DESIGN DATA
FOR RADIO TRANSMITTERS AND RECEIVERS

A REFERENCE BOOK OF TABLES AND SIMPLIFIED FORMULAS NECESSARY FOR THE CORRECT DESIGN OF RADIO CIRCUITS

ENGINEERING DATA IS MADE AVAILABLE TO THE EXPERIMENTERS, AND HELPFUL TABLES ARE PRESENTED TO THE RADIO ENGINEER

BY

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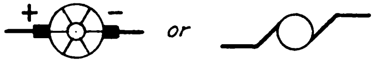
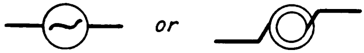
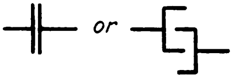
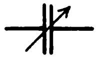
~ List of Symbols ~

Battery ------------------------- 

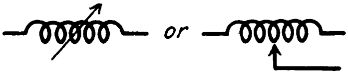
Direct Current Dynamo --- 

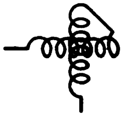
Alternating Current Generator ------------- 

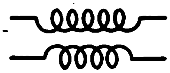
Fixed Capacitance (Condenser) -------------- 

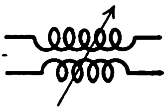
Variable Capacitance (Var. Condenser) ------------------ 

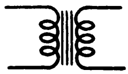
Fixed Inductance (Air Core Coil) ------------------ 

Variable Inductance (Air Core Coil) -------- 

Variometer (Variable Inductance) --- 

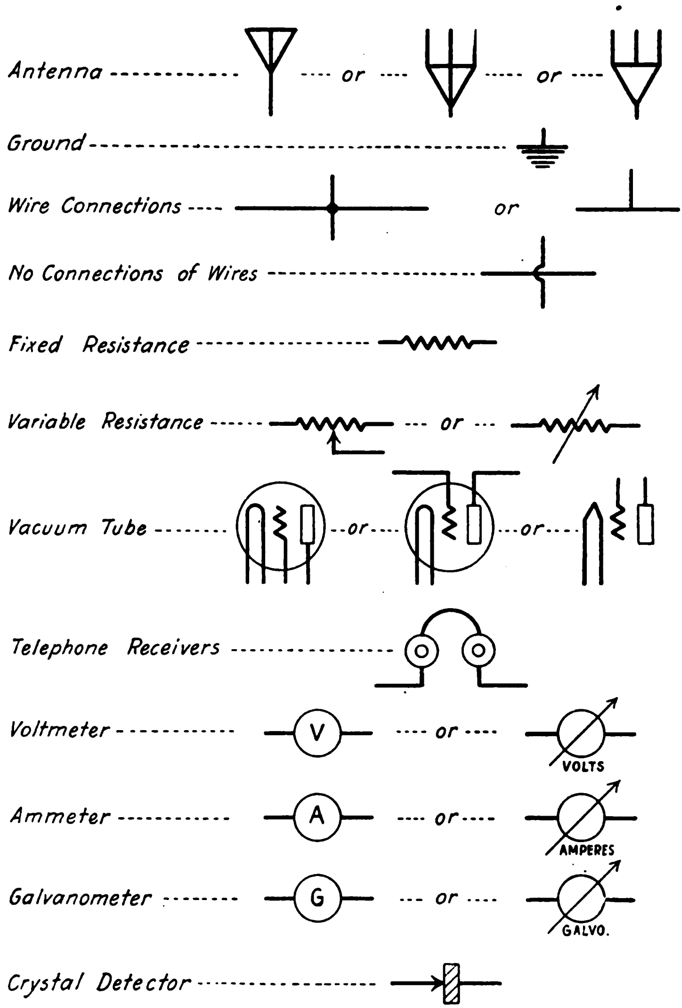
Fixed Coupling of Coils (Fixed Inductive Coupling) ---------- 

Variable Coupling of Coils --------- 

Transformer ------------------------- 

Iron Core Inductance (or Reactance Coil) ---------- 

~ LIST OF SYMBOLS ~



PREFACE

Probably because radio experimenters operate their instruments first, and learn about them afterward, they generally remain ignorant of the simple factors of design, the familiarity with which makes wireless work infinitely more interesting. If stations incorrectly designed, or just put together, would not work, this condition would be rectified, although radio might be less popular.

The essential problems have been stripped of mathematics which are beyond the average experimenter, in order that any one can build apparatus for a given performance.

Receiving circuits have been treated at greater length than sending sets, partly because there is more to say about them, and also because of the limitations of practicability in constructing transmitting apparatus at home.

February, 1922.

MEANING OF SYMBOLS USED IN FORMULAS

A = area of dielectric, in square inches.

av. = average.

C = capacity, in mfds.

d = diameter, in inches.

E = volts.

E_c = grid charge, in volts.

f = frequency, in cycles.

I = amperes.

I_a = filament current, in amperes.

K = coefficient of coupling.

k = constant.

L = inductance in centimeters.

l = length in inches.

l_a = axial width of torus of rectangular cross section, in inches.

M = mutual inductance in centimeters.

n = number of turns per inch.

r = radius, in inches.

r_a = distance from center of torus to center of cross-section of winding, in inches.

r_b = radius of cross-section of torus, in inches.

R_c = resistance in filament circuit to put charge on grid, in ohms.

t = thickness of dielectric, in inches.

t.p.i. = turns per inch.

λ = wave-length, in meters.

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DESIGN DATA FOR RADIO TRANSMITTERS AND RECEIVERS

PART I

CHAPTER I

OSCILLATING CIRCUITS

1. ELECTRICAL OSCILLATIONS.

Electrical oscillations can take place in a circuit containing inductance, capacity, and, necessarily, resistance, provided the resistance in ohms does not exceed

$$2\sqrt{\frac{L}{1{,}000 \times C}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

2. WAVE-LENGTH AND FREQUENCY.

Since electricity travels at the speed of light, 300,000,000 meters per second, the wave-length of a circuit, in respect to the frequency of the oscillations, is

$$\lambda = \frac{300{,}000{,}000}{f} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Table 1 gives the frequencies corresponding to wavelengths from 100 to 39,000 meters.

3. WAVE-LENGTH, INDUCTANCE AND CAPACITY.

The wave-length, and, therefore, the oscillation frequency, depend upon the amount of inductance and capacity in the circuit. Table 2 shows the wave-lengths of circuits having from 1,000 cms. inductance and 0.0001 mfd. capacity to 600,000,000 cms. and 0.002 mfd.

TABLE I—Frequency and Wave-length

Meters	Frequency	Meters	Frequency	Meters	Frequency
100	3,000,000	525	572,000	750	400,000
110	2,727,000	530	566,000	755	397,000
120	2,500,000	535	561,000	760	395,000
130	2,308,000	540	556,000	765	392,000
140	2,143,000	545	551,000	770	390,000
150	2,000,000	550	546,000	775	387,000
160	1,875,000	555	541,000	780	385,000
170	1,764,000	560	536,000	785	382,000
180	1,667,000	565	531,000	790	380,000
190	1,579,000	570	527,000	795	377,000
200	1,500,000	575	522,000	800	375,000
210	1,429,000	580	517,000	805	373,000
220	1,364,000	585	513,000	810	370,000
230	1,304,000	590	509,000	815	368,000
240	1,250,000	595	504,000	820	366,000
250	1,200,000	600	500,000	825	364,000
260	1,154,000	605	496,000	830	361,000
270	1,111,000	610	492,000	835	359,000
280	1,071,000	615	488,000	840	357,000
290	1,034,000	620	484,000	845	355,000
300	1,000,000	625	480,000	850	353,000
310	968,000	630	476,000	855	351,000
320	938,000	635	472,000	860	349,000
330	909,000	640	469,000	865	347,000
340	883,000	645	465,000	870	345,000
350	857,000	650	462,000	875	343,000
360	834,000	655	458,000	880	341,000
370	811,000	660	455,000	885	339,000
380	790,000	665	451,000	890	337,000
390	769,000	670	448,000	895	335,000
400	750,000	675	444,000	900	333,000
410	732,000	680	441,000	905	331,000
420	715,000	685	438,000	910	330,000
430	698,000	690	435,000	915	328,000
440	682,000	695	432,000	920	326,000
450	667,000	700	429,000	925	324,000
460	652,000	705	426,000	930	323,000
470	639,000	710	423,000	935	321,000
480	625,000	715	420,000	940	319,000
490	612,000	720	417,000	945	317,000
500	600,000	725	414,000	950	316,000
505	594,000	730	411,000	955	314,000
510	588,000	735	408,000	960	313,000
515	583,000	740	405,000	965	311,000
520	577,000	745	403,000	970	309,000

TABLE I—(*Continued*)

Meters	Frequency	Meters	Frequency	Meters	Frequency
975	308,000	1400	214,300	1850	162,200
980	306,000	1410	212,800	1860	161,300
985	305,000	1420	211,300	1870	160,400
990	303,000	1430	209,800	1880	159,600
995	302,000	1440	208,300	1890	158,700
1000	300,000	1450	206,900	1900	157,900
1010	297,100	1460	205,500	1910	157,100
1020	294,200	1470	204,100	1920	156,300
1030	291,300	1480	202,700	1930	155,400
1040	288,500	1490	201,300	1940	154,600
1050	285,700	1500	200,000	1950	153,800
1060	283,000	1510	198,700	1960	153,100
1070	280,400	1520	197,400	1970	152,300
1080	277,800	1530	196,100	1980	151,500
1090	275,200	1540	194,800	1990	150,800
1100	272,700	1550	193,500	2000	150,000
1110	270,300	1560	192,300	2020	148,500
1120	267,900	1570	191,100	2040	147,100
1130	265,500	1580	189,900	2060	145,600
1140	263,200	1590	188,700	2080	144,200
1150	260,900	1600	187,500	2100	142,900
1160	258,600	1610	186,300	2120	141,500
1170	256,400	1620	185,100	2140	140,200
1180	254,200	1630	184,000	2160	138,900
1190	252,100	1640	182,900	2180	137,600
1200	250,000	1650	181,800	2200	136,400
1210	247,900	1660	180,700	2220	135,100
1220	245,900	1670	179,600	2240	133,900
1230	243,900	1680	178,500	2260	132,700
1240	241,900	1690	177,400	2280	131,600
1250	240,000	1700	176,400	2300	130,400
1260	238,100	1710	175,400	2320	129,300
1270	236,200	1720	174,400	2340	128,200
1280	234,400	1730	173,400	2360	127,100
1290	232,600	1740	172,400	2380	126,000
1300	230,800	1750	171,400	2400	125,000
1310	229,000	1760	170,500	2420	124,000
1320	227,300	1770	169,500	2440	122,900
1330	225,600	1780	168,500	2460	121,900
1340	223,900	1790	167,600	2480	121,000
1350	222,200	1800	166,700	2500	120,000
1360	220,600	1810	165,700	2520	119,000
1370	219,000	1820	164,800	2540	118,100
1380	217,400	1830	163,900	2560	117,200
1390	215,800	1840	163,000	2580	116,300

TABLE I—(*Continued*)

Meters	Frequency	Meters	Frequency	Meters	Frequency
2600	115,400	3500	85,700	4400	68,200
2620	114,500	3520	85,300	4420	67,900
2640	113,600	3540	84,800	4440	67,600
2660	112,800	3560	84,300	4460	67,300
2680	111,900	3580	83,800	4480	67,000
2700	111,100	3600	83,400	4500	66,700
2720	110,300	3620	82,900	4520	66,400
2740	109,500	3640	82,400	4540	66,100
2760	108,700	3660	82,000	4560	65,800
2780	107,900	3680	81,500	4580	65,500
2800	107,100	3700	81,100	4600	65,200
2820	106,400	3720	80,700	4620	65,000
2840	105,600	3740	80,200	4640	64,700
2860	104,900	3760	79,800	4660	64,400
2880	104,200	3780	79,400	4680	64,100
2900	103,400	3800	79,000	4700	63,900
2920	102,700	3820	78,600	4720	63,600
2940	102,000	3840	78,200	4740	63,300
2960	101,300	3860	77,700	4760	63,000
2980	100,700	3880	77,300	4780	62,800
3000	100,000	3900	76,900	4800	62,500
3020	99,400	3920	76,500	4820	62,300
3040	98,700	3940	76,200	4840	62,000
3060	98,100	3960	75,800	4860	61,800
3080	97,400	3980	75,400	4880	61,500
3100	96,800	4000	75,000	4900	61,200
3120	96,200	4020	74,700	4920	61,000
3140	95,600	4040	74,300	4940	60,800
3160	95,000	4060	73,900	4960	60,500
3180	94,400	4080	73,600	4980	60,300
3200	93,800	4100	73,200	5000	60,000
3220	93,200	4120	72,800	5050	59,400
3240	92,600	4140	72,500	5100	58,800
3260	92,000	4160	72,100	5150	58,300
3280	91,500	4180	71,800	5200	57,700
3300	90,900	4200	71,500	5250	57,200
3320	90,400	4220	71,100	5300	56,600
3340	89,800	4240	70,800	5350	56,100
3360	89,300	4260	70,400	5400	55,600
3380	88,800	4280	70,100	5450	55,100
3400	88,300	4300	69,800	5500	54,600
3420	87,700	4320	69,500	5550	54,100
3440	87,200	4340	69,100	5600	53,600
3460	86,700	4360	68,800	5650	53,100
3480	86,200	4380	68,500	5700	52,700

TABLE I—(*Continued*)

Meters	Frequency	Meters	Frequency	Meters	Frequency
5750	52,200	8000	37,500	10500	28,600
5800	51,700	8050	37,300	10600	28,300
5850	51,300	8100	37,000	10700	28,000
5900	50,900	8150	36,800	10800	27,800
5950	50,400	8200	36,600	10900	27,500
6000	50,000	8250	36,400	11000	27,300
6050	49,600	8300	36,100	11100	27,000
6100	49,200	8350	35,900	11200	26,800
6150	48,800	8400	35,700	11300	26,500
6200	48,400	8450	35,500	11400	26,300
6250	48,000	8500	35,300	11500	26,100
6300	47,600	8550	35,100	11600	25,900
6350	47,200	8600	34,900	11700	25,600
6400	46,900	8650	34,700	11800	25,400
6450	46,500	8700	34,500	11900	25,200
6500	46,200	8750	34,300	12000	25,000
6550	45,800	8800	34,100	12100	24,800
6600	45,500	8850	33,900	12200	24,600
6650	45,100	8900	33,700	12300	24,400
6700	44,800	8950	33,500	12400	24,200
6750	44,400	9000	33,300	12500	24,000
6800	44,100	9050	33,100	12600	23,800
6850	43,800	9100	33,000	12700	23,600
6900	43,500	9150	32,800	12800	23,400
6950	43,200	9200	32,600	12900	23,300
7000	42,900	9250	32,400	13000	23,100
7050	42,600	9300	32,300	13100	22,900
7100	42,300	9350	32,100	13200	22,700
7150	42,000	9400	31,900	13300	22,600
7200	41,700	9450	31,700	13400	22,400
7250	41,400	9500	31,600	13500	22,200
7300	41,100	9550	31,400	13600	22,100
7350	40,800	9600	31,300	13700	21,900
7400	40,500	9650	31,100	13800	21,700
7450	40,300	9700	30,900	13900	21,600
7500	40,000	9750	30,800	14000	21,400
7550	39,700	9800	30,600	14100	21,300
7600	39,500	9850	30,500	14200	21,100
7650	39,200	9900	30,300	14300	21,000
7700	39,000	9950	30,200	14400	20,800
7750	38,700	10000	30,000	14500	20,700
7800	38,500	10100	29,700	14600	20,600
7850	38,200	10200	29,400	14700	20,400
7900	38,000	10300	29,100	14800	20,300
7950	37,700	10400	28,800	14900	20,100

TABLE I—(*Continued*)

Meters	Frequency	Meters	Frequency	Meters	Frequency
15000	20,000	18700	16,040	24800	12,100
15100	19,870	18800	15,960	25000	12,000
15200	19,740	19800	15,870	25200	11,900
15300	19,610	19000	15,790	25400	11,810
15400	19,480	19100	15,710	25600	11,720
15500	19,350	19200	15,630	25800	11,630
15600	19,230	19300	15,540	26000	11,540
15700	19,110	19400	15,460	26200	11,450
15800	18,990	19500	15,380	26400	11,360
15900	18,870	19600	15,310	26600	11,280
16000	18,750	19700	15,230	26800	11,190
16100	18,630	19800	15,150	27000	11,110
16200	18,510	19900	15,080	27200	11,030
16300	18,400	20000	15,000	27400	10,950
16400	18,290	20200	14,850	27600	10,870
16500	18,180	20400	14,710	27800	10,790
16600	18,070	20600	14,560	28000	10,710
16700	17,960	20800	14,420	28200	10,640
16800	17,850	21000	14,290	28400	10,560
16900	17,740	21200	14,150	28600	10,490
17000	17,640	21500	14,020	28800	10,420
17100	17,540	21600	13,890	29000	10,340
17200	17,440	21800	13,760	29200	10,270
17300	17,340	22000	13,640	29400	10,200
17400	17,240	22200	13,510	29600	10,130
17500	17,140	22400	13,390	29800	10,070
17600	17,050	22600	13,270	30000	10,000
17700	16,950	22800	13,160	31000	9,680
17800	16,850	23000	13,040	32000	9,380
17900	16,760	23200	12,930	33000	9,090
18000	16,670	23400	12,820	34000	8,830
18100	16,570	23600	12,710	35000	8,570
18200	16,480	23800	12,600	36000	8,340
18300	16,390	24000	12,500	37000	8,110
18400	16,300	24200	12,400	38000	7,900
18500	16,220	24400	12,290	39000	7,690
18600	16,130	24600	12,190		

TABLE II—Wave-length with C mfd. and L cms.

