. The I.F. coils on these sets are usually undercoupled. This obviates precise adjustment. Furthermore they have the unfortunate tendency of "peaking" at close to three thousand cycles. This of course tends to distort and overemphasize frequencies in that part of the audio spectrum. The output transformer of the smaller radio sets is invariably too small. This means that its inductance is too small since inductance is a direct function of the number of turns. This in turn causes further distortion*.

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*Note: The plate current of the final audio amplifier usually passes through the primary of the output transformer polarizing the iron stampings of the transformer; this reduces the magnetic permeability which in effect reduces the inductance of the transformer. This means that the bass register will be reduced if the transformer is not large enough. The reason for this is that inductive reactance is directly proportional to frequency.

5. The loudspeaker and cabinet in which it is enclosed is most important to faithful reproduction of sound. It will be treated separately on pages following.
6. The room in which the set is played has an important bearing on the quality of the sound heard. The reverberation period* of the room can be so long that speech will sound garbled and music will sound fine. On the other hand if the reverberation period is too short speech will sound clear and crisp but music will sound "tinny". A further effect of the room on sound is that different materials have different coefficients of absorption.# This means that almost every room will have different characteristics not only in reverberation period but in the absorption and reflection of different frequencies. A good example of this is the

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*Note: The reverberation period of a room has been arbitrarily defined by Sabine as the time for the energy density in a room to fall to the minimum audible value from an initial value 10^6 times as great, i.e. a range of 60 decibels. For small rooms of medium absorption the reverberation period is:

$$T = .050 \frac{V}{A}$$ where T is time in seconds
V is volume in cubic feet
A is total absorption in Sabins.

#Note: Materials have different average coefficients of absorption between each other and also each material has different coefficients of absorption for different frequencies.

contrast always found between singing in the shower and singing in the living room. In the former case the tile walls absorb very little sound so there is a build up of intensity which gives the person singing a false sense of his vocal abilities. In the living room on the other hand, where there is greater volume and where there are many absorbing materials this is not the case. The extreme example of absorption is found in the anechoic sound chambers of Harvard, UCLA and other institiutions. In these chambers you literally can hardly hear yourself talk.

7. The human ear itself is a source of sound distortion. As will be shown its characteristic at low intensity levels is to cut off low frequencies and high frequencies accentuating the middle range of 3000 - 5000 cycles where it is most sensitive.

It should be mentioned that despite all these handicaps to fidelity it is possible with frequency modulation system and with powerful narrow band spread speakers properly located in a large acoustically treated room to hear a symphony with greater fidelity than the person sitting in the concert hall.

This brief summary of the major factors involved in distortion of sound shows the great complexity of achieving faithful reproduction and the consequent difficulties when cost and size of equipment are added limiting factors.

After making a careful survey of the problems involved it was determined that a definite advance could be made in improving the acoustic qualities of a radio set through careful design of the loudspeaker chamber. This has been done on large sets with some success. However, on smaller sets it was found that little had been attempted or attained. It was thus decided work on a smaller set might prove worthwhile in this respect.

The first step in this work involved the study of loudspeakers themselves. The chapter following gives a review of the work done in this regard.

DISTORTION IN LOUDSPEAKERS

Nonlinear distortion occurs in loudspeakers when there is a nonlinear element in the vibrating system. A description of the most important non-linear elements follows:

1. The outside suspension system of the loudspeaker is a non-linear element in a direct radiator loudspeaker. The stiffness is not constant but is a function of the amplitude; in general increasing with increasing amplitude.[29] This type of distortion may be eliminated by placing the fundamental resonant frequency of the loudspeaker at the lower limit of the reproduction range. Above the fundamental resonant frequency the velocity of the cone is not appreciably affected by the suspension system because the mechanical reactance due to the compliance of the suspension system is small compared to the mechanical impedance of the rest of the system.[30]
2. Inhomogeneity of the flux density through which the cone travels is another souce of distortion. This can be eliminated by making the flux density associated with each turn independent of the amplitude. This requirement can be satisfied by making the voice coil large and slightly longer than the air gap.

3. Another non-linear element is the cone in the region from 100 to 1000 cycles. One effect of this is the production of subhermonics. Since the range from 100 to 200 cycles contains the most power in both speech and music[31] it is very important that distortion be reduced to a minimum in this range. Subharmonics are particularly objectionable since they are noticed by the ear more readilu than are higher harmonics. The reason for this appears to be that it is more difficult to mask a low tone. This means that subharmonics of very low intensity can be easily notived. One means of reducing subharmonic distortion in the low frequencies mentioned is to increase the rigidity of the cone[29]. In experimental work done by RCA it was shown that by increasing the cone thickness two and one half times the rigidity factor was increased fifteen times. This reduced distortion but the added weight of the cone necessitated the use of a heavy voice coil (25 grams). This is about 25 times the mass of the voice coil used in console type radio loudspeakers. It is thus obvious that this method of reducing harmonics is out of the question from a cost standpoint on loudspeakers to be used in low priced radio sets.

4. Distortion of the ordinary overload type is one of the most disturbing types of infidelity.[33] It occurs in small radio sets when speech and music are produced at high levels. Since a relatively small cone is driven through large amplitudes distortion occurs beyond the region in which Hooke's Law applies. Larger speakers are not subject to this trouble so much since they can produce adequate power output without large excursions of the cone.
5. Many small loudspeakers have unstable frequency regions. When a signal passes through these regions extraneous frequencies are produced. These frequencies are manifested as grunting sounds as the loudspeaker jumps from one stable frequency to another.
6. When the dimensions of a loudspeaker cone become comparable to a wave length of sound the system becomes directional. As the wave length becomes shorter, i.e. the frequency goes up the system becomes more directional. At the lower frequencies the directional effects are much less evident. This phenomenon has been explained theoretically by Huyghens and has been proven experimentally. It is difficult to rectify this condition simply by redesign of the cone since the factors controlling the radiation angle are the same as those which experience has shown con-

trol the frequency range.[34] The factors which cause the pattern to be widen intrinsically limit the frequency range. Therefore cones should be designed specifically for the range of frequencies desired or external means should be used to spread the higher frequencies.

Some of the factors which cause distortion in loudspeakers can be reduced in importance by proper design of the mounting of the loudspeaker. Commercially several cabinets have been designed improve speaker response. These commercial types will be briefly discussed on pages following as prologue to the acoustic design that was conceived for the purposes of the design described in this thesis.

T H E   H U M A N   E A R

As the final transducer of wave energy into sound the ear is of fundamental importance in any work involving acoustics. For this reason the most important characteristics of the ear affecting loudspeaking systems were explored.

RESPONSE FREQUENCY CHARACTERISTIC

Equal loudness level curves[35] show an extremely important characteristic of the human ear. Loudness* is a function of frequency and intensity as is shown by these curves. At the threshold of hearing it has been shown experimentally that at 100 cycles a note must be 38 decibels higher than a note of the same loudness at 1000 cycles to be heard.

FREQUENCY AND VOLUME RANGES IN SPEECH AND MUSIC

The reproduction of speech with perfect fidelity requires a frequency range of 100 to 8000 cycles and a volume range of 40 decibels. Orchestral music on the other hand requires a frequency range of 40 to 14,000 cycles and a volume range of 70 decibels. Since the normal ear is sensitive to the frequency range 20 to 15,000 cycles it more

---

*Note: Loudness of a sound is the magitude of the auditory sensation produced by the sound. A loudness scale must be so constructed that when loudness units (phons) are doubled the sensation will be doubled. Up to 8000 cycles the difference in loudness of pure tones is small for the same pressure. Above this frequency loudness decreases as frequency increases.

than fulfills the needs of speech and music. This of course is to be expected. An important limiting factor, however, is the fact that a good radio receiver does not cover a volume range of more than 50 decibels. This means that some form of volume compression must be used. It is also indicative of the need of having the radio turned up to a given volume level in order to hear speech and music faithfully. This brings out the point that it is best to have the loudspeaker at some distance from the ear since the loudness level close to the speaker is higher than that in the rest of the room and is likely to be uncomfortable to the person next to the radio while it is just right for the rest of the people in the room.

AUDITORY LOCALIZATION

The ear can determine the direction from which a sound is coming with great accuracy. A given sound arrives at the two ears at slightly different time intervals producing a difference in phase. This effect plus the effect of the difference in intensity of the sound at the ears (due to diffraction) gives the hearing mechanism its accuracy of localization.[37,38] Below 1000 cycles the difference in intensity due to diffraction is small. At the higher frequencies it becomes increasingly noticable. The characteristic of the ear to be a directional collecting system is a corollary to its localization characteristics. This is important to the radio designer since it means that the ear will tend to discriminate against reverberation and will be most sensitive to direct sounds from the radio speaker. It is therefore important that the speaker have a wide angle of distribution of all frequencies so that listeners in every part of a room can hear as much direct sound as possible.

MASKING

The reduction of the ability of a listener to hear one sound in the presence of another is known as masking. Masking audiograms for single frequency tones[39] show the exact relationship that exists between frequency and masking quality in decibels. These audiograms show that it is always easier to mask a high tone with a low tone than the reverse. This means in practical terms that distortion in the lower frequencies will have a harsher effect on the ear than distortion in the high frequencies since it is more difficult to mask the low frequencies.

NONLINEARITY OF THE EAR

The ear has been shown to be a nonlinear system since when a pure tone of high enough intensity is impressed upon the ear harmonics of the original tone are heard. Furthermore when two loud tones are sounded together a group of tones is heard, These tones consist of sum and difference frequencies and harmonics. This non-linearity infers that the elastic restoring force of the elements of the vibrating system is not proportional to the first power of the displacement. If a second power term is added the element is asymetrical the restoring force being different in magnitude for positive and negative displacements.*

---

*Note: Assume the displacement of the non-linear element may be expressed as follows:

$y = ap + bp^2$ where p equals actuating force
a equals a constant
b equals a constant

Suppose two harmonic forces are impressed upon the system:

$$p_1 = p_o \cos w_1 t \quad \text{and} \quad p_2 = p_o \cos w_2 t$$

Total force on the nonlinear element is:

$$p = p_o \cos w_1 t + p_o \cos w_2 t$$

Substituting this in the original equation:

$$y = ap_o \cos w_1 t + ap_o \cos w_2 t + \tfrac{1}{2} bp_o^2 \cos 2w_1 t + \tfrac{1}{2} bp_o^2 \cos 2w_2 t + bp_o^2 \cos(w_1 + w_2)t + bp_o^2 \cos(w_1 - w_2)t + bp_o^2$$

Six different frequencies will thus be heard by the ear. They are:

$w_1/2\pi$, $w_2/2\pi$ etc.

A C O U S T I C   S Y S T E M S

There have been attempts to improve the sound output of loudspeakers through the design of the cabinet in which they are encased. Some of these have been moderately satisfactory. However, for application to the design discussed in this thesis they were unsatisfactory. The systems studied were the The Magic Voice[40], The Acoustic Line[41], The Acoustical Labyrinth[42], The Compound Horn Loudspeaker[43], The Bass Reflex System[44], The Helmholtz Resonator[45], and The Low Frequency Horn[46]. Since the defects of these systems with respect to the design in question fall into general classifications it is unnecessary to explain each design mentioned. The references indicated will suffice if the reader is interested in detailed study. The main defects of these systems are:

1. They depend upon some form of cabinet resonance.
2. With the exception of the bass reflex system they are not amenable to the small dimensions desired in this thesis design.

The most objectionable loss in fidelity from loudspeakers is due to troubles in the low frequency region. (These troubles are explained elsewhere in this work.) To offset the loss in response which is inherent in the low frequency regions the systems mentioned depend on reinforcement of the sound waves in a given low frequency region below the region where response normally would fall off. However, the disadvantages of this approach are that resonance will be different for each cabinet due to changes in the structure of the cabinet and to inadequate dimensional dependability on the part of wood. This of course means expense to the manufacturer in adjusting each cabinet to respond properly.

Another unfortunate quality of resonant reinforcement is that it occurs over such a narrow frequency band. It thus has a tendency to cause a bump in the response curve. This means that it accentuates some of the low frequency notes but not others. Therefore amplitude distortion occurs.

"hangover" is another undesired quality which frequently occurs in the systems mentioned. This is a tendency of the notes in the resonant region to die out too gradually causing a blurring which is especially noticable in male speech.

Inherently the systems mentioned require loudspeaker chambers of large dimensions. This is true since large volumes are necessary for low frequency air resonance or for simple low frequency reinforcement. Since a loudspeaker chamber of small dimension was desired in this design, this was the final factor in discarding the known acoustic systems.

L O U D S P E A K E R C H A M B E R

In order to overcome the difficulties inherent in the existing loudspeaker chambers it was decided to do two things:

1. Use a completely enclosed chamber for the loudspeaker.
2. Damp the natural resonant frequency of the cone of the loudspeaker.

The reasons for choosing a completely enclosed loudspeaker chamber are the following:

1. It was most important to the design to have a small speaker chamber. The reason for this was economy in manufacture and ease of handling. A small chamber that is open at the back is subject to a variety of defects acoustically. The most important of these is the cancellation effects that occur due to the back wave from the loudspeaker. The back wave is of course 180° out of phase with the front wave. Therefore at specific frequencies, depending on the size of the chamber there will be a wave of sound from the back of the loudspeaker which will be out of phase with the wave from the front of the speaker. This will cause amplitude distortion. On the other hand there will be some frequencies where just the opposite effect will occur, i.e. there will be additive effects which will also cause amplitude distortion. For example in the chamber used the dimensions are approximately 16 inches wide by

10 inches deep by $12\frac{1}{2}$ inches high. Assuming that the back wave travels by the shortest path to the front of the speaker it will travel 32 inches. When 32 inches represent $\frac{1}{2}$ wave length or an odd multiple of $\frac{1}{2}$ wave length of sound there will be additive effects caused by the back wave, which is in phase with the front wave under these conditions. This will cause a certain group of low frequencies to be accentuated. Similarly when 32 inches represent a wave length or an even multiple of a wave length there will be cancellation effects caused by the front wave and the back wave being out of phase. At the low frequencies where these effects are most noticed this means that frequencies in the region of 210 cycles will be overaccentuated and frequencies in the neighborhood of 420 cycles will be underaccentuated. This effect has been verified experimentally by several observers. The result of this open back then on a small loudspeaker chamber is a response frequency curve that has alternate peaks and valleys. This effect is eliminated by the closed back loudspeaker.

