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New Design Method Optimizes Gain-Bandwidth

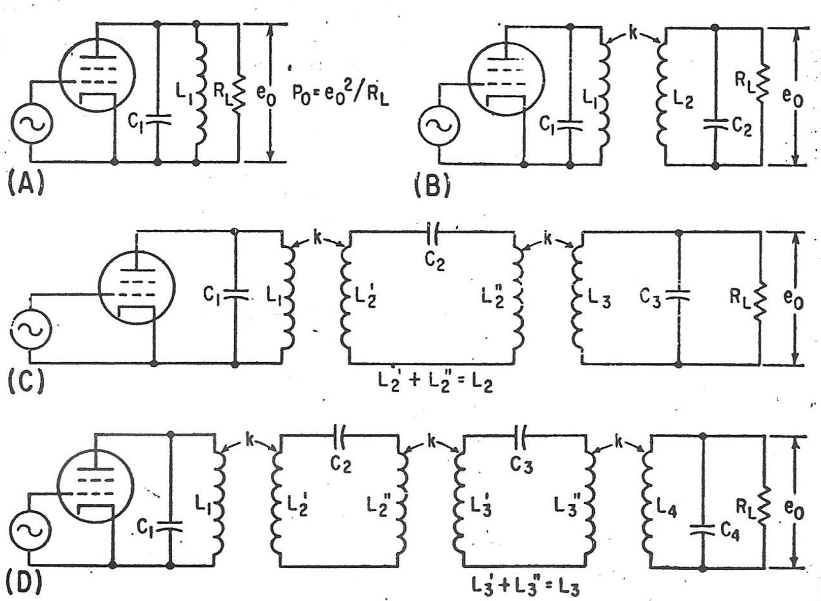
When power gain-bandwidth product is a prime consideration, this method for determining double tuned circuit parameters assures optimized design

By ALLEN I. SINSKY and HARVEY M. MAYROVITZ The Bendix Corp., Baltimore, Md.

POWER GAIN-BANDWIDTH is optimized by proper choice of double-tuned circuit parameters. A method is described here for determining these parameters and also the comparative improvement that a double-tuned circuit provides over a single-tuned circuit.

In designing r-f power amplifiers it is often necessary to couple the output of a tetrode or pentode stage to a resistive load such that the power into the load remains above a specified level over a given frequency band. Maximum attainable power gain-bandwidth product should be realized for each tube type.

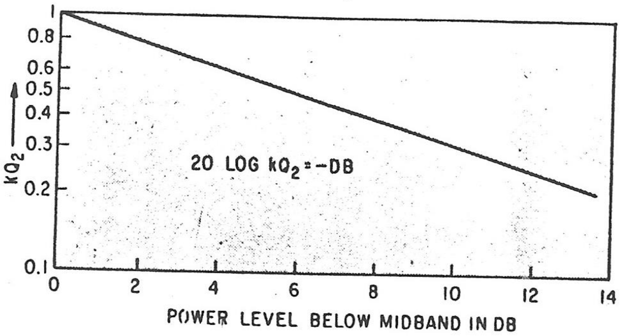
For a tetrode or pentode amplifier, when the screen and supressor grids provide good isolation between the input and output circuits, the output current can be considered as proportional to the input voltage only. For a given input voltage (constituting a given input power), the output power, and consequently the power gain (P_{out}/P_{in}), is a function of the plate load impedance. However, owing to the shunt output capacitance of the tube, the power gain is sensitive to frequency; a four-terminal network inserted between the output terminals of an amplifier tube and a frequency insensitive resistive load (R_L) optimizes power gain-bandwidth.

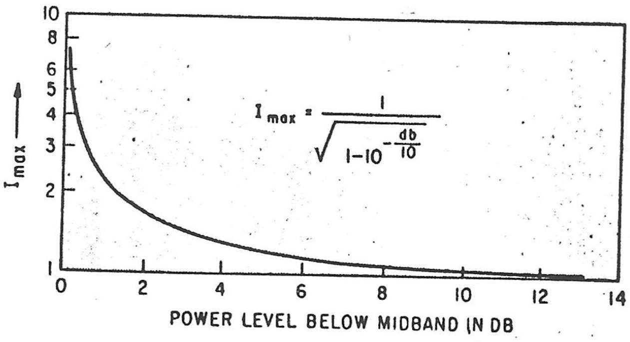


ISOCHRONOUSLY TUNED *coupled circuits: single tuned (A); double tuned (B); triple tuned (C); and quadruple tuned (D)—Fig. 1*

POWER GAIN-BANDWIDTH—Power gain-bandwidth is defined as the product of the mid-band power gain and the bandwidth at some prescribed power level below that at midband. In optimization of this parameter, it should be realized that more complex networks (Fig. 1C and Fig. 1D) have better frequency rejection characteristics than the double tuned circuit, but frequency rejection is not the prime consideration in this analysis.

