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Design Data for Tuned R-C Circuits

By the Engineering Department, Aerovox Corporation

SEVERAL purpose resistance-capacitance networks, of which the Wien bridge and parallel-T network are well-known examples, are useful as null circuits. These circuits find practical application as audio frequency meters, simple band-suppression filters, and as frequency-selective feedback networks in oscillators, amplifiers, and wave analyzers. In many instances, such R-C combinations are preferable to L-C circuits because of the relative simplicity of the former, their comparative freedom from the effects of magnetic fields, their compactness, ease of adjustment, and small size.

Either network may be set, by means of adjustment of the values of resistance *or* capacitance, to attenuate sharply one frequency (or very narrow band of frequencies), while transmitting all other frequencies more or less freely. The operation is simplified by simultaneously varying all of the adjustable arms of the circuit, and the null point may be shifted throughout a desired frequency band by properly proportioning the variable components.

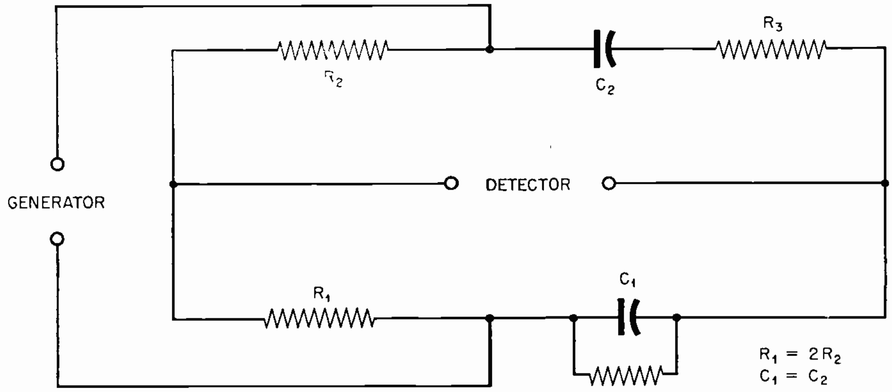

FIG.1

The Wien bridge and the parallel-T network give the same result in a slightly different manner. Circuit differences, however, recommend each arrangement to a particular application. This is in spite of some overlapping. The Wien bridge circuit is shown in Figure 1; the parallel-T network in Figure 2.

CIRCUIT COMPARISON

Wien Bridge. The Wien bridge is a four-arm circuit with ratio arms of pure resistance (R_1, R_2) and having resistance and capacitance in series

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in one arm (C_2-R_3) and resistance and capacitance in parallel in the adjacent arm (C_1-R_1). The equations for balance are:

$$(1)\quad \omega^2 = \frac{1}{C_1 C_2 R_3 R_4}$$

and

$$(2)\quad \frac{C_1}{C_2} = \frac{R_2}{R_1} - \frac{R_3}{R_4}$$

The null frequency is determined from the resistive and reactive component values according to the equation:

$$(3)\quad f_r = \frac{10^6}{6.28\sqrt{C_1 C_2 R_3 R_4}}$$

By making R_1 equal to twice R_2, and C_1 equal to C_2, R_3 and R_4 will be equal at all settings and Equation (3) may be simplified:

$$(4)\quad f_r = \frac{10^6}{6.28\ C_1 R_3}$$

In both Equations (3) and (4), f is in cycles per second, R in ohms, and C in microfarads.

In order to obtain single-dial control of the bridge, R_3 and R_1 may be ganged and tracked for simultaneous adjustment; or alternatively, C_1 and C_2 might so be ganged.

Parallel-T Network. As its name implies, this arrangement is a parallel connection of two T networks. A resistor in a given leg of one T is matched by a capacitor in the corresponding leg of the other T. If the two T's are kept symmetrical, R_1 is kept equal to R_2 and to twice R_3, and C_1 is made equal to C_2 and to one-half C_3, the equations for balance become:

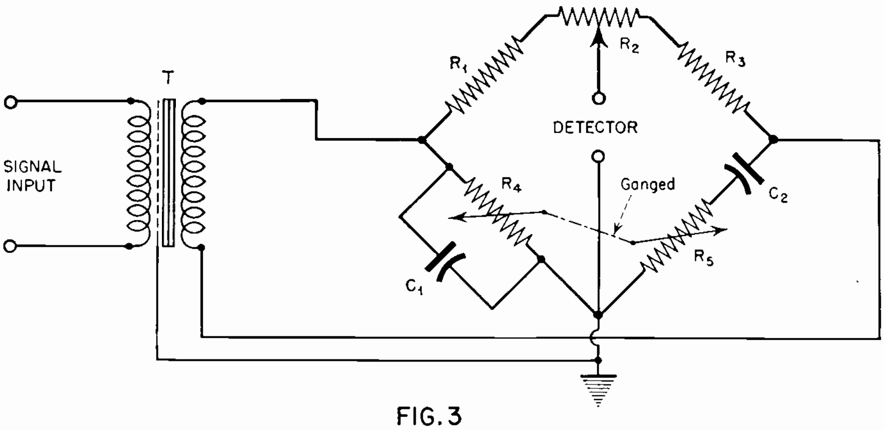
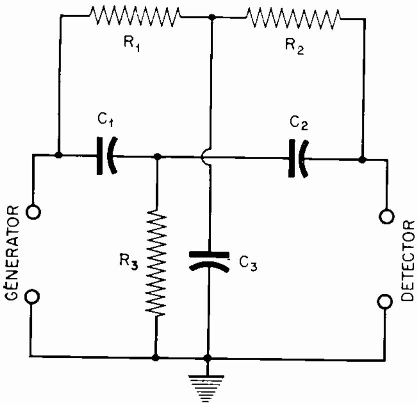


FIG. 3



$R_1 = R_2 = 2R_3$
$C_1 = C_2 = ½\ C_3$

FIG. 2

$$(5)\quad \frac{2}{\omega C_1} = R_1^2\,\omega C_3$$

and

$$(6)\quad \frac{1}{R_3(\omega C_1)^2} = 2R_1$$

Under the conditions of symmetry stated above, the resistance balance is continuously satisfied, and at null:

$$(7)\quad f_r = \frac{10^6}{6.28\ R_1 C_1}$$

Where f_r is in cycles per second,
R_1 in ohms, and
C_1 in microfarads.

Note that Equation (7) for the parallel-T network is identical with the null Equation (4) for the Wien bridge.

Single-dial control of null may be achieved in this circuit by ganging and tracking either all three resistors or all three capacitors. In both the Wien bridge and the parallel-T network, the resistors will generally be varied, since at audio frequencies the capacitors will be so large in value as to preclude tuning.

Comparison. Each circuit employs six components. From a standpoint of manipulation, the Wien bridge is perhaps the simplest of the two circuits in that a dual ganged resistor, R_3-R_1, takes care of all tuning. The parallel-T network, on the other hand, requires simultaneous variation of *three* components (R_1, R_2, and R_3) and well-tracked triple rheostats and potentiometers are not so readily obtained as dual types. But this slight disadvantage is outweighed by the fact that the parallel-T network affords a common connection (which may be grounded) between generator, network, and detector, while the Wien bridge does not. The Wien bridge has the disadvantage that it requires a well-shielded input transformer, and in some cases a similar output transformer, and accordingly cannot be used *directly* in some applications because of phase shifting by these transformers.

SELECTION OF COMPONENT VALUES

Resistance and capacitance values for both types of tuned R-C circuit may be determined by means of the equations given earlier in this article or, conveniently, from the Components Chart published on these pages.

The chart lists all resistance values for 22 common capacitances. These values are given directly for 19 frequencies between 100 and 1000 cycles per second, but values corresponding to other frequencies may be determined readily by simple multiplication or division of the chart values, as will be shown presently. Values are stated to the nearest tenth ohm, since standard laboratory decade resistors may be set to that closeness. Chart capacitance values are in microfarads.

