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NEGATIVE FEEDBACK

by

W. O. BALDWIN

THE RADIO CLUB OF AMERICA

11 West 42nd Street ★ ★ ★ New York City

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OF THE
RADIO CLUB OF AMERICA

Volume 29 1952 No. 2

NEGATIVE FEEDBACK

By
W. O. Baldwin*

Presented before the Radio Club on April 13, 1951

INTRODUCTION

Negative feedback as considered in this paper, is employed for the purposes of stabilizing gain, reducing distortion, extending frequency response and improving the phase characteristic of vacuum tube amplifiers. Emphasis here will be on the latter two, since if they are known the gain stabilization and distortion can be quickly calculated. Where phase shift is negligible, feedback design is simple and straight forward. Where it amounts to something approaching or in excess of 180 degrees it must be carefully considered along with amplitude response.

In the design of feedback systems, as in most realms of endeavor, it behooves one to be judicious in the selection of a proper technique and viewpoint, so that the work may be carried out with a minimum of labor and a maximum of insight into actual circuit behavior. There are several methods which may be used. One method of particular merit is presented in this paper. It enables easy visualization of circuit behavior and makes clear just what can be done, what cannot be done, and quickly suggests changes toward a more optimum design. Essentially this method is the scheme of using plots of the reciprocal gain-frequency response rather than simply the ordinary gain-frequency plots. This scheme eliminates the otherwise necessary addition and division of vectors.

The feedback problem is usually one of determining what the gain-frequency response should be without feedback to yield desired results with feedback. Objectively, this treatment emphasizes the usefullness of plots of the reciprocal gain-frequency response when, in addition to improved gain-stability, linearity; extension of bandwidth and close control of gain response is desired. This requires a knowledge of changes in response produced for various amounts of feedback and various types of feedback networks. These changes are quickly visualized in the following plots.

THE AMPLIFIER WITHOUT FEEDBACK

Figure No. 1 shows a simplified single stage amplifier, where screen and cathode bias circuits have been excluded and the tube is assumed to be operated in the linear portion of its characteristic. Screen and cathode circuits together with other considerations such as input admittance of the tube and its finite plate resistance are, in actual design, of importance, but here where the emphasis is on a design and analysis technique it is felt that this simplification is permissible.

Two resistance capacitance combinations completely control the frequency characteristic of this simple amplifier. They are the coupling capacitor-grid leak pair and the stray capacitance-plate load pair. The former causing fall off of gain at low frequencies and the latter at high frequencies. Since the tube itself has no frequency characteristic for the range of frequencies considered throughout this treatment, the analysis may be further simplified by considering, for the moment, only the response of the controlling networks. Their efforts may later be multiplied by the gain constant to give actual gain variations.

The output voltage of the low frequency determining network falls and is advanced in phase due to the leading current flowing in R_g. This is graphically represented in the locus to the right. The curve is far from complex; being a simple semi-circle. Pictured below the semi-circle is a straight line locus representing the reciprocal of gain; this is of even greater simplicity. It shows the input voltage required for constant unit output voltage; constant in amplitude and phase. It might also show the network loss as a function of phase angle or frequency. Mathematically the top curve is E_{in}Cos θ where $\theta = \tan F/F_o$. F_o is the frequency where the reactance of the capacitor is equal to the resistance R_g. Expressed in these terms the curves are quite general and represent all possible resistance-capacitance combinations. It will be noticed with this reciprocal gain locus that the input voltage must be increased (to overcome the network loss) and caused to lag in phase

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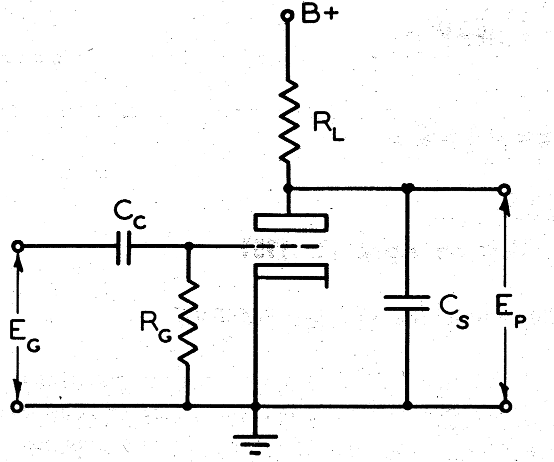
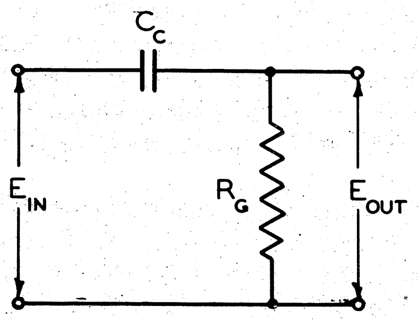
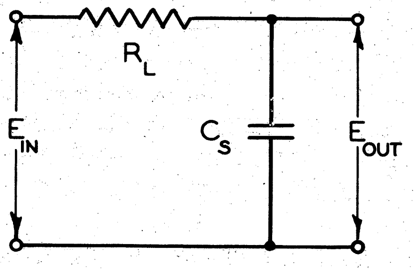
* Ballantine Laboratories, Inc., Boonton, N.J.