2. Another advantage of the closed back loudspeaker is that its low frequency response does not fall off as rapidly as that of an open back loud-

speaker. This is due to the fact that it acts as a simple source whose power output is proportional to the square of the frequency as shown by the follow equation:[32]

$P = 2\pi pck^2A^2$ = Average power in ergs per second

p = density of the medium in grams per cubic centimeter

c = velocity of sound in centimeters per second

k = 2/l

l = wave length in centimeters

$A = \frac{-SE_o}{4\pi}$

S = Area of the surface of the source in square centimeters

E_o = Maximum velocity in centimeters per second over the surface S

On the other hand the open back speaker acts as an acoustic doublet whose power output is proportional to the fourth power of the frequency. The power output of such a source is represented by this equation:[32]

$P = \frac{2}{3}\pi pck^4A^2$ = Average power in ergs per second

As a consequence of this fourth power proportionality the power output of a direct radiator loudspeaker falls off rapidly with frequency when the dimensions of the baffle are small compared to the wavelength.

On the other hand the back enclosed speaker has a power output that is independent of the frequency provided the system is mass controlled*. Thus it can be understood that the response of the back enclosed speaker will be superior to that of the open back. However, one additional point is important. That is the fundamental resonant period of the cone. It must be low enough to take advantage of the properties of the system mentioned. In general for small loudspeakers this is not the case.

3. Another important feature of the completely enclosed case is that the sound coming from it is less dependent on the position of the case in the room than is the sound coming from an open case. The quality of sound coming from an open backed case changes appreciably for instance when it is placed near a corner as compared to a more central location in the room.

It can now be understood that the completely enclosed speaker chamber acts as an infinite baffle; however, it does not, of course, have the bulk of a large baffle or its immobility.

DAMPING THE LOUDSPEAKER

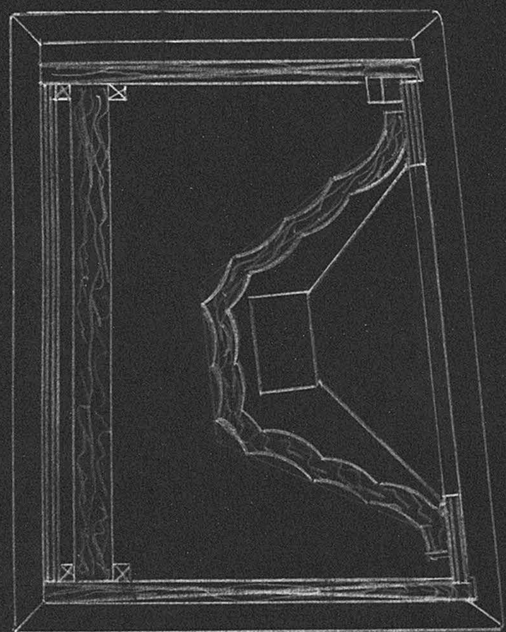
As has been stated previously one of the most annoying forms of distortion that occur in loudspeakers is the

*Note: The system is Mass Controlled if the velocity of the cone is inversely proportional to the frequency.

low frequency boom that occurs due to the large excursions the cone makes at the low frequencies and more precisely to the fact that the natural resonant frequency of small loud speaker cones is usually in the important low frequency region of 100 to 120 cycles. To damp this resonance then is important if the response frequency of the system is expected to be flat in the low frequencies mentioned.

This can be done by acoustical means, namely by placing damping material behind the loudspeaker. If this material is placed in close proximity to the speaker it will be most effective since there the movement of the displaced air is greatest. The determination, however, of the exact thickness and weight of material to use involves so many variables that it is best done empirically.[52] This was done as is mentioned in the test procedure discussion.

In addition to the damping material behind the loudspeaker additional damping material was placed a short distance from the back of the loudspeaker chamber to damp the wave motion which comes through the hemisphere of material behind the loudspeaker cone.



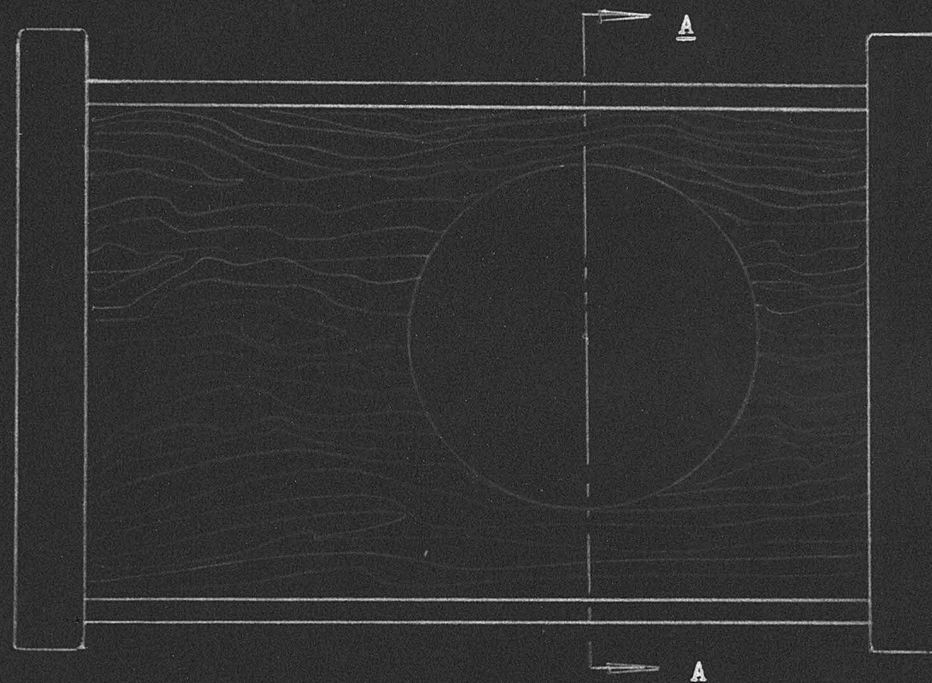
SECTION A ---- A

FIBERGLAS, RESIN IMPREGNATED

WEIGHT .47 POUNDS PER SQ.FT.

ABSORPTION COEFFICENTS

.25	at	128	cycles
.41	at	256	cycles
.86	at	512	cycles
.94	at	1024	cycles
.84	at	2048	cycles
.81	at	4096	cycles



REMOVABLE SPEAKER PANEL 3/8" PLYWOOD
SHOWN WITH SPEAKER CLOTH REMOVED

<u>ACOUSTIC</u> <u>DESIGN</u>

TEST PROCEDURE

The testing of the loudspeaker and the loudspeaker chamber was carried out in three major steps:

1. Response frequency* measurements and directional measurements were made with the loudspeaker mounted in a large baffle.
2. Response frequency measurements and directional measurements were taken with the speaker mounted in the designed chamber with the back and the proposed insulation arrangement removed.
3. Response frequency measurements and directional measurements were taken with the speaker mounted in the chamber with the back of the chamber enclosed and with the insulation arranged as specified in the design.

The work was done on the roof of a building with the test equipment mounted at all times eight feet above the roof. This practically obviated the possibility of reflections from other structures interfering with the true patterns of the loudspeaker output. The response frequency curves plotted are comparable to each other and to the curves of other investigators working under similar test conditions. The curves definitely show the effect of changing one element at a time in the system. The reason for this was of course to determine if the stipulated approach to the problem of damping the low frequency resonant hump of the loudspeaker was correct.

ANALYSIS OF RESULTS

The curves of Figure 2 show the response of the loud

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*Note: The response of a loudspeaker is a measure of the sound produced at a designated point in the medium with the electrical input, frequency and acoustic conditions specified.

speaker mounted in a baffle of dimensions eight feet by eight feet. As mounted under the test conditions mentioned above the true response of the loudspeaker is shown by these curves. It will be noted, as predicted previously (Engineering, Distortion in Loudspeakers), that there is a sharp rise in response at close to 100 cycles per second. Eliminating this rise is one of the major points of the chamber designed.

Figure 2 shows that the loudspeaker tested has a very poor response characteristic compared to absolute atandards of response. The ideal speaker would have a flat response of from 30 to 15,000 cycles. However, this is too much to expect from a speaker of this size and cost.

Figure 3 shows the response of the loudspeaker with the input(.4 volt) applied directly to the voice coil of the loudspeaker. The object of this test was to determine the limiting characteristics of the speaker transformer. A comparison of this curve with the 20 volt input curve of Figure 2 shows that the speaker transformer, when not polarized by the plate current of the final output tube in the radio, does not distort the output appreciably. For this reason and for the reason that the loudspeaker was originally designed to be used with its associated transformer all tests were conducted by applying the constant voltage inputs to the speaker transformer.

Figure 4 shows the response of the loudspeaker when mounted in the chamber designed with the back of the chamber and the proposed insulation arrangement removed. It will be noted that the greater part of the resonant hump of the Figure 2 seems to have disappeared. However, the curves of Figures 8 and 9 show the large volume of back radiation from the chamber under the conditions specified. This back radiation in the ordinary living room would be reflected from the surface toward which the back of the speaker chamber was facing causing a rise very similar to that shown in Figure 2 near 100 cycles. Note also the rise in the curve of Figure 4 at 300 cycles. This is due to the back radiation of the loudspeaker adding to the front radiation. This phenomenon is mentioned in more detail in the discussion of the Loudspeaker Chamber.

Figure 5 shows the response frequency characteristics of the loudspeaker chamber with the back enclosed and with the insulation placed as specified by the design. Note the complete elimination of the hump at 300 cycles. It will be noted that there is still a rise at 800 and 4000 cycles and a sharp dip at 1000 cycles. However, these variances are not as important in speech or music energy distribution as the frequencies corrected. Furthermore, they are best corrected electronically not mechanically.

A study of Figures 6 through 11 shows the tendency of the high frequencies to form a beam of energy rather than a uniform spread. As has been mentioned (see Distortion in Loudspeakers) this is a result of the inherent efficiency considerations in loudspeaker design and is not to be considered a fault unique in this particular speaker. For further discussion of this beaming tendency of loudspeakers and its elimination see Direction of Future Research.

CONCLUSION TO TEST PROCEDURE

In the time available for this work it would be foolish to claim that all the wrinkles of the system had been worked out. However, the curves show the great improvement in response which occurs when using the system designed in this work. It is recognized that the true test of a loudspeaker is not a matter of graphs; it is a matter of listening. However, the human ear is too insensitive to recognize small improvements which indicate a direction of approach. Thus instrumentation is necessary.

Please turn to the pages following (Figures 2 through 11) for a graphic review of the results of the test work.

ACKNOWLEDGEMENT

In carrying out the testing procedure great assistance was rendered by Earle R. Bunker and Jack H. Slaton, graduate students in Electrical Engineering at the California Institute of Technology. W. H. Pickering,Ph.D., Associate Professor of Electrical Engineering at the California Institute of Technology was extremely helpful in procuring the necessary equipment for the tests and in making suggestions for the most effective test procedure.

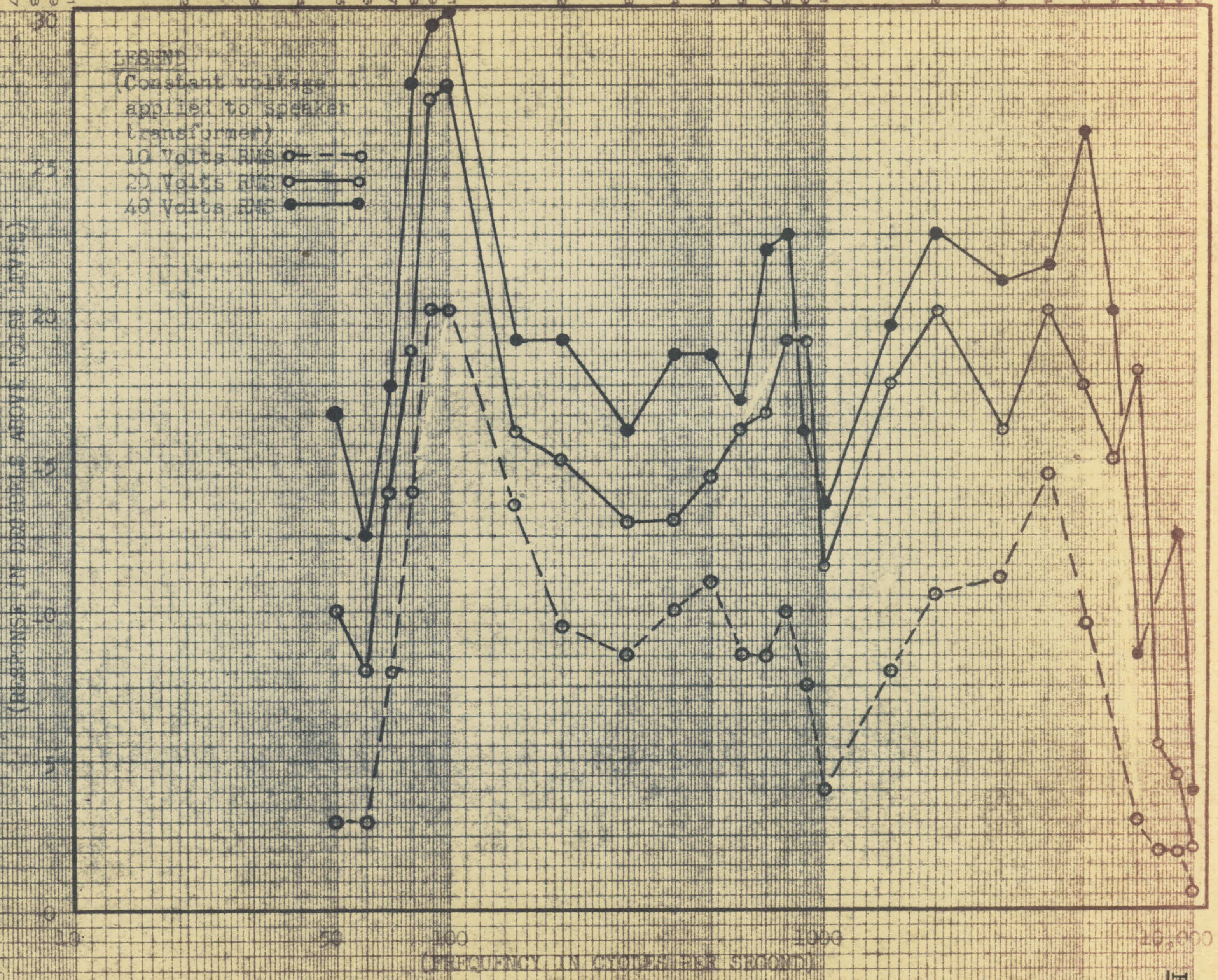


FIG. 2

RESPONSE FREQUENCY CHARACTERISTICS

Note: Eight inch loudspeaker tested in a baffle eight feet by eight feet. Loudspeaker used on all tests shown on this and the graphs following was Model 8ES1, The Rola Company Inc. Cleveland, Ohio.