C mfd.	1,000 cms.	2,000 cms.	3,000 cms.	4,000 cms.	5,000 cms.
0.0001......	19	27	33	38	42
0.0002......	27	38	46	53	60
0.0003......	33	46	57	65	73
0.0004......	38	53	65	75	84
0.0005......	42	60	73	84	94
0.0006......	46	65	80	92	103
0.0007......	50	71	86	100	112
0.0008......	53	75	92	107	119
0.0009......	57	80	98	113	126
0.0010......	60	84	103	119	133
0.0011......	63	88	108	125	140
0.0012......	65	92	113	131	146
0.0013......	68	96	118	136	152
0.0014......	70	100	122	141	158
0.0015......	73	103	126	146	163
0.0016......	75	107	131	150	169
0.0017......	78	110	135	155	174
0.0018......	80	113	139	160	179
0.0019......	82	116	142	164	184
0.0020......	84	119	146	169	188

C	6,000	7,000	8,000	9,000	10,000
0.0001......	46	50	53	57	60
0.0002......	65	71	75	80	84
0.0003......	80	86	92	98	103
0.0004......	92	100	107	113	119
0.0005......	103	112	119	126	133
0.0006......	113	122	131	139	146
0.0007......	122	132	141	150	158
0.0008......	131	141	151	160	169
0.0009......	139	150	160	170	179
0.0010......	146	158	169	179	188
0.0011......	153	165	177	188	198
0.0012......	160	173	185	196	206
0.0013......	166	180	192	204	215
0.0014......	173	187	199	212	223
0.0015......	179	193	206	219	231
0.0016......	185	199	213	226	238
0.0017......	190	206	220	233	246
0.0018......	196	212	226	240	253
0.0019......	201	217	232	246	260
0.0020......	206	223	238	253	267

TABLE II—(*Continued*)

C	12,000	14,000	16,000	18,000	20,000
0.0001......	65	71	75	80	84
0.0002......	92	100	107	113	119
0.0003......	113	122	131	139	146
0.0004......	131	141	151	160	169
0.0005......	146	158	169	179	188
0.0006......	160	173	185	196	206
0.0007......	173	187	199	212	223
0.0008......	185	199	213	226	238
0.0009......	196	212	226	240	253
0.0010......	206	223	238	253	267
0.0011......	217	234	250	265	280
0.0012......	226	244	261	277	292
0.0013......	235	254	272	288	304
0.0014......	244	264	282	299	315
0.0015......	253	273	292	310	326
0.0016......	261	282	302	320	337
0.0017......	269	291	311	330	348
0.0018......	277	299	320	339	358
0.0019......	285	307	329	349	367
0.0020......	292	315	337	358	377

C	25,000	30,000	40,000	50,000	60,000
0.0001......	94	103	119	133	146
0.0002......	133	146	169	188	206
0.0003......	163	179	206	231	253
0.0004......	188	206	238	267	292
0.0005......	211	231	267	298	326
0.0006......	231	253	292	326	358
0.0007......	249	273	315	353	386
0.0008......	267	292	337	377	413
0.0009......	283	310	358	400	438
0.0010......	298	326	377	421	462
0.0011......	313	342	395	442	484
0.0012......	326	358	413	462	506
0.0013......	340	372	430	481	526
0.0014......	353	386	446	499	546
0.0015......	365	400	462	516	565
0.0016......	377	413	477	533	584
0.0017......	389	426	491	550	602
0.0018......	400	438	506	565	619
0.0019......	411	450	520	581	637
0.0020......	421	462	533	596	653

TABLE II—(*Continued*)

C	70,000	80,000	90,000	100,000	120,000
0.0001	158	169	179	188	206
0.0002	223	238	253	267	292
0.0003	273	292	310	326	358
0.0004	315	337	358	377	413
0.0005	353	377	400	421	462
0.0006	386	413	438	462	506
0.0007	417	446	473	499	546
0.0008	446	477	506	533	584
0.0009	473	506	536	565	619
0.0010	499	533	565	596	653
0.0011	523	559	593	625	685
0.0012	546	584	619	653	715
0.0013	569	611	645	680	744
0.0014	590	631	669	705	772
0.0015	611	653	690	730	800
0.0016	631	674	715	754	826
0.0017	650	695	737	777	851
0.0018	669	715	759	800	876
0.0019	687	735	780	822	900
0.0020	705	754	800	843	923

C	140,000	160,000	180,000	200,000	250,000
0.0001	223	238	253	267	298
0.0002	315	337	358	377	421
0.0003	386	413	438	462	516
0.0004	446	477	506	533	596
0.0005	499	533	565	596	666
0.0006	546	584	619	653	730
0.0007	590	631	669	705	789
0.0008	631	674	715	754	843
0.0009	669	715	759	800	894
0.0010	705	754	800	843	942
0.0011	740	791	839	884	1,075
0.0012	772	826	876	923	1,032
0.0013	804	859	912	961	1,075
0.0014	834	892	946	997	1,115
0.0015	864	923	979	1,032	1,154
0.0016	892	954	1,011	1,066	1,192
0.0017	920	983	1,042	1,099	1,229
0.0018	946	1,011	1,073	1,131	1,264
0.0019	972	1,041	1,102	1,162	1,299
0.0020	997	1,066	1,131	1,192	1,333

TABLE II—(*Continued*)

C	300,000	400,000	500,000	600,000	700,000
0.0001	326	377	421	462	499
0.0002	462	533	596	653	705
0.0003	566	653	730	800	864
0.0004	653	754	843	923	997
0.0005	730	843	942	1,032	1,115
0.0006	800	923	1,032	1,131	1,221
0.0007	864	997	1,115	1,221	1,320
0.0008	923	1,066	1,192	1,306	1,410
0.0009	979	1,131	1,264	1,385	1,496
0.0010	1,032	1,192	1,333	1,460	1,577
0.0011	1,083	1,250	1,398	1,531	1,654
0.0012	1,131	1,306	1,460	1,599	1,727
0.0013	1,177	1,359	1,520	1,665	1,798
0.0014	1,221	1,410	1,577	1,727	1,866
0.0015	1,264	1,460	1,632	1,788	1,932
0.0016	1,306	1,509	1,686	1,846	1,995
0.0017	1,346	1,554	1,737	1,904	2,056
0.0018	1,385	1,599	1,788	1,959	2,116
0.0019	1,423	1,643	1,837	2,012	2,174
0.0020	1,460	1,686	1,885	2,065	2,230

C	800,000	900,000	1,000,000	1,200,000	1,400,000
0.0001	533	565	596	653	705
0.0002	754	800	843	923	997
0.0003	923	979	1,032	1,131	1,221
0.0004	1,066	1,131	1,192	1,306	1,410
0.0005	1,192	1,264	1,333	1,460	1,577
0.0006	1,306	1,385	1,460	1,599	1,727
0.0007	1,410	1,496	1,577	1,727	1,866
0.0008	1,509	1,599	1,686	1,846	1,995
0.0009	1,599	1,696	1,788	1,959	2,116
0.0010	1,686	1,788	1,885	2,065	2,230
0.0011	1,768	1,875	1,977	2,165	2,339
0.0012	1,846	1,959	2,065	2,262	2,443
0.0013	1,922	2,039	2,149	2,354	2,543
0.0014	1,995	2,116	2,230	2,443	2,639
0.0015	2,065	2,190	2,308	2,529	2,732
0.0016	2,133	2,262	2,384	2,612	2,821
0.0017	2,198	2,332	2,457	2,692	2,908
0.0018	2,262	2,399	2,529	2,770	2,992
0.0019	2,324	2,465	2,598	2,846	3,074
0.0020	2,384	2,529	2,665	2,920	3,154

TABLE I—Continued

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]			[illegible]		

TABLE II—(*Continued*)

C	9,000,000	10,000,000	12,000,000	14,000,000	16,000,000
0.0001....	1,788	1,885	2,065	2,230	2,384
0.0002....	2,529	2,665	2,920	3,154	3,372
0.0003....	3,097	3,264	3,576	3,863	4,129
0.0004....	3,576	3,770	4,129	4,460	4,768
0.0005....	3,998	4,214	4,617	4,987	5,331
0.0006....	4,379	4,617	5,057	5,462	5,840
0.0007....	4,731	4,987	5,462	5,900	6,306
0.0008....	5,057	5,331	5,840	6,306	6,741
0.0009....	5,364	5,654	6,192	6,693	7,152
0.0010....	5,654	5,960	6,529	7,052	7,539
0.0011....	5,930	6,251	6,848	7,396	7,909
0.0012....	6,192	6,529	7,152	7,724	8,261
0.0013....	6,449	6,796	7,444	8,040	8,594
0.0014....	6,693	7,052	7,724	8,344	8,922
0.0015....	6,902	7,299	7,996	8,637	9,233
0.0016....	7,152	7,539	8,261	8,922	9,536
0.0017....	7,373	7,771	8,511	9,196	9,828
0.0018....	7,587	7,996	8,761	9,459	10,110
0.0019....	7,796	8,215	9,000	9,721	10,410
0.0020....	7,996	8,429	9,230	9,973	10,660

C	18,000,000	20,000,000	25,000,000	30,000,000	40,000,000
0.0001....	2,529	2,665	2,980	3,264	3,770
0.0002....	3,576	3,770	4,214	4,617	5,331
0.0003....	4,379	4,617	5,161	5,659	6,529
0.0004....	5,057	5,331	5,960	6,529	7,539
0.0005....	5,654	5,960	6,663	7,299	8,429
0.0006....	6,192	6,529	7,299	7,996	9,233
0.0007....	6,693	7,052	7,885	8,637	9,973
0.0008....	7,152	7,539	8,429	9,233	10,660
0.0009....	7,587	7,996	8,940	9,794	11,310
0.0010....	7,996	8,429	9,423	10,320	11,920
0.0011....	8,386	8,840	10,750	10,830	12,500
0.0012....	8,761	9,233	10,320	11,310	13,060
0.0013....	9,119	9,611	10,750	11,770	13,590
0.0014....	9,459	9,973	11,150	12,210	14,100
0.0015....	9,794	10,320	11,540	12,640	14,600
0.0016....	10,110	10,660	11,920	13,060	15,090
0.0017....	10,420	10,990	12,290	13,460	15,540
0.0018....	10,730	11,310	12,640	13,850	15,990
0.0019....	11,020	11,620	12,990	14,230	16,430
0.0020....	11,310	11,920	13,330	14,600	16,860

TABLE II—(*Continued*)

C	50,000,000	60,000,000	70,000,000	80,000,000	90,000,000
0.0001....	4,214	4,617	4,987	5,331	5,654
0.0002....	5,960	6,529	7,052	7,539	7,996
0.0003....	7,299	7,996	8,637	9,233	9,794
0.0004....	8,429	9,233	9,973	10,660	11,310
0.0005....	9,423	10,320	11,150	11,920	12,640
0.0006....	10,320	11,310	12,210	13,060	13,850
0.0007....	11,150	12,210	13,200	14,100	14,960
0.0008....	11,920	13,060	14,100	15,090	15,990
0.0009....	12,640	13,850	14,960	15,990	16,960
0.0010....	13,330	14,600	15,770	16,860	17,880
0.0011....	13,980	15,310	16,540	17,680	18,760
0.0012....	14,600	15,990	17,270	18,460	19,590
0.0013....	15,200	16,650	17,980	19,220	20,390
0.0014....	15,770	17,270	18,660	19,950	21,160
0.0015....	16,320	17,880	19,320	20,650	21,900
0.0016....	16,860	18,460	19,950	21,330	22,620
0.0017....	17,370	19,040	20,560	21,980	23,320
0.0018....	17,880	19,590	21,160	22,620	23,990
0.0019....	18,370	20,120	21,740	23,240	24,650
0.0020....	18,850	20,650	22,300	23,840	25,290

C	100,000,000	120,000,000	140,000,000	160,000,000	180,000,000
0.0001....	5,960	6,529	7,052	7,539	7,996
0.0002....	8,429	9,233	9,973	10,660	11,310
0.0003....	10,320	11,310	12,210	13,060	13,850
0.0004....	11,920	13,060	14,100	15,090	15,990
0.0005....	13,330	14,600	15,770	16,860	17,880
0.0006....	14,600	15,990	17,270	18,460	19,590
0.0007....	15,770	17,270	18,660	19,950	21,160
0.0008....	16,860	18,460	19,950	21,330	22,620
0.0009....	17,880	19,590	21,160	22,620	23,990
0.0010....	18,850	20,650	22,300	23,840	25,290
0.0011....	19,770	21,650	23,390	25,000	26,520
0.0012....	20,650	22,620	24,430	26,120	27,700
0.0013....	21,490	23,540	25,430	27,180	28,830
0.0014....	22,300	24,430	26,390	28,210	29,920
0.0015....	23,080	25,290	27,320	29,200	30,970
0.0016....	23,840	26,120	28,210	30,160	31,990
0.0017....	24,570	26,920	29,080	31,080	32,8[illegible]0
0.0018....	25,290	27,700	29,920	31,990	33,720
0.0019....	25,980	28,460	30,740	32,860	34,850
0.0020....	26,650	29,200	31,540	33,720	35,760

TABLE II—(*Continued*)

C	200,000,000	250,000,000	300,000,000	400,000,000	500,000,000
0.0001....	8,429	9,423	10,320	11,920	13,330
0.0002....	11,920	13,330	14,600	16,860	18,850
0.0003....	14,600	16,320	17,880	20,650	23,080
0.0004....	16,860	18,850	20,650	23,840	26,650
0.0005....	18,850	21,080	23,080	26,650	29,800
0.0006....	20,650	23,080	25,290	29,200	32,640
0.0007....	22,300	24,930	27,320	31,540	35,260
0.0008....	23,840	26,650	29,200	33,720	37,700
0.0009....	25,290	28,270	30,970	35,760	39,980
0.0010....	26,650	29,800	32,640	37,700	42,140
0.0011....	27,950	31,250	34,240	39,530	44,200
0.0012....	29,200	32,640	35,760	41,290	46,170
0.0013....	30,390	33,980	37,220	42,980	48,050
0.0014....	31,540	35,260	38,630	44,600	49,870
0.0015....	32,640	36,500	39,980	46,170	51,610
0.0016....	33,720	37,700	41,290	47,680	53,310
0.0017....	34,750	38,850	42,560	49,150	54,950
0.0018....	35,760	39,980	43,790	50,570	56,540
0.0019....	36,740	41,080	45,000	51,960	58,090
0.0020....	37,770	42,140	46,170	53,310	59,600

To determine the wave-length resulting from a given combination of inductance and capacity, locate the value of L at the top of the table, and run down the column until opposite the C required.

Wave-length can be calculated by the formula

$$\lambda = 59.6\sqrt{LC} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\text{or } L = \frac{\lambda^2}{3552\,C} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$\text{or } C = \frac{\lambda^2}{3552\,L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

4. FREQUENCY, INDUCTANCE, CAPACITY.

Frequency, corresponding to given values of L and C, can be found by determining the wave-length, Table 2, and the frequency corresponding to that wave-length, Table 1. Or, if desired, the wave-length can be determined from (3) and the frequency from (1).

5. INDUCTANCE IN CIRCUIT.

Formulas for wave-length are for the total amount of inductance in the circuit. Thus, if inductances are in series or parallel, the resultant value must be found and substituted in the wave-length formula.

A. Non-coupled inductances in series. The total L when two or more inductances are in series is the sum

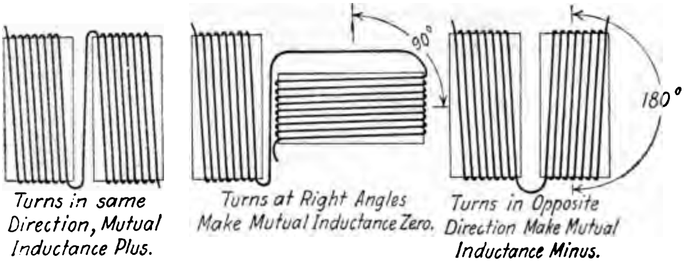

Fig. 1.—Mutual Inductance or Coupling can be Varied by Changing the Relative Position of Two Coils.

of the inductances, if they are not coupled magnetically, or

$$L = L_1 + L_2 + L_3, \text{ etc.} \quad . \quad . \quad . \quad . \quad (6)$$

B. Coupled inductances in series. Two coupled coils in series, such as the coils of a variometer, give a total inductance, if the coils are aiding, of

$$L = L_1 + L_2 + 2\,M, \quad . \quad . \quad . \quad . \quad (7)$$

$$\text{or } L = L_1 + L_2 - 2\,M, \quad . \quad . \quad . \quad . \quad (8)$$

where the coils oppose each other. If connections between the coils are such that the current passes as if through a continuous coil, the coils will be aiding.

C. Coupled inductances in parallel. Two coupled coils in parallel, aiding, give a total inductance of

$$L = \frac{L_1 \times L_2 - M^2}{L_1 + L_2 - 2\,M} \quad . \quad . \quad . \quad . \quad (9)$$

$$\text{or } L = \frac{L_1 \times L_2 - M^2}{L_1 + L_2 + 2\,M} \quad . \quad . \quad . \quad . \quad (10)$$

when they are opposing.

D. Non-coupled coils in parallel. Two coils in parallel, not coupled inductively, give a total inductance.

$$L = \frac{L_1 \times L_2}{L_1 + L_2} \quad \ldots \ldots \quad (11)$$

E. Mutual inductance. Two coupled coils, connected in series or parallel, have a certain value of mutual inductance between them due to the coupling of the magnetic lines of force, which increases or decreases the total inductance in the circuit, according to whether the coils aid or oppose each other. When two coils are in series, if they are aiding,

$$M = \frac{L - L_1 - L_2}{2} \quad \ldots \ldots \quad (12)$$

or, opposing,

$$M = \frac{L_1 + L_2 - L}{2} \quad \ldots \ldots \quad (13)$$

It is very difficult to calculate the mutual inductance between two coils except when they are of the same

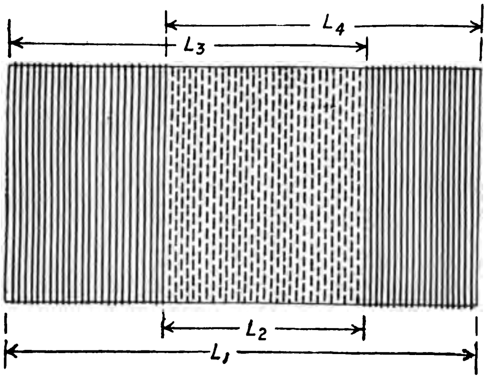

Fig. 2.—When Calculating the Mutual Inductance of Coils of this Type, it is Considered that a Continuous Winding Separates Them.

diameter, have the same number of turns per inch, and are coaxial. Fig. 2 illustrates the method. The coils are separated by a distance L_2. The inductance L_1 is first calculated as if the winding continued across the separating space. L_2 is calculated as if it were wound with the same number of turns per inch as is used in the coils, L_3 and L_4 and determined in the same manner. Then

$$M = L_1 + L_2 - L_3 - L_4 \quad . \quad . \quad . \quad . \quad (14)$$

The change of inductance in a variometer is due to the varying mutual inductance between the coils as their relative positions are varied. Mutual inductance is not considered in designing loose couplers and similar instruments in which the coils are not connected together electrically.