Single Stage Amplifier

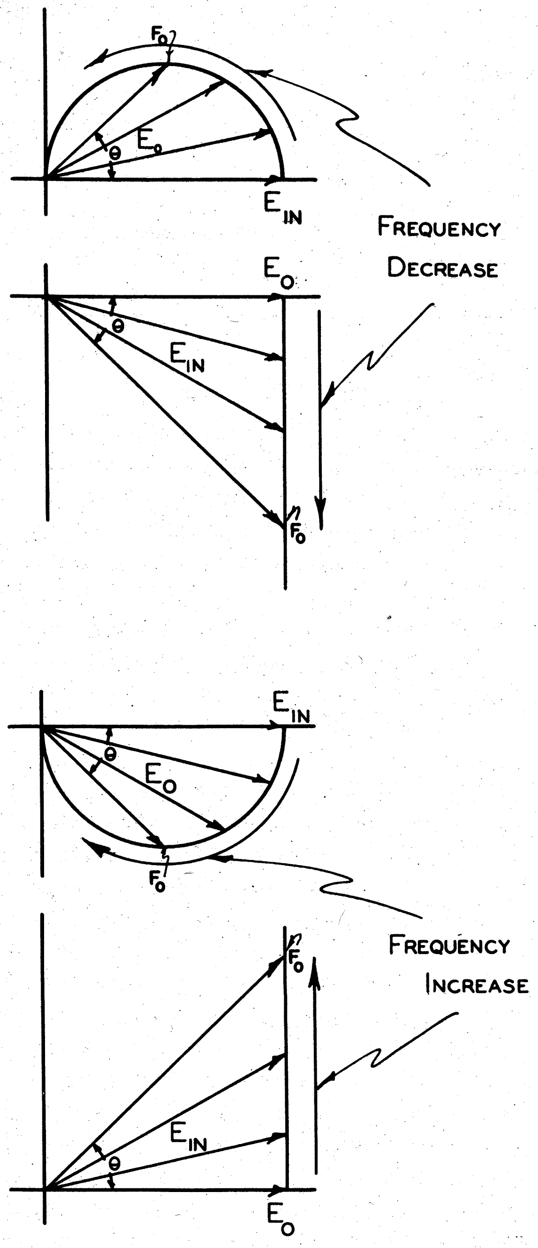


Low Frequency



High Frequency

Equivalent Circuits

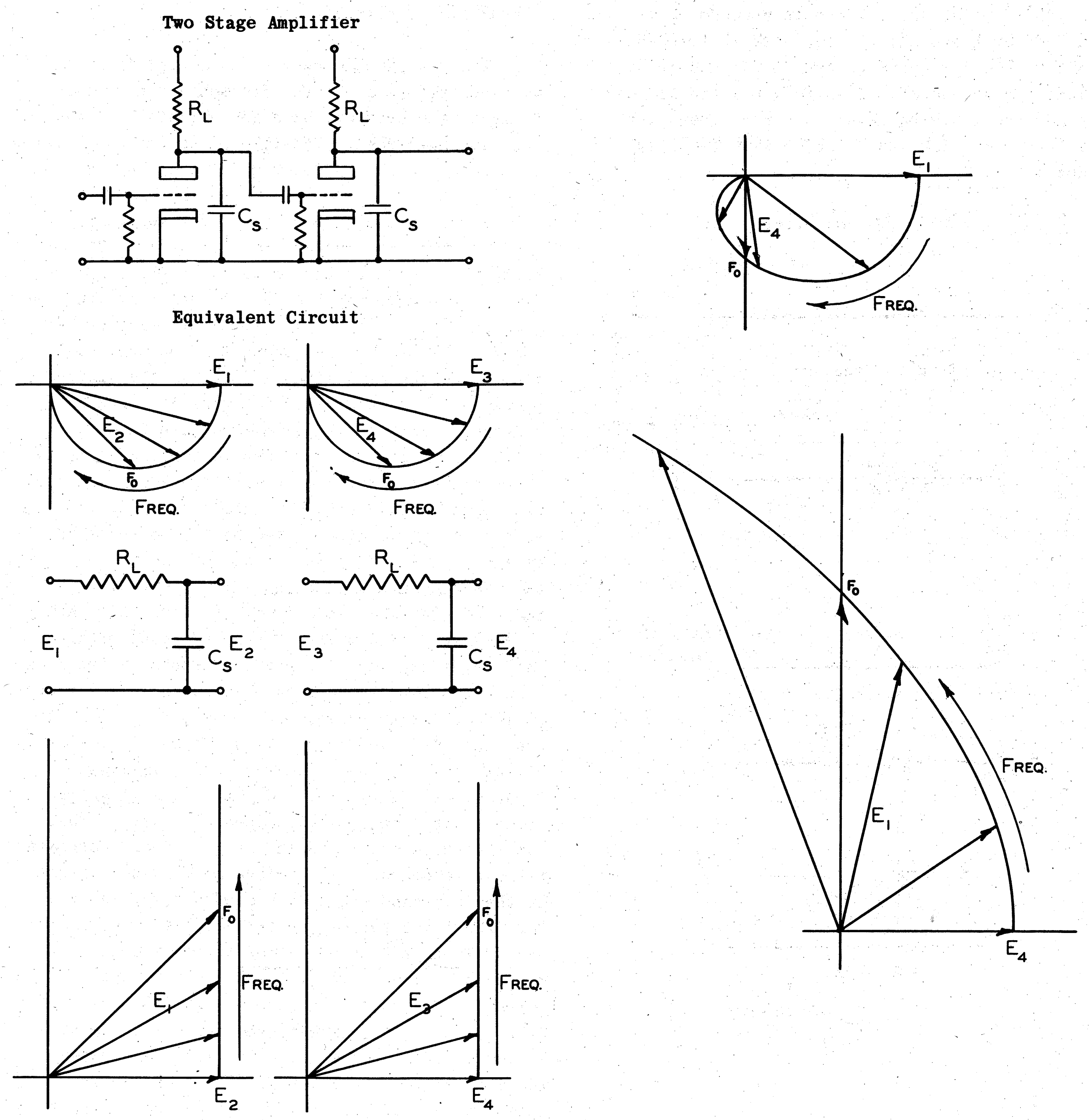


Locus Diagrams

FIGURE 1

It will be noticed with this reciprocal gain locus, that the input voltage must be increased (to overcome the network phase lead), in order that the output voltage remain constant in amplitude and phase as the frequency is decreased.

A similar situation exists for the high frequency end of this amplifier. The effects are shown in the two loci at the lower right of Figure 1. Here the output falls and lags in phase as the frequency is increased. This occurs, as in the low frequency case, once the reactance of the capacitor is comparable with the resistance. The curve is also a semi-circle. The reciprocal is plotted below and illustrates that an increase in input voltage and an advance of its phase must be made to hold the output constant. The vector at 45 degrees represents the voltage acting at the F_0 frequency. This is the 3 db frequency where the output is down 3 db (0.707) or the input is (in the reciprocal plots) up 3 db (1.414).


Two Stage Amplifier

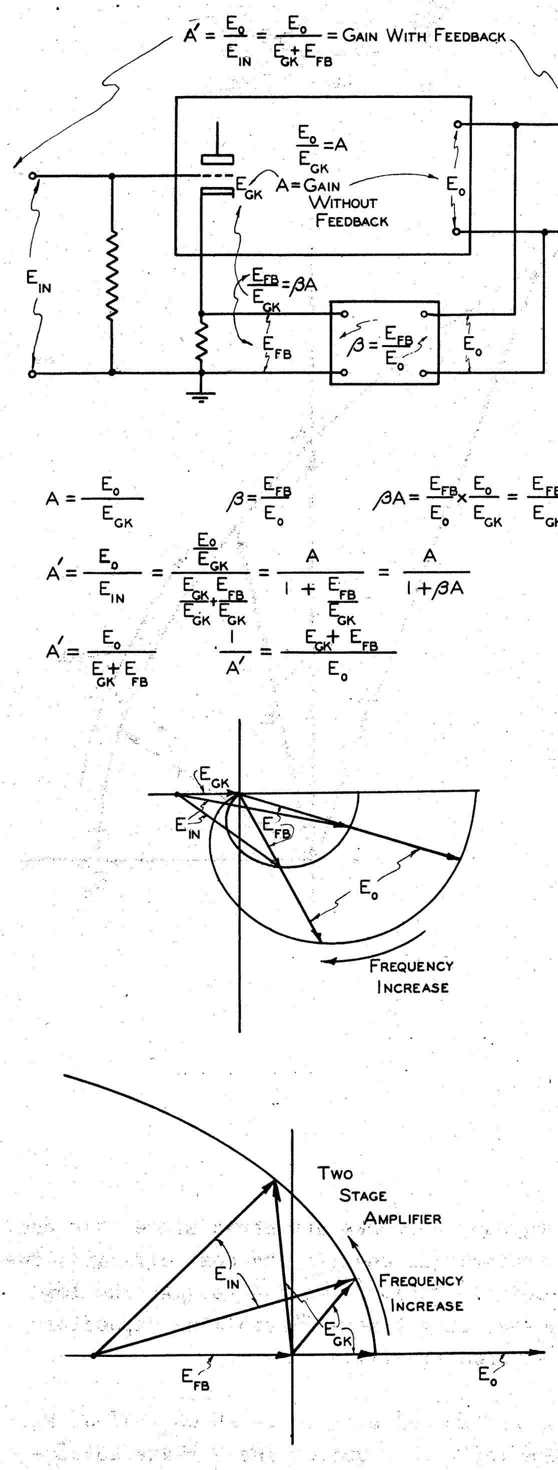
Equivalent Circuit

FIGURE 2

Figure No. 2 shows two of these single stage amplifiers in cascade. Each stage, it is assumed, has the same F_0 frequency and its response is the same as outlined in Figure No. 1. The response of these stages in cascade is, of course, the product of the single stage responses or the product of the single stage curves. These are shown at the right. The response would be down 6 db (or by ½) and lagging by twice 45, or 90 degrees. Only the high frequency networks are shown since this end of the spectrum is usually the most difficult due to irreducible stray capacitances. At the low frequencies, many times, controlling capacitors may be altered at will.

The reciprocal gain curve shows that at F_0, twice the input is required and a phase advance of 90 degrees to hold the output constant, i.e., to its midband value where there is assumed no attenuation or phase shift. Increase in frequency beyond F_0 would require greater input and lead. At infinite frequency, infinite input and 180 degree advance would be required. Here then, lets say, is an amplifier to which we wish to apply feedback.

Two Stage Amplifier



$$A = \frac{E_0}{E_{GK}} \qquad \beta = \frac{E_{FB}}{E_0} \qquad \beta A = \frac{E_{FB}}{E_0} \times \frac{E_0}{E_{GK}} = \frac{E_{FB}}{E_{GK}}$$

$$A' = \frac{E_0}{E_{IN}} = \frac{\frac{E_0}{E_{GK}}}{\frac{E_{GK}}{E_{GK}} + \frac{E_{FB}}{E_{GK}}} = \frac{A}{1 + \frac{E_{FB}}{E_{GK}}} = \frac{A}{1+\beta A}$$

$$A' = \frac{E_0}{E_{GK}+E_{FB}} \qquad \frac{1}{A'} = \frac{E_{GK}+E_{FB}}{E_0}$$

FIGURE 3

THE AMPLIFIER WITH FEEDBACK

We know with respect to this amplifier, if our assumptions as to the frequency controlling elements are correct, both the variation of gain and its reciprocal. Detailed plots are shown later with more accurate indication of frequency scales.