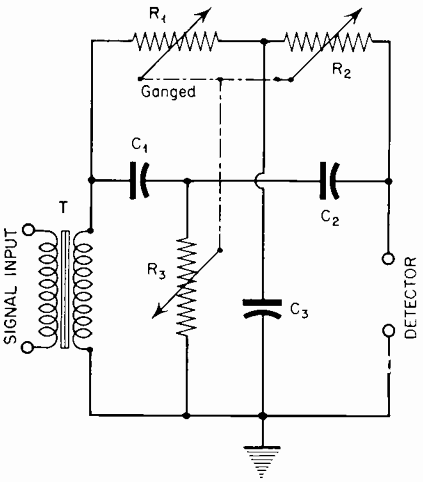


FIG. 4

AT ALL FREQ.		100 c.p.s.		150 c.p.s.		200 c.p.s.		250 c.p.s.		300 c.p.s.	
C_1, C_2	C_3	R_1, R_2	R_3	R_1, R_2	R_3	R_1, R_2	R_3	R_1, R_2	R_3	R_1, R_2	R_3
0.001	0.002	1,591,545.0	795,770.0	1,061,797.2	530,460.3	795,770.0	397,885.0	636,616.0	318,308.0	530,460.3	265,230.1
0.002	0.004	795,577.2	397,886.0	520,541.2	260,270.6	397,886.0	198,943.0	318,308.8	159,154.4	265,230.8	132,615.4
0.003	0.006	530,462.9	265,231.5	353,659.7	176,829.8	265,231.5	132,615.7	212,185.2	106,092.6	176,803.3	88,401.6
0.004	0.008	397,886.2	198,943.0	265,270.6	132,635.3	198,943.0	99,471.5	159,154.4	79,577.2	132,615.4	66,307.7
0.005	0.01	318,309.0	159,154.5	212,216.6	106,108.3	159,154.5	79,577.2	127,323.6	63,661.8	106,092.4	53,046.2
0.006	0.012	265,247.9	132,624.0	176,840.8	88,420.4	132,624.0	66,312.0	106,099.2	53,049.6	88,407.1	44,203.5
0.007	0.014	227,352.2	113,676.0	151,575.6	70,787.8	113,676.0	56,838.0	90,940.8	45,470.4	75,776.4	37,888.2
0.008	0.016	198,943.1	99,471.5	132,635.3	66,317.6	99,471.5	49,735.7	79,577.2	39,788.6	66,307.7	33,153.8
0.009	0.018	176,836.6	88,418.0	117,896.6	58,948.3	88,418.0	44,209.0	70,734.4	35,367.2	58,939.4	29,469.7
0.01	0.02	159,154.5	79,577.0	106,108.0	53,054.0	79,577.0	39,788.5	63,661.6	31,830.8	53,046.0	26,523.0
0.02	0.04	79,577.2	29,788.6	42,054.2	21,027.1	29,788.6	14,894.3	21,830.9	10,915.4	16,523.1	8,261.5
0.03	0.06	53,046.2	26,523.1	35,365.9	17,682.9	26,523.1	13,261.5	21,218.5	10,609.2	17,680.3	8,840.1
0.04	0.08	39,788.6	19,894.3	26,527.0	13,263.5	19,894.3	9,947.1	15,915.4	7,957.7	13,261.5	6,630.7
0.05	0.1	31,830.9	15,915.4	21,221.7	10,610.8	15,915.4	7,957.7	12,732.4	6,366.2	10,609.2	5,304.6
0.06	0.12	26,515.1	13,257.6	17,677.7	8,838.8	13,257.6	6,628.8	10,606.1	5,303.0	8,837.5	4,418.7
0.07	0.14	22,727.3	11,363.6	15,152.3	7,576.1	11,363.6	5,681.8	9,090.9	4,545.4	7,575.0	3,787.5
0.08	0.16	19,894.3	9,947.1	13,263.5	6,631.7	9,947.1	4,973.5	7,957.2	3,978.6	6,630.8	3,315.4
0.09	0.18	17,682.1	8,841.0	11,788.6	5,894.3	8,841.0	4,420.5	7,072.8	3,536.4	5,893.4	2,946.7
0.1	0.2	15,915.4	7,957.7	10,610.8	5,305.4	7,957.7	3,978.8	6,366.2	3,183.1	5,304.6	2,652.3
0.25	0.5	6,366.2	3,183.1	4,244.3	2,122.1	3,183.1	1,591.5	2,546.5	1,273.2	2,121.8	1,060.9
0.5	1.0	3,183.1	1,591.5	2,122.2	1,061.1	1,591.5	795.7	1,273.2	636.6	1,060.9	530.5
1.0	2.0	1,591.5	795.8	1,061.1	530.5	795.8	397.9	636.6	318.3	530.5	262.2