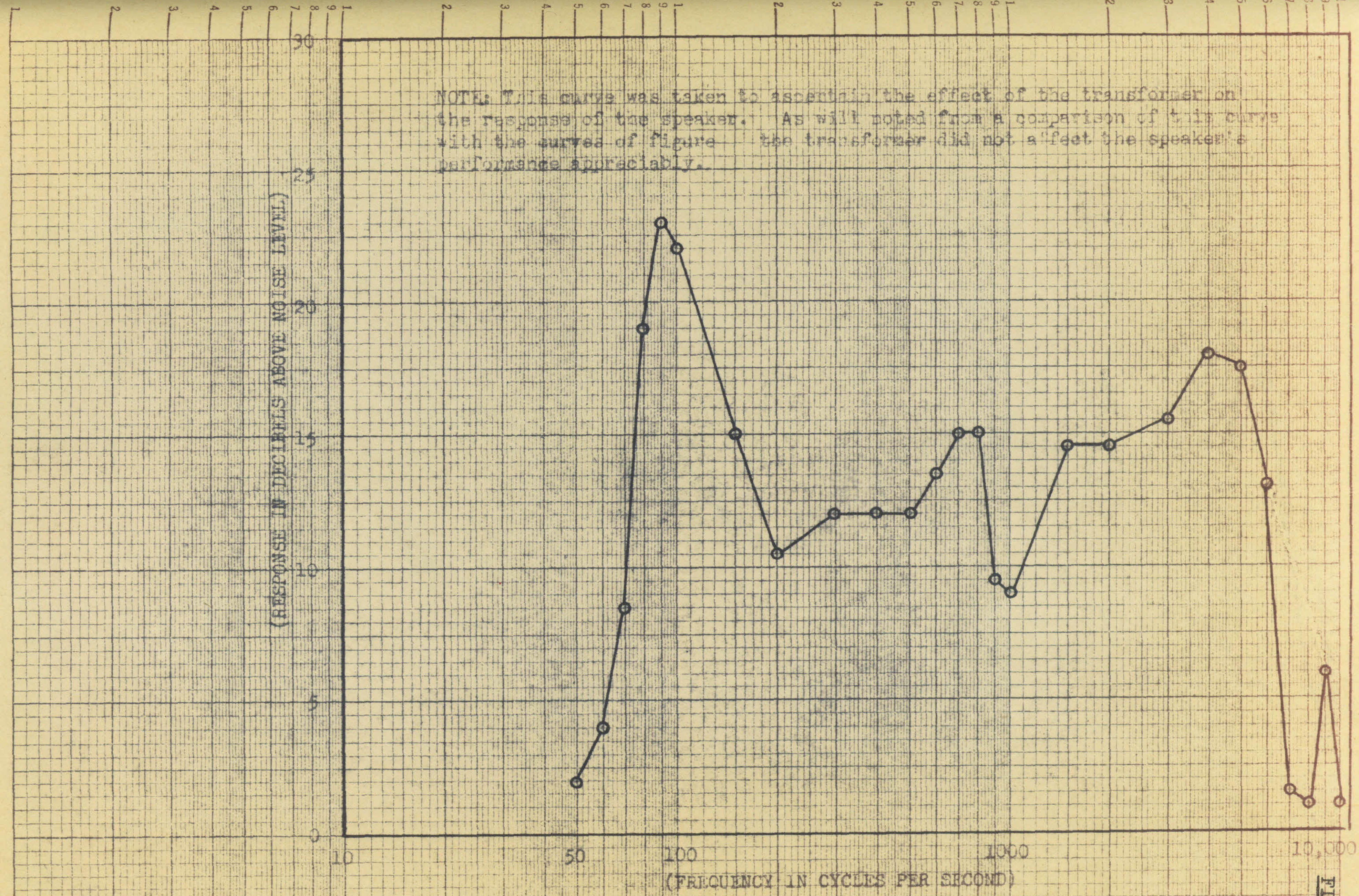


FIG.3

RESPONSE FREQUENCY CHARACTERISTIC*

*Note: Eight inch loudspeaker tested in a baffle eight feet by eight feet. .4 Volts applied to speaker voice coil. This should be similar to graph showing 20 volts input to the speaker transformer.

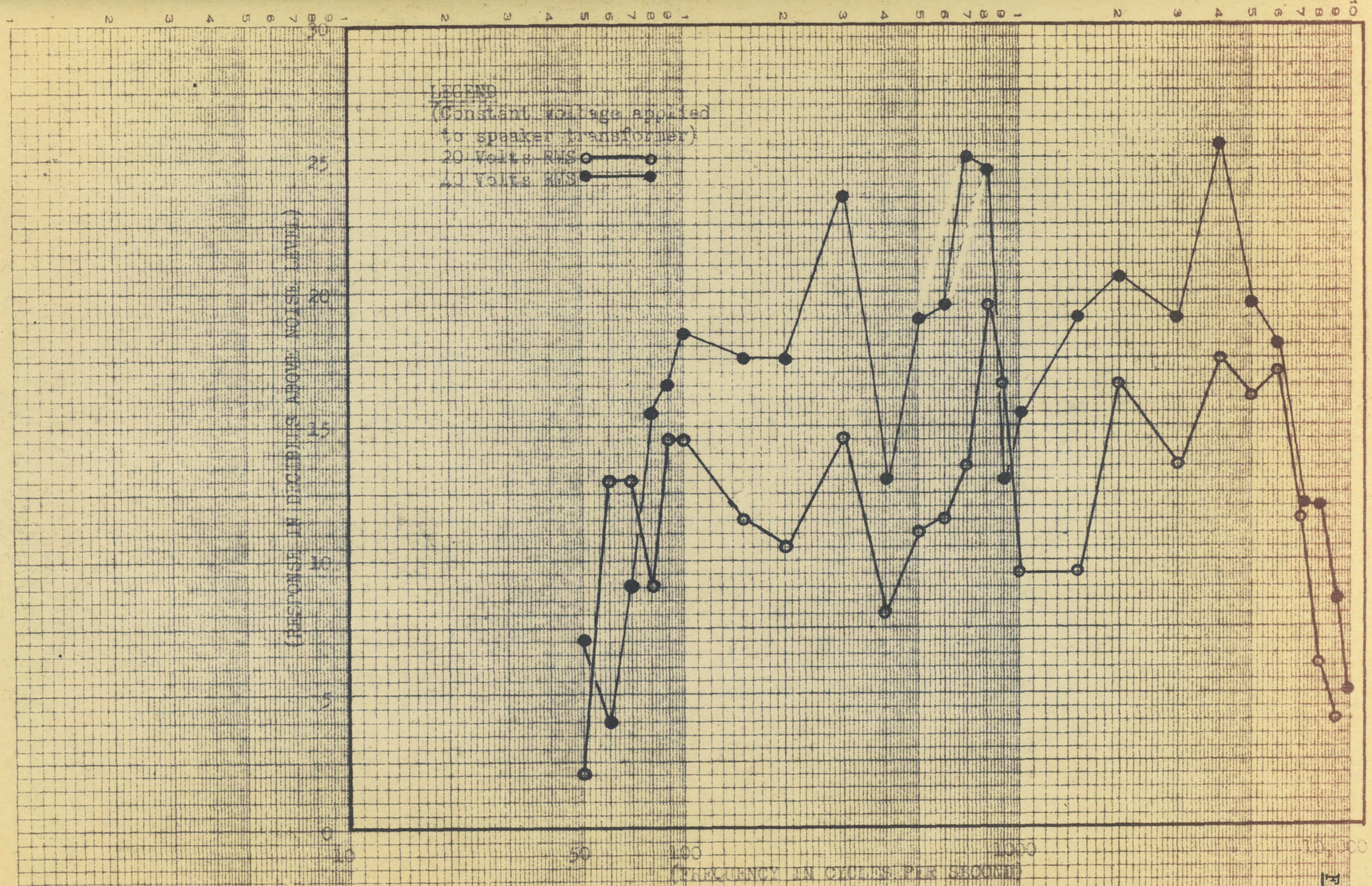


FIG. 4

RESPONSE FREQUENCY CHARACTERISTICS

Note: Eight inch speaker tested in speaker chamber used for the curves of Figure . However, these curves show output of chamber without back and without interior insulation.

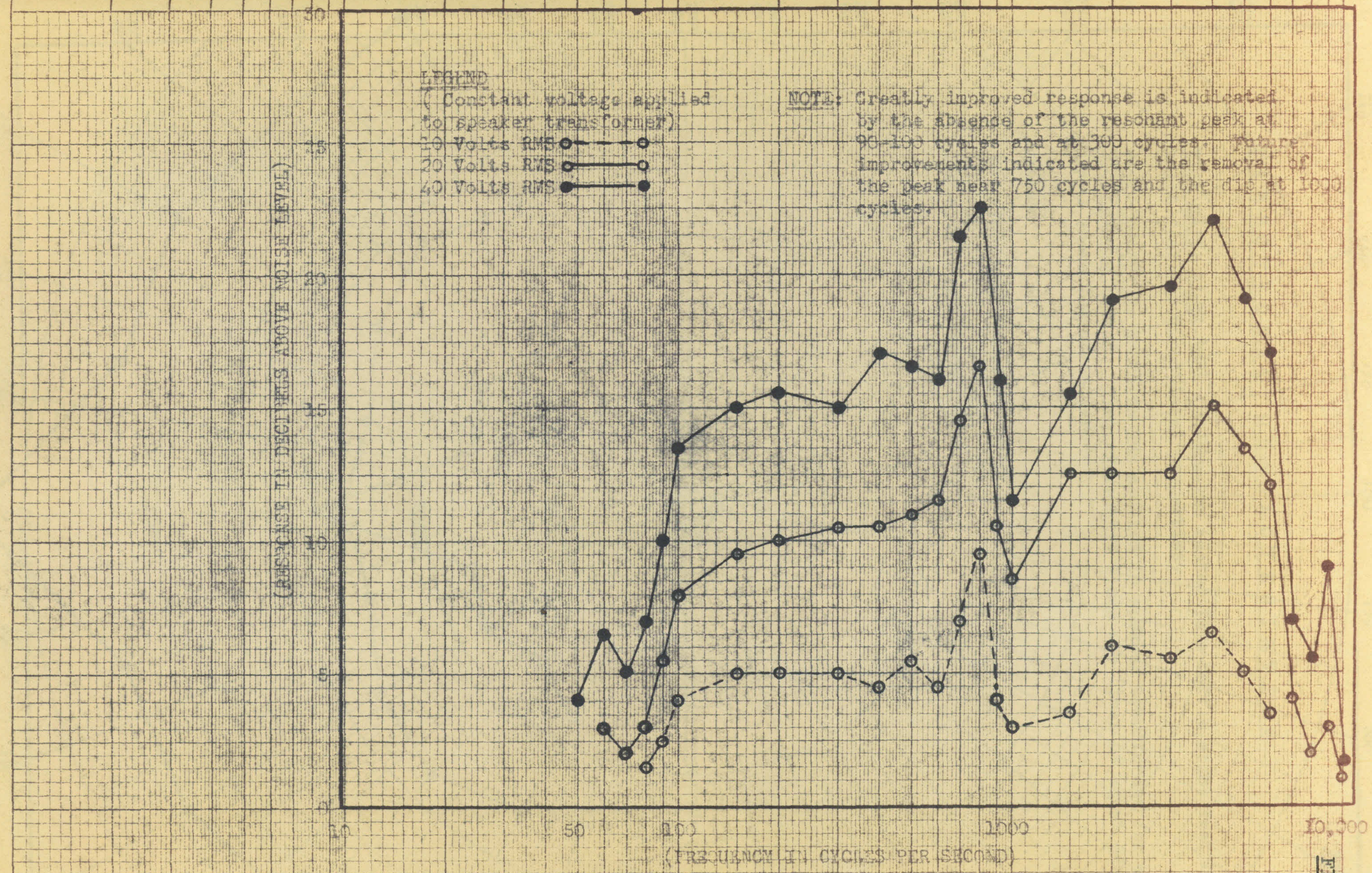


FIG.5

RESPONSE FREQUENCY CHARACTERISTICS

Note: Eight inch speaker tested in specially designed speaker chamber. The most important aim of the design is to eliminate the resonant hump of the loudspeaker, which for this speaker occurs between 90-100 cycles.