Holding this information for a moment, reference to Figure No. 3 gives us most of the pertinent relations for the general feedback amplifier. In particular one should note that the loop gain is BA, i.e., the gain from the grid-cathode input point, to the cathode ground output point. Also, that the gain with feedback is the (output) ÷ (the input without feedback plus the feedback voltage.) Both the input without feedback and the feedback voltage are referred to the same output. The reciprocal of the gain with feedback, and for the moment considering the output at unity, is simply the input without feedback plus the feedback voltage. The plot to the left shows both the response with and without feedback, i.e., the input voltage required in either case. All that is necessary is a shift of the reference origin. This holds for amplifiers with no-phase-shift feedback networks. In this case where the curve is the reciprocal of the gain; where the output is held constant; and the feedback voltage is a fraction of this output; the feedback voltage may be positioned to the left of the origin where it will be added to the input without feedback curve. The curve with reference to the origin is the response without feedback. With reference to a new origin at the left hand end of the feedback voltage vector, the curve represents the response with feedback. In this case where the feedback vector at mid-band is about 2.5 times the grid to cathode voltage, the input with feedback is 2.5 plus 1 or 3.5. This is, of course, the common 1 + BA factor. It may be seen that a given amplitude and phase increase without feedback results in a lesser amount with feedback. In general it may be said that negative feedback reduces both amplitude and phase variations.

DETAILED PLOTS OF RESPONSE

The treatment thus far has been quite general and only roughly quantitative. Figure No. 4 shows the reciprocal gain plot in greater detail. Here the loss and phase shift may be read off in terms of the single stage F_0 frequency. The inner curve is for a two stage amplifier with identical time

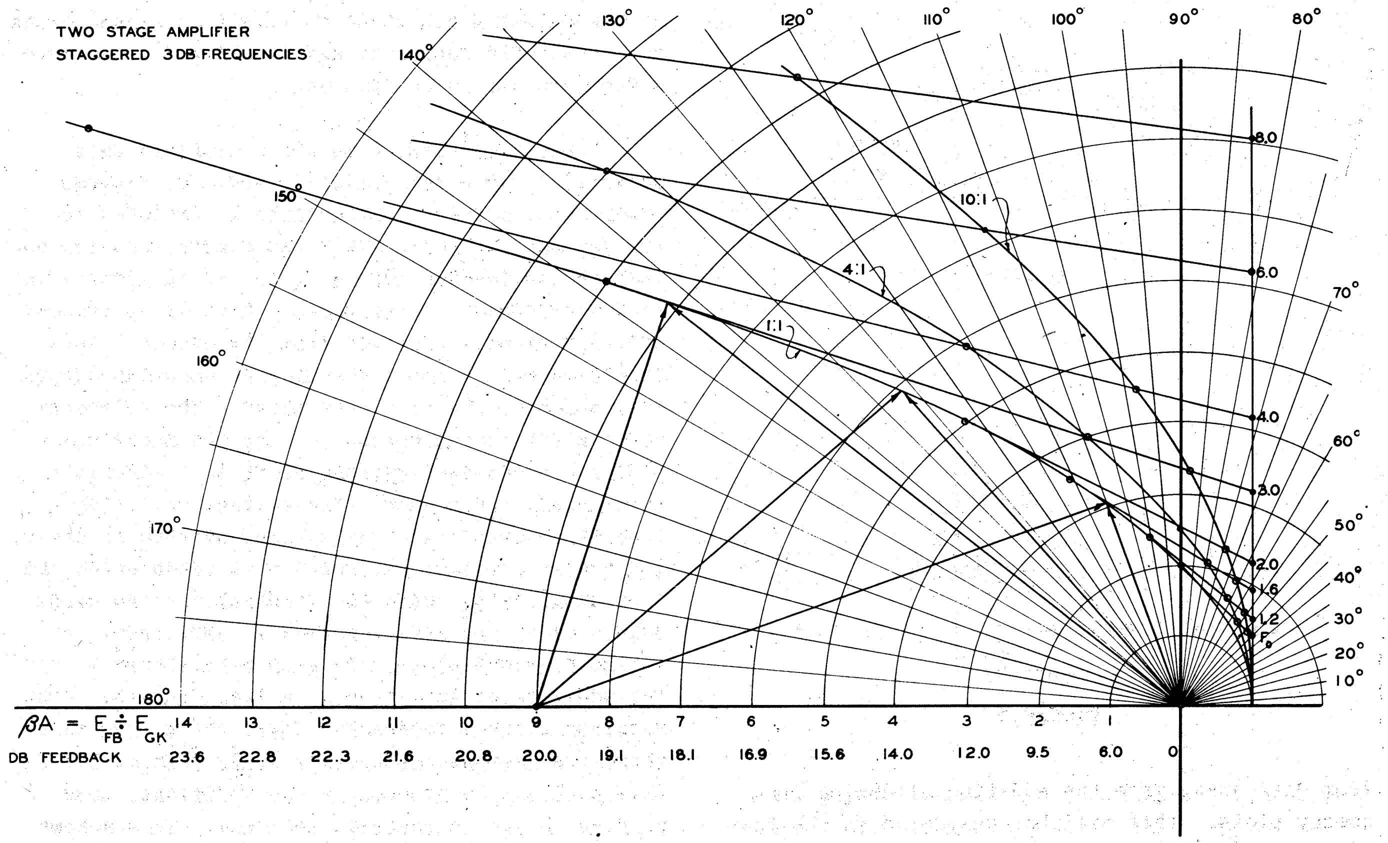


FIGURE 4

constants or F_o frequencies. The curves labeled 4:1 and 10:1 correspond to two stage amplifiers where the F_o of one of the stages is four times or ten times the other stage. F_o reference is to the poorest stage. This is referred to as staggering of the amplifier stages. The limiting case where one stage is without loss, i.e., has infinite bandwidth, the locus reduces to the vertical line, similar to Figure No. 1, which is the response reciprocal of the single stage. As one would expect, the curves have less loss and less phase shift when the F_o frequency of the wider-bandwidth stage is increased with respect to the F_o frequency of the poorer or reference stage. Frequency with respect to F_o is numbered on the single stage response vertical, and the intersecting lines running therefrom over to the curves of lesser staggering.

Turning our attention to the inner curve and viewing this with respect to the point corresponding to a feedback voltage of 9 times the mid-band input voltage without feedback, we note that at about 2.8 times F_o the vector or input with feedback drawn from point 9 has a minimum value. This corresponds to a maximum of the gain since this is a plot of its reciprocal and hence is a peak in the gain frequency response. This is a benefit of this type presentation; peaks such as these being immediately recognized. Also of note, are two other points on this two identical stage locus to which vectors have been drawn from point 9 and the origin. These are the infinite stability points or frequencies. A change in the forward gain, represented by a change in length of the vector from the origin (the input without feedback) produces little change in the input with feedback since the vectors are at right angles. This is true, of course, only for small angles. No change in phase is made since the variations are assumed to be caused by tube transconductance change. For two stage amplifiers of greater staggering these points will be closer, and for more than a critical amount they will merge and be lost. Should a greater amount of feedback be introduced it may be possible to once again have the vectors at right angles and hence produce one or two of these points.

The point 9 corresponds to 20 db feedback since 9 + 1 = 10 = 1 + BA. Decibles feedback appear below the BA or E_{fb}/E_{gk} scale. The curves may be plotted from trigonometric computations or

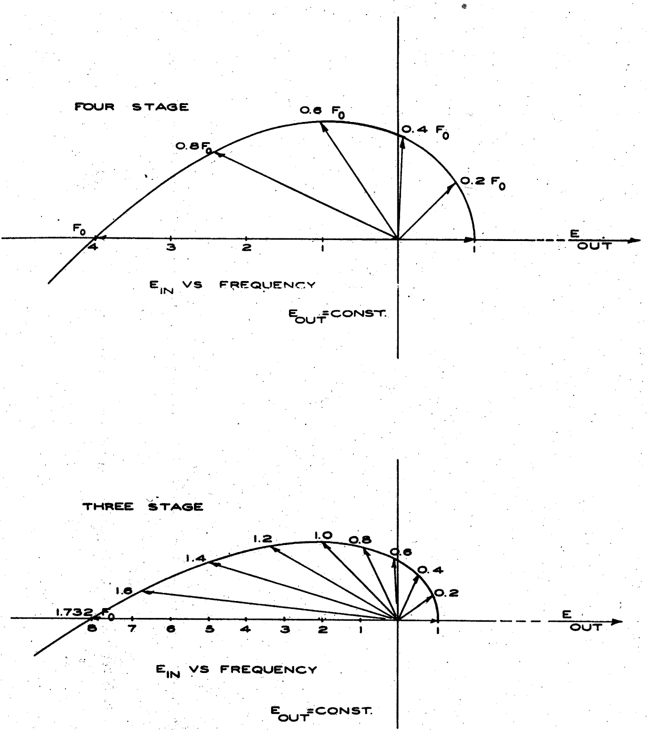


FIGURE 5

from data drawn from the addition of db-log frequency plots. This will be considered in the last part of this paper.