AT ALL FREQ.		350 c.p.s.		400 c.p.s.		450 c.p.s.		500 c.p.s.		550 c.p.s.	
C_1, C_2	C_3	R_1, R_2	R_3	R_1, R_2	R_3	R_1, R_2	R_3	R_1, R_2	R_3	R_1, R_2	R_3
0.001	0.002	454,703.0	227,351.5	397,885.0	198,942.5	353,640.2	176,820.1	318,308.0	159,154.0	289,342.0	142,671.0
0.002	0.004	227,352.1	113,676.0	198,943.0	99,471.5	176,820.5	88,410.2	159,154.4	79,577.2	144,671.3	72,335.6
0.003	0.006	151,553.3	75,776.6	132,615.7	66,307.8	117,868.9	58,934.4	106,092.6	53,046.3	96,438.1	48,219.0
0.004	0.008	113,676.0	56,838.0	99,471.5	49,735.7	88,410.3	44,205.1	79,577.2	39,788.6	72,335.7	36,167.8
0.005	0.01	90,940.9	45,470.4	79,577.2	39,788.6	70,728.2	35,364.1	63,661.8	31,830.9	57,868.6	28,934.3
0.006	0.012	75,781.3	37,890.6	66,312.0	33,156.0	58,938.1	29,469.0	53,049.6	26,524.8	48,222.1	24,111.0
0.007	0.014	64,954.5	32,477.2	56,838.0	28,419.0	50,517.6	25,258.8	45,470.4	22,735.2	41,332.6	20,666.3
0.008	0.016	56,838.0	28,419.0	49,735.7	24,867.8	44,205.1	22,102.5	39,788.6	19,894.3	36,167.8	18,083.9
0.009	0.018	50,522.0	25,261.0	44,209.0	22,104.5	39,292.9	19,646.4	35,367.2	17,683.6	32,148.8	16,074.4
0.01	0.02	45,470.3	22,735.1	39,788.5	19,894.2	35,364.0	17,682.0	31,830.8	15,915.4	28,934.2	14,267.1
0.02	0.04	22,435.3	11,217.6	19,894.3	9,947.1	17,682.1	8,814.0	15,915.4	7,957.7	14,467.1	7,233.5
0.03	0.06	15,155.3	7,577.6	13,261.5	6,630.7	11,786.9	5,893.9	10,609.2	5,304.6	9,643.8	4,821.9
0.04	0.08	11,367.6	5,683.8	9,947.1	4,973.5	8,841.0	4,420.5	7,957.7	3,978.8	7,233.6	3,616.8
0.05	0.1	9,094.1	4,547.0	7,957.7	3,978.8	7,072.8	3,536.4	6,366.2	3,183.1	5,786.9	2,898.4
0.06	0.12	7,575.4	3,787.7	6,628.8	3,314.4	5,891.7	2,945.8	5,303.0	2,651.5	4,820.5	2,410.2
0.07	0.14	6,493.2	3,246.6	5,681.8	2,840.9	5,050.0	2,525.0	4,545.5	2,272.7	4,131.8	2,066.9
0.08	0.16	5,683.8	2,841.9	4,973.6	2,486.8	4,420.5	2,210.2	3,978.9	1,989.4	3,616.8	1,808.4
0.09	0.18	5,051.8	2,525.9	4,420.5	2,210.2	3,928.9	1,964.4	3,536.4	1,768.2	3,214.6	1,607.3
0.1	0.2	4,547.0	2,273.5	3,978.8	1,989.4	3,536.4	1,768.2	3,183.1	1,591.5	2,893.4	1,446.7
0.25	0.5	1,818.8	909.4	1,591.5	795.7	1,414.6	707.3	1,273.2	636.6	1,157.4	578.7
0.5	1.0	909.4	454.7	795.8	397.9	707.3	353.6	636.6	318.3	578.7	289.3
1.0	2.0	454.7	227.3	397.9	198.8	353.6	176.8	318.3	159.1	289.3	144.6

