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REPORT No. R-1035

DATE 8 March 1934

SUBJECT

Pre-selector Circuits

S67/46 3-8

BUREAU OF ENGINEERING
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BY

NAVAL RESEARCH LABORATORY
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NAVY DEPARTMENT

BUREAU OF ENGINEERING

Report on

Pre-selector Circuits

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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Approved by:	H. R. Greenlee, Captain, U.S.N., Director
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APPENDICES

Nine plates showing selectivity of the circuits as schematically diagrammed on each plate.

I AUTHORIZATION

The work reported upon herein deals with the investigation of pre-selector circuits and is a part of the work authorized by Bureau of Engineering letter S67/46(2-27-W8) of 14 April 1933.

II OBJECT

Investigation of pre-selection circuits suitable for use preceding the first tube of a receiver and having for their purpose the protection of the first tube against overloads produced by the operation of near-by transmitters on frequencies near to the resonant frequency of the receiver. The additional purposes of a suitable pre-selector circuit are to improve the selectivity of the receiver and to improve the signal-to-external noise ratio. This investigation is a part of Problem R5-7 assigned by the subject authorization and having for its object, "the investigation, and design and model construction of new shipboard radio receiving equipment to better fill the needs of the Naval Service in the light of improvements in the radio art".

This objective was not attained for the reason that the problem was cancelled. Such tests as were completed are reported herein.

III DESCRIPTION OF TESTS

Tests were conducted on two general types of pre-selector circuits; namely, (a) circuits consisting of a parallel tuned circuit placed in series with the antenna input terminal for the purpose of presenting a large impedance to currents of the undesired frequency, to which frequency the pre-selector circuit is made parallel resonant; (b) circuits wherein a signal equal in amplitude and in phase opposition to the undesired signal is introduced in the receiver input so as to balance out the undesired signal.

Computations were made of the parameters of a pre-selector circuit consisting of three cascaded and inductively coupled tuned circuits. Experimental confirmation of the excellence of such a pre-selector, as indicated by the computations, could not be obtained because of the cancellation of the problem.

IV METHOD OF CONDUCTING TESTS

(a) The schematic wiring diagram of the first pre-selector circuit tested appears on Plate 1. The inductance of each tuned circuit consisted of 230 microhenries. The effective resistance of each at 600 kilocycles was 4.3 ohms. The computed "Q" is, therefore, 202.

The test signal E_1 consisted of a 600 kilocycle carrier modulated 30% by 1,000 cycles. The test signal was first applied to the grid of the first tube of a broadcast receiver and the broadcast receiver tuned and adjusted so that an arbitrary standard audio output was obtained when $E_1 = 100$ microvolts. The grid of the first tube (hereinafter termed the receiver input) was then connected at E_2.

In order to resonate circuit 2, a large non-inductive resistor was temporarily inserted in place of circuit #1. Circuit 2 was then resonated for maximum receiver output.

The signal E_1 was again connected to the receiver input, its frequency increased by 1% and the receiver resonated to this frequency. The receiver input was then reconnected at E_2 and the signal generator reconnected at E_1 and circuit 1 was tuned to produce a minimum receiver output which was equivalent to a minimum E_2.

In this manner, the receiver was used as a vacuum tube voltmeter to indicate that the voltage E_2 was maintained constant at 100 microvolts. The signal E_1, necessary to produce $E_2 = 100$ uv, was read direct from the attenuator of the signal generator. The necessity for retuning the receiver and for adjusting its volume control to maintain standard sensitivity (100 uv) at each frequency used, made testing rather laborious, but an ordinary vacuum tube voltmeter would have had so little sensitivity as to require greater signal voltages at E_1, than could be obtained conveniently.

The data obtained in this manner consisted of the values of signal voltage E_1 required to maintain E_2 constant at 100 microvolts at frequencies differing from resonant frequency by given percents.

In order that all such "selectivity curves" might be directly comparable, it was desirable that the value of E_1 at resonance should be 1 microvolt in all cases. For this reason, each value of E_1 and its accompanying value of E_2 for each frequency was divided by the value of E_1 at resonance. In consequence, all curves will have a common origin at $E_1 = 1$ at resonance and the curves will represent the value of E_1 necessary to maintain E_2 constant at the value $\frac{\text{100 microvolts}}{E_1 \text{(at resonance)}}$. This constant value of E_2 is noted on each curve plate.

(b) The schematic wiring diagram of the second pre-selector circuit tested appears on Plate 2. The method of test is identical with that described in par. IV (a).

(c) In the case of the circuit appearing on Plate 4, it was found that a dip appeared in the curve at frequencies less than 600 kilocycles - 2%. The lower frequency limit of the receiver was 600 kilocycles - 6%. For this reason, the resonant test frequency was changed from 600 kilocycles to 700 kilocycles and the same circuit arrangement used at the new frequency as shown on Plate 5.

(d) The schematic wiring diagram of the "phase matching" or "balanced" pre-selector appears on Plate 8. In this test, circuits 2 and 3 were tuned to produce a maximum E_3 at resonant frequency with the tube "VT" inoperative.