To illustrate how a feedback amplifier may become oscillatory, the curves of Fig. 5 have been included. These are representative of three and four stage amplifiers where the phase shift may exceed 180 degrees. Here it is apparent that if there is a gain of four in the case of the four stage amplifier or eight in the case of the three stage when the phase shift is 180, the amplifier will oscillate. For gains (loop gains) less than this extreme, peaks will occur in the gain response. If permissible, staggering of the amplifier stages will permit reasonable amounts of feedback to be introduced without excessive peaks or oscillation.

REACTIVE FEEDBACK NETWORKS

All plots thus far have been drawn on the basis of return circuits in which there is no phase shift over the frequency range considered. It has been shown that, thru the use of plots of the gain reciprocal, easy transference from response without feedback to response with feedback is achieved. Also that undesirable peaks may occur in the response with feedback. Thru the use of special feedback networks, which do have changes in transmission and phase vs frequency, these peaks or undesirable responses may be altered to achieve a response closer to optimum.

Depicted in Fig. 6 is the reciprocal gain curve of a two stage amplifier and the response which results when an inductance is included in the feedback circuit. This inductance produces an increase in feedback and a "lead" in the loop gain as the frequency is increased. Here it is assumed that a current is derived from the output. This is the case in current feedback or when the output is fedback thru a high resistance. The reference here is the output current. With the knowledge that for a constant current drive to the resistance-inductance network, the voltage will rise from its midband value of I_0R and advance in phase, the behavior may be represented as shown below the horizontal axis. Here the feedback voltage winds counterclockwise and increases in amplitude. As in the previous plots, the gain with feedback is the addition of the feedback voltage and the input required without feedback. Therefore we see that where the response ordinarily would peak at 2.8 F_0, this peak may be reduced by the additional loss produced by an increase in feedback. This scheme employing reciprocal plots is well suited to the study of reactive return circuits.

DEMONSTRATION

Fig. 7 shows the circuit of an amplifier that was demonstrated during the presentation of this paper. It is a three stage amplifier; tho as far as the feedback loop is concerned, it is only a two stage. The last stage simply acts as a cathode follower to return the feedback voltage. The transconductance of this last stage is stabilized, altho the amplifier is not stabilized against variations in the plate load. Provision is made in this amplifier for staggering of the stages by adding capacitance to one or the other stages in varying degrees. Using an audio sweep generator and setting the capacitors equal, the feedback was set to produce the aforementioned peak in response. Characteristics were viewed on a cathode ray oscillograph. It was shown that inclusion of an inductance in the feedback network effectively reduced the peak and flattened the response. Also, shunting the feedback resistor with a capacitor and thereby introducing additional lag in the system so that the phase might exceed 180, produced an oscillator. Staggering of the stages, by having

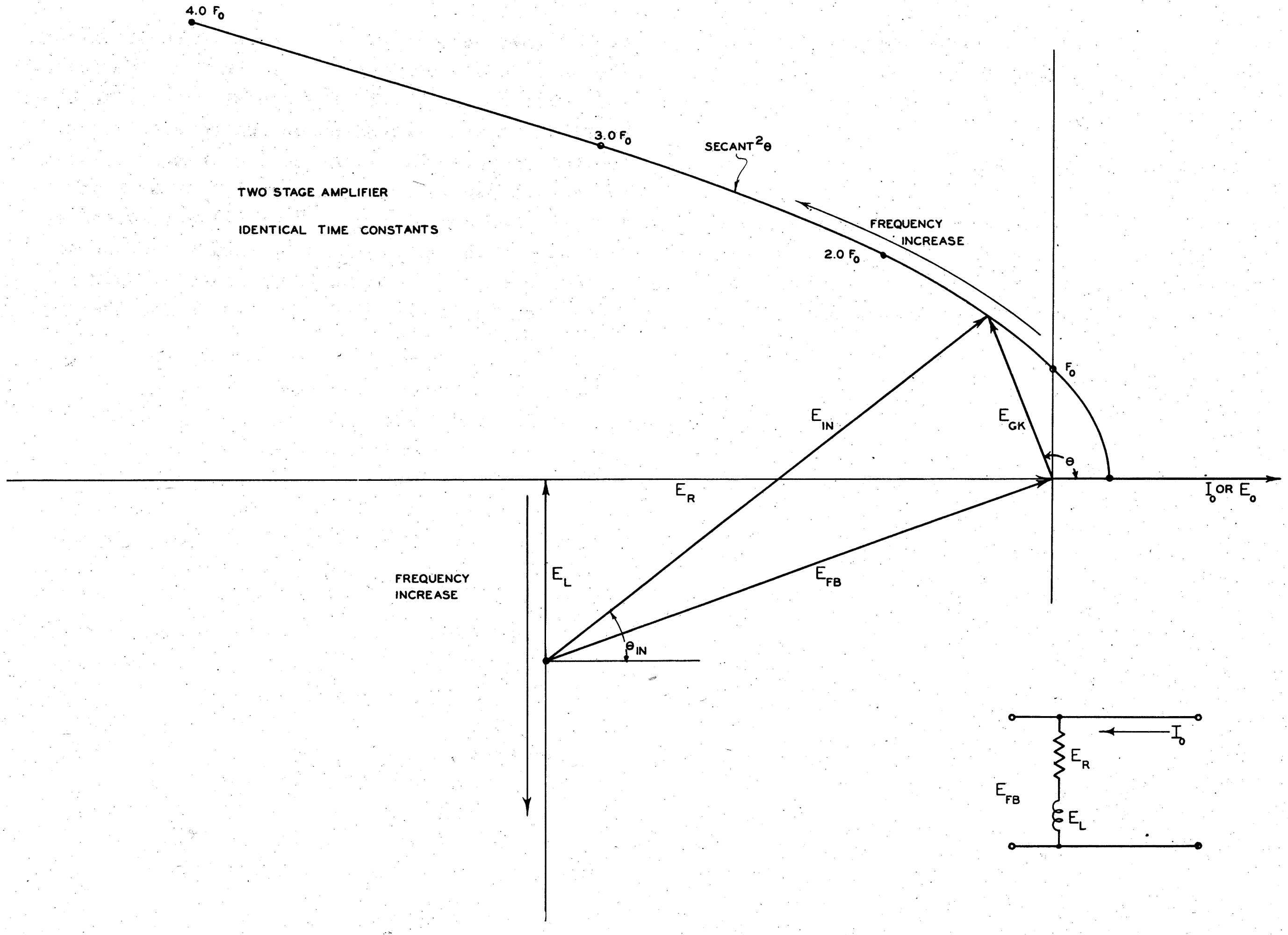


FIGURE 6

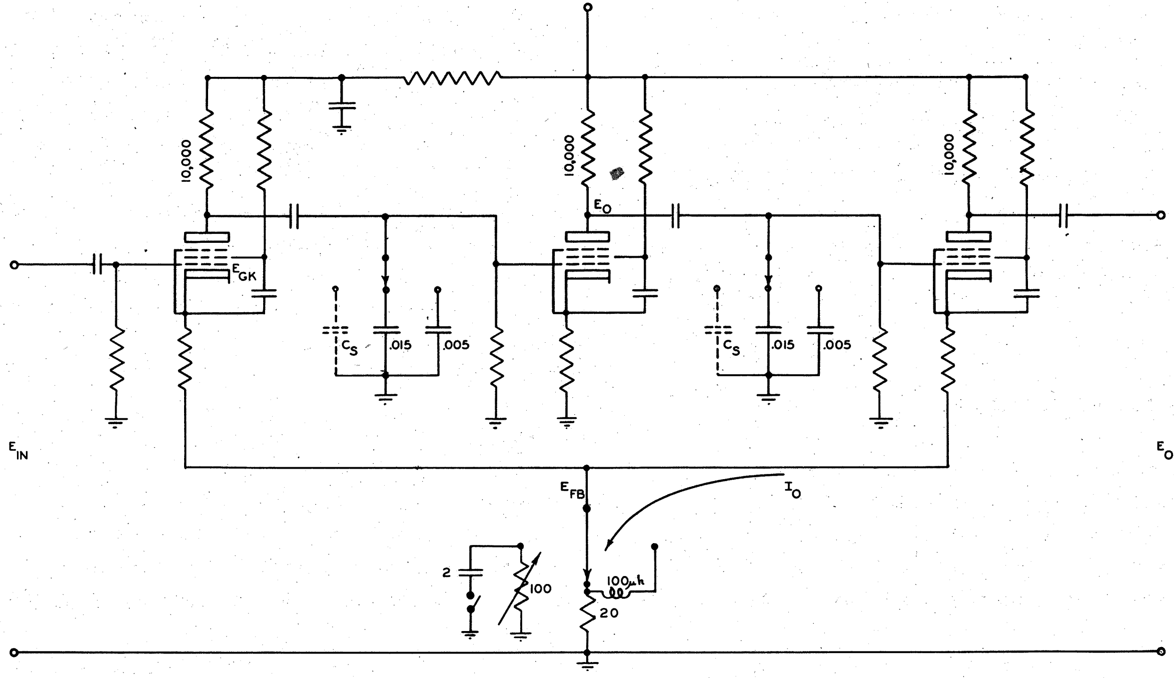


FIGURE 7

unequal capacitors, also was demonstrated as a solution to peak reduction problem.