The power gain-bandwidths of the single, double, triple and quadruple isochronously tuned, transistionally coupled circuits of Fig. 1 were determined assuming an infinite Q for all but the output loops. This is a valid approximation if the Q's of the





OPTIMUM *KQ₂* *(to left) and maximum power gain-bandwidth improvement of double tuned circuit over single tuned circuit (right) for various values of db—Fig. 2*

primary and intermediate loops can be made as large as desired while the loaded Q of the output loop remains small in comparison.

It was found that the improvement in power gain-bandwidth of the transitionally double-tuned circuit was $\sqrt{2}$ times better than that of a single tuned circuit and that the additional improvement with the more complex networks was small and rapidly approaching a finite limit. Considering the additional losses (that is, intermediate Q's not infinite), increased cost, and inherent tuning problems in the more complex networks it becomes evident that the most desirable configuration is the double-tuned circuit.

POWER LEVEL—Frequently, it is the bandwidth at levels other than the half power points that are of interest. It is, therefore, desirable to formulate the conditions necessary to achieve the maximum gain-bandwidth product when the bandwidth is measured to some arbitrary power level below that at center frequency.

The improvement factor (I), which is the improvement in power gain-bandwidth of a double-tuned circuit over a single-tuned circuit, has been derived and is given by:

$$I = \left[2(kQ_2)^2 - 1 + \sqrt{1 - 4(kQ_2)^2 + 4(kQ_2)^4\, 10^{db/10}}\right]^{1/2} \Big/ (kQ_2)^2 \sqrt{2(10^{db/10} - 1)} \qquad (1)$$

Where k is the coefficient of coupling, Q_2 is the loaded secondary Q (refer to Fig. 1B), and db is the power in decibels below midband power corresponding to the level at which the improvement is determined. Equation 1 reveals that, for any value of db, the improvement (I) depends only upon the product of kQ_2 rather than upon their individual values.

For a particular value of db there is a value of kQ_2 that maximizes I. This value, found by differentiation, is

$$kQ_2 = 10^{-db/20} \qquad (2)$$

Substituting the value of kQ_2 from eq. 2 back into eq. 1 gives the maximum improvement (I_{max}) of the double-tuned circuit over the single-tuned circuit for a particular value of db. This value of I_{max} is

$$I_{max} = \frac{1}{\sqrt{1 - 10^{-db/10}}} \qquad (3)$$

Equations 2 and 3 are plotted in Fig. 2 so that it is possible to find the maximum attainable improvement over the single tuned circuit as well as the value of kQ_2 to achieve this improvement. The value of k is found to be equal to the percentage bandwidth for maximum power gain bandwidth improvement so that Q_2 and k can be uniquely determined.

An example of the use of this analysis is given in a problem. It is desired to build an r-f tetrode power amplifier stage such that the power output remains greater than 4 db below the center frequency power output 5 Mc either side of the band center. The band center frequency is 100 Mc. Maximum power gain-bandwidth is desired.

The values of k and Q_2 are found and the power gain-bandwidth is determined. Step I: The value of k is equal to the percentage bandwidth, $k = \Delta f/f_o =$ 10Mc/100Mc = 0.1. Step II: The value of kQ_2 corresponding to 4 db is found from Fig. 2 to be 0.63. Step III: Solving for Q_2, knowing k and kQ_2, $Q_2 = 6.3$.

The power gain bandwidth improvement is found from Fig. 2 to be 1.29 times better than that of a single-tuned circuit.

SUMMARY—This analysis provides a method for choosing double-tuned circuit parameters when power gain-bandwidth product is the prime design consideration. The curves of Fig. 2 allow the designer to establish quickly the values of these parameters for his application.

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