6. COEFFICIENT OF COUPLING.

The amount of coupling between the coils, expressed in per cent., is

$$K = \sqrt{\frac{M^2}{L_1 L_2}} \times 100 \quad . \quad . \quad . \quad . \quad (15)$$

F. Measurement of inductance. The simplest way to measure inductance is to shunt around the coil a calibrated condenser, exciting the circuit with a buzzer. When the wave-length of the circuit is measured with a wave-meter, the inductance can be found, knowing the wave-length and capacity of the shunt condenser, by (4). Fig. 3 shows the connections.

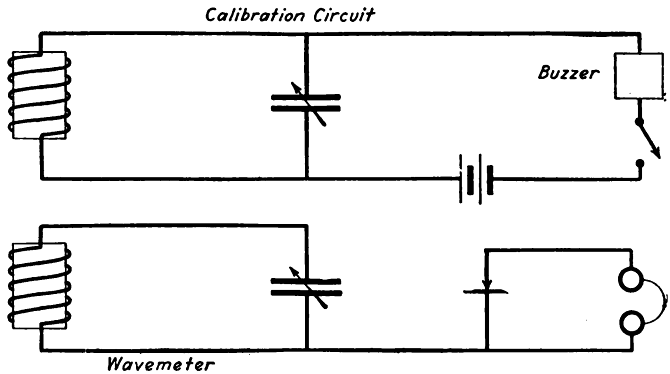

Fig. 3.—Inductance or Capacity can be Measured by Means of this Circuit.

7. CAPACITY IN CIRCUIT.

As is the case with inductances, wave-length and similar formulas require the total capacity in the circuit. That is, if condensers are in series or parallel, the resultant capacity must be determined and substituted in the formulas.

A. Condensers in series. Two condensers of the same capacity, wired in series, give a total capacity of

$$C = \frac{C_1 + C_2}{4} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (16)$$

Two condensers of different capacities, in series, give

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (17)$$

Where there are several different capacities,

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} \quad . \; . \; . \; . \; . \; . \quad (18)$$

Table 3 shows the resultant capacity when two condensers of various capacities are in series.

B. Condensers in parallel. Two or more condensers in parallel give a resultant capacity equal to the sum of the capacities. That is,

$$C = C_1 + C_2 \quad . \; . \; . \; . \; . \; . \; . \; . \quad (19)$$

C. Distributed capacity. Because of the difference in potential between the turns of a coil, an inductance possesses a certain amount of local capacity. This distributed capacity acts as a shunt condenser around the coil. However, the value is not considered in designing circuits, nor can it be calculated. In a well-designed inductance, the capacity value can be neglected.

It is important to keep this capacity as low as possible

TABLE III—EFFECTIVE CAPACITY IN mfds

C tuning	0.0001	0.0002	0.0003	0.0004	0.0005
0.0001.....	0.000050	0.00006	0.00007	0.00008	0.00008
0.0002.....	0.000060	0.00010	0.00012	0.00013	0.00014
0.0003.....	0.000075	0.00012	0.00015	0.00017	0.00019
0.0004.....	0.000080	0.00013	0.00017	0.00020	0.00022
0.0005.....	0.000083	0.00014	0.00019	0.00022	0.00025
0.0006.....	0.000086	0.00015	0.00020	0.00024	0.00027
0.0007.....	0.000088	0.00015	0.00021	0.00025	0.00029
0.0008......	0.000089	0.00016	0.00022	0.00026	0.00031
0.0009.....	0.000090	0.00016	0.00023	0.00027	0.00032
0.0010.....	0.000091	0.00017	0.00023	0.00028	0.00033
0.0011.....	0.000092	0.00017	0.00024	0.00029	0.00034
0.0012.....	0.000092	0.00017	0.00024	0.00030	0.00035
0.0013.....	0.000093	0.00017	0.00024	0.00031	0.00036
0.0014.....	0.000093	0.00018	0.00025	0.00031	0.00037
0.0015.....	0.000094	0.00018	0.00025	0.00032	0.00038
0.0016.....	0.000094	0.00018	0.00025	0.00032	0.00039
0.0017.....	0.000094	0.00018	0.00026	0.00032	0.00039
0.0018.....	0.000095	0.00018	0.00026	0.00033	0.00040
0.0019.....	0.000095	0.00018	0.00026	0.00033	0.00040
0.0020.....	0.000095	0.00018	0.00026	0.00033	0.00040

C tuning	0.0006	0.0007	0.0008	0.0009	0.0010
0.0001.....	0.00009	0.00009	0.00009	0.00009	0.00009
0.0002.....	0.00015	0.00015	0.00016	0.00016	0.00017
0.0003.....	0.00020	0.00021	0.00022	0.00023	0.00023
0.0004.....	0.00024	0.00025	0.00026	0.00027	0.00028
0 0005.....	0.00027	0.00029	0.00030	0.00032	0.00033
0.0006.....	0.00030	0.00032	0.00034	0.00036	0.00038
0.0007.....	0.00032	0.00035	0.00037	0.00039	0.00041
0.0008.....	0.00034	0.00037	0.00040	0.00042	0.00044
0.0009.....	0.00036	0.00039	0.00042	0.00045	0.00047
0.0010.....	0.00038	0.00041	0.00044	0.00047	0.00050
0.0011.....	0.00039	0.00043	0.00046	0.00049	0.00053
0.0012.....	0.00040	0.00044	0.00048	0.00051	0.00055
0.0013.....	0.00041	0.00045	0.00050	0.00053	0.00057
0.0014.....	0.00042	0.00046	0.00051	0.00055	0.00058
0.0015.....	0.00043	0.00047	0.00052	0.00057	0.00060
0.0016.....	0.00044	0.00048	0.00053	0.00058	0.00061
0.0017.....	0.00044	0.00049	0.00054	0.00059	0.00063
0.0018.....	0.00045	0.00050	0.00055	0.00060	0.00064
0.0019.....	0.00045	0.00051	0.00056	0.00061	0.00065
0.0020.....	0.00046	0.00052	0.00057	0.00062	0.00066

as it causes a reduction of the signal strength and makes the tuning broad.

D. Measurement of capacity. Capacity can be measured in a manner similar to that in Section 5 F, except that a standard inductance is used instead of a calibrated condenser. Then the capacity of the condenser is given by (5).

CHAPTER II

RADIO ANTENNAS

The present-day developments of radio telegraph has made it possible to obtain some results with almost anything for an antenna, from tin cans to wire fences, or even with no antenna at all. The radio experimenters, however, are interested in more practical devices than bedspring or tree antennas.

Radio antennas are generally divided into three classes, antennas, or structures of elevated wires, loop antennas, or coils not connected to the ground, and condenser antennas, made up of elevated plates, not grounded.

In making antenna circuit calculations, only the capacity of the antenna or condenser antenna is considered, while in the loop, only the inductance is considered.

8. ANTENNAS.

A. Single-wire types. The long, low, single wire is the best for receiving, though it is not as efficient for sending as the multi-wire types. Three sizes which have been standardized by the General Apparatus Company are 30 feet high at each end, and 100, 200 and 300 feet long, known as the short, long, and super-range types.

The short-range size is for 200-meter reception. The average capacity is 0.0002 mfd.

A long-range antenna is for receiving commercial stations up to 5,000 meters, although greater wave-lengths can be received by the use of large loading coils. The capacity is generally 0.0004 mfd.

The super-range type is intended for long-wave reception over great distances. Its capacity is approximately 0.0005 mfd.

B. V Types. Particularly for portable work, the United States Signal Corps has employed two wires stretched out at an agle of 60°. Such an antenna with wires 100 feet long, 20 feet above the ground, has a capacity of about 0.0004 mfd. and gives good results.

C. Multi-wire types. Although single-wire antennas can be used for sending, several horizontal wires give better results. The General Apparatus Company has adopted as a standard 200-meter antenna four wires 2 feet apart, 80 feet long, and 30 feet high at both ends. The capacity is approximately 0.0005 mfd.

It makes very little difference whether the lead-in is brought from the center or end. When the antenna is erected on the roof of an apartment house, the height is taken as the elevation above the roof.

D. Umbrella types. Essentially the umbrella type antenna is made of a wooden or metal mast, the wires of which form the antenna. If the mast is wooden, the wires are connected together near the ground, or if it is metal, the wires are connected to the mast. Galvanized iron drain pipe is often used for a mast as it is so light and easy to handle, yet sufficiently strong for moderate-size aerials. Oftentimes it is possible to mount the mast on the ridge pole of a house, running the wires to the ends of the ridge pole and to gables.

This type is good for transmitting and receiving.

9. LOOP ANTENNAS.

The loop antenna, consisting of a coil or flat spiral, is used extensively for an indoor aerial, for direction finding, and for cutting down interference. While to equal the receiving or transmitting range of an antenna, it must approach the latter in size, very long distance work can be accomplished with an amplifier and even with a single audion if the signals are from a high-powered station.

A. Square-cage loop. The inductance of a square-cage loop can be determined with sufficient accuracy for design purposes by the use of formula (27), in which the radius r, is taken as

$$r = \frac{\text{Length of one size} \times 1.2}{2} \quad . \; . \; . \quad (20)$$

and diameter, d, as

$$d = \text{length of one side} \times 1.2 \quad . \; . \; . \quad (21)$$

The other terms of equation (27) can be applied directly to the dimensions of the loop.

B. Square flat loop. Formula (27) can be used for the approximate inductance of a square flat loop by substituting the average radius for r,

$$r = \frac{\text{av. length of outer and inner side} \times 1.2}{2} \quad . \quad (22)$$

the average diameter for d,

$$d = \text{av. length of outer and inner sides} \times 1.2 \quad . \quad (23)$$

the length, l, as

$$l = \frac{\text{outer side—inner side}}{2} \quad . \; . \; . \quad (24)$$

and the turns per inch, measured at right angles to one of the sides, for n.

C. Leads. Connections to a loop antenna must be as short as possible, and arranged in such a way that there is no inductance or capacity effect to other conductors or grounded metal bodies.

D. Capacity in loops. Distributed capacity in loop antennas causes a broadening of the tuning. Every effort must be made, therefore, to keep the insulation of maximum value. Bare wire is generally used for the winding so that there will not be losses in the insulation. Bakelite supports, which do not absorb moisture, are necessary to support the wire. As an added precaution, corrugations or slots may be made between the grooves holding the wire. Loops should be mounted indoors, so that no moisture or dust will collect on the supports.

E. Directional distortion. Metal objects distort the radio waves, introducing errors in the directional indications. Also, loops set up near the water are inaccurate.

As the distortion varies at different wave-lengths, correction tables must be made at different wave-lengths.

10. CONDENSER ANTENNAS.

Very little work has been done, up to the present time, on condenser antennas, so that no data is available. Antennas made up of two horizontal net works of wire, one over the other, both insulated from the ground, were used early in radio work. The recent developments are in the form of plates or copper screens, one acting as the antenna, and the other as the ground. The condenser is charged by the radio waves, discharging into the apparatus, in the case of a receiver, or conversely in the case of a transmitter.

A. Experimental types. Experiments with small condenser antennas have shown them equal for receiving purposes to a small loop. Plates have been used made of fine-mesh copper screen 10 feet square, separated 10 or 12 inches. They were thoroughly insulated from the ground and from each other.

11. AIRPLANE ANTENNAS.

Airplane antennas are generally in the form of one or more trailing wires, with the stay wires and engine acting as the ground. Antennas erected laterally on the upper plane, or types having a short mast, have proved inefficient because of their low capacity and radiation resistance.

A. Single trailing wire. The following data was taken with a single stranded cable trailing from lower wing, at the first rib from the left of the fuselage of a Curtiss JN machine flying at an altitude of 2,000 feet.

Length of Wire	Capacity in mfd.	Natural λ in Meters
100 ft.	0.000185	165
150	0.000205	185
200	0.000225	215
300	0.000260	275
400	0.000290	350
500	0.000305	435
600	0.000315	525

Under the same conditions, these resistance measurements were taken. The values are the total resistance of the antenna, and not simply the radiation resistance.

Length of Wire Feet	Ohms					
	250 λ	300 λ	400 λ	500 λ	600 λ	900 λ
100.........	2.0	1.0	0.6	....	....	...
200.........	10.3	6.0	3.6	2.4	1.1	...
300.........	....	...	8.5	5.2	3.6	2.0
400.........	....	...	...	11.0	7.0	3.6
500.........	....	...	...	....	12.3	5.6
600.........	....	...	...	....	....	7.8

The directive effect of a single trailing wire is shown by the data below. It will be noted that there is a slight distortion to the left, the side on which the antenna was fastened. The antenna was 500 feet long, and the measurements were taken under the conditions just described. The values of received energy represent the relative signal strength at a station one mile from the airplane.

Direction	Received Energy
Dead ahead	190
30° left ahead	205
60° left ahead	200
90° left	105
120° left astern	20
150° left astern	5
Dead astern	8
30° right ahead	165
60° right ahead	130
90° right	80
120° right astern	33
150° right	13

B. Two trailing wires. Greater efficiency has been obtained with two trailing wires, fastened to the struts of the machine, but broken by insulators 5 feet from the struts. Leads are brought off at the insulators to the fuselage. The wires and engine were used as a ground.

In a series of tests with 40-feet, 50-feet, and 60-feet wires attached to the outer struts, the natural wavelength was found to be 65, 73, and 80 meters, with a resistance at 100 meters of 2.3, 3.5, and 8.0 ohms respectively. When fastened to the inner struts the wave-length was 58, 70, and 77 meters, with a resistance of 2.25, 3.75, and 4 ohms respectively.

Means were not at hand to measure the capacity, but it was found that capacity was less when the wires were secured to the inner struts. In the latter case, a variation of capacity was noted when the machine was ascending or descending steeply, probably due to the change in the relative position of the antenna wires and stay wires.

The transmission ahead was approximately two times as good as astern.

12. ANTENNA RESISTANCE.

Like all other circuits, an antenna circuit contains a certain amount of resistance. There is a useful resistance, called radiation resistance, and a wasteful resistance, which must be kept as low as possible, due to losses in the circuit.

A. Components of the antenna resistance. The resistance of an antenna is due to

1. Useful
   - (*a*) Loss of energy radiated as radio signals.
2. Wasteful
   - (*a*) Loss of energy in resistance of ground connections.
   - (*b*) Poor insulation.
   - (*c*) Corona discharges from overloaded antenna.
   - (*d*) Dielectric absorption.
   - (*e*) Absorption from near-by structures.
   - (*f*) Loss in resistance of conductors.

B. Antenna resistance. The resistance of an antenna is equal to the resistance of a non-inductive circuit which will absorb the same amount of power. This value can be measured readily.

C. Radiation resistance. The radiation resistance is equal to the resistance of a non-inductive circuit which will absorb the same amount of power as is radiated by the antenna in radio signals.

D. Ground resistance. The resistance of the ground connection and conductors is practically constant at varying frequencies.

E. Dielectric Absorption. Power losses from dielectric absorption increase with the wave-length. If the wave-length reaches the natural period of a near-by structure, there will be a decided hump in the resistance wave-length curve.

F. Static capacity. The capacity of an antenna, with no apparatus connected, is called the static capacity. This is the value of capacity used in designing antenna circuits.

G. Natural wave-length. Since an antenna possesses inductance and capacity, it will oscillate at the corresponding wave-length, known as the natural wave-length, when it is excited by auxiliary means.

H. Test data. The following measurements were made on a 60° V type antenna 30 feet high, with each leg 100 feet long. An inductance in series with the antenna and ground was varied to increase the length of the radiated waves.

Natural λ, 230 meters.

Static capacity 0.000345 mfd.

It should be noted that the useful resistance is greatest

λ in meters	Radiation Resistance	Absorption Resistance	Ground Resistance	Total Antenna Resistance
250......	36.0	2.0	5.0	43.0
300......	26.0	3.0	5.0	34.0
350......	19.5	3.5	5.0	28.0
400......	15.0	4.0	5.0	24.0
500......	10.0	5.5	5.5	21.0
600......	6.5	6.5	6.5	19.5
700......	5.0	8.0	6.5	19.5
800......	3.5	8.0	7.0	19.5
900......	2.5	10.5	7.0	20.0
1,000......	2.0	11.5	7.5	21.0
1,200......	2.0	14.0	8.0	24.0

when the least loading is used in the antenna circuit. Also, that the total resistance rises rapidly beyond a certain loading point without increasing the radiation resistance.

I. Measurement of antenna resistance. Fig. 4 shows a circuit used in measuring antenna resistance. The secondary of the oscillation transformer can be connected either to the antenna and ground or to a non-inductive resistance and a variable air-condenser.

The condenser should be adjusted to a value equal to the static capacity of the antenna. First, the antenna

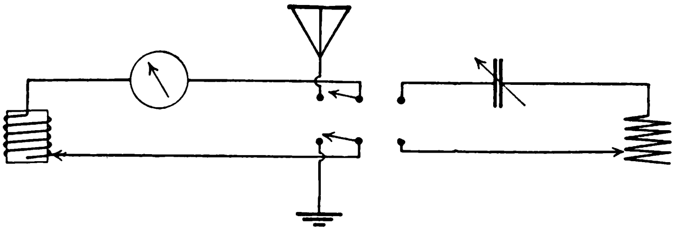

Fig. 4.—To Measure the Resistance of an Antenna, the Later is Replaced by a Dummy Circuit.

is connected, and a reading taken on the hot-wire ammeter. Then the switch is thrown to the dummy antenna, and the non-inductive resistance varied until the ammeter is at the postion previously determined. The direct current resistance of the resistor will then be equal to the resistance of the antenna.

J. Errors. If possible, this measurement should be made with a vacuum tube oscillator in order that low voltages can be used. This will reduce the likelihood of losses in the dummy air condenser, resulting in too low an indication of the antenna resistance.

The non-inductive resistance must be made of non-magnetic wire, wound back and forth over bakelite strips, with the adjacent wires as close as possible to neutralize the inductance of the wires. The antenna resistance reading will be low if there is appreciable inductance in the resistor.

13. ANTENNA CAPACITY.

The capacity of an antenna is due to the condenser effect between the elevated wires and the earth, which act as two plates, insulated by the atmosphere.

A. Measurement of antenna capacity. Fig. 5 gives the circuit used to measure the capacity of an antenna. This method requires only a calibrated condenser.

The switch is thrown to the antenna, and the signals from the buzzer are tuned in at the coupled detector

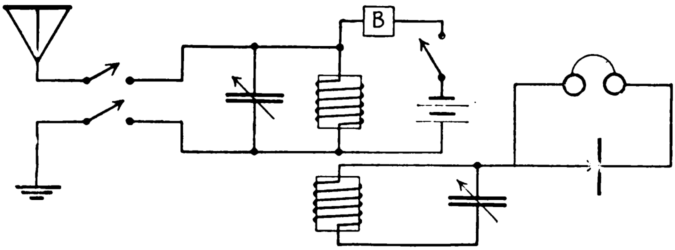

Fig. 5.—Diagram of Apparatus for Measuring Antenna Capacity.

circuit. Then the switch is opened, disconnecting the antenna. Without touching the detector circuit adjustment, the calibrated condenser is varied until the signals come in again at maximum intensity. The amount of increase in capacity equals the capacity of the antenna.