AT ALL FREQ.		600 c.p.s.		650 c.p.s.		700 c.p.s.		750 c.p.s.		800 c.p.s.	
C_1, C_2	C_3	R_1, R_2	R_3	R_1, R_2	R_3	R_1, R_2	R_3	R_1, R_2	R_3	R_1, R_2	R_3
0.001	0.002	265,309.7	132,652.8	244,778.8	122,389.4	227,271.9	113,635.9	212,152.3	106,076.1	198,942.5	99,471.7
0.002	0.004	132,655.2	66,327.6	122,389.7	61,194.8	113,636.2	56,818.1	106,076.4	53,038.2	99,471.5	49,735.7
0.003	0.006	88,428.2	44,214.1	81,585.2	40,792.6	75,750.1	37,875.0	70,719.7	35,359.8	66,307.9	33,153.9
0.004	0.008	66,327.6	33,163.8	61,194.9	30,597.4	56,818.1	28,409.0	53,038.2	26,519.1	49,735.7	24,867.8
0.005	0.01	53,017.1	26,508.5	48,955.9	24,477.9	45,454.5	22,727.2	42,430.6	21,215.3	39,788.6	19,894.3
0.006	0.012	44,216.8	22,108.4	40,795.1	20,397.5	37,877.4	18,938.7	35,357.5	17,678.7	33,156.0	16,578.0
0.007	0.014	37,899.6	18,949.8	34,966.7	17,483.3	32,465.9	16,232.9	30,306.0	15,153.0	28,419.0	14,209.5
0.008	0.016	33,163.8	16,581.9	30,597.4	15,298.7	28,409.1	14,204.5	26,519.1	13,259.5	24,867.9	12,433.9
0.009	0.018	29,478.6	14,739.3	27,197.4	13,598.7	25,252.2	12,626.1	23,572.2	11,786.1	22,104.5	11,052.2
0.01	0.02	26,531.0	13,265.5	24,477.9	12,238.9	22,727.2	11,363.6	21,215.2	10,607.6	19,894.2	9,947.1
0.02	0.04	13,265.5	6,632.7	12,238.9	6,119.4	11,363.6	5,681.8	10,607.6	5,303.8	9,947.2	4,473.6
0.03	0.06	8,842.8	4,421.4	8,158.5	4,079.2	7,574.9	3,787.4	7,071.0	3,535.5	6,630.8	3,315.4
0.04	0.08	6,632.7	3,316.3	6,119.5	3,059.7	5,681.8	2,840.9	5,303.8	2,651.9	4,973.6	2,486.8
0.05	0.1	5,306.2	2,653.1	4,895.6	1,247.8	4,545.4	2,272.7	4,243.0	2,121.5	3,922.6	1,961.3
0.06	0.12	4,420.1	2,210.0	4,078.0	2,039.0	3,786.4	1,893.2	3,534.5	1,767.2	3,314.4	1,657.2
0.07	0.14	3,788.6	1,894.3	3,495.4	1,747.7	3,245.4	1,627.7	3,029.5	1,514.7	2,840.9	1,420.4
0.08	0.16	3,316.4	1,658.2	3,059.7	1,529.8	2,840.9	1,420.4	2,651.9	1,325.9	2,486.8	1,443.4
0.09	0.18	2,947.6	1,473.8	2,719.5	1,359.7	2,525.0	1,262.5	2,357.0	1,178.5	2,210.3	1,105.1
0.1	0.2	2,653.1	1,326.5	2,447.8	1,223.9	2,272.7	1,136.3	2,121.1	1,060.5	1,989.4	994.7
0.25	0.5	1,061.2	530.6	979.1	489.5	909.1	454.5	848.6	424.3	795.8	397.9
0.5	1.0	530.6	265.3	489.5	244.7	454.5	227.2	424.3	212.1	397.9	198.9
1.0	2.0	265.1	132.5	244.8	122.4	227.3	113.6	212.1	106.0	198.9	99.45