CALCULATION OF PHASE SHIFT

Many times it is difficult to measure phase shift, and it may be too laborious or impossible to calculate because of circuit parameters which are difficult to measure. Fig. 8 demonstrates a method that is possibly of use in these situations. The only requirement is that it must be possible to introduce feedback into the system with an accurate knowledge of the transmission characteristics of the return network. With the requirement fulfilled, a response is run on the amplifier with and without feedback and the reciprocal determined and plotted. With the amount of feedback known, two vectors are positioned on the horizontal axis representing the input without feedback and the feed-

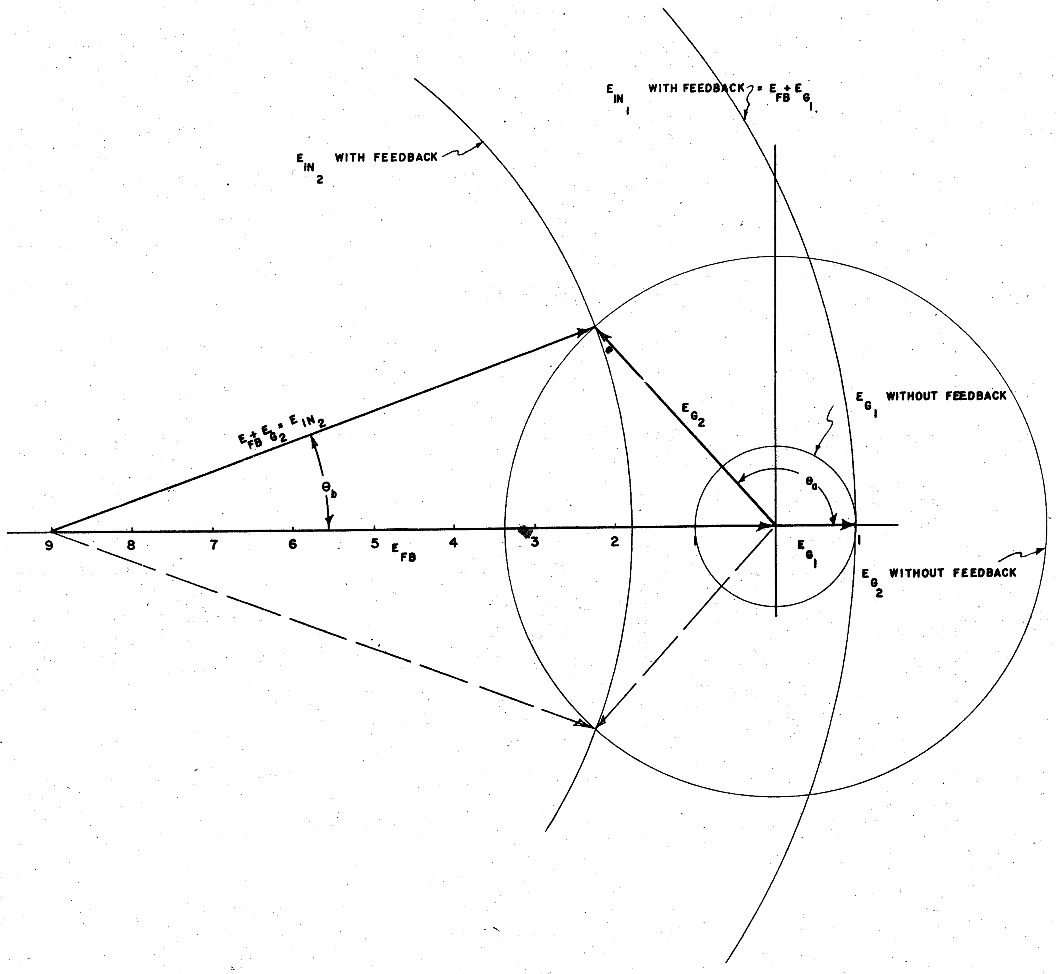


FIGURE 8

back voltage at some frequency where there is known to be a flat response and/or no phase shift. Then circles of the input with and without feedback are drawn. The intersection determines the phase shift of the amplifier with and without feedback. There are two points of course. One corresponds to the high frequency end of the response, the other to a similar situation at the low end. It may be necessary to properly select the amount of feedback so that good resolution is attained.

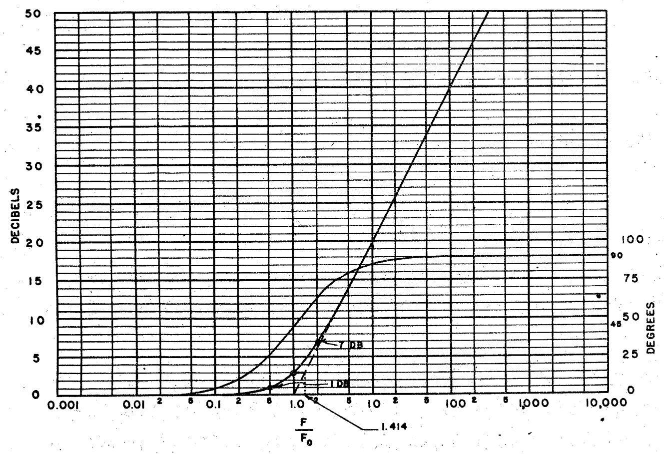


FIGURE 9

CONSTRUCTION OF CURVES FROM DB-LOG FREQUENCY PLOTS

Fig. 9 shows the reciprocal response of a single RC network plotted in terms of decibels and log of the frequency. The plot is a normalized one, since frequency has been referred to F_O. Of note is that at F_O (F/F_O = 1) the input is 3 db up and the phase is 45 degrees. Beyond about F/F_O = 3 the curve rises at 6 db/octave. The curve may be constructed by first drawing the asymptote; then a point 1 db above the asymptote at one octave below F_O and 1 db above the asymptote at one octave above F_O.

Use of this curve to determine the response of a two stage amplifier with 10:1 staggering is shown in Fig. 10. Here appear two of the curves separated by 10 in frequency. They are added, since addition of the logs is multiplication of single stage numeric responses. An approximate curve may be more quickly drawn from just the asymptotes. The staggered response falls at 6 db/octave at F_O and 12/octave at 10 F_O. Conversion to straight gain reciprocal must be carried out before a polar locus can be constructed. This is simply done by cross-reference to a 6 db/octave (20 db / decade) line drawn on the plot of Fig. 10. In this case it could be the asymptote. As an example, where the response is 3 db up, running over to the asymptote, then down to the frequency scale (which is now to be conceived in terms of voltage gain) we find a 1.414 gain increase.