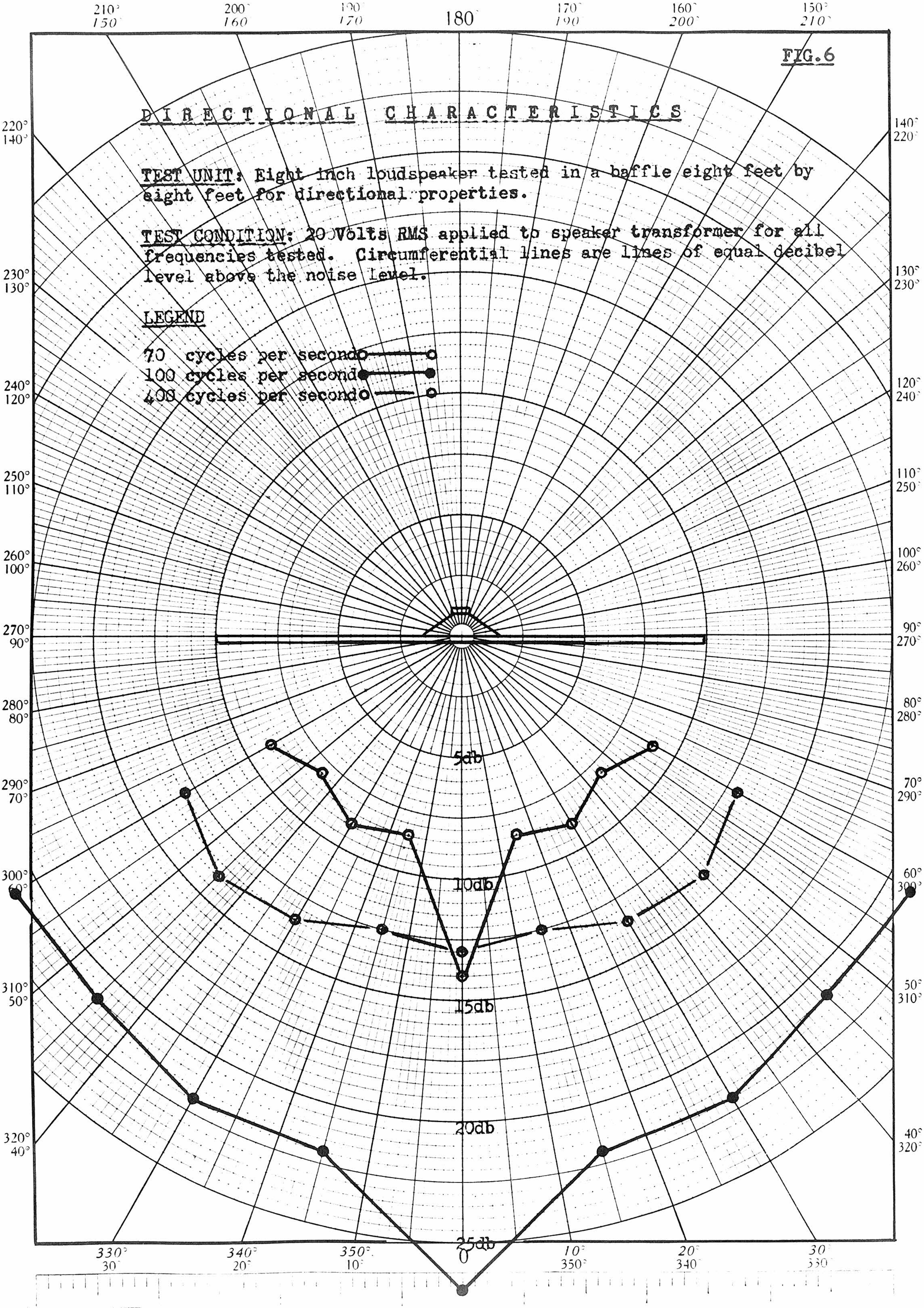
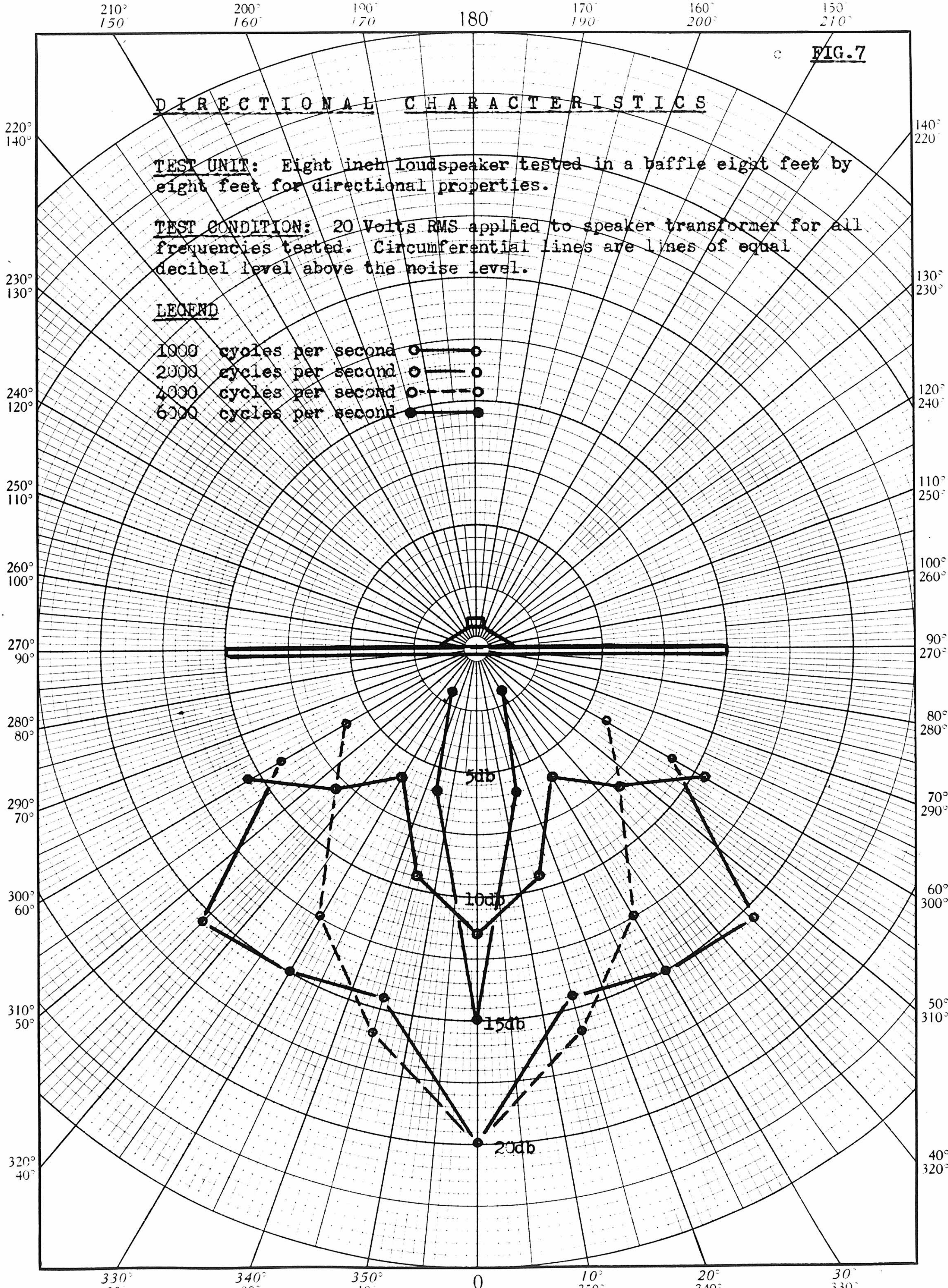


FIG.6
DIRECTIONAL CHARACTERISTICS
TEST UNIT: Eight inch loudspeaker tested in a baffle eight feet by eight feet for directional properties.
TEST CONDITION: 20 Volts RMS applied to speaker transformer for all frequencies tested. Circumferential lines are lines of equal decibel level above the noise level.
LEGEND
70 cycles per second
100 cycles per second
400 cycles per second
5db
10db
15db
20db
25db
180°
0
210° 150°
200° 160°
190° 170°
170° 190°
160° 200°
150° 210°
220° 140°
230° 130°
240° 120°
250° 110°
260° 100°
270° 90°
280° 80°
290° 70°
300° 60°
310° 50°
320° 40°
140° 220°
130° 230°
120° 240°
110° 250°
100° 260°
90° 270°
80° 280°
70° 290°
60° 300°
50° 310°
40° 320°
330° 30°
340° 20°
350° 10°
10° 350°
20° 340°
30° 330°

FIG.7


DIRECTIONAL CHARACTERISTICS
TEST UNIT: Eight inch loudspeaker tested in a baffle eight feet by eight feet for directional properties.
TEST CONDITION: 20 Volts RMS applied to speaker transformer for all frequencies tested. Circumferential lines are lines of equal decibel level above the noise level.
LEGEND
1000 cycles per second
2000 cycles per second
4000 cycles per second
6000 cycles per second
5db
10db
15db
20db
180
0

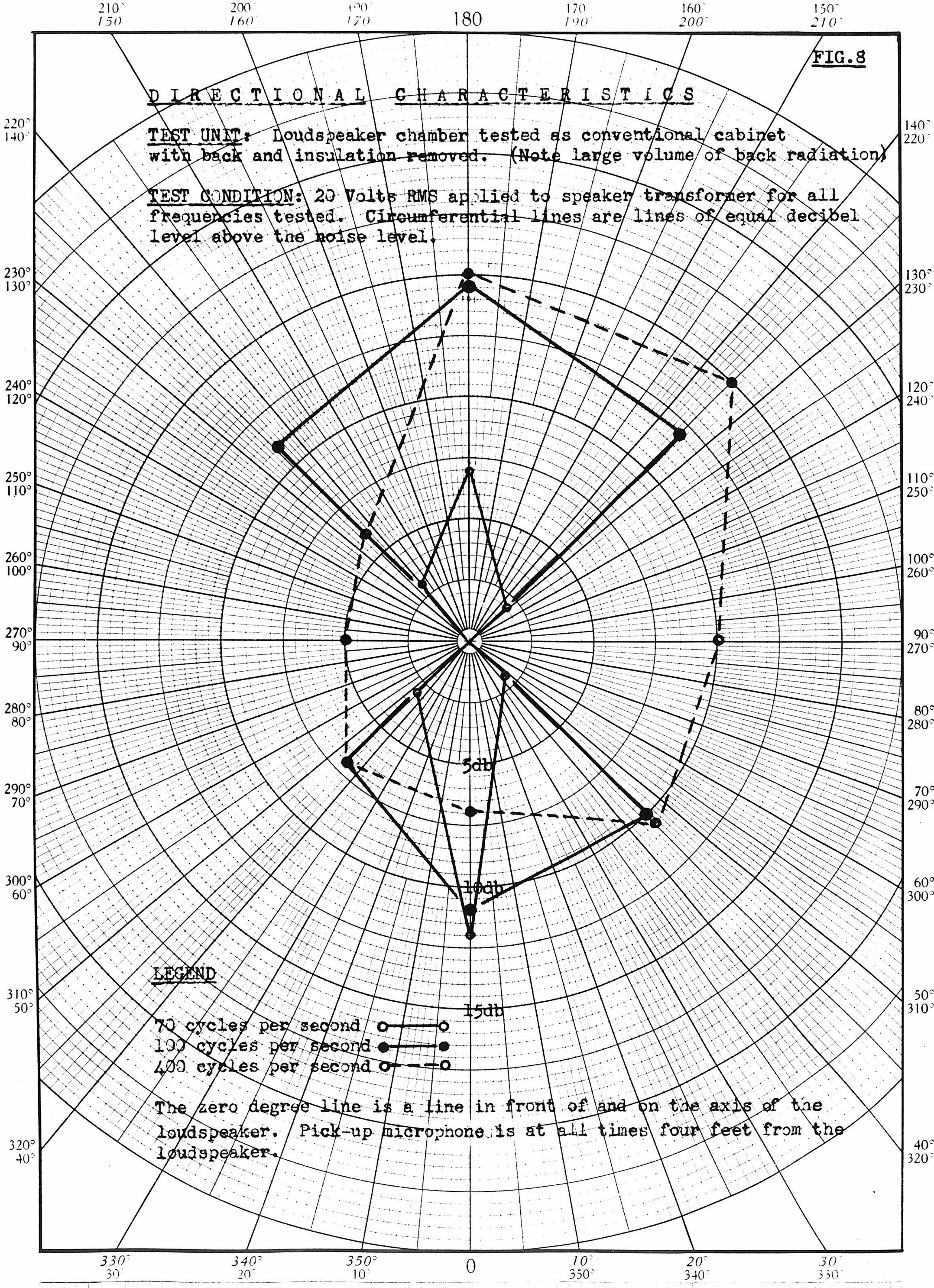


FIG.8
DIRECTIONAL CHARACTERISTICS
TEST UNIT: Loudspeaker chamber tested as conventional cabinet with back and insulation removed. (Note large volume of back radiation)
TEST CONDITION: 20 Volts RMS applied to speaker transformer for all frequencies tested. Circumferential lines are lines of equal decibel level above the noise level.
5db
10db
15db
LEGEND
70 cycles per second
100 cycles per second
400 cycles per second
The zero degree line is a line in front of and on the axis of the loudspeaker. Pick-up microphone is at all times four feet from the loudspeaker.
180
0

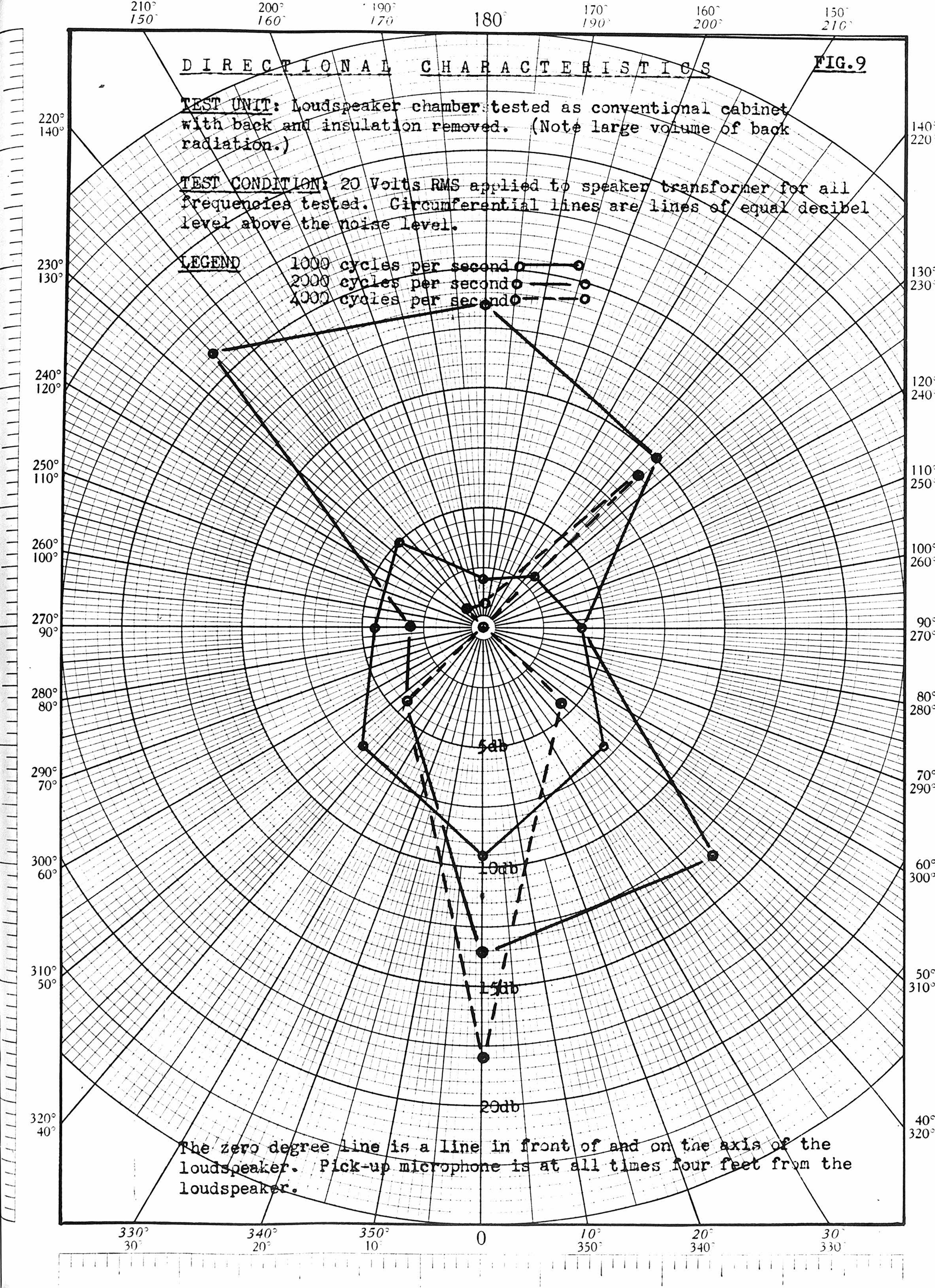
DIRECTIONAL CHARACTERISTICS

FIG.9

TEST UNIT: Loudspeaker chamber tested as conventional cabinet with back and insulation removed. (Note large volume of back radiation.)