B. Errors. This method does not take into consideration the inductance of the antenna which, however, is very small compared to the capacity. Therefore, the reading is slightly high. It can be applied to antennas or condenser antennas, but not to loops.

C. Exact measurement of antenna capacity. The actual capacity can be determined by the formula

$$C = \frac{\lambda^2_1 - \lambda^2_2}{\lambda^2_2} \times C_1 \quad . \quad . \quad . \quad . \quad (25)$$

A small inductance is connected in series with the antenna and ground, with a buzzer around the coil, Fig. 6. The wave-length of the circuit is measured, giving a value λ_1. Then a series condenser of known capacity, C_1, is inserted, and the wave-length taken again, λ_2. C, the capacity of the antenna, is determined by substituting and solving (25).

14. ANTENNA INDUCTANCE.

The inductance of a loop antenna can be determined with sufficient accuracy for practical purposes from the

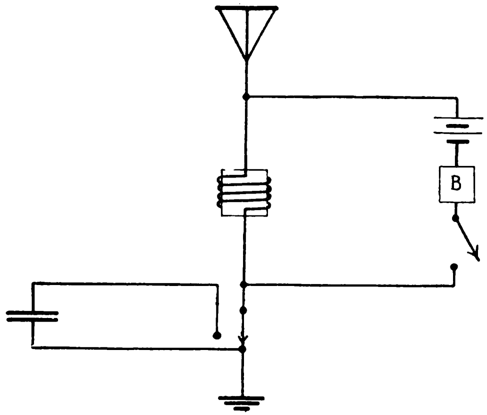

Fig. 6.—A More Exact Method of Determining the Capacity of an Antenna.

formulas in Section 9. Measurements of inductance can be made with the circuit in Fig. 6, using a known inductance in place of the condenser.

$$L = \frac{\lambda^2_1}{\lambda^2_2 - \lambda^2_1} \times L_1 \quad . \quad . \quad . \quad . \quad (26)$$

The wave-length λ_1, without the known inductance, is first measured, then, with the known inductance L_1 cut in, the new wave-length, λ_2, is measured. L, the inductance of the antenna, is determined by substituting and solving (26).

PART II

RECEIVING EQUIPMENT

CHAPTER III

DESIGN OF INDUCTANCES

15. LOSSES IN INDUCTANCES.

If an audion detector is to be used for receiving, every means must be employed to maintain a high voltage across the coils.

A. Distributed capacity. Distributed capacity is due to the difference in potential between the turns, while the losses occur in the dielectric between the turns and are also due the shunt condenser action of the capacity. Colored covering introduces losses; use uncolored wire. Shellac absorbs moisture; use Sterling insulating varnish, or better, G-A-lectric varnish to keep the wires in place. Cardboard or fiber tubing absorb moisture and introduce losses; use hard rubber or G-A-lite tubing. The larger the diameter of the coil, the greater the difference in potential between the turns. The capacity of the coil also served to increase its effective resistance.

One of the best ways to wind a coil is to use bare wire wound over a circular cage of hard rubber strips, though this method is seldom practical. Another method is to use bare wire spaced with thread, removing the thread when the coil is wound. A coat of G-A-lectric will keep the wires in place. If taps are to be taken off, the wire can be run, at those points, over a 1-inch length of Empire tubing cut in half lengthwise. Soldering can be done when the coil is wound and varnished. Distributed capacity weakens the signals, and makes the tuning broad.

B. High frequency resistance. Conductors carrying currents of radio frequency offer a higher resistance than to direct currents, due to the localization of the current in the conductors, generally known as skin effect. On a straight wire, the current travels near the surface, instead of permeating the entire cross-section. When the wire is curved, the current is on the inside of the circle. Because of the diminished area of the path, the resistance is increased.

The effect of increasing the resistance is to make the signals weaker, and to broaden the tuning.

High frequency cable is used on all high-grade receiving apparatus to keep down the resistance. It should be remembered, however, that merely making up a cable of enameled wires does not reduce the resistance. Imperfect insulation between the wires, such as break in the enamel, causes losses. Inferior covering over the wires makes trouble.

The standard high frequency cables are 10–No. 38, 20–No. 38 and 3 x 16–No. 38. The 10–38 is for coils in which space is an important factor. It can be made into banked windings of 2 or 3 layers. 20–30 is most widely used. Banked windings of several layers can be made with it. 3 x 16–38 is made of 16 cables of three twisted wires all twisted together. This is the best, as it distributes each wire evenly throughout the cross section. The outside covering of all these cables should be of two layers of unbleached silk.

Tests made on coils having iron, copper, or brass in the magnetic field show that the resistance is greatly increased, and, contrary to the general opinion, brass and copper cause a loss practically as great as iron. Therefore, in designing coil supports and controls, the metal parts should be kept as far away from the inductances as possible.

TABLE IV

Values of K for Use in Formulas (27), (28)

Diameter / Length	K	Diameter / Length	K	Diameter / Length	K
0.00	1.0000	2.00	0.5255	7.00	0.2584
.05	.9791	2.10	.5137	7.20	.2537
.10	.9588	2.20	.5025	7.40	.2491
.15	.9391	2.30	.4918	7.60	.2448
.20	.9201	2.40	.4816	7.80	.2406
0.25	0.9016	2.50	0.4719	8.00	0.2366
.30	.8838	2.60	.4626	8.50	.2272
.35	.8665	2.70	.4537	9.00	.2185
.40	.8499	2.80	.4452	9.50	.2106
.45	.8337	2.90	.4370	10.00	.2033
0.50	0.8181	3.00	0.4292	10.00	0.2033
.55	.8031	3.10	.4217	11.00	.1903
.60	.7885	3.20	.4145	12.00	.1790
.65	.7745	3.30	.4075	13.00	.1692
.70	.7609	3.40	.4008	14.00	.1605
0.75	0.7478	3.50	0.3944	15.00	0.1527
.80	.7351	3.60	.3882	16.00	.1457
.85	.7228	3.70	.3822	17.00	.1394
.90	.7110	3.80	.3764	18.00	.1336
.95	.6995	3.90	.3708	19.00	.1284
1.00	0.6884	4.00	0.3654	20.00	0.1236
1.05	.6777	4.10	.3602	22.00	.1151
1.10	.6673	4.20	.3551	24.00	.1078
1.15	.6573	4.30	.3502	26.00	.1015
1.20	.6475	4.40	.3455	28.00	.0959
1.25	0.6381	4.50	0.3409	30.00	0.0910
1.30	.6290	4.60	.3364	35.00	.0808
1.35	.6201	4.70	.3321	40.00	.0728
1.40	.6115	4.80	.3279	45.00	.0664
1.45	.6031	4.90	.3238	50.00	.0611
1.50	0.5950	5.00	0.3198	60.00	0.0528
1.55	.5871	5.20	.3122	70.00	.0467
1.60	.5795	5.40	.3050	80.00	.0419
1.65	.5721	5.60	.2981	90.00	.0381
1.70	.5649	5.80	.2916	100.00	.0350
1.75	0.5579	6.00	0.2854	......	......
1.80	.5511	6.20	.2795	......	......
1.85	.5444	6.40	.2739	......	......
1.90	.5379	6.60	.2685	......	......
1.95	.5316	6.80	.2633	......	......

16. SINGLE LAYER SOLENOIDS.

The single layer solenoid, wound on a tube of circular cross section, is the most common type used in radio work.

A. Inductance. The inductance can be determined by

$$L = 100.2\, n^2 r^2\, 1\, k \quad . \; . \; . \; . \quad (27)$$

where k is a factor determined by the ratio of the diameter to the length, found in Table IV. If the diameter, length, and inductance are known, then the turns per inch required are

$$n = \sqrt{\frac{L}{100.2\, r^2\, l\, k}} \quad . \; . \; . \; . \; . \; . \quad (28)$$

Table V shows the turns per inch of wire having different kinds of insulation, and Table VI, the feet per pound.

TABLE V

Turns per Inch of Copper Wire with Various Insulations

B. & S. Gauge	Enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cotton Enamel	Silk Enamel
18......	23	21	19	23	22	20	22
19......	26	24	21	26	24	23	24
20......	29	26	23	29	27	25	27
21......	32	29	25	32	30	27	30
22......	37	33	29	36	33	31	34
23......	41	37	32	40	37	34	37
24......	46	40	34	44	41	38	42
25......	51	44	37	49	45	42	46
26......	57	48	41	54	50	46	51
27......	64	54	44	60	54	50	57
28......	74	59	47	67	60	55	63
29......	80	64	50	74	65	60	69
30......	90	70	54	82	71	65	76
31......	101	75	57	90	77	71	84
32......	112	82	60	99	83	77	92
33......	127	88	64	108	90	83	101
34......	141	95	67	119	97	89	110
35......	158	101	71	129	104	95	120
36......	178	108	74	140	111	102	131

10–38 H. F. Cable, 45 turns per inch.
20–38 H. F. Cable, 40 turns per inch.
3 x 16–38 H. F. Cable, 20 turns per inch.

The number of feet required to wind a coil is

$$\text{feet of wire} = 0.2619\, d\, l\, n \quad . \quad . \quad . \quad (29)$$

Complete data for the length, diameter and inductance is given in Inductance Tables, by M. B. Sleeper.

17. BANK WOUND COILS.

Where space limitations require shorter coils than can be made with a single layer coil, bank winding can be used. The method is indicated below.

		10 14 18
	6 9 12	8 9 13 17
3 5 7	4 5 8 11	5 6 7 12 16
1 2 4 6	1 2 3 7 10	1 2 3 4 11 15

The two bank coil is started by winding two complete turns on the coil, then jumping the wire up between the first and second for another turn, down again, up, and so

TABLE VI

Feet per Pound of Copper Wire with Various Insulations

B. & S. Gauge	Enamel	Single Cotton	Double Cotton	Single Silk	Double Silk	Cotton Enamel	Silk Enamel
18......	200	196	189	201	199	196	202
19......	253	246	237	255	252	242	248
20......	320	311	298	324	319	307	315
21......	404	387	370	400	389	380	394
22......	509	488	401	501	493	479	497
23......	642	612	584	632	631	600	622
24......	810	763	745	799	779	750	781
25......	1019	953	903	1008	966	933	982
26......	1286	1201	1118	1263	1202	1166	1232
27......	1620	1500	1422	1584	1543	1457	1548
28......	2042	1860	1759	1988	1917	1824	1946
29......	2570	2370	2207	2520	2485	2288	2433
30......	3218	2860	2529	3165	3009	2810	3031
31......	4082	3482	2768	3933	3683	3473	3793
32......	5132	4234	3737	4913	4654	4267	4737
33......	6445	5141	4697	6129	5689	5267	5956
34......	8093	6317	6168	7646	7111	6461	7427
35......	10,197	7755	6737	9680	8856	7835	9207
36......	12,890	9511	7877	12,162	10,869	9437	11,485

on. The same principle is followed out in coils of a greater number of banks. By this method, the distributed capacity is made lower than if the coil were of several horizontal layers.

Banked windings are sometimes made as high as 8 or 10, though the capacity is increased greatly with more than 3 or 4 layers. High frequency cable and small solid wires can be banked most easily, although it takes considerable practice for one who is not familiar with the process. The work can be facilitated by using a blunt screw-driver to make the bends in the wire.

A. Inductance. The inductance can be determined closely by (27) using the average diameter of the winding for d, and the total number of turns per inch for n. That is, n would be the product of the turns per inch of the wire and the number of layers.

18. FIGURE EIGHT COILS.

Figure eight coils are used as variometers or coupling coils where space is limited. To vary the coupling, the coils are placed end to end, and one coil turned axially. It will be seen that a figure eight coil is made up of two semi-circular coils with their flat sides together. If, in a variometer, the two sets of coils are similarly placed and aiding, the inductance is maximum. Turned 90°, with the straight sides at right angles, the mutual inductance is 0. At 90° more, the coils will be similarly placed but opposing, giving a minimum inductance. Used as coupling coils, it is only necessary to turn one coil 90° to change from maximum to minimum coupling.

To wind a figure eight coil, start at the inside of the slot, wind around the tube to the other side of the slot, through the slot, and around the tube in the opposite direction. It is not advisable to have a part of the coil of circular winding and part figure eight, as this introduces high frequency losses in the circular part. There is no advantage in making a figure eight coil more than

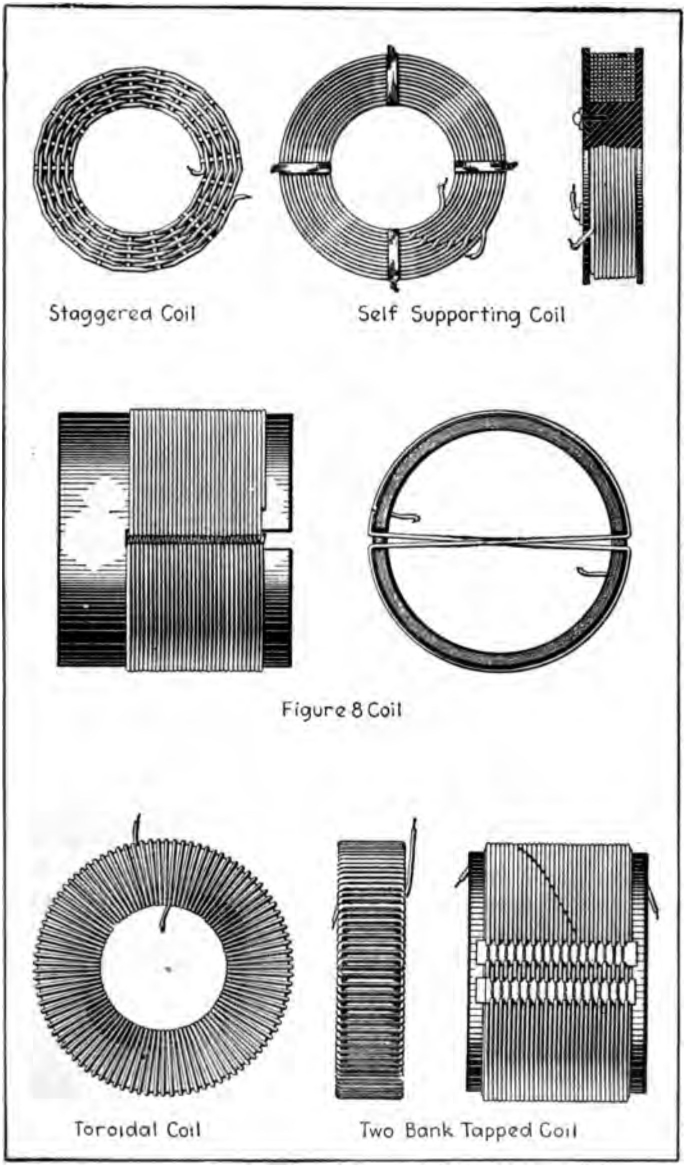

Fig. 7.—Illustrating Some of the Methods by which Coils are Wound.

2 inches long, as the mutual inductance between the outer turns would be negligible.

A. Inductance. Inductance of a figure eight coil is given by

$$L = L_1 k \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (30)$$

where k is a constant taken from Table VII. The value

TABLE VII

Constant k for formula (30)

Length Diameter	K	Length Diameter	K	Length Diameter	K
0.02	1.550	0.20	1.550	0.30	1.465
0.04	1.550	0.22	1.550	0.31	1.450
0.06	1.550	0.23	1.545	0.32	1.435
0.08	1.550	0.24	1.540	0.33	1.420
0.10	1.550	0.25	1.530	0.34	1.400
0.12	1.550	0.24	1.520	0.35	1.383
0.14	1.550	0.27	1.510	0.36	1.366
0.16	1.550	0.28	1.495	0.37	1.348
0.18	1.550	0.29	1.480	0.38	1.330

of L_1 is determined as if it were a single layer solenoid, from (27).

19. MULTILAYER COILS.

There is a right and wrong way to wind multilayer coils as indicated below.

	13	14	15	16	17	18
	7	8	9	10	11	12
right	1	2	3	4	5	6
	13	14	15	16	17	18
	12	11	10	9	8	7
wrong	1	2	3	4	5	6

In the correct method, each layer is started on the same side of the coil, with the result that the maximum potential between turns is, in this example, due to a difference of 6 turns, while in the wrong method, it is 12 turns. Some of the United States Navy equipment employs coils wound in this way, with a layer of paper between each layer of wire.

A. Inductance. The inductance of a multilayer coil can be determined by the formula.

$$L = \frac{31.90\, n^2 \text{ total } r^2 \text{ av.}}{0.23\, r \text{ av.} + 0.44\, l + 0.39\, w} \quad . \quad . \quad (31)$$

The average radius is

$$r \text{ av.} = \frac{\text{outside diam.} + \text{inside diam.}}{4} \quad . \quad (31a)$$

and the radial depth,

$$w = \frac{\text{outside diam.} - \text{inside diam.}}{2} \quad . \quad (31b)$$

To find the total number of turns required for a multilayer coil, knowing the required inductance, the length, the average diameter and radial depth.

$$n \text{ total} = \sqrt{\frac{L\,(0.23\, r \text{ av.} + 0.44\, l + 0.39\, w)}{31.9\, r^2 \text{ av.}}} \quad (32)$$

Then the turns per inch of wire to give the proper number of total turns, according to the required length and radial depth, is

$$t.\,p.\,i. = \sqrt{\frac{n \text{ total}}{l\, w}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

20. TOROIDAL COILS.

Toroidal coils are wound on closed rings of rectangular round cross section. They present the advantage of having no external field. The only way that coupling to a torus can be effected is by putting several turns directly over the coil winding. Conductors wound around the ring or placed beside the ring coaxially produce no coupling effect.

A needle, consisting of a brass or wooden strip, about 12 inches long, notched at the ends, is used to wind torii. The wire is first wound onto the needle. Then the needle can be passed readily through the center of the ring.

A. Inductance. Formula (34) gives the inductance of a torus of circular cross-section.

$$L = 12.57\, n^2 \left(2.54\, r_a - \sqrt{2.54\, r_a - 2.54\, r_b}\right) \quad . \; . \quad (34)$$

The inductance of a torus of rectangular cross-section is

$$L = 4.606\, n^2\, l_a \log_{10} \frac{r_{\text{outer}}}{r_{\text{inner}}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (35)$$

The number of turns which can be wound in a single layer on a torus is

$$n_{\text{total}} = 3.1416\, d_{\text{inner}}\, t.\, p.\, i. \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (36)$$

To obtain the maximum inductance, a torus should have a large cross-sectional area, rather than a large outside diameter.