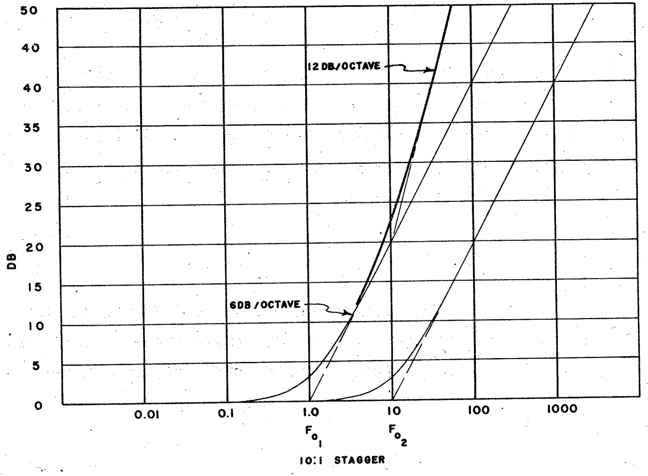


FIGURE 10

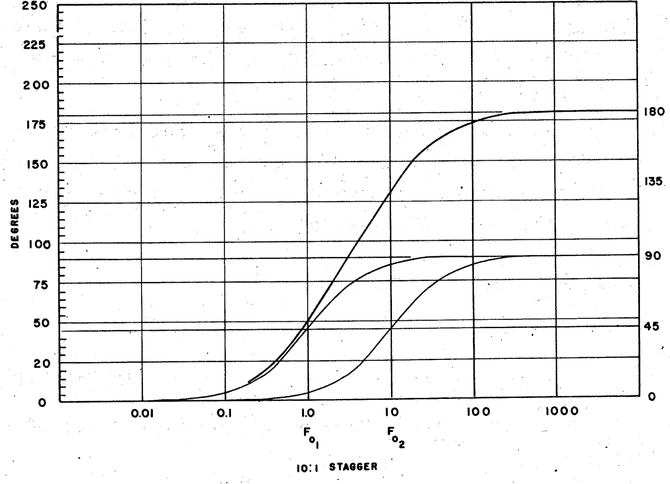


FIGURE 11

Fig. 11 shows 10:1 staggering of the phase curves. With these and the information of Fig. 10 a curve similar to one for 10:1 stagger shown in Fig. 4 may be constructed.

ACKNOWLEDGMENT - The author wishes to express his appreciation to F.H.Shepard,Jr. for his assistance during the preparation of this paper; to W.A.Knoop for some of the equipment used during the demonstration, and, of course, to Ballantine Laboratories for a full measure of opportunity and encouragement.

"SURVEY OF RADIO-FREQUENCY TRANSMISSION LINES AND WAVE GUIDES"

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The Board of Directors has increased the price of the large Transmission Line Issue of the Proceedings to $1.50 per copy. Unfortunately the copy was set up and in the hands of the printer before the Board made this decision, consequently Volume 28, No. 2 carried our usual price notice of fifty cents per copy. Your editor regrets any confusion arising from this error.

NEW MEETING PLACE

A new meeting place has been investigated and was used for the April meeting. It is the General Electric Auditorium located at 51st Street and Lexington Ave. in New York City. A Child's restaurant is located in the building. Some members had dinner prior to the meeting in this restaurant.

Reprinted from New York Herald Tribune, Jan. 23, 1952

HUMAN NATURE TO BLAME

To the New York Herald Tribune:

I have been a licensed radio amateur for many years.

After World War I United States radio amateurs with their short-wave transmitters, and due to improved technological progress, were able to communicate with other radio amateurs in almost every part of the world.

The thought at that time was that this would foster international friendships, cement good will between foreign countries and go a long way toward preventing further wars. As you well know it did nothing of the kind. Since then we have had World War II, and it looks as thought we are getting ready for World War III, despite the fact that amateurs are still conducting two-way radio communication throughout the world.

I don't want to be a sourpuss, but in the future let's remember that scientific achievement, etc., is not what prevents war or causes war. The trouble is still inherent with human nature. Until we can change the mental reasoning of men so they will no longer be motivated by greed, there can be no "Peace on earth, good will toward man."

CHARLES F. JACOBS

New York, Jan. 18, 1952.

ANNUAL RADIO CLUB BANQUET

The 42nd Annual Banquet of The Radio Club of America was held on December 4, 1951 at the Advertising Club of America.

Dr. Millard C. Faught, president of The Faught Co., Inc. of New York City was the guest speaker. Dr. Faught spoke on the subject "Radio and Television - Why?"

The theme of Dr. Faught's most interesting talk may be briefly summarized in this excerpt:

> "We have, out of habit, looked on radio - and now television - as notable advances in the art of communication. But, as suggested previously, they are obviously also channels of distribution - and indeed for most commodities of knowledge and entertainment, they are excellent vehicles, instantaneous and unhampered by traffic jams, weather, shortage of baby sitters, and the like. Television is next best to being present in the flesh at the scene of origin of all manner of programs - and it renders unnecessary the moving of one's flesh beyond the family living room.
>
> This is truly a notable step forward in distribution or the "marketing" of all manner of products consumable through the eyes, ears and mind. Moreover, television is ideally suited to conveying those very commodities, the present enjoyment of which requires the taking of the consumer to the product.
>
> But, there is still lacking one factor, and a highly essential one, before the communications marvel of television can be exploited as an electronic distribution system. There has to be a way of collecting for the commodities so delivered, at the receiving end of the broadcast".

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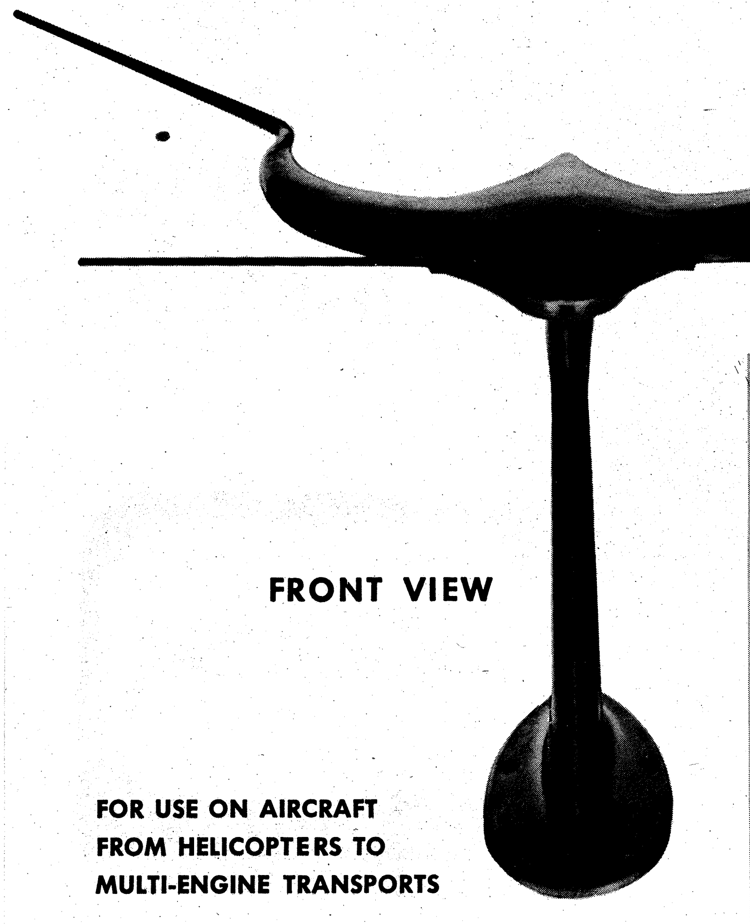

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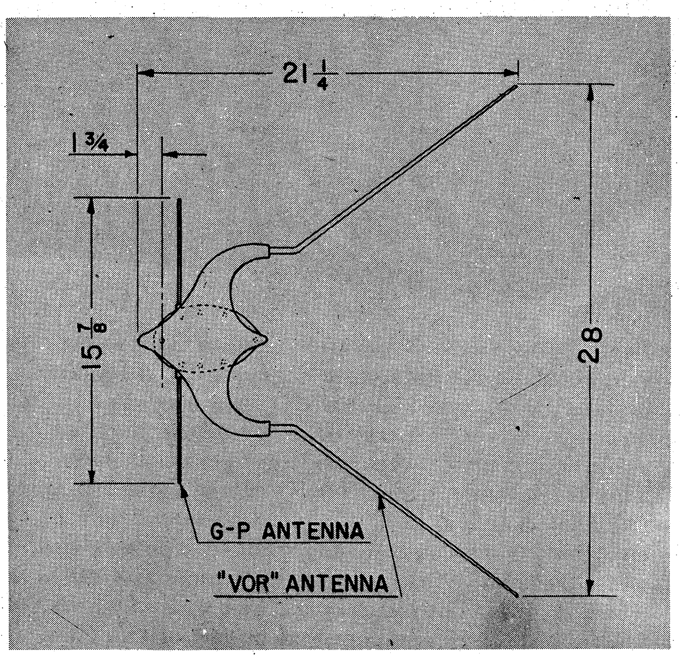
FRONT VIEW