AT ALL FREQ.		850 c.p.s.		900 c.p.s.		950 c.p.s.		1000 c.p.s.			
C_1, C_2	C_3	R_1, R_2	R_3	R_1, R_2	R_3	R_1, R_2	R_3	R_1, R_2	R_3		
0.001	0.002	187,165.1	93,582.5	176,820.1	88,410.0	167,525.5	83,762,7	159,154.5	79,577.2		
0.002	0.004	93,582.8	46,791.4	88,410.3	44,205.1	83,762.9	41,881.4	79,577.2	39,788.6		
0.003	0.006	62,382.4	31,191.2	58,934.4	29.467,2	55,836.4	27,918.2	53,046.3	26,523.1		
0.004	0.008	46,791.4	23,395.7	44,205.1	22,102.5	41,881.5	20,940.7	39,788.6	19,894.3		
0.005	0.01	37,433.1	18,716.5	35,364.1	17,682.0	33,476.8	16,738.4	31,830.9	15,915.4		
0.006	0.012	31,193.2	15,596.6	29,469.0	14,734.5	27,920.0	13,960.0	26,524.8	13,262.4		
0.007	0.014	26,736.6	13,368.3	25,258.8	12,629.4	23,931.1	11,965.5	22,735.2	11,367.6		
0.008	0.016	23,395.7	11,697.8	22,102.6	11,051.3	20,940.7	10,470.3	19,894.3	9,947.1		
0.009	0.018	20,795.9	10,397.9	19,646.5	9,823.2	18,613.7	9,306.8	17,683.6	8,841.8		
0.01	0.02	18,716.5	9,358.2	17,682.0	8,841.0	16,752.6	8,376.3	15,915.4	7,957.7		
0.02	0.04	9,358.3	4,679.1	8,841.0	4,420.5	8,376.3	4,188.1	7,957.7	3,978.8		
0.03	0.06	6,291.3	3,145.6	5,893.4	2,946.7	5,583.6	2,791.8	5,304.6	2,652.3		
0.04	0.08	4,679.1	2,339.5	4,420.5	2,210.2	4,188.1	2,094.0	3,978.9	1,989.4		
0.05	0.1	3,743.3	1,871.6	3,536.4	1,768.2	3,350.5	1,675.2	3,183.1	1,591.5		
0.06	0.12	3,118.2	1,559.1	2,945.8	1,472.9	2,790.9	1,395.4	2,651.5	1,325.7		
0.07	0.14	2,672.7	1,336.3	2,525.0	1,262.5	2,392.3	1,196.6	2,272.7	1,136.3		
0.08	0.16	2,339.6	1,169.8	2,210.2	1,105.1	2,094.1	1,047.5	1,989.4	994.7		
0.09	0.18	2,079.4	1,039.7	1,964.5	982.2	1,861.2	930.6	1,768.2	884.1		
0.1	0.2	1,871.6	935.8	1,768.2	884.1	1,675.2	837.6	1,591.5	795.7		
0.25	0.5	748.7	374.3	707.3	353.6	660.1	330.0	636.6	318.3		
0.5	1.0	374.3	187.1	353.6	176.8	335.0	167.5	318.3	159.1		
1.0	2.0	187.2	93.6	176.8	88.4	167.5	83.7	159.1	79.5		

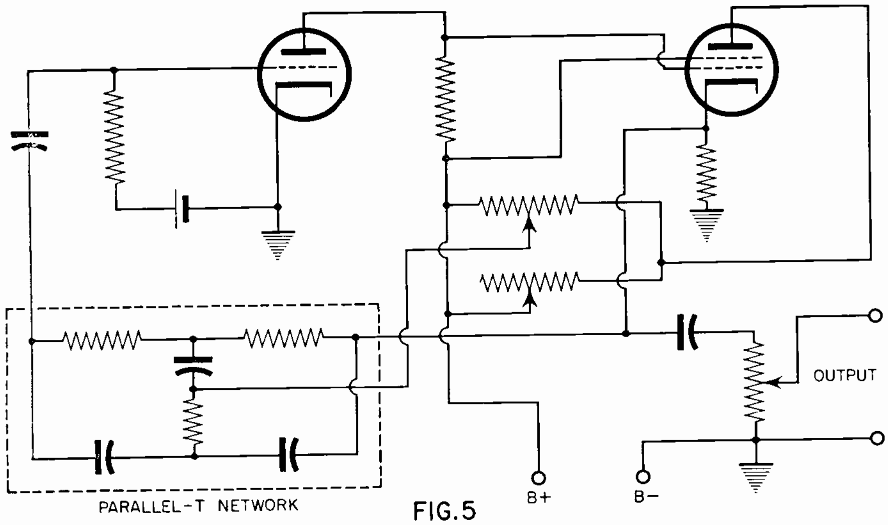


FIG.5

C_1, C_2, C_3, R_1, R_2, and R_3 values are given directly for the parallel-T network. Thus, it is discovered that R_1 and R_2 for a 400-cycle null will be 39,788.5 ohms when C_1 and C_2 each are 0.01 mfd. and C_3 is 0.02 mfd. R_3 will be 19,894.2 ohms.