Next the tube "VT" was made operative, the frequency of E_1 set at the undesired signal frequency, and the potentiometer R_2 varied together with the tuning of the plate circuit #1, which was loosely coupled to circuit #3 until a minimum voltage was obtained at E_3.

(e) The schematic wiring diagram of a three circuit inductively coupled, cascaded, pre-selector circuit appears on Plate 9. The time available did not permit this circuit to be set up and tested. However, an attempt was made to predict the amount of selectivity obtainable from such a circuit in the following manner:

$$\text{Let } R + J\left(\omega L - \frac{1}{\omega C}\right) = Z_1 = R + J\left(X_L - X_C\right) \tag{1}$$

$$\text{Let } + J\omega KL = Z_2 = +JKX_L \tag{2}$$

The circuit diagram on Plate 9 is divided into sections labeled A to E. Each of the following impedances, with subscripts A to E, represent the impedance between the lines cut by section so indicated when looking into the network to the right of the section indicated. The voltages E with subscripts from A to E represent the voltage existing between lines at the point cut by the section, resulting from the application of E_1 at the input.

$$Z_A = Z_1 \tag{3}$$

$$Z_B = \frac{Z_1 Z_2}{Z_1 + Z_2} \tag{4}$$

$$Z_C = \frac{Z_1(Z_1 + 2Z_2)}{Z_1 + Z_2} \tag{5}$$

$$Z_D = \frac{Z_1 Z_2 (Z_1 + 2Z_2)}{Z_1^2 + 3Z_1 Z_2 + Z_2^2} \tag{6}$$

$$Z_E = \frac{Z_1(Z_1 + Z_2)(Z_1 + 3Z_2)}{Z_1^2 + 3Z_1 Z_2 + Z_2^2} \tag{7}$$

$$I_1 = \frac{E_1}{Z_E} = \frac{E_1(Z_1^2 + 3Z_1 Z_2 + Z_2^2)}{Z_1(Z_1 + Z_2)(Z_1 + 3Z_2)} \tag{8}$$

$$E_D = I_1 Z_D = \frac{E_1 Z_2 (Z_1 + 2Z_2)}{(Z_1 + Z_2)\ (Z_1 + 3Z_2)} \tag{9}$$

$$E_C = E_D \tag{10}$$

$$I_2 = \frac{E_C}{Z_C} = \frac{E_1\ Z_2}{Z_1 (Z_1 + 3Z_2)} \tag{11}$$

$$E_B = I_2\ Z_B = \frac{E_1\ Z_2^2}{(Z_1 + Z_2)(Z_1 + 3Z_2)} \tag{12}$$

$$E_A = E_B \tag{13}$$

$$I_3 = \frac{E_A}{Z_A} = \frac{E_1\ Z_2^2}{Z_1 (Z_1 + Z_2)(Z_1 + 3Z_2)} \tag{14}$$

$$E_3 = I_3 X_C = \frac{E_1 Z_2^2 X_C}{Z_1 (Z_1 + Z_2)(Z_1 + 3Z_2)} \tag{15}$$

From equations (1) and (2)

$$|Z_2|^2 = (KX_L)^2 \tag{16}$$

$$|Z_1| = \left[R^2 + (X_L - X_C)^2\right]^{1/2} \tag{17}$$

$$|Z_1 + Z_2| = \left[R^2 + (X_L - X_C + KX_L)^2\right]^{1/2} \tag{18}$$

$$|Z_1 + 3Z_2| = \left[R^2 + (X_L - X_C + 3KX_L)^2\right]^{1/2} \tag{19}$$

Substituting equations (16) to (19) in equation (15) produces:

$$E_3 = \frac{E_1\ (KX_L)^2\ X_C}{\left[R^2 + (X_L - X_C)^2\right]^{1/2} \left[R^2 + (X_L - X_C + KX_L)^2\right]^{1/2} \left[R^2 + (X_L - X_C + 3\ KX_L)^2\right]^{1/2}} \tag{20}$$

Here X_L and X_C depend on frequency. In the near vicinity of that frequency which makes X_L equal X_C, a small percent increase in frequency causes X_L to increase by the same small percentage and causes X_C to decrease by the same small percentage. (Error in last statement is negligible for changes in frequency as large as 10%.) However, this same small percentage increase of frequency causes a tremendous change in the value of $X_L - X_C$. In fact, if "P" represents the percentage change in frequency (expressed as a decimal) from that frequency which makes $X_L - X_C = 0$, then the value of the term $X_L - X_C$ becomes 2PX where X is the reactance of the inductance or the capacity at that frequency which makes $X_L - X_C = 0$.