TEST CONDITION: 20 Volts RMS applied to speaker transformer for all frequencies tested. Circumferential lines are lines of equal decibel level above the noise level.

LEGEND
1000 cycles per second o———o
2000 cycles per second o— — —o
4000 cycles per second o- - - -o



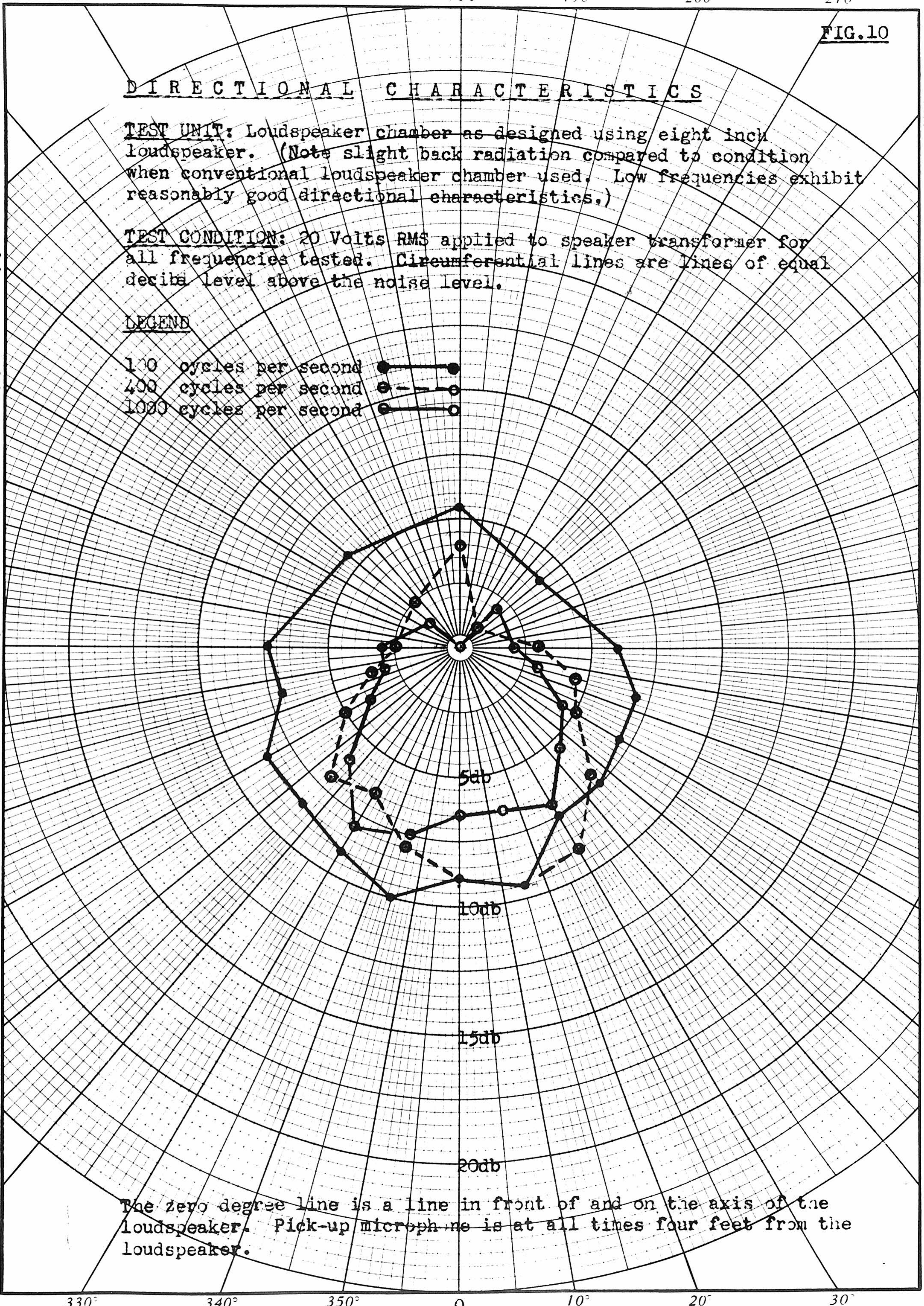
The zero degree line is a line in front of and on the axis of the loudspeaker. Pick-up microphone is at all times four feet from the loudspeaker.

FIG.10

DIRECTIONAL CHARACTERISTICS

TEST UNIT: Loudspeaker chamber as designed using eight inch loudspeaker. (Note slight back radiation compared to condition when conventional loudspeaker chamber used. Low frequencies exhibit reasonably good directional characteristics.)

TEST CONDITION: 20 Volts RMS applied to speaker transformer for all frequencies tested. Circumferential lines are lines of equal decibel level above the noise level.



The zero degree line is a line in front of and on the axis of the loudspeaker. Pick-up microphone is at all times four feet from the loudspeaker.

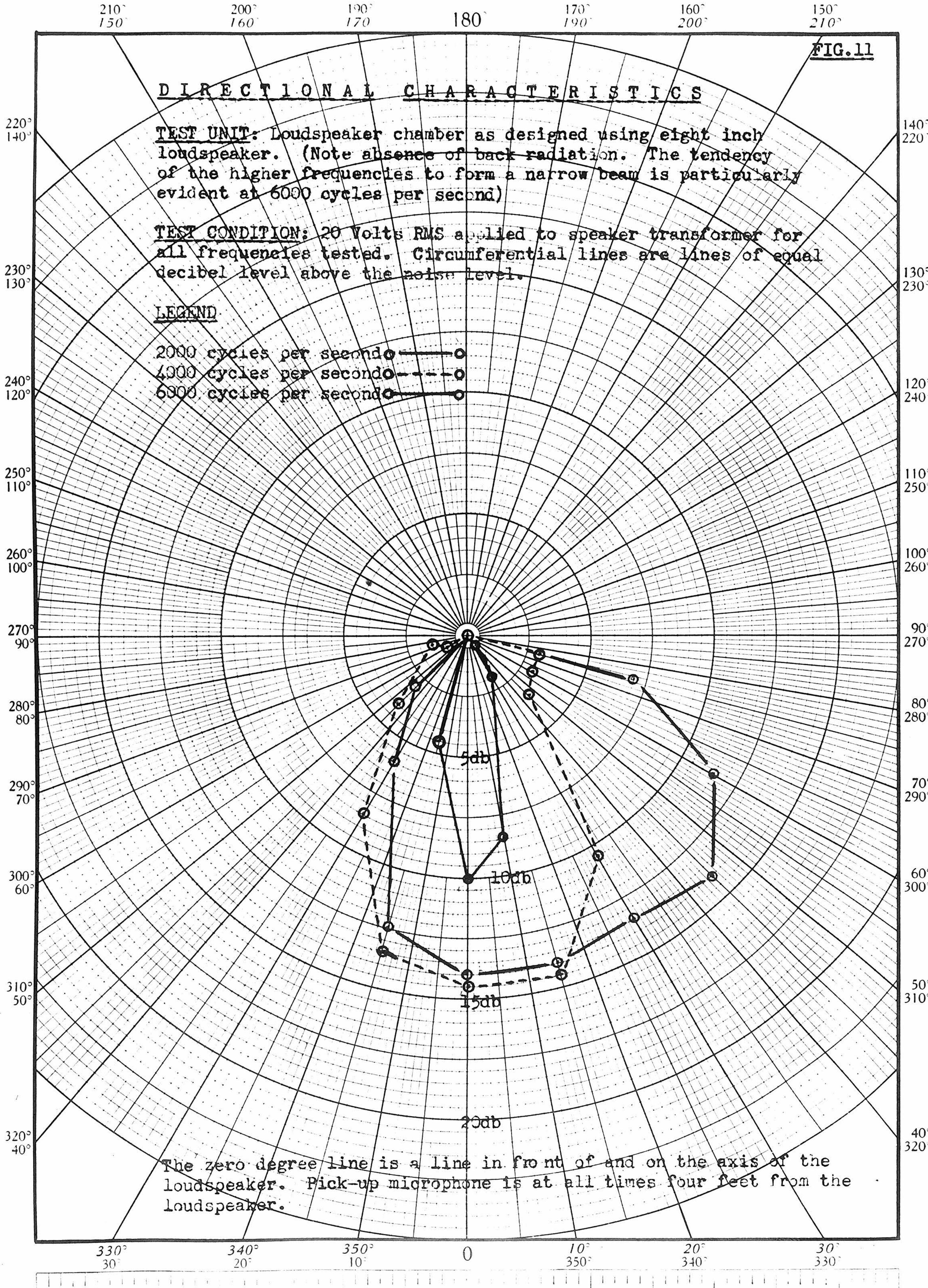


FIG.11
DIRECTIONAL CHARACTERISTICS
TEST UNIT: Loudspeaker chamber as designed using eight inch loudspeaker. (Note absence of back radiation. The tendency of the higher frequencies to form a narrow beam is particularly evident at 6000 cycles per second)
TEST CONDITION: 20 Volts RMS applied to speaker transformer for all frequencies tested. Circumferential lines are lines of equal decibel level above the noise level.
LEGEND
2000 cycles per second
4000 cycles per second
6000 cycles per second
5db
10db
15db
20db
The zero degree line is a line in front of and on the axis of the loudspeaker. Pick-up microphone is at all times four feet from the loudspeaker.
180°
0
210° 150°
200° 160°
190° 170°
170° 190°
160° 200°
150° 210°
220° 140°
230° 130°
240° 120°
250° 110°
260° 100°
270° 90°
280° 80°
290° 70°
300° 60°
310° 50°
320° 40°
140° 220°
130° 230°
120° 240°
110° 250°
100° 260°
90° 270°
80° 280°
70° 290°
60° 300°
50° 310°
40° 320°
330° 30°
340° 20°
350° 10°
10° 350°
20° 340°
30° 330°

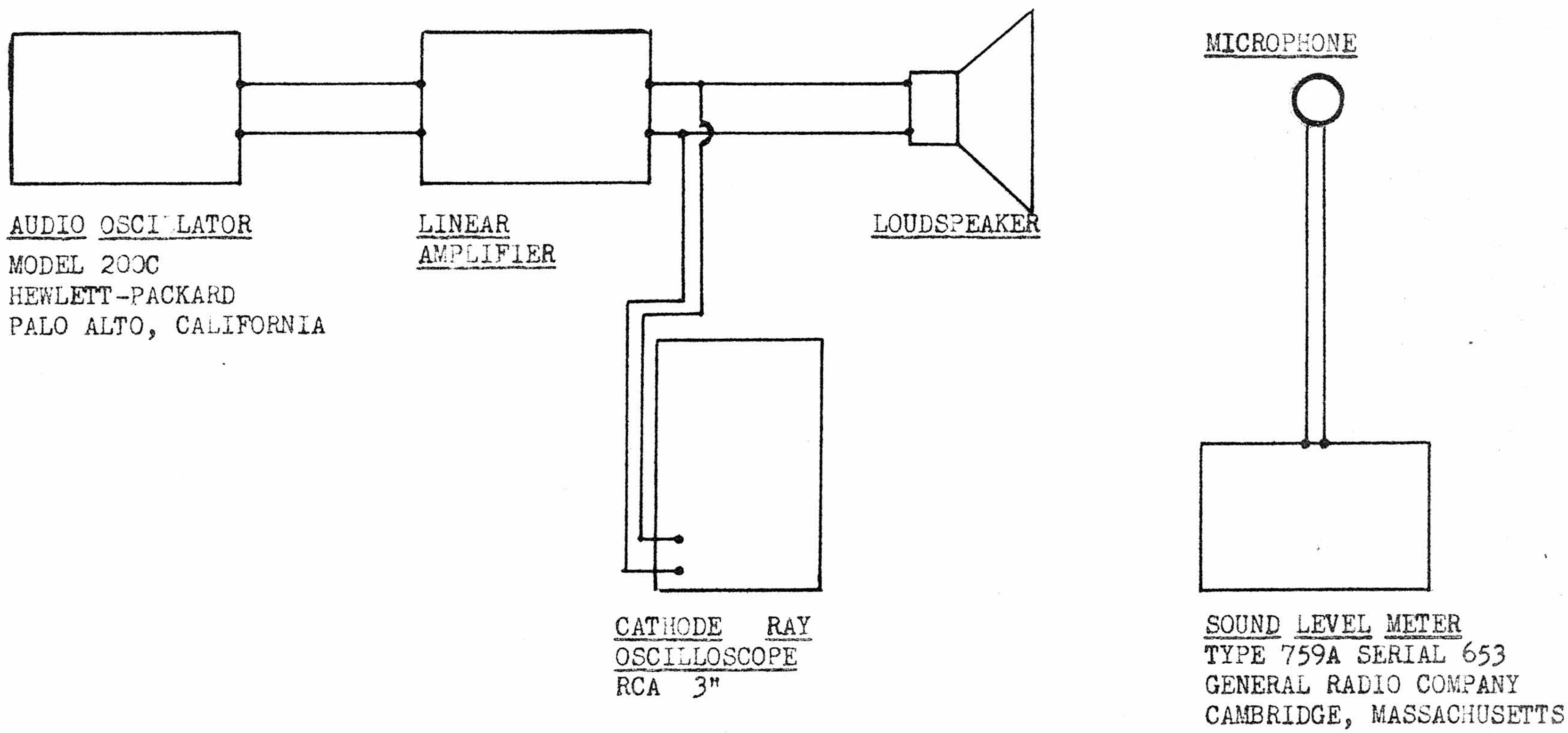

AUDIO OSCILLATOR
MODEL 200C
HEWLETT-PACKARD
PALO ALTO, CALIFORNIA
LINEAR
AMPLIFIER
LOUDSPEAKER
CATHODE RAY
OSCILLOSCOPE
RCA 3"
MICROPHONE
SOUND LEVEL METER
TYPE 759A SERIAL 653
GENERAL RADIO COMPANY
CAMBRIDGE, MASSACHUSETTS

FIG. 12

PRODUCTION FACILITIES

The company with which the thesis work was done had two main production factories:

1. Cabinet construction
2. Chassis assembly and final assembly

The cabinet plant was equipped to manufacture all types of plywood and filled wood cabinets including complete finishing operations. Space and machinery was available for very high production. However, there were no facilities for forming plywood. That type of work was done by a supplier of formed plywood parts. These parts were preferred on smaller sets due to the economies achieved by using fewer parts and by using preformed parts which speeded assembly time. Plywood had the disadvantage of being hard on production tools due to its resin content. Also the cost of formed plywood per piece is higher than a similar piece of filled wood(i.e. wood with a veneered surface). These disadvantages precluded the use of plywood on larger sets.