For the Wien bridge, both capacitance values will be the same and are selected in the C_1, C_2 column of the chart. The two resistor values likewise are identical, and will be found in the R_1, R_2 column for the desired null frequency. Thus, a Wien bridge with a null frequency of 900 cycles per second will require resistors of 29,469 ohms each when both capacitances are 0.006 mfd.

When designing a Wien bridge or a parallel-T network for a frequency (F_X) other than those given by the chart, first locate the 100-cycle resistor values corresponding to the chosen capacitances. Then multiply the resistor values thus obtained by 100 F_X. In some instances (as when F_X is in kilocycles), it is more desirable first to locate the 1000-cycle resistor values and to multiply these by $1000/F_X$.

APPLICATIONS

Audio Frequency Meters. In the Wien bridge version (Figure 3) satisfactory constants for 20-15,000 cycle coverage are: R_1 2000 ohms, R_2 100 ohms, R_3 1000 ohms, and C_1 and C_2 each 0.0166 mfd. R_1 and R_3 are sections of a dual, ganged 500,000-ohm rheostat.

Constants for the parallel-T a. f. meter (Figure 4) for 20-15,000-cycle coverage are: C_1 and C_2 each 0.0166 mfd., C_3 0.0332 mfd. R_1, R_2, and R_3 are sections of a triple, ganged rheostat—R_1 and R_2 each are ½ megohm; R_3 ¼ megohm. Transformer T may be provided with an internal shield, but this is not imperative.

A. F. Oscillators. The Scott oscillator circuit employing a parallel-T network for degenerative feedback is shown in Figure 5. This circuit is a direct-coupled amplifier with regenerative and degenerative feedback. Degeneration through the parallel-T network occurs on all frequencies except the resonant frequency of the network. Gain of the amplifier accordingly is cancelled on all but that frequency, and regenerative feedback can establish oscillation only upon the network null frequency.

Single-frequency oscillation is obtained in a somewhat comparable manner by employing a Wien bridge feedback circuit, as shown in Figure 6. This circuit has the disadvantage that transformer coupling is required in the feedback circuit.

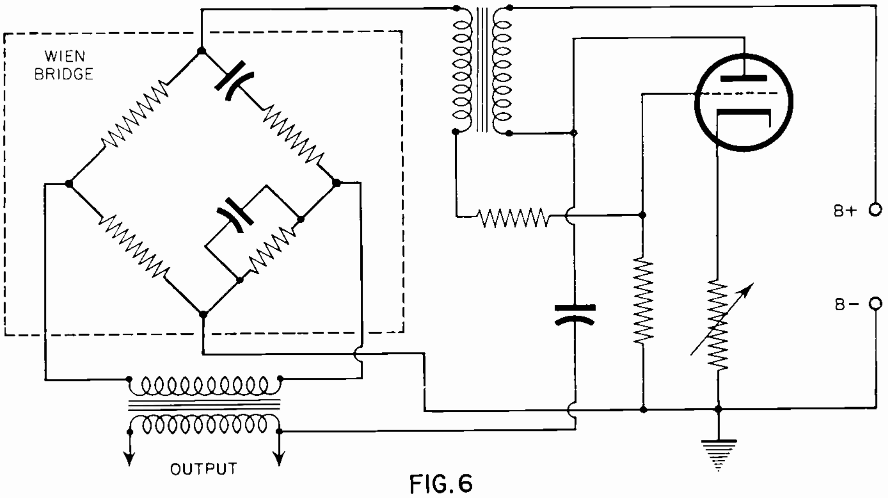


FIG.6

In either of the oscillator circuits, variable-frequency operation may be obtained by simultaneous variation of resistance or capacitance elements, as described earlier in this article.

R-C-Tuned Wave Analyzer. By eliminating the regenerative feedback in the Scott oscillator (Figure 5), a selective amplifier is obtained. If the "tunable" components of the parallel-T network are then made variable, the amplifier may be tuned successively to a fundamental frequency and its various harmonics. An output v.t. voltmeter will indicate the amplitude of each harmonic with respect to the fundamental and thus give a measure of distortion.