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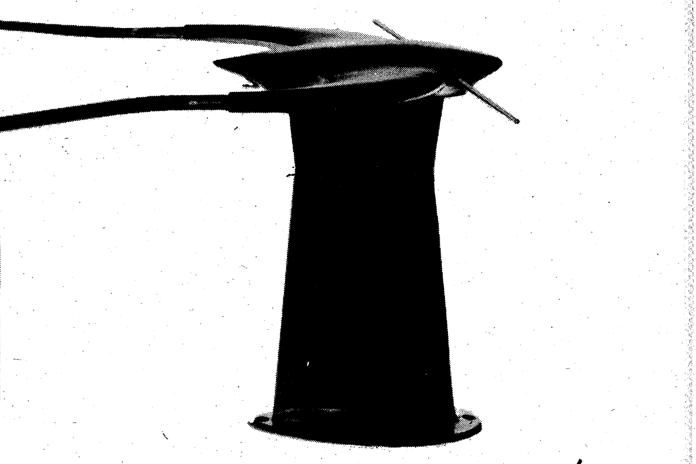

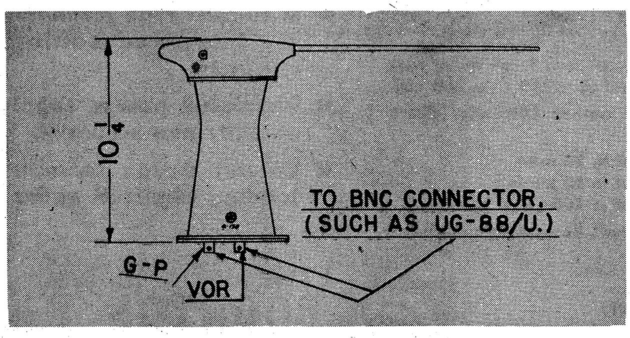

SIDE VIEW

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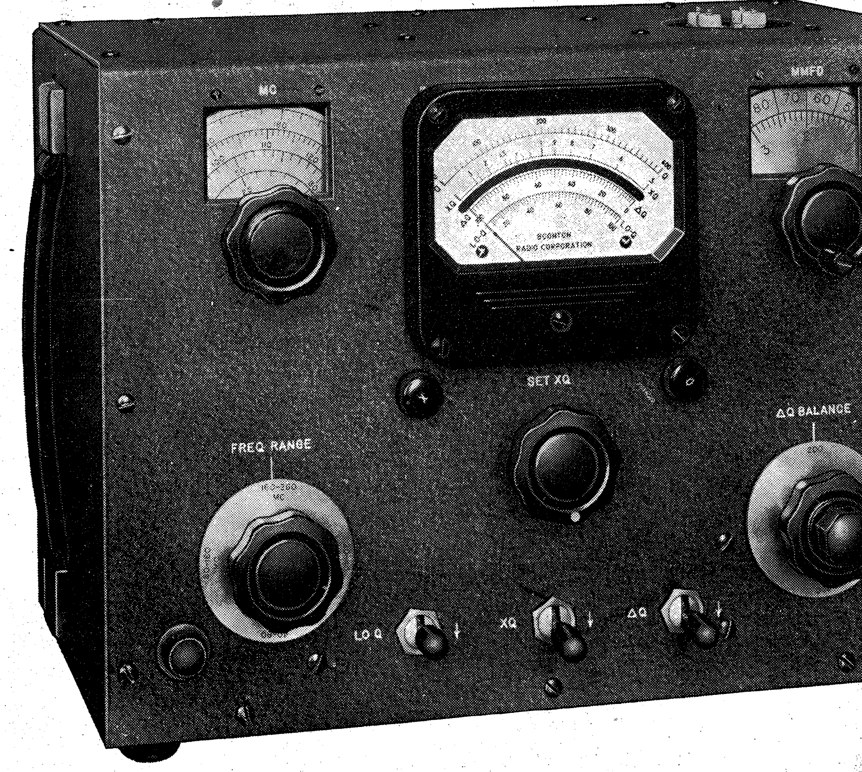
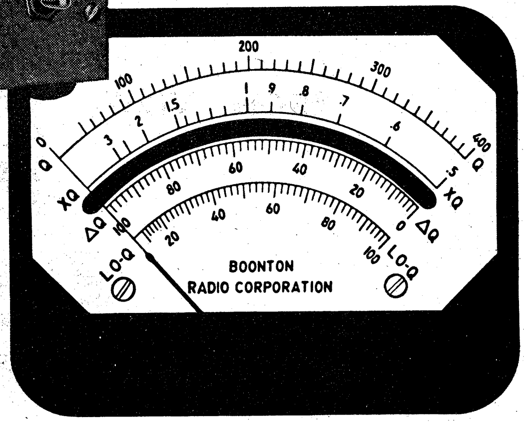
Measure Differential Q

with The Q METER Type 190-A





In Designing Tuned Circuits the effect on Q of adding capacitors, iron cores, or resistors must frequently be determined. The Q of the separate components is also often needed. These measurements made on Q Meters formerly available required the use of a small difference between two large Q values in various formulæ. This led to large errors. The Q Meter Type 190-A reads the difference between the Q of a reference circuit and the Q of this circuit when new components are added. The scale that indicates this *Differential Q* has a sensitivity 4 times as great as the scale which reads *Q*. The accuracy and ease with which *Differential Q* can be read is greatly improved by use of the *190-A Q Meter.*

The Q Meter Type 190-A has a "Lo Q" scale which reads Q down to a value of 5. The internal resonating capacitor is directly read and has a vernier arrangement for accurate reading of capacitance. The dial rotates approximately 10 times in covering the capacitance range. All readings are made on a single meter corrected for parallax.

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SINGLE, EASY-TO-READ METER WITH PARALLAX CORRECTION FOR ALL FUNCTIONS

- Q indicating voltmeter: 50 to 400.
- Multiply Q scale: 0.5 to 3.0.
- A differential Q scale for accurately indicating the difference in Q between two test circuits.
- Additional accurate expanded scale for measuring low values of Q.
- A counter type resonating capacitor dial for improved setting and reading accuracy.
- Regulated power supply for increased stability and accuracy.
- Careful design to minimize instrument loading of circuit under test.

BRC

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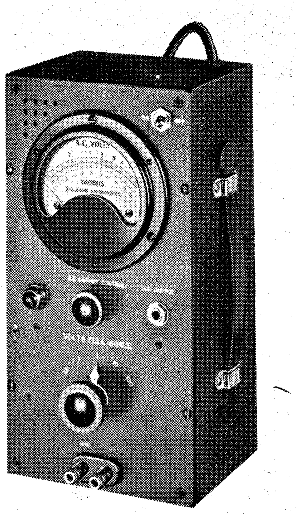
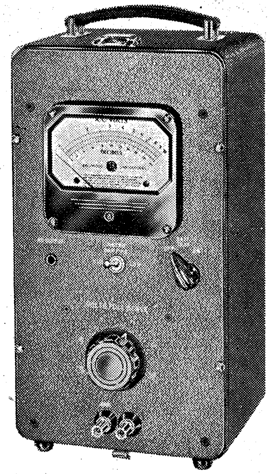
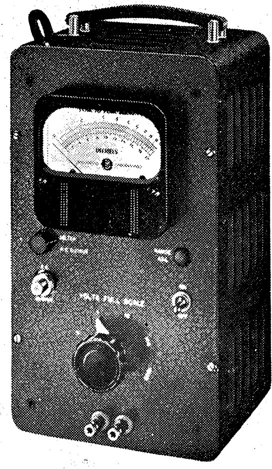
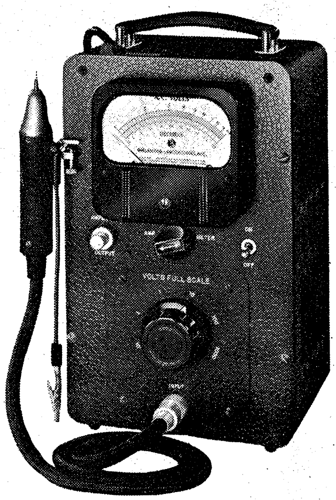
BALLANTINE