The joints in practically all the cabinet work were glued with a phenolic resin. This is standard practice in the mass production of radio chassis. There were no electronic gluing facilities used for the total quick assembly of finished cabinets or subassemblies. All Gluing work was done by the slower hot press method.

The company was particulary interested in seeing a new radio developed which did not entail large set-up costs but which if sales warranted could be adapted to high production techniques readily.

Chassis assembly and final assembly were done in the same plant. Chassis assembly was done by a group of women on a nonmoving line; each women did a standard group of operations. The movable line was not used since production did not warrant the large capital outlay involved.

The production of each chassis was broken down into standard groups of operations. Therefore a change to a new chassis entailed considerable expense. For this reason it was decided to use a standard chassis. This greatly increased the ease of adapting the design to the production methods of the company. If the chassis with minor changes could be adequately fitted into the design one important aspect of the industrial design ideal would be satisfied: using existing facilities and subassemblies in an inventive way to satisfy more fully the needs of the manufacturer and the ultimate consumer.

Although for the present the standard chassis was used it was suggested that future developments emphasize increasing compactness when this could be done without sacrificing ease of production and serviceability.

Specific recommendations were:

1. Lower the main tuning capacitor. This would reduce the overall height of the cabinet required to house the chassis. Electrically this would effect the set since the rotor is grounded. The stationary plates have a capacitive relationship to the rotating plates and to the chassis but the distance between the two sets of plates is so much less than the distance between stationary plates and the chassis that the capacitance and thus the reactance of stationary plates to the chassis is unimportant.

2. Eliminate the slide rule dial assembly with its troublesome pulley arrangement in favor of a round dial which would use a simple planetary gear arrangement to achieve the necessary gear reduction to make fine tuning possible. Gears of Micarta (cloth impregnated with a phenolic resin) could be used for this purpose.

3. Turn power transformer on its side. It now stands upright.

Another change that was suggested was made to increase the ease of using the set. It was:

1. Make the ON-OFF switch part of the volume control instead of part of the tone control as it is now. The quickest reaction of most people is to turn the dials at either end of the dial group since the central dials are usually less used. The volume control on this set is the left hand control. The tuning dial is the right hand control and the tone control is the central knob.

B I B L I O G R A P H Y

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III CHOICE OF DESIGN

The final choice of the design was an attempt to integrate all the variables involved in the most satisfactory way to the producer and to the consumer.

At the completion of the market and consumer research many idea sketches were drawn with the aim being to incorporate the desirable features found by the consumer surveys and to make the radio as practical as possible from the manufacturer's standpoint. These sketches were finally consolidated so that from them three definite designs evolved, a table model radio, a medium sized two piece table or floor model, and a large two piece radio-phonograph. These designs were discussed with company executives and engineers. The large two piece radio-phonograph was best liked by the company. However, it was felt that this design should be held in abeyance in favor of the medium sized two piece radio. The medium sized radio would be more efficacious as a mass production product; the reason for this is that due to its lower cost more people could afford to buy it and due to its size it would fit more easily into smaller homes, which are the trend in building. Furthermore it was thought that the medium sized set would fill a gap in the radio industry; a set with fine enough tone and appearance to be placed in the living room yet low enough in cost to be purchased by families with moderate incomes.

In addition to this there has been little work done to improve the acoustics of radios of this size. In the larger more expensive sets where economy in production is not so important the acoustic problems can be more easily solved. Furthermore as is explained (see Acoustic Systems) the very fact of the larger size aids the acoustical engineer.

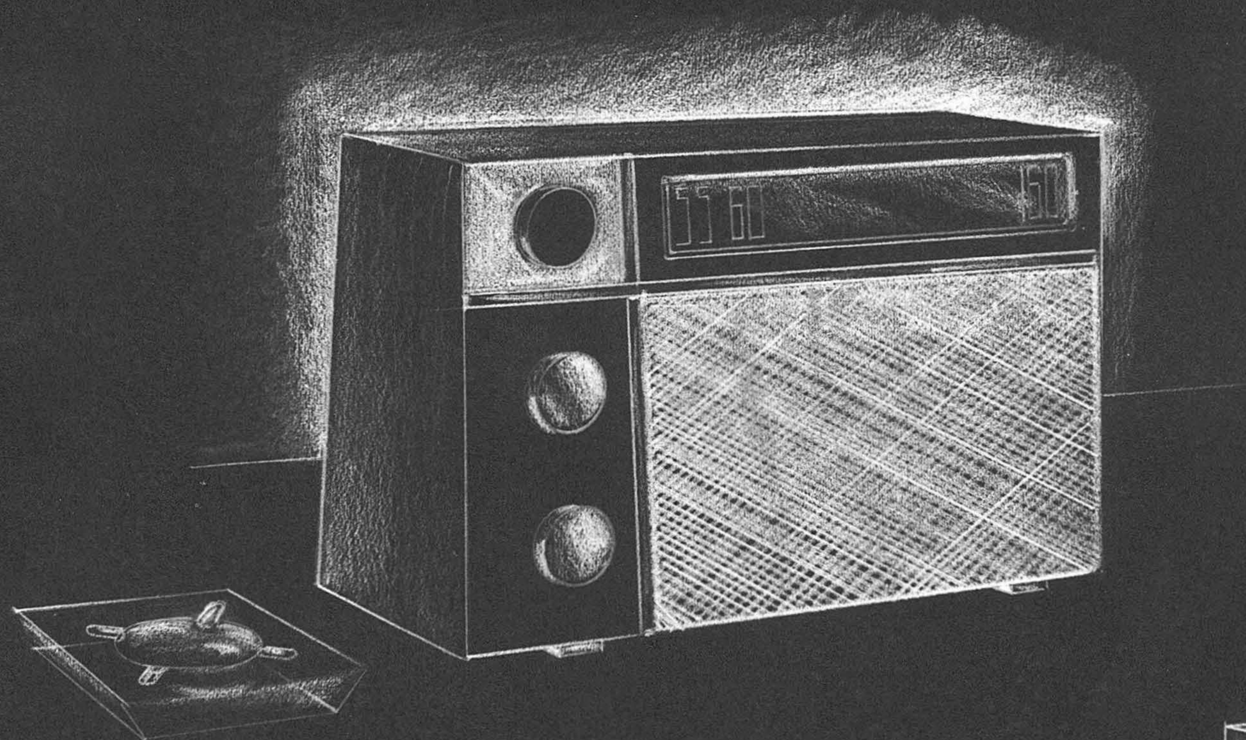
TABLE MODEL RADIO

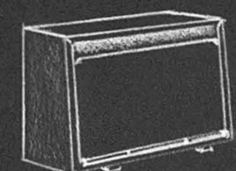
FEATURES

Prominent tuning knob eliminates fumbling for proper knob.

Opening in back serves as handle without marring clean simplicity of the set.

Eccentrically located speaker reduces tendency of the set to vibrate.





BACK VIEW

PRELIMINARY SKETCH

TABLE MODEL RADIO

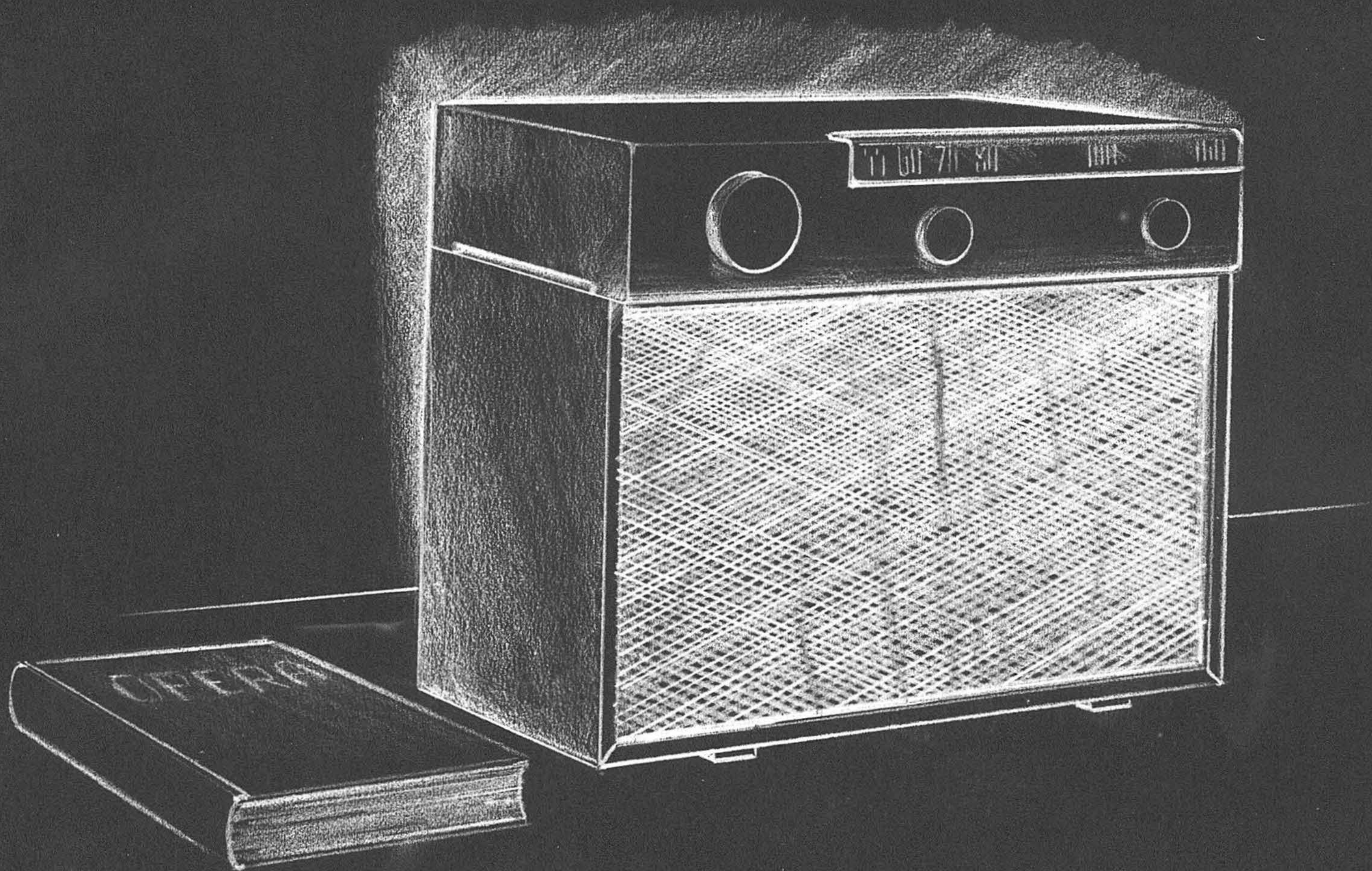
DIMENSIONS	12" wide 9"high
	$5\frac{1}{2}$" deep at base
	$4\frac{1}{2}$" deep at top

TWO PIECE TABLE OR FLOOR MODEL RADIO

FEATURES: Large tuning dial, visible front and top.

Speaker can be placed at some distance from the radio proper. The radio can be conveniently tuned sitting down.

Versatility of the set is evident since it can be used together as shown or apart. It thus fits readily into many different environments.



PRELIMINARY SKETCH

TWO PIECE, TABLE OR FLOOR MODEL RADIO

DIMENSIONS

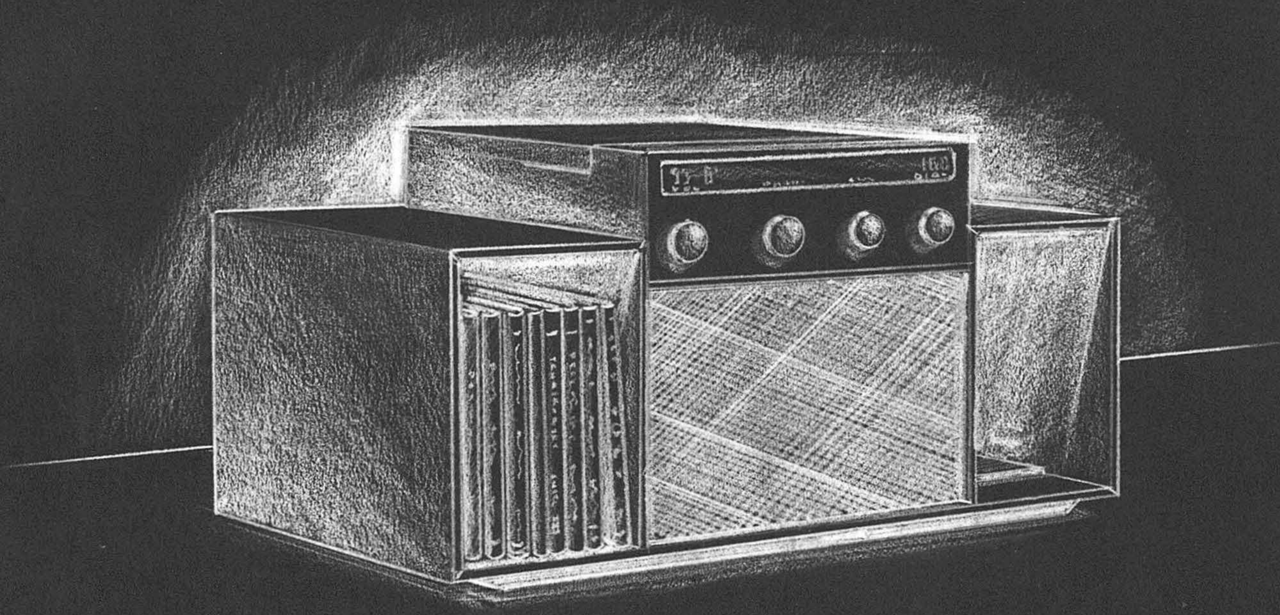
Overall	15"wide,	12½"high,	7½"deep
Speaker	15"wide,	8½"high,	7½"deep
Radio	15"wide,	4"high,	8"deep

TWO PIECE RADIO-PHONO COMBINATION

FEATURES Radio-phono unit separates from combined loudspeaker and record cabinet enabling smaller unit to be placed on a table beside a chair.

Records weight down loudspeaker chamber reducing tendency of chamber to vibrate at the low frequencies.

Finger space under record albums facilitates their removal from cabinet.