21. STAGGERED COILS.

Where a self-supporting coil is required, the staggered winding is often employed. This type of coil is made on a removable core, in which an odd number of pins are set radially. The wire is woven back and forth on the pins. Sometimes two rows of pins are used, making it possible to get a greater inductance with no increase in diameter over a single row coil.

There is no formula for calculating the inductance of these coils, as too many varying factors enter in to their design.

22. VARIATION OF COUPLING.

There is a great variety of ways to vary the coupling between two coils, the particular one of which should be selected according to the design and space requirements. It should be remembered, in designing the coil supports, that any metal in the magnetic field increases the high frequency resistance of the winding.

A. Coaxial in and out type. The coils are mounted coaxially, with one stationary and the other movable toward or from the first. This is applicable to

Solenoids	Multilayer and
Pancake	Staggered coils

Various methods of effecting the movement are given in Fig. 8.

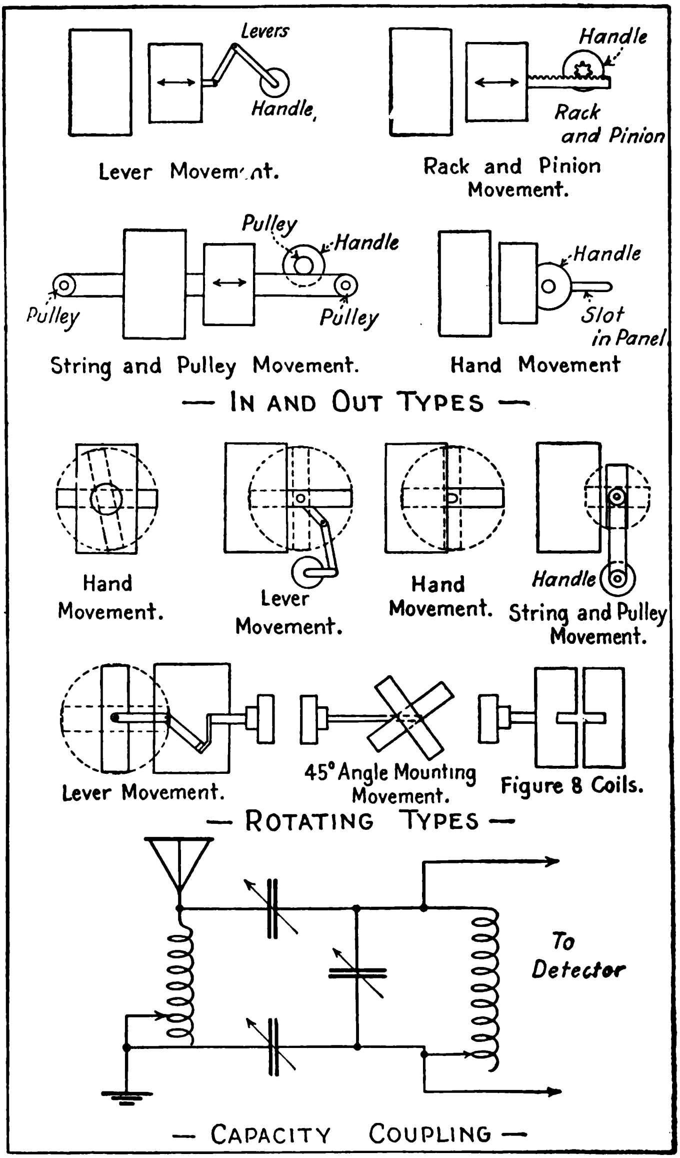

Fig. 8.—Various Ways in which the Coupling between Two Coils can be Varied.

B. Rotating Types. A number of ways to vary inductance by rotating one coil are given in Fig. 8. The coils can be wound on cylindrical or spherical forms. They can be separated considerably at maximum coupling, for very tight coupling is not essential. The coefficient of coupling need not exceed 5%.

C. Capacity coupling. There is also an electrical method of coupling sometimes used, though offering small advantage. This is done by interposing two condensers,

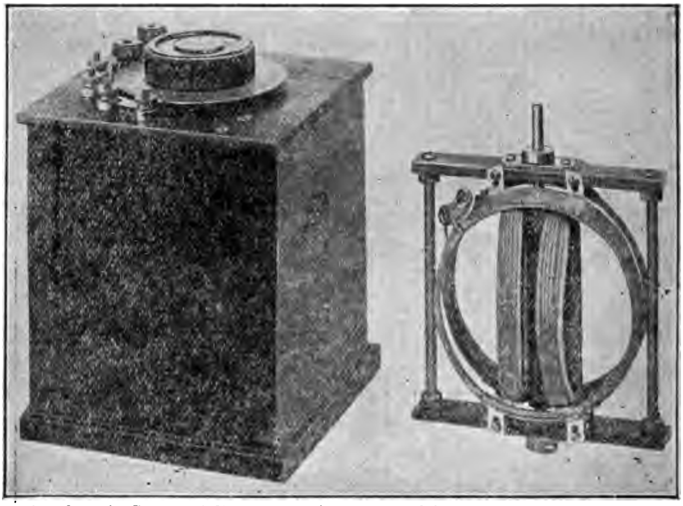

Fig. 9.—A General Radio Variometer with Self-supporting Coils.

operated by the same handle, between the primary and secondary coils. Coupling is maximum at maximum capacity. The condenser should be of 0.0005 mfd. each.

The wave-length to which the primary and secondary circuits are tuned is not controlled by the coupling condensers.

23. VARIATION OF INDUCTANCE

Inductance can be varied by changing the self-inductance of one coil or by varying the mutual inductance between two coils.

A. Variation of mutual inductance. Any of the methods in Fig. 8, except the capacity coupling, can be employed by connecting the coils in series or parallel. Resulting effective inductance is given by the formulas in Section 5. It is necessary to have the coils as close together as possible in order to obtain a large variation. When the planes of the windings are at right angles, the mutual inductance is *O*.

B. Sliders. Sliding contacts for radio coils are not

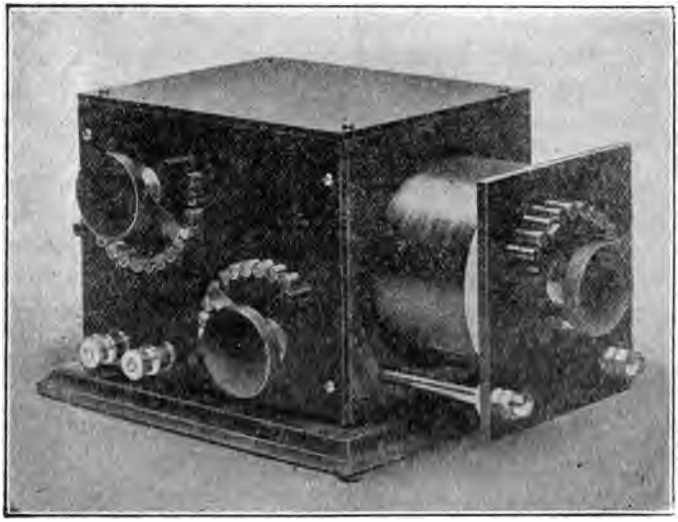

Fig. 10.—A Well-designed Loose Coupler from the Radio Equipment Company.

good because they give a poor contact, wear away the wire, short circuit the turns with grains of copper, and touch more than one turn at a time.

C. Single switches. Where no variable condenser is used to tune to the wave-length between the inductance switch taps, the taps should be brought out as frequently as possible. If a tuning condenser is employed, the taps should be arranged to give a wave-length overlap of 10 per cent. to 20 per cent., by the condenser between the inductance steps.

D. Double switches. Units and tens switches are often used without tuning condenser. One set of taps is taken off with short steps, while the other set are in steps equal to the total number of turns controlled by the first switch.

E. Geared switches. A set of units and tens switches can be geared together so that, while the contact of the tens switch is moving from one point to another, the units switch will rotate through its range. Thus both switches can be controlled by a single handle.

F. Dead-end switches. Some dead-end switches are so arranged that the unused sections of the coil are disconnected from each other and the part in use. The purpose is to prevent the unused sections from absorbing energy.

A better and simpler way is to short-circuit the unused turns by connecting the switch-blade to the end of the coil. This method is not good for large inductances, however, as the inductance and capacity of the unused part may have a wave-length sufficiently great to be a lower harmonic of the waves in the active section. In such a case, the coil should be short-circuited at several points in the unused part.

G. Method of bringing out taps. Inductance coil taps should not be in the form of a loop, but a single wire soldered to the winding at the coil. This keeps down distributed capacity losses. Taps should be arranged in an orderly manner, not bunched together. Where taps are brought out from moving coils, they should be clamped by bakelite strips or secured in such a way that the bending strain will not be concentrated at the soldered joints.

CHAPTER IV

DESIGN OF RECEIVING CONDENSERS

A variable condenser for tuning should have a low, direct current resistance through the connected parts, negligible dielectric losses across the plates, and in the insulating material separating the two sets of plates.

24. CAPACITY OF AN AIR CONDENSER

The capacity of an air condenser is given by the formula

$$C = \frac{A}{445604\,t} \quad \ldots\ldots \quad (37)$$

$$\text{or } A = 445604\,t\,C \quad \ldots\ldots \quad (38)$$

$$\text{or } t = \frac{A}{445605\,C} \quad \ldots\ldots \quad (39)$$

The value of A, the area of the dielectric, refers to the total area between the plates. Thus, if a condenser is made of three fixed and two movable plates, each of 5 square inches, at maximum capacity there will be four dielectric areas, each of 5 square inches, making a total area A of 20 square inches.

25. LOSSES IN RECEIVING CONDENSERS.

A. Dielectric losses. These losses include those in the medium separating the plates, as well as in the insulating supports. While there is practically no loss in an air dielectric, collections of dust on the plates are harmful. All corners should be rounded, so there will be no concentrated fields around points between the sets of plates.

Fibre, mica, bakelite, and similar materials interposed between the plates cause a serious power absorption.

The leakage path between the sets of plates should be long, and the dielectric of bakelite, hard rubber, or porcelain. Bakelite is not as good as the other materials, though it is satisfactory if in the form of a large plate. Moulded end plates are very poor, as shown by tests in which, at 200 meters, the losses ran as high as 50 per cent.

Small insulating bushings, set in metal end plates, cause a concentration of the electrostatic field, resulting in large losses.

B. Resistance losses. Condensers should be so constructed that there is a negligible resistance in the leads

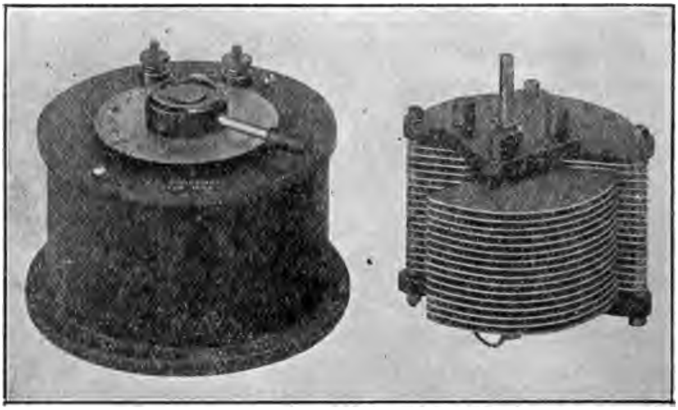

Fig. 11.—A Straight Line Type Condenser made by the General Radio Company.

and between the connected plates. The leads should have large contacting surfaces of constant pressure, or they should be soldered. The washers separating the plates should be large enough to give a good contact. Condensers having milled supports to which the plates are soldered are best.

C. Effect of losses. Condenser losses reduce the signal strength and give broad tuning. Used with an audion detector, they reduce the voltage on the grid.

26. TYPES OF VARIABLE CONDENSERS.

A. Sliding plate type. Condensers made with one set of plates sliding in and out on grooved insulating supports are obsolete. They are not satisfactory mechanically, and have losses due to the collection of dust on the support. Moreover, they require a large amount of space.

B. Rotating straight line type. This type of condenser has semi-circular rotating plates, giving a constant ratio of scale degrees to capacity. Almost all tuning condensers are of this sort.

C. Square law type. To give a straight line wavelength calibration, the square law condenser is made with offset variable plates so that the dielectric area is in porportion to the squares of the scale degrees, Fig. 13. In general, there is little advantage in using this type over the straight line type except where the straight wavelength calibration is necessary, as it takes up more space for its capacity than the straight line type.

D. Geometric progression type. Decremeters require a condenser giving a calibration curve in the form of a geometric progression.

27. DESIGN FEATURES.

A. Bearings. The bearings for the rotary plates of a variable condenser should be of brass, with a steel shaft.

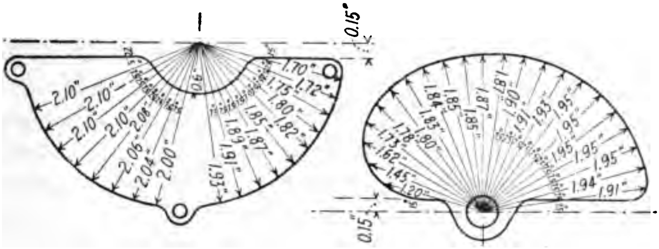

Fig. 12.—Shape of Square Law Type Condenser Plates.

They should be conical, or have large surfaces, and adjustable, so that any wear which may develop can be taken up. Light condensers work satisfactory if the shaft works in a hole in the bakelite end pieces, though this design is not good for calibrated instruments. The use of a pointed screw for a lower bearing is to be avoided, for the point, carrying the weight of the rotary plates, soon wears off, changing the capacity.

B. Rigidity. Greatest rigidity is attained in condensers having brass plates soldered in milled brass supports. However, the usual washer spacing is satisfactory, if the supporting rods are properly proportioned to the weight of the condenser. The shaft and washers of the variable plates must be extra large to keep the plates in place.

C. Connections. There are several ways to make connections to the rotary plates. A switch arm can be fastened to the shaft moving on a semi-circular ring secured to the rear end plate. Spring washers are good if the contacting surface is large. Braided pig-tails or coiled copper ribbon, soldered to the shaft, are good if the condenser is not used in an accurately calibrated circuit.

D. Balanced Condensers. Large condensers are made with one-half of the plates on one side, and half on the other, to balance the weight of the rotary plates. Other types have a balancing weight on the shaft.

E. Double condensers. To obtain double the capacity of the ordinary condensers in the same space, condensers are made with two sets of fixed and rotary plates. The sets of rotary plates, mounted on a single shaft, are insulated from each other. One set of fixed plates is connected to one set of rotary plates, and the other set of fixed plates to the other rotary set. Leads are taken from the two fixed sets. Capacity is minimum when the connected plates are interleaved, and maximum when opposite plates are interleaved.

A more complete description is given in *Everyday Engineering*, November, 1919.

F. Double wave-length range type. When a variable condenser is used with an adjustable inductance, only 180° of the rotary movement is usable, and, when turned from minimum to maximum, it must be turned back to minimum for the next inductance step.

The double wave-length range type has two sets of fixed plates and one rotary set. A switch is arranged on the shaft which connects one fixed set to the first induc-

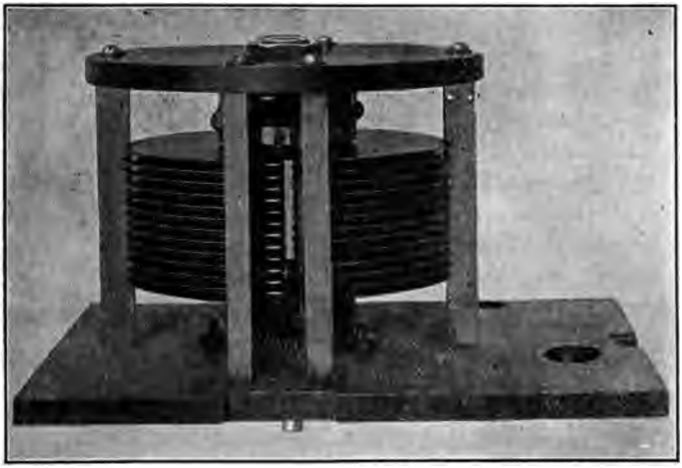

Fig. 13.—Condensers of this Type are Used in Wave Meters for the Signal Corps.

tance step. When the capacity is maximum with that set, the switch connects the other fixed set to the next tap, making the capacity minimum again.

G. Milled condensers. A very expensive, though extremely rugged way of building a condenser is to mill the sets of plates from a solid metal block. Attempts have been made to die-cast condensers, but this is expensive because a final milling operation is necessary because the plates warp slightly when taken from the casting machine.

H. Vernier condenser. Five variations of capacity are determined by means of a separate knob with a reducing gear to the condenser shaft, or by a small two-plate condenser shunted across the large condenser. Another method, used by the de Forest Company, is to have a single plate, mounted on the shaft, which can be adjusted by a separate handle with respect to the top plate of the fixed set.

I. Metal cases and shields. To prevent slight variation of capacity due to the capacity to ground of the body, condensers should be put in metal cases, connected to the ground, or shielded by a grounded metal plate. Often times the receiving set panel is covered, at the rear, with a grounded copper, brass, or aluminum sheet. When this is done, care must be taken to prevent eddy current losses in the plate by making a number of slits across it, and keeping the coils and wiring several inches back.

J. Scales. While 360° ordinarily constitute a circle, it is usual to use 200°, or 100° for a semi-circle, on radio condenser scales.

28. MICA AND PAPER CONDENSERS.

A. Capacity. The capacity of a condenser having a mica dielectric is

$$C = \frac{A}{6855.45\,t}$$

and of a paraffined paper condenser.

$$C = \frac{A}{12731.5\,t}$$

Owing to the variations in the dielectric constants of different specimens, the results obtained will be only approximate, varying as much as 15 to 20 per cent.

B. Use of Mica and Paper Condensers. In the tuning circuits of receivers nothing but air condensers should be used, as the losses in mica and paper condensers are large at high frequencies. As grid, bridging, or audio frequency tuning condensers however, they are satisfactory.

The humidity of the atmosphere will vary the capacity and losses in these condensers. Therefore, they should be thoroughly impregnated and sealed.

CHAPTER V

AUDION DETECTOR CIRCUITS

The enormous amount of data which has been worked out on audion detectors makes it necessary to keep, in this book, to the practical considerations. Readers interested in the theoretical side of this subject are referred to the series of articles by L. M. Clement, starting in the April, 1919, issue of *Everyday Engineering Magazine.*

29. THE THREE CIRCUITS OF THE AUDION.

Three separate circuits are employed with an audion—the filament, grid, and plate circuits.