Selective Amplifier. If the circuit described in the previous section is set by means of the parallel-T network, to a single-frequency, a sharply-tuned single-frequency amplifier is obtained. Such a unit is invaluable in bridge detectors, selective signal systems, distortion meters, etc.

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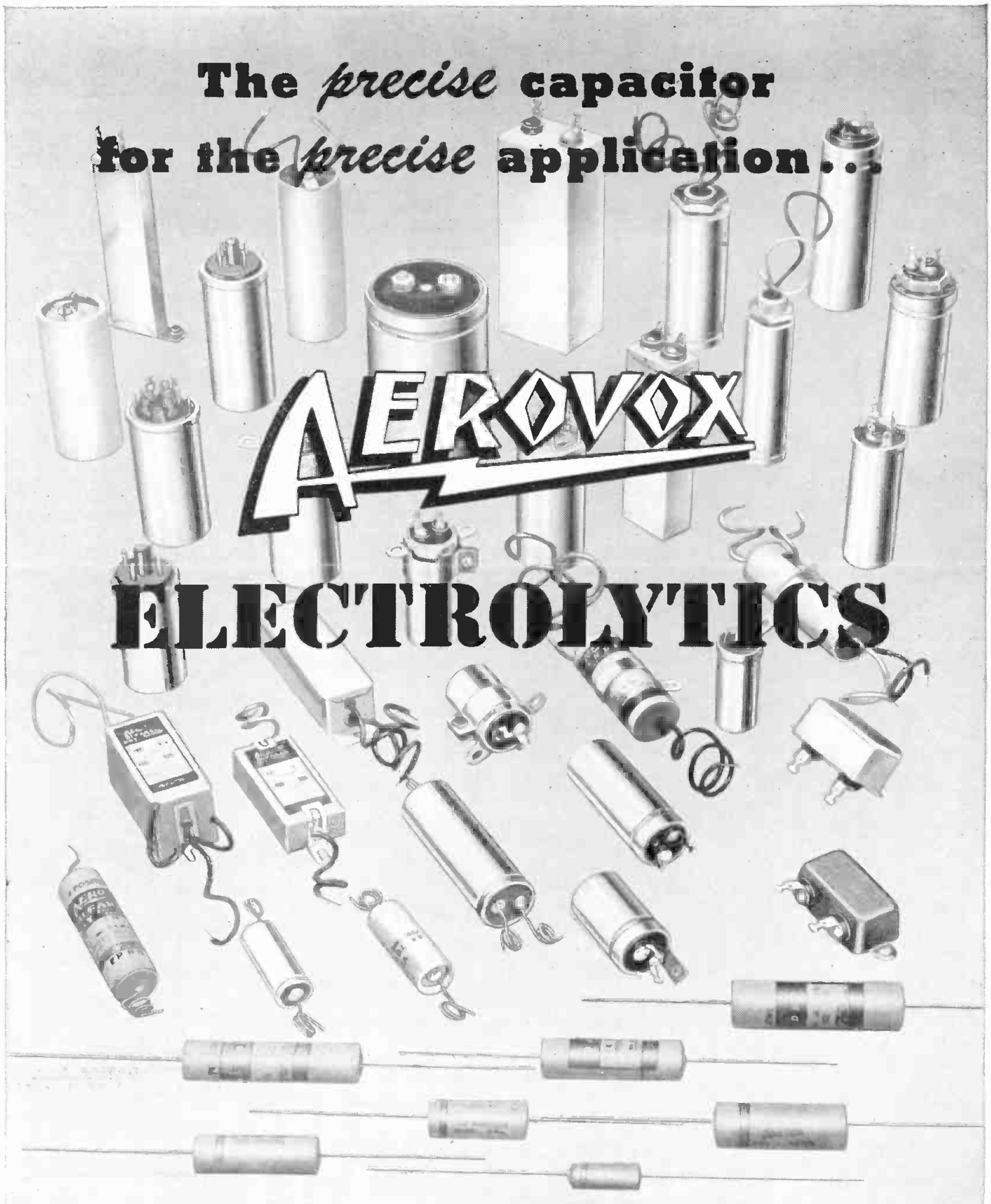

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