P R E L I M I N A R Y   S K E T C H

TWO PIECE RADIO-PHONO COMBINATION

DIMENSIONS

Overall	35"wide,	22"high,	18"deep
Speaker	35"wide,	16"high,	18"deep
Radio-P.	19"wide,	9"high,	18"deep

The two-piece idea is used for the following reasons:

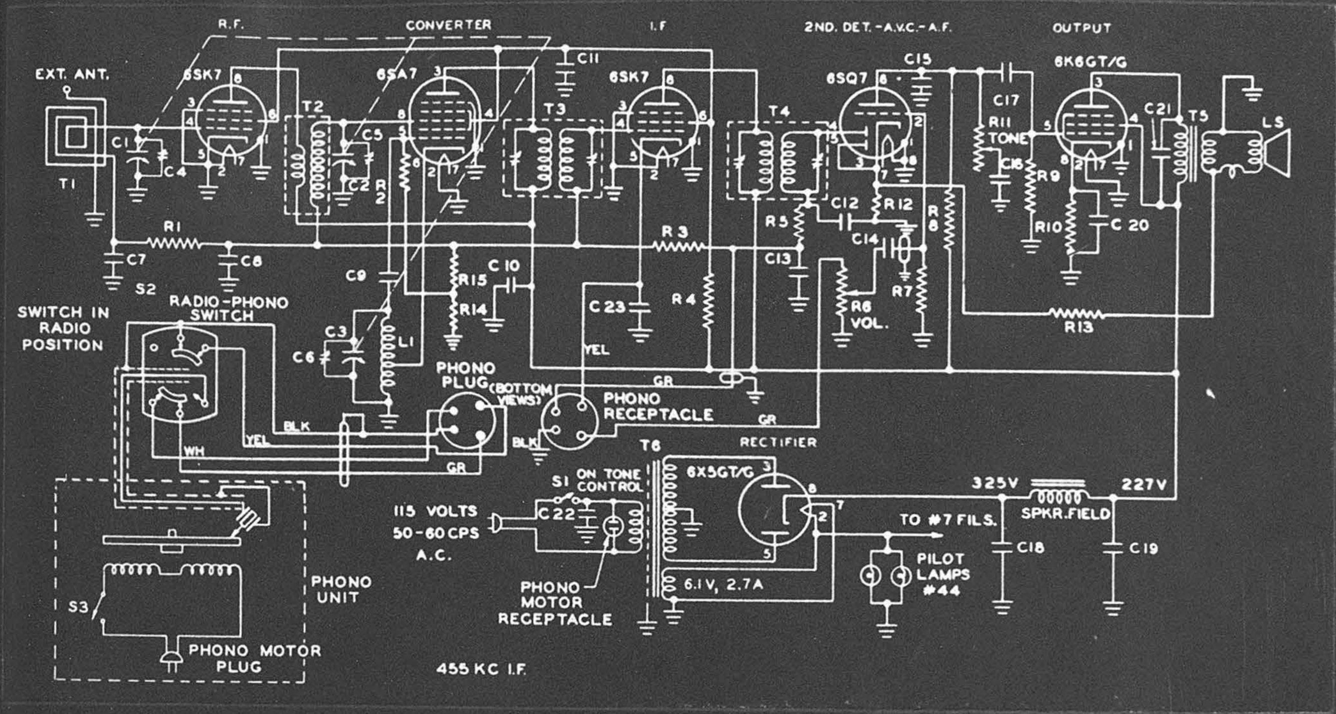
1. Separation of the radio proper from the loudspeaker enables the user to have the radio controls close at hand yet suffer none of the adverse affects of having the speaker blasting into his ear.
2. The radio is more versatile in that it can be used together or apart. It can thus be adapted to the individual needs of purchasers more readily.
3. Repairs are more easily made on this set than on sets of similar quality since the whole radio unit can be conveniently taken to the dealer and tested. Further more it is possible to make many repairs on the set without removing it from its cabinet due to the removable cover on the bottom of the cabinet.

The attachment of the radio and loudspeaker electrically is accomplished by means of the extension cord of four wires. Two of these are for the signal to the primary of the loudspeaker transformer and two are used for the negative feedback circuit to the first audio amplifier as is shown in the electric circuit diagram. An investigation was made of the possiblities of using a small transmitter to tune the main set as was done by Philco in one of their expensive sets. However, this was not used due to the difficulties which arise when the next door neighbor turns on his set or his electric razor. Frequently, enough signal is transmitted to turn on the remote tuned set. An additional reason for not using such a unit is that the development time which the company would be obliged to take to perfect it would make its actual use less probable.

The physical attachment of the radio and loudspeaker chamber is accomplished by the combined handle, leg and frame braces of the loudspeaker chamber which control lateral motion and by the legs of the radio which fit over the loudspeaker chamber and thus control back and forth motion. Although means of clamping the two units more rigidly together were considered they were not used in the design since control of the vertical relationship between the two pieces added something to the cost but little to the practicality of the design.

ELECTRIC CIRCUIT DESIGN

A standard superhetrodyne circuit of the company with which the work was done was used. (For photostat of this circuit see the following page.) A standard circuit was used since it can be readily adapted to the proposed two piece radio. Its use also obviates expensive new production and development requirements. The circuit is designed to drive a six, eight or ten inch speaker. To properly match the output impedance of the set the speaker must have a voice coil impedance of 3.2 ohms. The power output of this set is 1¼ watts.



(TOP) ELECTRIC CIRCUIT DESIGN Note phono outlet.

(RIGHT) COMPONENT PARTS LIST

C1-C2-C3	THREE-SECTION VARIABLE (388-388-180 MMF)	4400
C4-C5-C6	TRIMMERS; PART OF VARIABLE COND.	
C7-C8	.05 MFD. 200 VOLT, TUBULAR PAPER	4100
C9, C12, C13, C15	100 MMF. ± 20% MICA	4000
C10, C11, C23	.05 MFD. 400 VOLT, TUBULAR PAPER	4101
C14.	.005 MFD, 600 VOLT, TUBULAR PAPER	4102
C16, C17	.01 MFD. 600 VOLT, TUBULAR PAPER	4103
C18-C19-C20	DRY ELECTROLYTIC (20-20-20 MFD/450-450-25 V.)	4200
C21	.001 MFD, 600 VOLT, TUBULAR PAPER	4104
C22	.01 MFD, 600 VOLT, TUBULAR PAPER (METAL CAN)	4105
	AUTOMATIC RECORD PLAYER	9011
L1	OSCILLATOR COIL	5200
LS	LOUDSPEAKER, 4"x6" (1500-OHM FIELD)	9000
R1, R8	.22 MEGOHM ± 20%, ½ WATT	4500
R2	10,000 OHM ± 20%, ½ WATT	4515
R3	2.2 MEGOHM ± 20%, ½ WATT	4502
R4	10,000 OHM ± 10%, 2 WATT	4503
R5	47,000 OHM ± 20%, ½ WATT	4504
R6	.5 MEGOHM POTENTIOMETER (VOLUME)	4804
R7, R15	10 MEGOHM ± 20%, ½ WATT	4505
R9	.47 MEGOHM ± 20%, ½ WATT	4506
R10	560 OHM ± 10%, ½ WATT	4507
R11	.25 MEG. POTENTIOMETER WITH SWITCH (TONE)	4805
R12	47 OHM ± 20%, ½ WATT	4508
R13	330 OHM ± 20%, ½ WATT	4509
R14	15,000 OHM ± 20%, ½ WATT	4521
S1	ON-OFF SWITCH (ON TONE CONTROL)	
S2	RADIO-PHONO SWITCH	6001
T1	ANTENNA LOOP	5223
T2	R.F. COIL (SHIELDED)	5202
T3	INPUT I.F. TRANSFORMER (455 K.C.)	5203
T4	OUTPUT I.F. TRANSFORMER (455 K.C)	5204
T5	AUDIO OUTPUT TRANSFORMER	5100
T6	POWER TRANSFORMER	5000
S3	PHONO. MOTOR SWITCH (PART OF RECORD PLAYER	

The set and the chassis on which it was mounted constituted one of the basic challenges of the design since the dimensions of the chassis and the location of the components of the set on it were relatively fixed.

CHOICE OF MATERIAL

In the consumer research overwhelming preference for cabinets of wood was shown particularly for sets to be used in the living room. Therefore wood construction was of course indicated. The exact type of wood was not specified since the variety of wood used is so dependent on the wood available in the current "tight" wood market. For the purpose of the pilot model of this radio a solid wood with veneer was suggested. Veneer construction has the advantage that cheaper woods can be used in the core of the piece. Furthermore veneer construction is less subject to shrinkage cracks and to changes in dimension than solid wood[48]. In addition to this more care can be taken in the selection of surface wood in veneered furniture. The manufacturer can dry veneer stock quickly and cheaply and he can utilize all of his wood to best advantage.

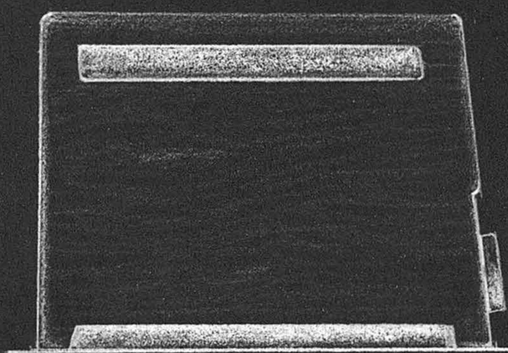
R A D I O

Top unit of two piece radio that can be used together or apart. Radio and loud-speaker connected electrically by means of a four wire extension cord.

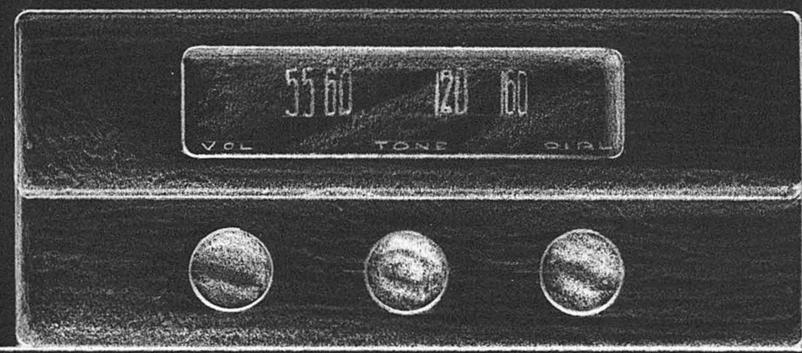
FEATURES Large easily read tuning dial with knob designations embossed in it.

Side openings act as handles and means of ventilating the set.

Removable bottom panel permits servicing without removing set from cabinet.



SIDE VIEW



FRONT VIEW

R A D I O

To be used in conjunction with the loudspeaker chamber on the following page; the radio fits snugly on top of this chamber if desired.

DIMENSIONS

Details shown in black line drawings in appendix.

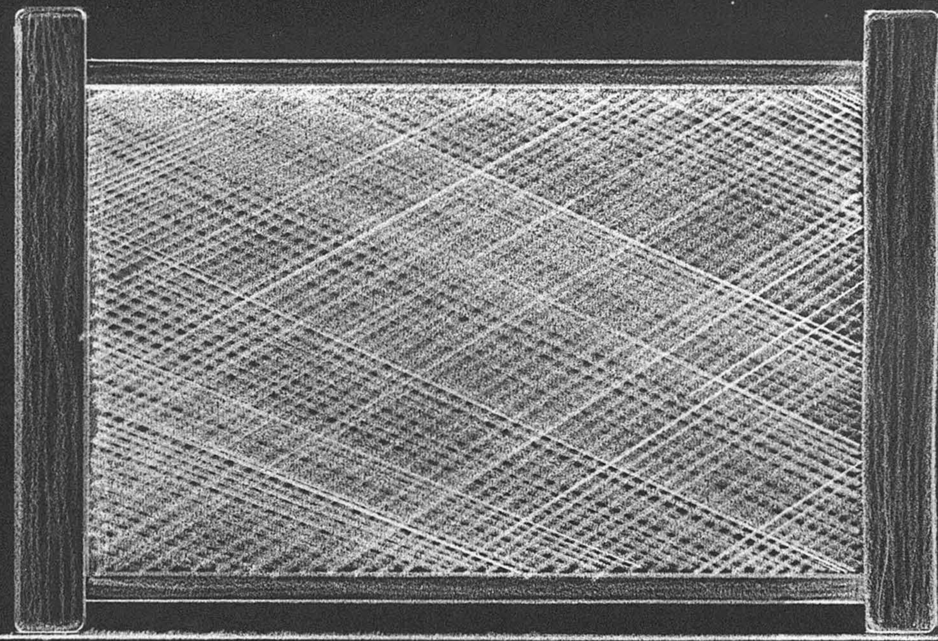
LOUDSPEAKER CHAMBER

Unit onto which the radio set on the previous page fits.

FEATURES End pieces serve the fourfold function of stiffening the chamber, acting as legs for the chamber, acting as handles for the radio when it is used on the chamber.

Speaker panel although easily removable is acoustically tight fit when in place.