Now, calling "X" a constant (because it changes so little compared to $X_L - X_C$) we may rewrite equation (20) as follows:

$$E_3 = \frac{E_1 K^2 X^3}{\left\{\left[R + (2PX)^2\right]\left[R^2 + (2PX + KX)^2\right]\left[R^2 + (2PX + 3KX)^2\right]\right\}^{1/2}} \qquad (21)$$

It is usually more convenient to plot the value of E_1, required to maintain E_3 constant, for various values of P. This equation is obtained by inverting equation (21) as follows:

$$E_1 = \frac{E_3\left\{\left[R^2 + (2PX)^2\right]\left[R^2 + (2PX + KX)^2\right]\left[R^2 + (2PX + 3KX)^2\right]\right\}^{1/2}}{K^2 X^3} \qquad (22)$$

A selectivity curve of a typical three circuit pre-selector of this type is plotted on Plate 9. A voltage gain of 11.4 (E_3 / E_1) is obtained at resonance, while the input voltage required to maintain the same E_3 at 0.5% off resonance is 8.2 times that required at resonance. This represents good selectivity.

Referring to equation (22), it is unfortunate that E_1 is not a minimum when $P = 0$, that is when $X_L - X_C = 0$, as this coincidence would simplify plotting. However, E_1 is a minimum in the vicinity of $P = -\frac{K}{2}$, the exact value of P which makes E_1 a true minimum depends upon the values of R and X. The exact value of P could be found by differentiating equation (22) with respect to P and by equating $dE_1/dp = 0$.

Certain simplifications will assist in this differentiation. It should be noted that E_1 will be a minimum when the value of the terms within the curl brackets is a minimum. To simplify writing this equation, we will write the terms inside the curl bracks as follows:

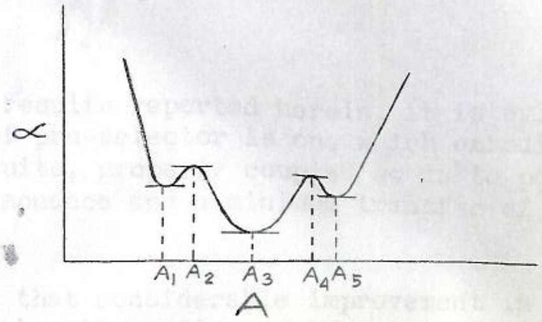
$$\propto = \left[R^2 + A^2\right]\left[R^2 + (A + V)^2\right]\left[R^2 + (A + 3V)^2\right]$$

Here $A = 2PX$, $V = KX$

Then to find the values of "A" which make $\propto$ a minimum we differentiate with respect to "A" and equate to zero.

$$\frac{d\propto}{dA} = 0 = 3A^5 + 20A^4V + (44V^2 + 3R^2)A^3 + (9V^3 + 27V^2 + 8VR^2)A^2 + (9V^4 + 32V^2R^2 + 3R^4)A + (3V^3R^2 + 9V^2R^2 + 4VR^4) \qquad (23)$$

Because this is a fifth power equation in terms of "A", there are five values of A (in terms of R and V) which will make the equation equal to zero. These values are shown graphically below:



Of these five values it is desired to find the values of A_1, A_3, and A_5 in terms of R and V. Knowing these values of "A", it would be possible to determine the exact value of K (coupling coefficient) which would cause these minima to occur within any desired percentage of A_3.

Unfortunately the factors of equation (23) are not immediately evident, but until these factors are found, equation (22) is of considerable value in determining the selectivity of such a circuit for any selected value of K.

V TEST RESULTS

(a) The circuit of Plate 1 is not satisfactory. Although a selectivity of 16 to 1 is obtained at 1% above resonance from the action of the parallel tuned circuit, the selectivity at other points is negligible.

(b) The same comments apply to the circuit of Plate 2.

(c) The same comments apply to the circuit of Plate 3.

(d) The circuit of Plate 4 is obviously unsatisfactory because of the series resonance effect for the total circuit produced by the 25 micromicrofarad capacitor.

(e) The circuits of Plates 5, 6, and 7, are unsatisfactory for similar reasons.

(f) The circuit of Plate 8 is only a slight improvement over the foregoing circuits. Although a selectivity of 245 to 1 is obtained at 2% above resonance, the selectivity at other points is not particularly good.

(g) The circuit of Plate 9 seems to be most satisfactory. A selectivity of 8.3 to 1 is obtainable (for the constants given) at 0.5% on each side of resonance and this ratio is always increasing as the frequency departs from resonant frequency. It would be highly desirable that this circuit be set up to verify the computations and to determine its adaptability to existing equipment

VI CONCLUSIONS

From the test results reported herein, it is evident that the most satisfactory type of pre-selector is one which embodies a cascade of tuned resonant circuits, properly coupled so as to permit a maximum transfer of energy at resonance and a minimum transfer of energy at any other frequency.

It is believed that considerable improvement in duplexability and in signal-to-external-noise ratio can be obtained by the use of a properly designed pre-selector circuit preceding the RAA and RAB receivers.

VII RECOMMENDATIONS

It is recommended that there be assigned to this Laboratory, a problem requiring the completion of the investigation of pre-selector circuits of the cascade-coupled type, for the purpose of designing preselectors for use in conjunction with the Model RAA and the Model RAB receivers, such pre-selectors to comprise a unit external to the receiver and so arranged as to be switched out of the circuit at will.