A. Filament Circuit. The filament circuit comprises a source of current, a current regulator, and the audion filament, from which negatively charged electrons are radiated.

B. Plate Circuit. Across the filament and plate of the audion a high voltage battery and indicating device or amplifying circuit are connected. The battery breaks down the space between filament and plate, drawing the emission from the filament to the plate.

C. Grid Circuit. The controlling voltage from the tuning circuit is applied to the grid. Varying the charge on the grid changes the filament-plate current.

30. AUDION CHARACTERISTICS.

Control of Plate Current. The plate current is varied in three ways:

(*a*) By changing the voltage of the plate or *B* battery.

(*b*) By changing the filament current.

(*c*) By putting a charge on the grid.

Modern vacuum tubes require no fine variation of the plate voltage. The battery to be used is generally specified for the particular tube, and is kept constant. Increasing the plate voltage decreases the resistance between filament and plate, and increases the plate current up to the point of saturation.

Filament current is also kept constant. The best tubes, such as the Western Electric types, have a filament which

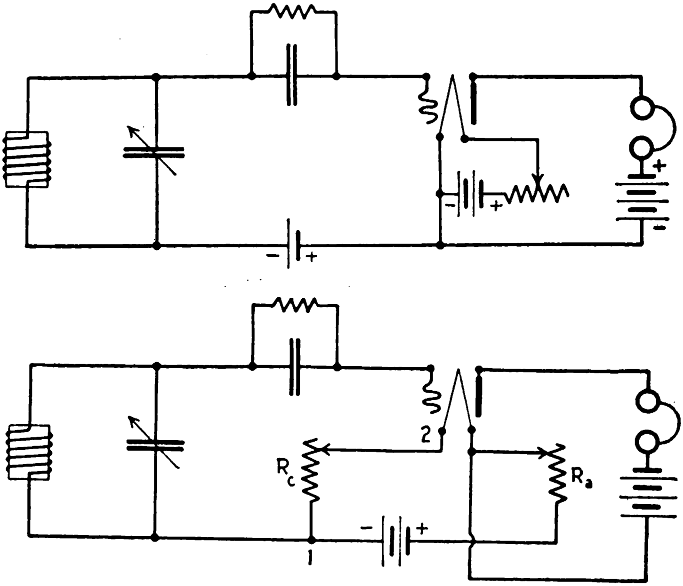

Fig. 14.—Two Methods by which a Negative Charge can be put on the Grid.

burns at a dull red. Others, with tungsten filaments, require a current sufficient to make them glow brilliantly. Increasing the filament current increases the electronic emission up to the point of saturation for the given plate voltage.

Changes in the plate current from the incoming signals are produced by the charges put upon the grid of the tube. A positive charge increases the plate current, and a negative charge decreases it. It is advisable, however, to keep a small negative charge on the grid, so that incoming positive charges will not be great enough to make the grid positive. The reason for this is that, when the grid is positive, a small amount of current flows from the filament to the plate. This is the same as putting a resistance across the tuning coil, thus reducing the signal strength and broadening the tuning.

Fig. 14 shows two methods for putting a permanent negative charge on the grid. The first circuit has a battery of 1.5 or 3.0 volts, the negative or zinc side connected to the grid. A finer adjustment, without an extra battery, is obtained by the second circuit.

It will be seen that, due to the resistance, R_c, there is a difference in potential between point 1 and 2. If the negative side of the battery goes to point 1, the grid will be negative with respect to the filament. The amount of negative grid potential is

$$E_c = I R_c$$

Different tubes require different grid charges for maximum signal strength. Also, a slight change for telegraph and telephone signals is needed. While the negative grid charge and corresponding resistance can be determined from a grid voltage, plate current curve of the tube, the easiest way is to determine the value of resistance experimentally, using the correct filament current. Then a fixed R_c can be inserted. A variable filament resistance, R_a, will make it possible to keep the filament current at the right value in case the voltage of the filament battery drops down.

The circuit in Fig. 14 shows a high resistance leak of 0.5 meghom around the grid condenser. Without this resistance the grid charge control will not function.

Signals are considerably improved when the grid is adjusted to the right potential.

31. THE GRID CIRCUIT.

A. Tuning apparatus. As previously explained, the plate current is controlled by voltage changes on the grid.

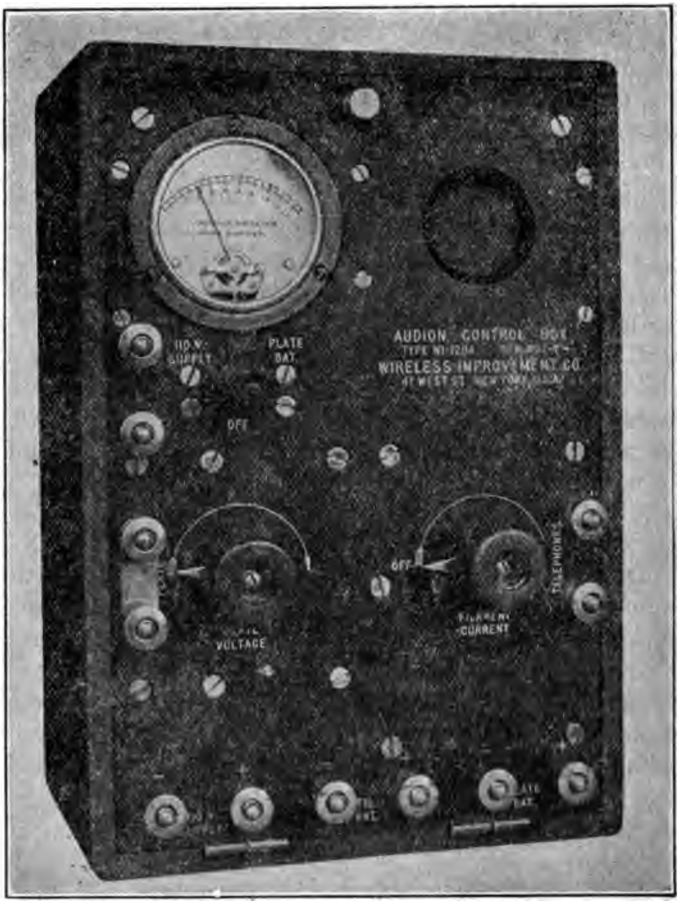

Fig. 15.—A Wireless Improvement Audio Control Box Operating on Batteries or 110 Volts Direct Current.

To obtain the maximum voltage from the incoming signals, the secondary tuning inductance must have a minimum capacity and high frequency resistance. **Most** careful consideration should be given to the design of the coil. The tuning condenser is also an important factor. The capacity should be as small as is practical for tuning purposes.

B. Grid condenser. It is usually said that the grid condenser keeps the negative charge off the grid. The

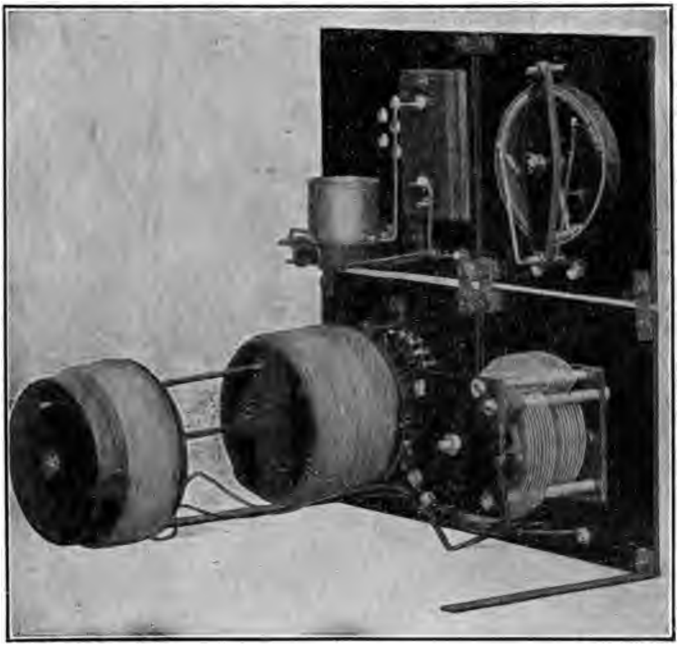

Fig. 16.—A Standardized Panel Type Audion Receiver for Short Waves.

grid is isolated from the tuning circuit by the condenser. The positive half cycles of the incoming voltage causes a current to pass from the filament, which is positive with respect to the grid, to the grid. During the negative half cycles, no current flows. Thus a negative charge is accumulated on the grid, and this charge, as explained in Section 30, reduces the plate current. A train of oscillations serves to put one charge on the grid, with a corresponding single charge in the plate current through the telephones. Thus the vibrations of the telephone receiver diaphragm correspond to the spark frequency of the transmitter, and not the radio frequency.

C. Grid leak. If the insulation of the grid condenser were perfect, the negative charges would pile up and ren-

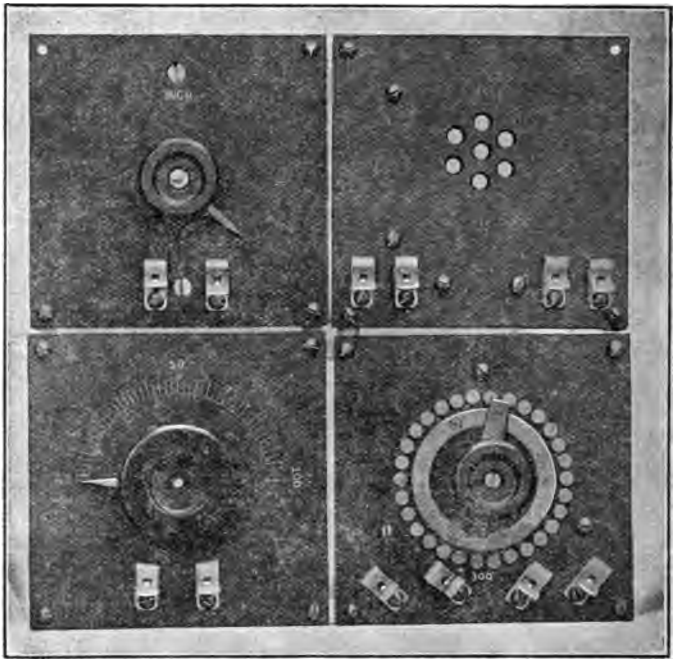

Fig. 16a.—The Controls for the Set Shown in Fig. 16.

der the tube inoperative. However, these charges leak off between the wave trains. To prevent blocking, that is, the accumulation of negative charges, a resistance of 500,000 to 1,000,000 ohms is usually connected around the grid condenser.

The grid leak is usually made of a small strip of paper dipped in water-proof ink, or of a lead-pencil mark across a piece of paper. Popping noises and rumblings in the telephones are often due to microphonic action in the grid leak.

32. THE PLATE CIRCUIT.

A. Plate impedance. There is a certain value of resistance between the filament and plate, varied by the

Fig. 17.—A Telephone transformer is used to match the Impedance of the Audion.

adjustments of the circuit. In the average receiving tube, this is taken as 50,000 to 100,000 ohms. To obtain the maximum effect in the phones, the telephones should have a high resistance at average speech frequencies, 800 cycles. For greatest efficiency, telephone transformers are used so that the impedance of the circuit across the filament and plate will equal the plate impedance.

B. Tuning in the plate circuit. Some circuits call for radio frequency tuning in the plate circuit. This is generally unsatisfactory as it introduces a difficult adjustment, and, in the matter of amplification of signals, offers no advantage. Audio frequency tuning has been found entirely unsatisfactory. The subject of feed-back coupling is treated in a separate Section.

C. **Control of plate voltage.** While standard 22.5-volt batteries are almost universally used to supply the voltage across the plate and filament, it is sometimes necessary to adjust the voltage. This can be done by a simple switch or by means of a potentiometer. Since a potentiometer is really a high resistance shunt across the battery, a small amount of current is wasted through the resistance. Therefore, the potentiometer should be of 10,000 to 25,000 ohms, and a switch should be inserted so that the battery can be disconnected when not in use.

Carbon sectors are most generally used. They are made up with a porcelain body coated with graphite. A carbon contact must be used because a metal contact deposits tiny grains on the graphite sector which reduce its resistance.

D. **Noises.** Howling and squealing sounds in the telephones are largely due to poor plate voltage adjustment or capacity or inductive coupling back to the grid circuit. Plate circuit wiring should be well separated from all grid circuit connections.

E. **Bridging condenser.** A condenser of 0.001 mfd. is often connected around the phones and *B* battery to act as a by-pass for radio frequencies which may be present in the plate circuit. A mica or air condenser, preferably variable, should be used.

CHAPTER VI

OSCILLATING AUDION CIRCUITS AND UNDAMPED WAVE RECEIVERS

Although there is a multiplicity of methods for making an audion circuit oscillate, only the best and most widely used are described here.

33. INDUCTIVELY COUPLED OSCILLATORS.

A. Tickler coil coupling. The tickler coil, Fig. 18, is most often used to amplify spark signals and to make the

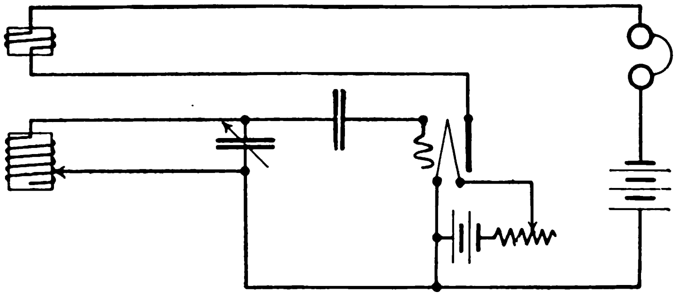

Fig. 18.—The Typical Tickler Coil Circuit for Regeneration or Undamped Wave Reception.

audion oscillate. It is simply a small inductance in the plate circuit coupled to the secondary of the loose coupler or to a separate coil in series with the secondary inductance.

There seems to be no optimum inductance value for the tickler coil. It is often made equal to the secondary for short waves, and as small as 0.1 the secondary inductance for long waves.

Coupling to the secondary must be adjustable to obtain the proper feedback action from the plate circuit to the grid side.

B. Tapped secondary coupling. With a circuit as in Fig. 19 no adjustment is needed, though the strength of the oscillations can be varied by changing the taps which

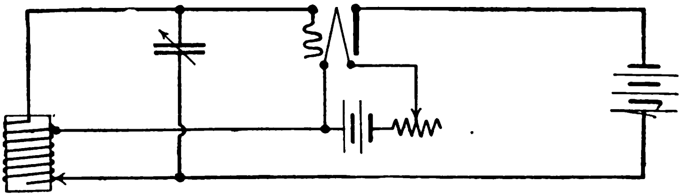

Fig. 19.—The Secondary Circuit of an Undamped Wave Receiver.

goes to the filament. Ordinarily, the tap is taken off at a point just below the center, toward the end connected to the plate.

The wave-length is not varied by changing the coupling tap. It is determined by the total inductance of the secondary and the secondary tuning condenser.

34. CAPACITY COUPLED OSCILLATORS.

A. Separated tuning condenser method. In this circuit Fig. 20, two separate tuning condensers are used, in

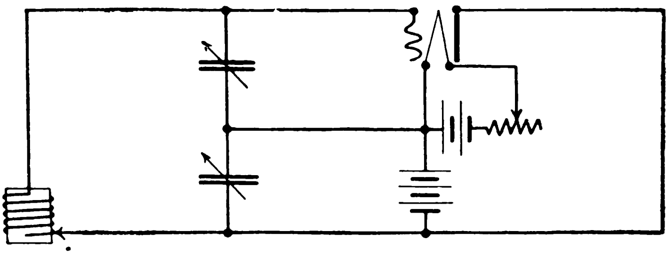

Fig. 20.—Capacity Coupling is Used in this Oscillating Circuit.

the connection from the center running to the filament. The strength of the oscillations can be varied by making one condenser larger or smaller with respect to the other.

The wave-length depends upon the inductance of the secondary coil and the capacity of the two condensers. It should be remembered that these condensers are in series. This introduces difficulties because of which this type of circuit is seldom used for receiving.

B. Tickler condenser method. The coupling condenser shown in Fig. 21 is made of two fixed and one variable plate, arranged so that when capacity is increased between

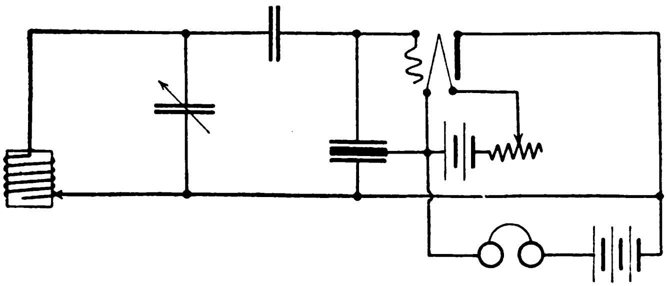

Fig. 21.—Another Method for Making the Circuit Oscillate.

one fixed plate and the variable plate, the capacity to the other fixed plate will be reduced. The fixed and variable plates may be semicircular 3 and 2½ inches in diameter respectively.

C. Grid and plate bridging condenser method. Feed-back coupling can be accomplished by connecting a vari-

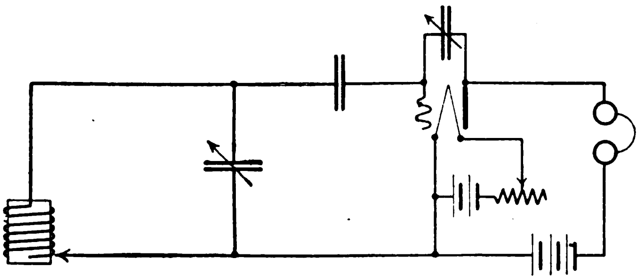

Fig. 22.—A Bridging Condenser Provides Coupling between the Plate and the Grid Circuits.

able condenser of 0.0005 mfd. maximum across the grid and plate. However, the adjustable is not stable on the strength of the oscillations easily controlled. Fig. 22 gives the circuit.

D. Other methods. Almost any way in which, by capacity an inductive coupling, the plate circuit is connected with the grid will make a tube oscillate in varying degrees.