SIDE VIEW



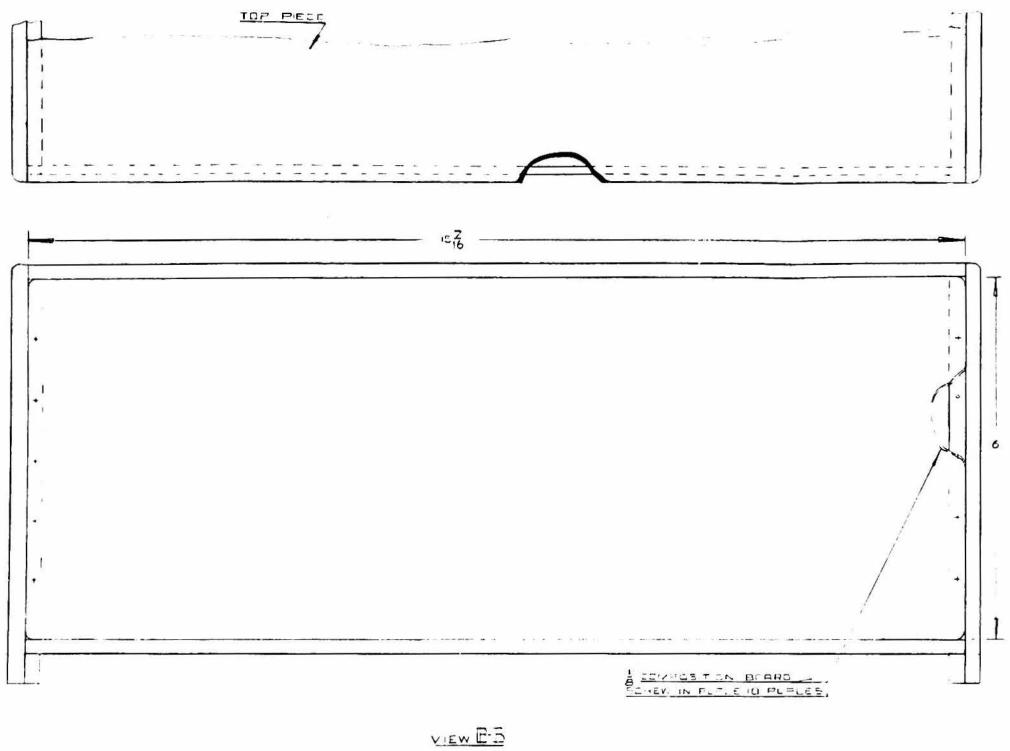
FRONT VIEW

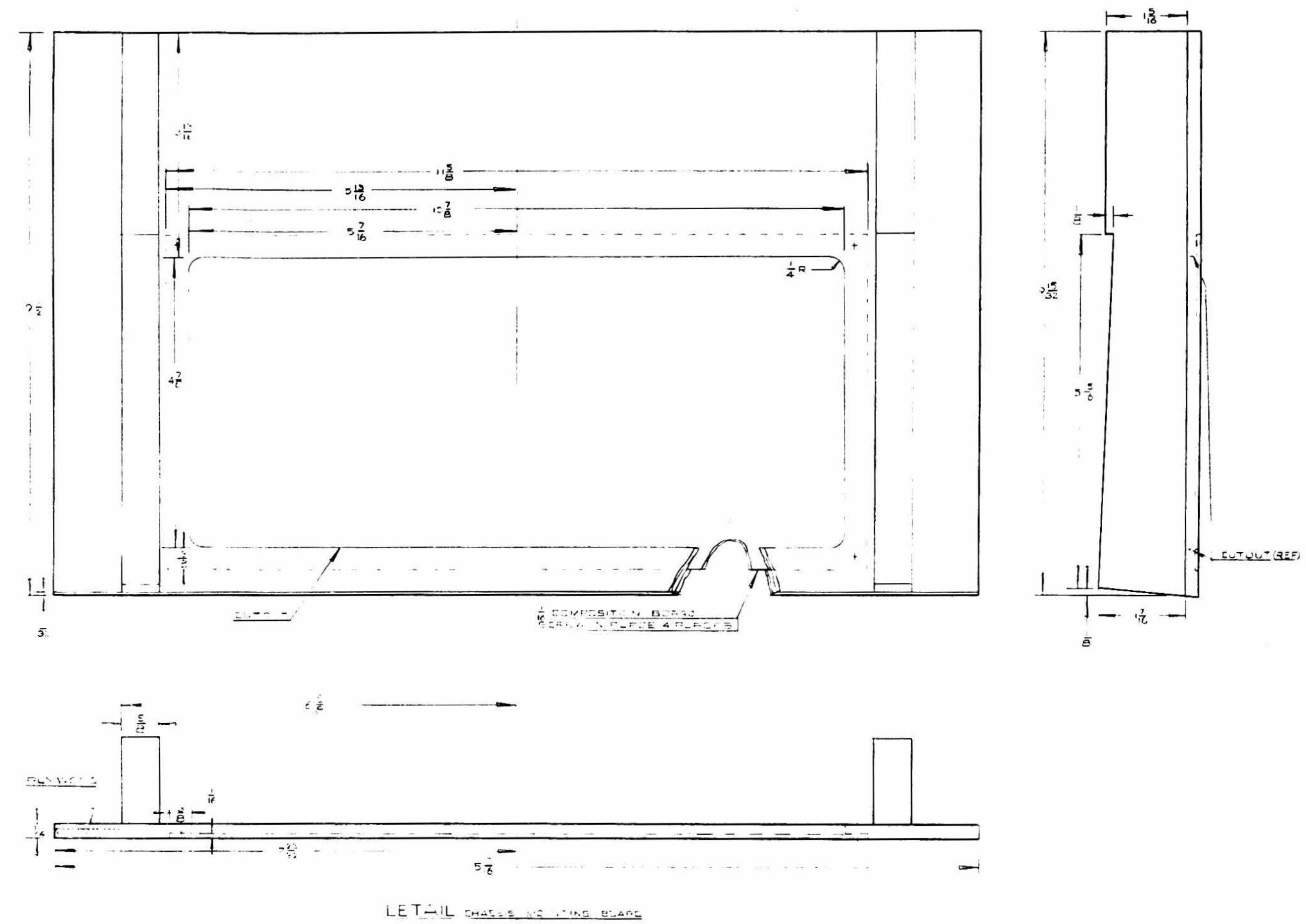
LOUDSPEAKER CHAMBER

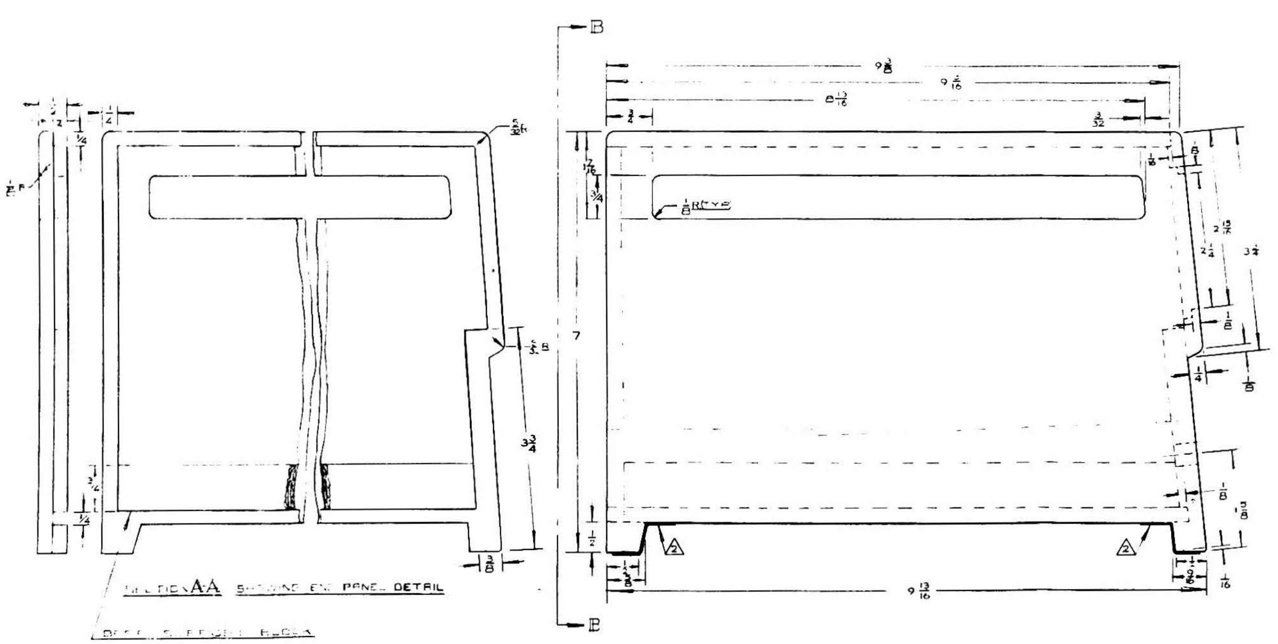
Radio on previous page fits snugly between end pieces (which are a combined stiffener, handle and leg to the chamber).

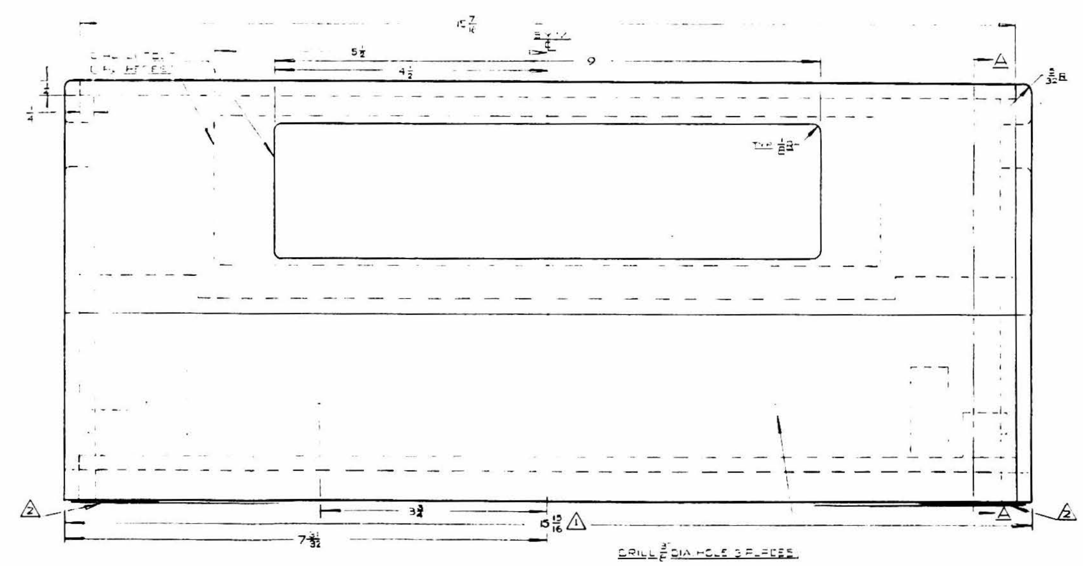
DIMENSIONS

Details shown in black line drawings in appendix.





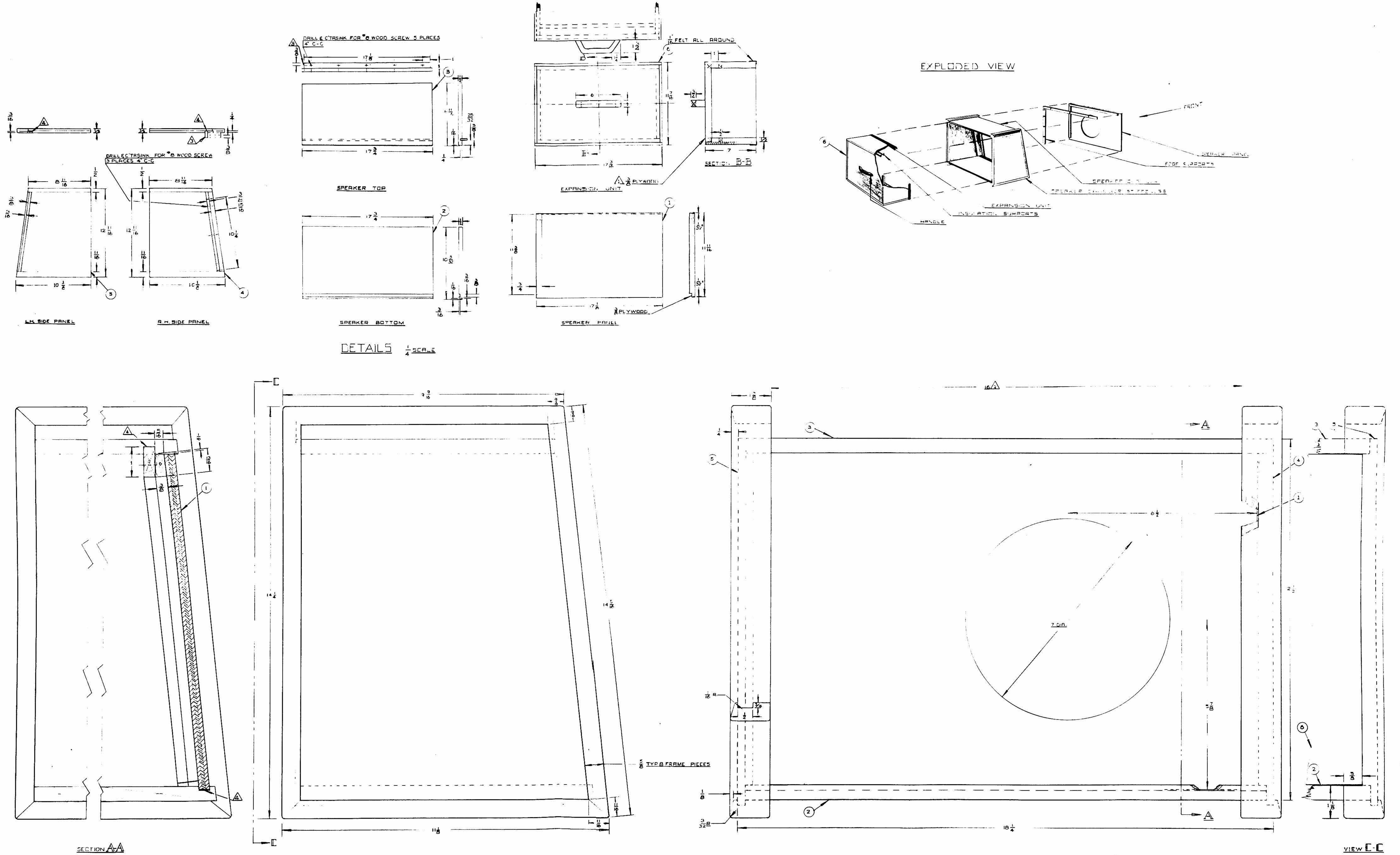




NOTES:
1. HOLD THIS DIMENSION
2. $\frac{1}{16}$" FELT STRIPPING

SCALE: FULL
MATERIAL: WHITE OAK
FINISH: GRAY

RADIO
EXPERIMENTAL MODEL
H KECK 4-12-47



NOTES:

1. EXPANSION UNIT MUST MOVE WITH SNUG FIT IN SPEAKER CHAMBER
2. HOLD THIS DIMENSION
3. SEPARATE PART MUST BE REMOVABLE
4. LINE WITH 1/8" FELT

SCALE: FULL (EXCEPT AS NOTED)
MATERIAL: WHITE OAK
FINISH: GRAY

SPEAKER CHAMBER
EXPERIMENTAL MODEL
H. KECK 4-7-47

IV DIRECTION OF FUTURE RESEARCH AND DEVELOPMENT

One phase of improving the fidelity of the sound output from the louspeaker has only been touched upon. This is a dispersing system for the high frequency beam which is always more directional than the low frequency output. U.S. Patent 2,102,212 is one step in this direction but its cost and difficulty of mounting and bracing make it impractical for the low priced set. A better way of dispersing the high frequencies could be achieved by a carefully designed diffraction grating. The length, width and thickness of the slits in the grating would have to be well calculated. The flat unit would be easily assembled into any cabinet. Furthermore it would have less tendency to load the speaker and to set up spurious vibrations than the vertical fins used in the patent mentioned.

Design of the two piece unit so that a record player could be later be bought and used with the set would increase the utility of the design. Futhermore it would allow people to buy the set gradually, one unit at a time.