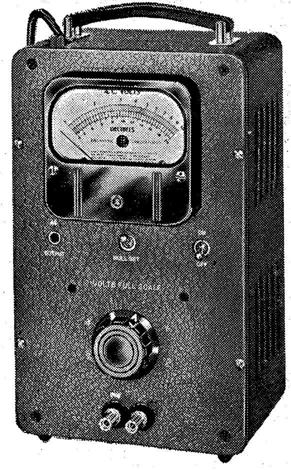
STILL THE FINEST IN ELECTRONIC VOLTMETERS


MODEL 300

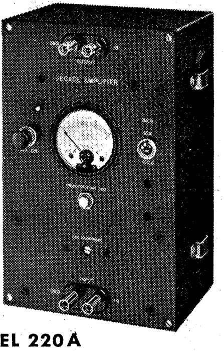

MODEL 302B

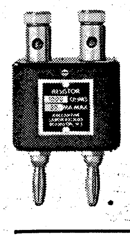

MODEL 305


MODEL 314


MODEL 310A

MODEL	FREQUENCY RANGE	VOLTAGE RANGE	INPUT IMPEDANCE	ACCURACY
300	10 to 150,000 cycles	1 millivolt to 100 volts	1/2 meg. shunted by 30 mmfds.	2% up to 100 KC 3% above 100 KC
302B Battery Operated	2 to 150,000 cycles	100 microvolts to 100 volts	2 megs. shunted by 8 mmfds. on high ranges and 15 mmfds. on low ranges	3% from 5 to 100,000 cycles; 5% elsewhere
305	Measures peak values of pulses as short as 3 microseconds with a repetition rate as low as 20 per sec. Also measures peak values for sine waves from 10 to 150,000 cps.	1 millivolt to 1000 volts Peak to Peak	Same as Model 302B	3% on sine waves 5% on pulses
310A	10 cycles to 2 megacycles	100 microvolts to 100 volts	Same as Model 302B	3% below 1 MC 5% above 1 MC
314	15 cycles to 6 megacycles	With probe, 1 millivolt to 1000 volts. Without probe, 100 microvolts to 1 millivolt	With probe, 11 megs. shunted by 6 mmfds. Without probe, 1 meg. shunted by 25 mmfds.	3% except 5% above 3 megacycles


MODEL 220A BATTERY OPERATED DECADE AMPLIFIER gives exact voltage gains of 10 or 100, permitting a corresponding increase in voltmeter sensitivity from 10 to 150,000 cycles.

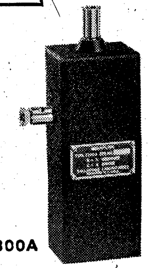


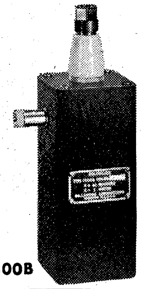
PRECISION SHUNT RESISTORS

Four different types of Precision Shunt Resistors, varying from 1 to 1000 ohms, permit the Voltmeters to be used to measure currents from 1 ampere to one-tenth of a microampere.

MULTIPLIERS

Five different types of Multipliers, whose input resistance varies from 5 to 40 megohms, permit the voltage range of the Voltmeters to be increased 10 or 100 times.


1300A


1300B

BALLANTINE pioneered circuitry and manufacturing integrity assure the maximum in

SENSITIVITY • ACCURACY • STABILITY

- All models have a single easy-to-read logarithmic voltage scale and a uniform DB scale.
- The logarithmic scale assures the same accuracy at *all* points on the scale.
- Multipliers, decade amplifiers and shunts shown above extend range and usefulness of voltmeters.
- Each model may also be used as a wide-band amplifier.

For further information, write for catalog

BALLANTINE LABORATORIES, INC.

BOONTON, NEW JERSEY, U. S. A.

MEASUREMENTS CORPORATION

Laboratory Standards

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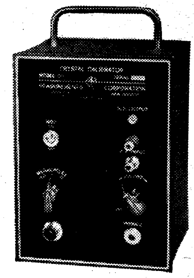
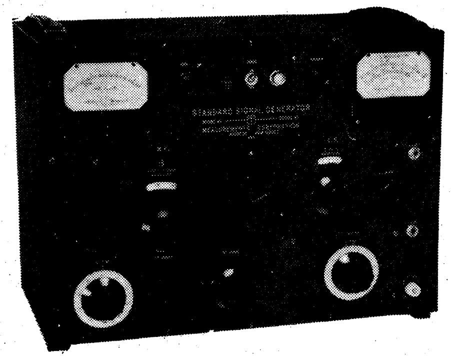
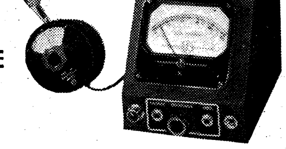


CRYSTAL
CALIBRATOR
Model 111
250 Kc. to 1000 Mc.

U. H. F. OSCILLATOR
Model 112
300 Mc. to 1000 Mc.



STANDARD SIGNAL GENERATOR
Model 82
20 Cycles to 50 Mc.



MEGACYCLE
METER
Model 59
2.2 Mc. to 400 Mc.

STANDARD SIGNAL GENERATORS

MODEL	FREQUENCY RANGE	OUTPUT RANGE	MODULATION
65-B	75 Kc.-30 Mc.	0.1 microvolt to 2.2 volts	AM. 0 to 100% 400 cycles or 1000 cycles External mod., 50-10,000 cycles
78	15-25 Mc.; 195-225 Mc. 15-25 Mc.; 90-125 Mc. other ranges on order	1 to 100,000 microvolts	AM. 8200-400 cycles 625-400 cycles Fixed at approximately 30%
78-FM	86 Mc.-108 Mc.	1 to 100,000 microvolts	Deviation 0-300 kc, 2 ranges FM. 400-8200 cycles, External modulation to 15 Kc.
80	2 Mc.-400 Mc.	0.1 to 100,000 microvolts	AM. 0 to 30% 400 cycles or 1000 cycles External mod., 50-10,000 cycles.
82	20 cycles to 200 Kc. 80 Kc. to 50 Mc.	0-50 volts 0.1 microvolt to 1 volt	Continuously variable 0-50% from 20 cycles to 20 Kc.
84	300 Mc.-1000 Mc.	0.1 to 100,000 microvolts	AM. 0 to 30%, 400, 1000, or 2500 cycles. Internal pulse modulator. External mod., 50-30,000 cycles.
90	20 Mc.-250 Mc.	0.3 microvolt to 0.1 volt	Continuously variable, 0 to 100% Sinusoidal modulation 30 cycles-5 Mc. Composite TV modulation.

U.H.F. OSCILLATOR

MODEL	FREQUENCY RANGE	OUTPUT RANGE	OUTPUT IMPEDANCE
112	300 Mc. — 1000 Mc.	Maximum varies between 0.3 volt and 2 volts. Adjustable over 40 db range.	50 ohms

PULSE GENERATOR

MODEL	FREQUENCY RANGE	PULSE WIDTH	OUTPUT
79-B	60 to 100,000 cycles	Continuously variable from 0.5 to 40 microseconds	Approximately 150 volts positive with respect to ground. "Sync Output" 75 volts positive with respect to ground.

SQUARE WAVE GENERATOR

MODEL	FREQUENCY RANGE	WAVE SHAPE	OUTPUT
71	Continuously variable 6 to 100,000 cycles	Rise time less than 0.2 microseconds with negligible overshoot	Step attenuator: 75, 50, 25, 15, 10, 5 peak volts fixed and 0 to 2.5 volts continuously variable.

U.H.F. RADIO NOISE and FIELD STRENGTH METER

MODEL	FREQUENCY RANGE	INPUT VOLTAGE RANGE
58	15 Mc. to 150 Mc.	1 to 100,000 microvolts in antenna. 1 to 100 microvolts on semi-logarithmic output meter, balanced resistance attenuator with ratios of 10, 100 and 1000 ahead of all tubes.

VACUUM TUBE VOLTMETERS

MODEL	VOLTAGE RANGE	FREQUENCY RANGE	INPUT IMPEDANCE
62	0-1, 0-3, 0-30 and 0-100 volts AC or DC	30 cycles to over 150 Mc.	Approximately 7 mmfd.
62-U.H.F.	0-1, 0-3, 0-30 and 0-100 volts AC or DC	100 Kc. to 500 Mc.	Approximately 2 mmfd.
67	.0005 to 300 volts peak-to-peak	5 to 100,000 sine-wave cycles per second	1 megohm shunted by 30 mmfd.

MEGACYCLE METER

MODEL	FREQUENCY RANGE	FREQUENCY ACCURACY	MODULATION
59	2.2 Mc. — 400 Mc.	Within ±2%	CW or 120 cycles fixed at approximately 30%. Provision for external modulation

CRYSTAL CALIBRATOR

MODEL	FREQUENCY RANGE	FREQUENCY ACCURACY	HARMONIC RANGE
111	250 Kc. — 1000 Mc.	0.001%	.25 Mc. Oscillator: .25-450 Mc. 1 Mc. Oscillator: 1-600 Mc. 10 Mc. Oscillator: 10-1000 Mc.

BRIDGES

MODEL	INDUCTANCE (L)	CAPACITANCE (C)	AC RESISTANCE (R)
102	0.5 microhenry to 110 henries	1 mmf. to 110 mfd. Power factor 0-30%	1 ohm to 11 megohms

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