35. LOCALLY OSCILLATING CIRCUITS FOR UNDAMPED WAVE RECEPTION.

A. Heterodyne reception. This reception of undamped waves is accomplished by imposing a slightly different frequency on the incoming oscillations. If, for example, oscillations of 100,000 cycles are being received, and local oscillations of 101,000 cycles are impressed, a beat note of 1,000 cycles will be produced in the telephones. This

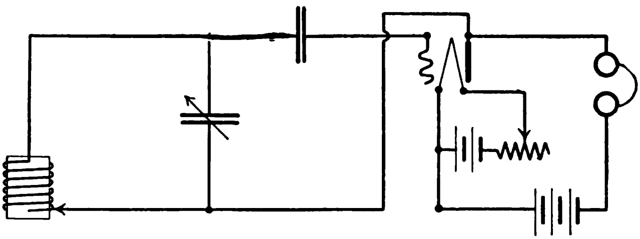

Fig. 23.—The Ultraudion Circuit for Undamped Wave Reception.

method, while good for short waves, causes a loss, by detuning, at long wave-lengths.

In practice, the primary circuit is closely tuned to the transmitter. The secondary is detuned, to give an audible frequency. So it is that the secondary circuit is not adjusted to the frequency of the received signals.

At short waves, a slight detuning in wave-length makes a large difference in frequency, so that this effect is not pronounced. Long waves, however, have a low frequency. Thus a small difference in frequency requires a considerable change in wave-length.

Consider Fig. 25. This shows the signal strength when a receiver is tuned above and below the wave-length of the transmitter. A maximum amount of energy flows in the secondary when it is adjusted to 18,000 meters, but, at 17,000 the wave-length for a 1,000-cycle beat note, only 55 per cent. of the available energy is being used. This is obviously a considerable loss, of special importance when the signals are weak.

That this percentage of loss decreases with the wave-length is shown by Fig. 25. Here the curve shows the energy in the secondary when it is tuned above and below

Fig. 24.—This Wireless Special Set Contains an Oscillating Circuit Which Can Be Connected to the Secondary.

the wave-length of a 200-meter transmitter. The detuning to produce 1,000-cycle beats is less than 1 meter, and practically no energy is lost.

On wave-lengths about 5,000 meters, heterodyne reception should be accomplished by means other than the use of a detuned, oscillating circuit. The simplest method is to set up a separate oscillator, coupled to a straight receiving set.

B. Tickler Coils. There seems to be no definite relation between the inductance of a tickler coil, used as a

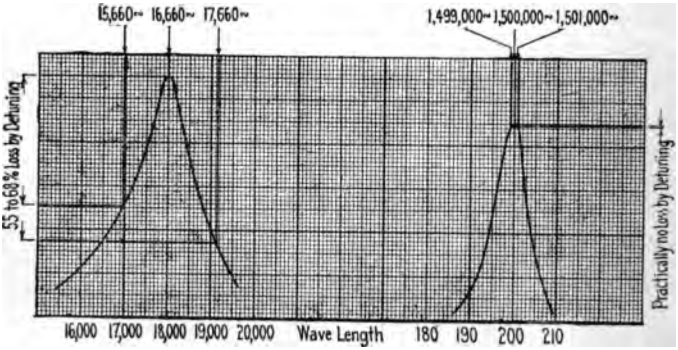

Fig. 25.—Showing the Loss at Long Waves from the Use of a Locally Oscillating Receiver.

feedback from the plate to the grid circuit, and the wavelength of the signals received.

For short waves the tickler is usually made with an inductance nearly equal to that of the secondary, while

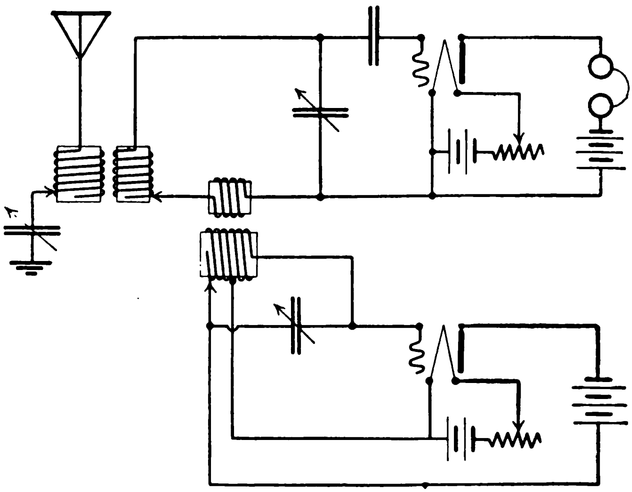

Fig. 26.—The Separated Oscillator Provides the most Efficient Means for Receiving Undamped Waves.

on long waves the tickler may be as low as 0.15 of the secondary inductance.

36. SEPARATE OSCILLATORS

The tapped coil oscillator is the easiest to handle and was for heterodyne reception. A coil coupled to the receiving set can be put in series with the main inductance of the oscillator, or the oscillator coil itself can be coupled to the primary of the receiving oscillation transformer.

Provision for varying the coupling is necessary so that the strength of the oscillations induced in the receiving circuit will be equal to those received at the antenna.

PART III

CHAPTER VII

DAMPED WAVE TRANSMITTERS

The mathematical design of transmitting circuits involves separate problems to which many books are already devoted. It is obviously impossible to dispose of the subject in one, or even many chapters. Experimenters usually do the easiest thing, which in this case is the most satisfactory and practical—that is, they buy their sending equipment.

Because this is a book for the practical experimenter, formulas and data on building spark coils and transformers will not be given. Either instrument can be purchased as cheaply as it can be made, and the manufactured article will, if it comes from a reputable concern, represent an amount of experimental work beyond almost any experimenter.

Another feature which, from the title of this book, might be expected here, but will not be found, is data on resonance circuits. Such considerations were introduced by power engineers long ago, but the field of experimenters is just beginning to be aware that resonance circuits have been used.

However, it is impractical to introduce this subject in this book because two of the essential factors cannot be determined, one, the characteristics of the power generator and, two, the characteristics of the transformer.

There is also the wave-length limitation which prohibits experiments which might result in an increased efficiency of the sending set.

Thus it will be seen that the possibilities for designing a spark coil or transformer set are reduced almost to the consideration of possible expenditure, the source of power available, and the wave-length of the oscillating circuits. This is not intended to infer, however, that there is no choice between the various instruments on the market or the types which can be built by the experimenter, but that the limitations preclude large variations from the standard designs, and that extensive experiments on transmitting apparatus call for the equipment of a commercial laboratory.

37. SPARK COIL SETS.

The spark coil, though often condemned as being responsible for much interference, is really good for short-distance transmitting when properly handled.

A. Types of coils. A spark coil cannot be judged by the length of the spark which it gives. The spark should be a short, heavy flame, hot enough to ignite a piece of paper. Power consumption is a more accurate way to classify spark coils, as is done in the transformer.

The vibrator should produce a fairly high note with very little sparking at the contacts. Current consumption is increased with the vibrator speed.

B. Current supply. Dry batteries can be used to run a spark coil, but a storage battery gives better results and, over a period of months, is more economical. Electrolytic rectifiers for 110 volts a. c. or electrolytic interrupters for d. c. are satisfactory, if purchased from a reliable company, although some which have been put out are only good for blowing fuses. A step down transformer does not give a good transmitting note unless the vibrator can be synchronized with the a. c.

C. Telegraph key. Any type of light telegraph key can be used to operate small spark coils. The contacts should be cleaned frequently to prevent a high resistance connection which would reduce the current to the coil.

D. Plain spark gap. A plain spark gap is most often used. The contacts should be of zinc, about ¼ inch in diameter, and flat at the adjacent faces.

One contact should have a threaded adjustment and a knob of insulating material so that the gap can be altered while the set is in operation. A bakelite or marble base is required to prevent leakage across the gap.

E. Rotary spark gap. Because the speed of the vibrator is not steady, it is impossible to synchronize the vibrator and spark gap. However, the rotary gap can be used if the gap is very short and the rotor run at a high speed.

F. Quenched spark gap. Very satisfactory results have been obtained by turning down silver half-dollars for quenched spark-gap faces. Fig. 27 shows form. Mica

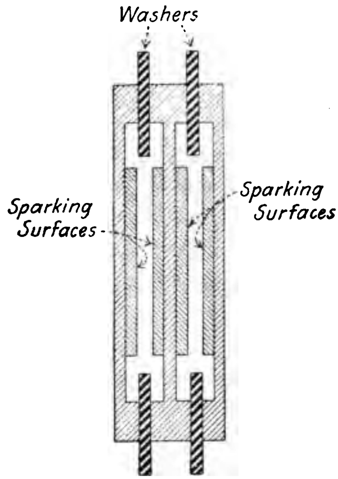

Fig. 27.—A Sectional View of a Simple Quenched Spark Gap.

rings can be used as separators. Two single and one double-gap sections are enough for a spark coil. They should be mounted between two flat surfaces in such a way that they can be pressed tightly together without warping the silver gaps.

G. Transmitting condenser. Considerable loss occurs in an imperfect transmitting condenser. The usual home-made glass plate type is particularly liable to fall down in this respect. However a spark coil sets, good results can be obtained if the condenser is carefully built.

Ordinary window glass is not good. Photographic plates are the best that can be obtained readily. They should be covered on both sides with heavy tinfoil, pressed free from wrinkles. A switch is required so that eight to sixteen glass plates, 5 x 7 inches, can be connected.

Moulded or mica condenser of 0.004 or 0.005 mfd. are preferable.

H. Oscillation transformer. An oscillation transformer must be used even with a spark coil set, to allow an adjustment of the coupling and decrement. The primary should have three turns of copper ribbon or edgewise wound strip 5 to 8 inches in diameter. For the secondary, eight turns are required, of a diameter 2 inches greater than that of the secondary. A space of 3/8 or 1/2 inch between the turns is sufficient.

The secondary should be arranged to pull out or turn away from the primary so that the coupling can be varied. Clips are needed so that all of the turns are available for tuning.

I. Hot wire ammeter. To measure current in the secondary circuit, a hot wire ammeter is needed. A range up to 2 amperes is sufficient for the average spark coil set.

J. Wiring. The importance of the wiring must not be overlooked. The length of the leads can be reduced by grouping the instruments. No. 14 bare or insulated copper wire is large enough. Small wires or loose connections increase the resistance of the circuit and make the decrement higher. This must be compensated for by loosening the coupling which decreases the power radiated.

38. TRANSFORMER SETS.

A. Closed core transformers. The closed core transformer is operated on 60-cycle a. c. or higher frequencies. It has the disadvantage of requiring an external controlling impedance for, when a discharge occurs across the secondary, the secondary winding is practically short-circuited, with the result that an excessive current is drawn by the primary. This must be controlled by an impedance in series with the primary circuit. Such an impedance is made up of a laminated or iron wire core 8 inches long and 1½ inches square or in diameter, as the case may be, wound with 300 turns of No. 18 annunciator wire tapped every 50 turns. This impedance will serve for a ¼ or ½ kilowatt transformer. For a 1 kilowatt transformer, No. 16 wire is needed.

B. Magnetic leakage transformers. A magnetic leakage transformer is so constructed that, if the leakage gap

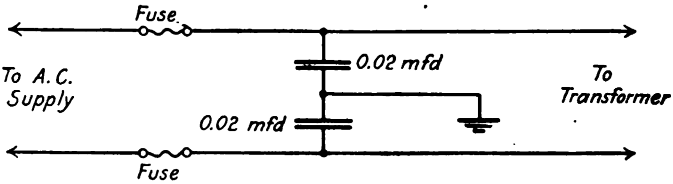

Fig. 28.—The Circuit of a Protecting Device for 110-Volt Supply Lines.

were closed, the primary and secondary would be, in effect, wound on two separate closed cores. The Clapp-Eastham type *T* transformers are built in that way.

The advantage of this type is that it is self-controlling. When a discharge takes place across the secondary, lines of magnetic force stream the leakage gap, virtually closing the part of the core on which the secondary is wound. The impedance of the secondary is increased thereby, and an excessive current is unable to flow.

C. Protective devices. The underwriters' rules call for a protective device to prevent surges from the transformer back into the live. Fig. 28 gives the connections for a single and satisfactory type.

Two condenser of 0.02 mfd. are connected across the line, with a ground connection between them. Fuses are also needed, of a size to carry a 50 per cent. transformer overload.

D. Telegraph keys. Because a current drawn by a transformer is large, the key contacts must have surfaces

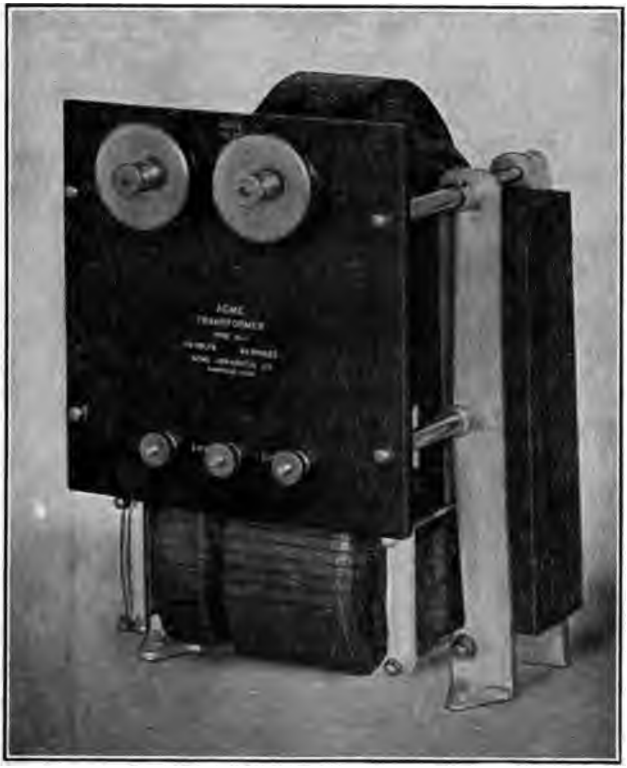

Fig. 29.—The Acme Transformer Contains a Controlling Impedance.

¼ to ½ inch in diameter. Sparking the contacts can be reduced by shunting them with a paper condenser of 0.01 mfd.

E. Current supply. Transformers are generally designed to work on 110 volts a. c. In ordering a transformer, it is necessary to state the frequency of the current supply. When 500 or 1,000 cycles is available, it offers the advantage of a higher spark note, and makes possible the use of a smaller condenser and transformer.

F. Plain spark gaps. The high voltages and the heavy current handled by the spark gap of a transformer set requires comparatively heavy construction and the best of insulation. Gap faces should range from ½ inch in diameter for ¼ kilowatt to ¾ inch for 1 kilowatt. Zinc, nickel, steel, silver, or brass are used for the electrodes. Radiators behind the electrodes are needed if the transmitter is used for very long at a time. It is important to have the gap faces absolutely parallel, otherwise the sparking will occur at one point instead of over the entire surface.

The International Radio Company uses an excellent type of gap, made of plates 1½ inches in diameter and

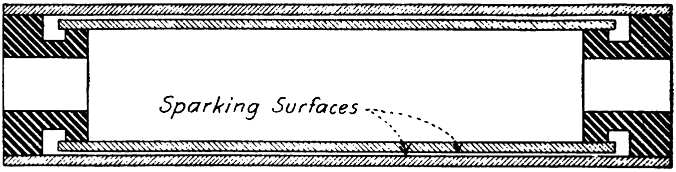

Fig. 30.—A Sectional View of the Lowenstien Type Quenched Spark Gap.

⅛ inch thick, separated by mica washers. Four to eight of these plates are used, depending upon the power. The sparking takes place around the edges of the plates. A bakelite rod, passing through the center, holds the gaps and washers in place.

For the base, bakelite is preferable. If cost or difficulties of obtaining it prohibit the use of a heavy bakelite base, a ¼ inch plate can be mounted on a hollowed wooden base.

G. Quenched spark gaps. A disadvantage of the quenched gap on a 60-cycle set is the low note which it produces. For this reason this type is seldom used for experimenters' transmitters. An interesting gap originated by the Lowenstien Company is shown in **Fig. 30.**

It consists of two concentric brass or copper cylinders, sealed and separated by bakelite washers, This is simple to make and just as good as the usual type. If the gap heats excessively, a fan, operated by a battery motor, can be arranged to send an air current through the gap.

Fig. 31.—An Excellent Example of the Oscillation Transformer, from the International Radio Company.

H. Rotary spark gaps. Most of the rotary spark gaps for experimental sets now on the market are of inefficient design. The purpose of the rotary gap is to provide a short, low resistance gap during the time of the first discharge of the condenser, and to damp out the oscillations which follow the first impulse, by increasing the length and resistance of the gap.

To accomplish such a result the electrodes should not be large, for they will not increase the gap length quickly enough. Broad, blunt-edged electrodes, parallel to the axis of the motor shaft, are preferable. In this case the stationery electrode is in the plane of the rotor. This also requires a blunt-edged electrode.

The rotor can be cut from a solid piece of brass 1/8 inch thick, insulated from the motor shaft by a bakelite plate. It is essential that the rotor runs true, otherwise the gaps will not be of the same length, and vibration will be created. The stationery electrode must be closely adjustable.

Rotary spark gaps with several gaps are not good.

I. Transmitting condenser. Particularly on large sets, the condenser is a source of serious losses, the greatest of which are those in the dielectric. Other losses are due to resistance and discharges around the plates.

Glass-plate condensers, if made from specially selected glass, are satisfactory, though they are liable to break down if overloaded to any great extent. This is also true of the Leyden jar types.

Murdock moulded condensers are, perhaps, the most practical for experimental use. They are efficient, withstand fair overloads, and are not expensive.

Mica condensers are best of all, in the matter of efficiency, but their cost puts them beyond most experimenters.

J. Oscillation transformer. Heavy insulating pillars of bakelite are needed to support the turns of the oscillation transformer. As little metal as possible aside from the conductors should be used in this instrument for the high frequency currents induce eddy losses in the metal parts.

Edgewise wound ribbon or solid copper wire present considerable resistance, for the current tends to crowd on

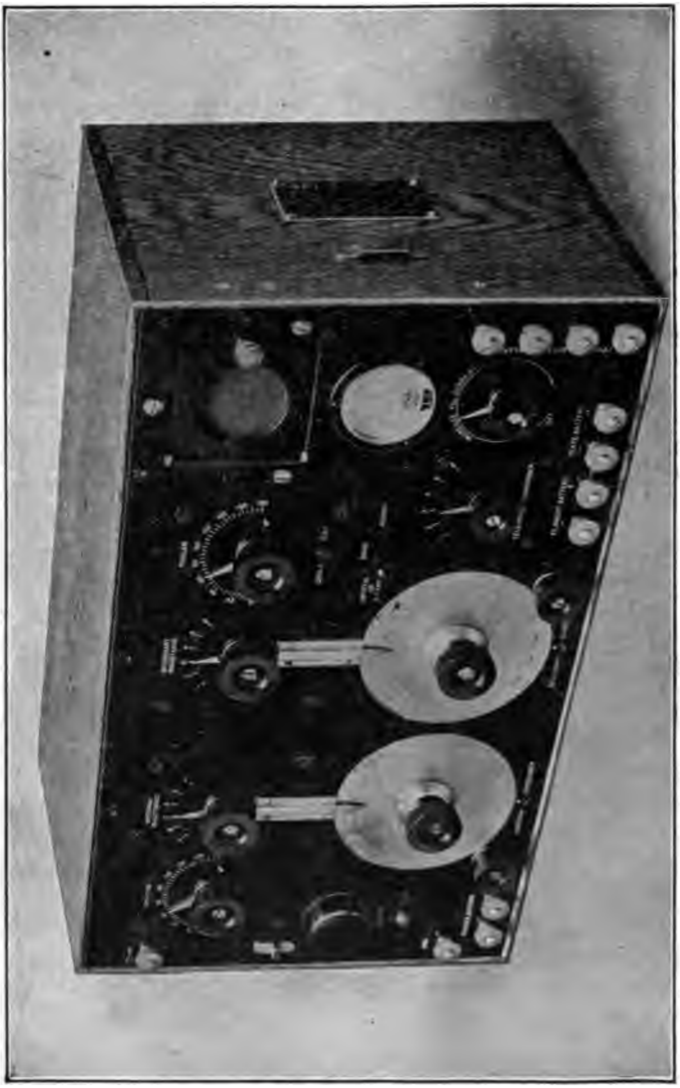

Fig. 32.—Receivers of this Type were Built by the Wireless Specialty Company, for the U. S. Navy Destroyers.

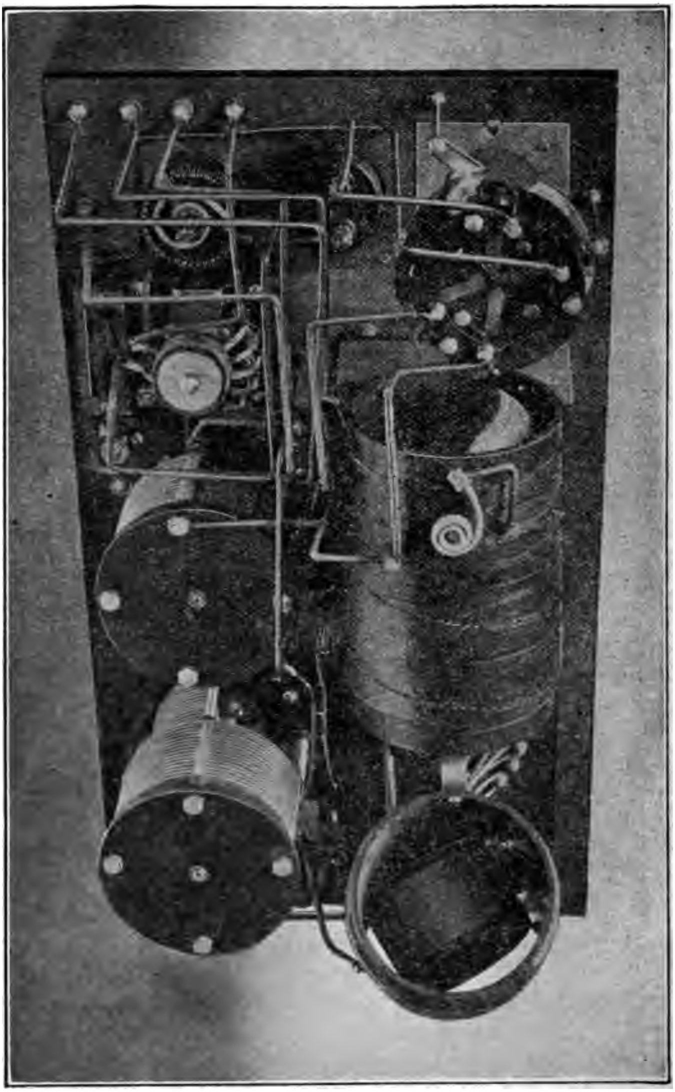

Fig. 33.—Rear View of the Set Shown in Fig. 32.

the inner diameter of the conductor. Therefore flat copper strip, $\frac{1}{4}$ to $\frac{1}{2}$ inch wide, should be used wound in the form of a solenoid or flat pancake. The thickness is not important, though it should be No. 24 B. & S. gauge or more.

39. TRANSFER AND LIGHTING SWITCHES.

Experimenters often construct their instruments and antennas with great care, insulating each part carefully, but neglect the transfer and lightning switches. Insulation at these points is as important as at any others. A slate base and the dust, largely carbon particles, which collect on an exposed lightning switch, form a good conducting path between the antenna and the ground.

Both transfer and lightning switches should be set upon corrugated insulating pillars, with the leakage path between antenna and ground several inches in length.

CHAPTER VIII

VACUUM TUBE TRANSMITTERS

For telegraphy, either damped or undamped, and telephony, the vaccum tube has taken a permanent place in the radio field, in competition with the older spark coil and transformer. 200 meter undamped telegraphy has the disadvantages of being difficult to heterodyne at the receiving station. This can be overcome, however, by the use of the rotary tone condenser.

Modulated vacuum tube transmitters in which a buzzer or tone circuit is employed to alter the undamped oscillations into audio-frequency groups are already popular. The low power telephone has also established itself among experimenters. Vacuum tubes of high power, that is ¼ to 1 kilowatt, have not come into use because of the difficulty in obtaining the tubes. At present, therefore, experimental sets are confined to the use of De Forest Marconi *VT*'s, a type which leaves much to be desired when employed as transmitting bulbs.

The design of a 200 meter set is quite a different problem from that of the commercial type. Moreover, some of the apparatus calls for the cut and try method which has been so largely eliminated in receiving circuits. Consequently, this chapter must be more on how to make rather than how to design vacuum tube sets.

40. ESSENTIALS OF VACUUM TUBE TRANSMITTING CIRCUITS.

A. The four circuits. A modulated vacuum tube transmitter can be divided into four circuits, the radiating, oscillating reaction and modulation circuits. If undamped waves are employed the modulation circuit is, of course, omitted. The radiating circuit includes an inductance, possibly a tuning condenser, and the antenna and ground. The oscillating circuit contains an inductance and capacity to which energy is supplied from the plate circuit. Means of coupling to the oscillating circuit either electro-magnetic or electrostatic, connected with the grid or filament, comprise the reaction circuit. In the modulation circuit is a telephone transmitter, tone circuit, or buzzer by means of which a varying change can be placed on the grid of the reaction circuit.

As a matter of fact these four circuits are often arranged in such a way that the same instruments are in the two or three of the dividing circuits. Of the many combinations, a few of the most successful are described in the following sections:

41. A SIMPLE TRANSMITTER.

The advantage of this type of undamped wave set is that one or more tubes can be used without complicating the circuit, and that an unusually small number of instruments is required. It can be used as a modulated telegraph or telephone set, as will be shown in Sections 42 and 43.

A. Antenna tuning inductance. The entire coil or part of it can be used in the radiating circuit, depending upon the amount of inductance needed to give, with the antenna capacity, the wave-length required. High frequency cable should be used on the coil, to keep the resistance of the radiating circuit as low as possible. Taps are provided to give a rough adjustment of the inductance.

B. Antenna variometer. A small coil is mounted inside the open end of the inductance just described, to allow a close adjustment of the total inductance in the radiating circuit. The dimensions of the winding can be determined by the data given in the previous chapters.

C. Coupling adjustment. By following the wiring, diagram Fig. 34, it can be seen that a part of the tuning inductance is included in the plate or oscillating circuit. By varying the plate switch, the coupling to the antenna can be regulated.

D. Reaction coupling. The inductance of the reaction coil, connected across the grid and filament, cannot be

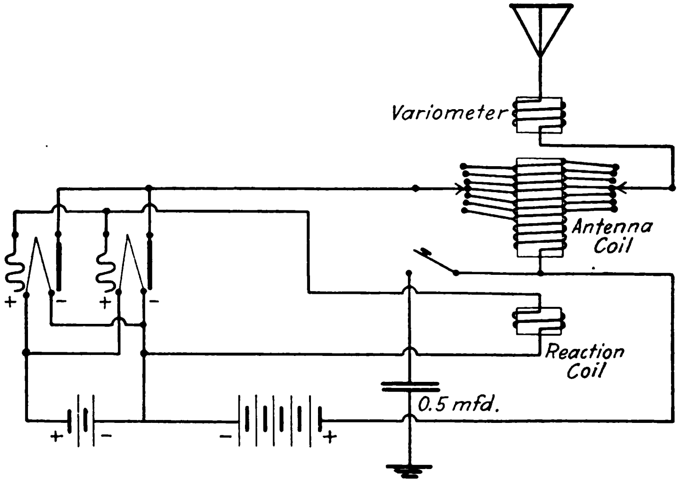

Fig. 34.—Undamped Wave Transmission can be Accomplished with this Circuit.

figured accurately. Practice, however, shows that it should have an inductance value nearly equal to that of the antenna coil. This winding can be of solid wire, as its resistance is not important. It should be located at the closed end of the antenna coil.

E. Transmitting key. Telegraphic signals are made by opening and closing the plate circuit. A condenser of 0.5 mfd. can be seen in the ground circuit. This does not affect the wave-length, but prevents the short-circuiting of the d. c. voltage supply to the plate.

F. Additional tubes. More vacuum tubes can be added to increase the power by connecting the plate and girds in parallel, and the filaments in series or parallel

G. Method of adjusting. The radiated wave-length depends upon the antenna capacity inductance of the tuning coil, of the variometer, and the mutual inductance between these two coils. Radiation is dependent upon the reaction coupling and plate coupling. An advantage of this set is that it will operate efficiently over a considerable range of wave-length and antenna resistances.

42. A MODULATED TRANSMITTER.

The circuit for this set is given in Fig. 35. The instruments are the same as those described in Section 41, with

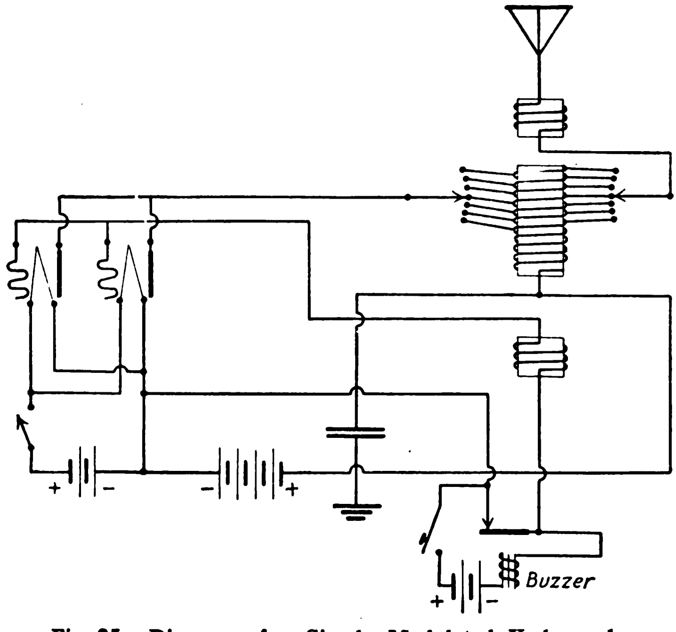

Fig. 35.—Diagram of a Simple Modulated Undamped Wave-Transmitter.

the addition of a buzzer, the vibrator of which is inserted in the grid circuit. When the filament switch is closed, undamped waves are radiated from the antenna. Operating the buzzer by means of the key puts a varying charge on the grid of the tube, modulating the oscillations to form audio-frequency groups. While this method is not as efficient as the vacuum tube modulation, it is satisfactory for smaller sets.

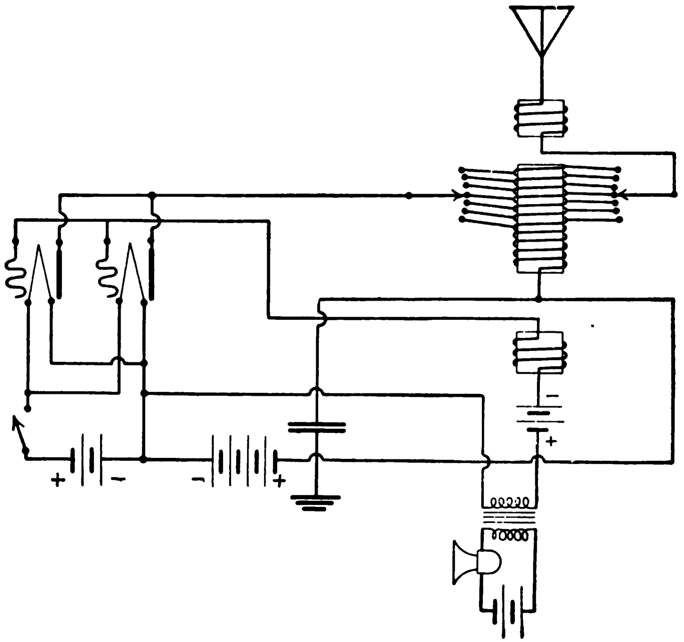

Fig. 36.—**The Addition of a Telephone Modulator Makes Possible the Transmission of Speech.**

43. A TELEPHONE TRANSMITTER.

In Fig. 36 is a diagram of a telephone set, using instruments similar to those described in Section 41. A telephone transmitter and modulation transformer are employed to impress the voice frequencies on the grid circuit. For experimenting, a small open core transformer with a step up ratio of 1 to 10 can be employed. There are several good types of modulation transformers on the market.

An adjustable battery is inserted in the grid to adjust the voltage on the grid of the tube.

44. ANOTHER TYPE OF TRANSMITTER.

A type of transmitter little known to experimenters is shown in Fig. 37. The main inductance is divided into four coils, wound close together on the same tube. In the middle are two coils in series with a variometer winding. As the diagram shows, they are in the antenna or radiating circuit. At one end there is a coil of 5 to 10 turns, con-

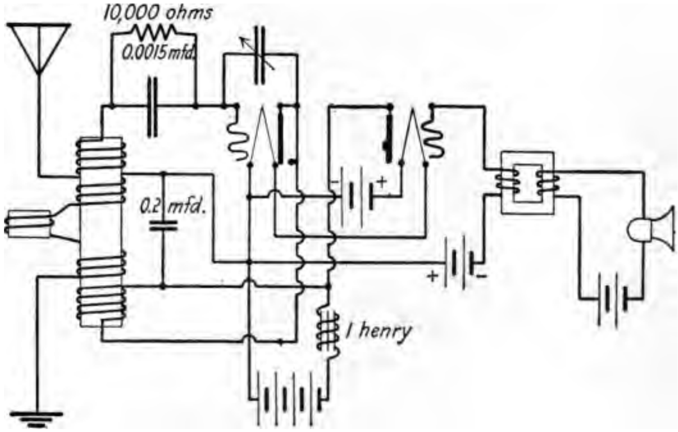

Fig. 37.—Another Circuit for a Wireless Telephone Set.

nected to the grid, and at the other end a coil of the same size, in the plate circuit.

All the tuning is done with the antenna coils, variometer, and a 0.0005 mfd. maximum variable condenser. This set will operate over a short range of wave-length and antenna capacities and resistances, maintaining a fairly constant output, a characteristic lacking in many circuits.

Modulation is effected by means of an auxillary tube. It will be seen that a modulation transformer is connected to the grid of the second tube. The plate current supply

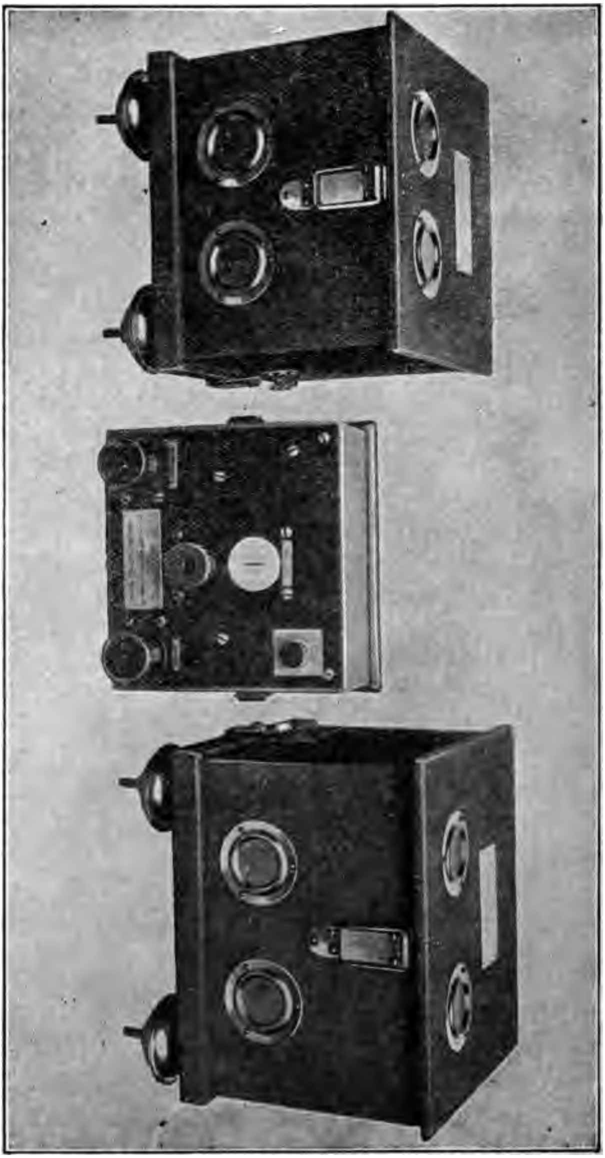

Fig. 38.—Western Electric Vacuum Tube Transmitting and Receiving Equipment.

to both tubes passes through an iron core choke coil of about 1 henry. This coil, by reason of its high impedance, maintains the current at a constant amplitude. Therefore, when the current in the modulator tube is decreased by the application of a negative charge on its grid, from the modulation transformer, the current in the first or oscillator tube must increase, and *vice versa.* Thus the undamped waves are generated by the oscillations unmodulated at voice frequencies. This is the most efficient method.

This circuit can be used for undamped wave telegraphy by omitting the modulator or circuit and choke coil, or an oscillating circuit, of such constants as to produce audio-frequency note, can be connected in place of the transformer shown in Fig. 37. In that case, the choke coil should be left in the circuit.

45. LOOP TRANSMITTERS.

Where a loop is to be used as an antenna, it can be in shunt with a variable air-condenser, across the antenna and ground posts. Another system sometimes used is to replace the inductance in Fig. 19 with a loop, taking the center tap from the middle of the loop as is done on the coil.

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