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The Multicoupler Antenna System for Apartment Buildings*

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THE growth of the radio receiver industry has created an urgent demand for a radio wave distributing system for the operation of the innumerable radio sets in apartment houses and other large buildings in the great centers of population to supplant the individual aerial wires with their hideous appearance on the roofs.

The means of providing every radio set in an apartment house with the proper signal energy from broadcasting stations must be such that:

(1) It will supply sufficient signal strength well above any disturbing noises.

(2) It must permit the use of all commercial as well as special types of radio receiving sets.

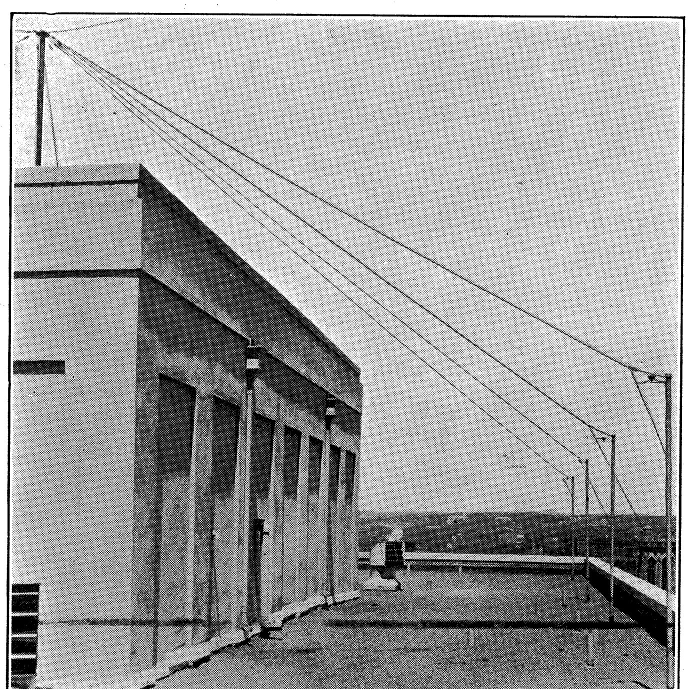
(3) The operation of one or more sets must not affect the performance of the other sets connected to the system to an extent that may be detected by any of the listeners.

(4) It must be simple and the cost of installation and maintenance must be low.

It is the object of this paper to show how the Multicoupler Antenna System fulfills the above conditions, as well as to briefly describe the theory of its operation and the practical development of the system for commercial installations.

There have been a number of attempts made to operate a plurality of radio receivers from one source of signal voltage. As soon as the vacuum tube was sufficiently developed as an electronic "relay" or repeater, some engineers used it as a coupling device of very high input impedance to transfer the signal voltage to the radio receiver. It was used also, or at least proposed to be used, for the purpose of obtaining a voltage amplification between the antenna and a two wire transmission line that would distribute the voltage to the individual coupling tubes. In connection with these tubes all kinds of selectors were proposed to be attached to reinforce weak stations and to obtain further selectivity in the radio receivers themselves. Such arrangements are too expensive and complicated.

Other attempts were made to operate radio receivers by means of conductors which existed in the building, such as gas and water pipes, heating systems, telephone leads and electric light circuits. The indoor type antenna became quite popular when sensitive sets were first developed commercially. Unfortunately, in all the latter cases there was present either one or all of the objections resulting from interference, noisy operation and generally unsatisfactory performance of the sets. To overcome all of these difficulties, a great deal of experimental and development work



Aerial arrangement to feed 200 apartments.

* *Delivered before the Club, Feb. 16, 1931.*

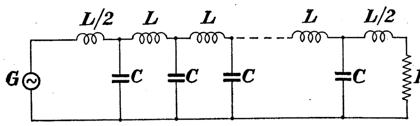


Fig. 1. Elementary coupler line.

was undertaken by the writers. The idea of a single radio frequency line of distribution, without vacuum tubes or other apparatus subject to renewal and upkeep, was developed after many tests both in the laboratory and out-of-doors. The Multicoupler Antenna System of reception and distribution was evolved until it reached a very satisfactory commercial stage, the theory of which will be given very briefly, as this paper aims particularly at the practical end and at the results of commercial operation for a period of about three years.

Theory of the Multicoupler Antenna System

It will be seen that the Multicoupler Antenna System consists essentially of a uniform attenuation line connecting a good antenna to a number of radio receivers, the line being connected to a terminal resistance at the other end. The signal voltage is supplied to the various radio receivers by means of multicouplers. The most elementary representation of a multicoupler line consists of a generator G, Fig. 1, which impresses an e.m.f. through an artificial line containing inductances L and condensers C to a resistance (R_o). The inductances and condensers have small losses and are such that $R_o=\sqrt{L/C}$. At all frequencies from o to $\omega=2/\sqrt{LC}$, the voltage will reach R with very small attenuation. The multicoupler, however, is not a filter section per se and does not act as such.

If, the resistances in series with the coils and in shunt with the condensers are of appreciable magnitude, the propagation constant per section will be

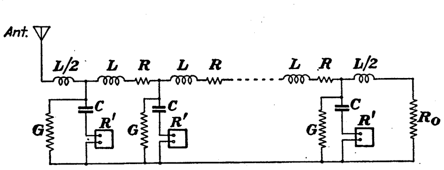


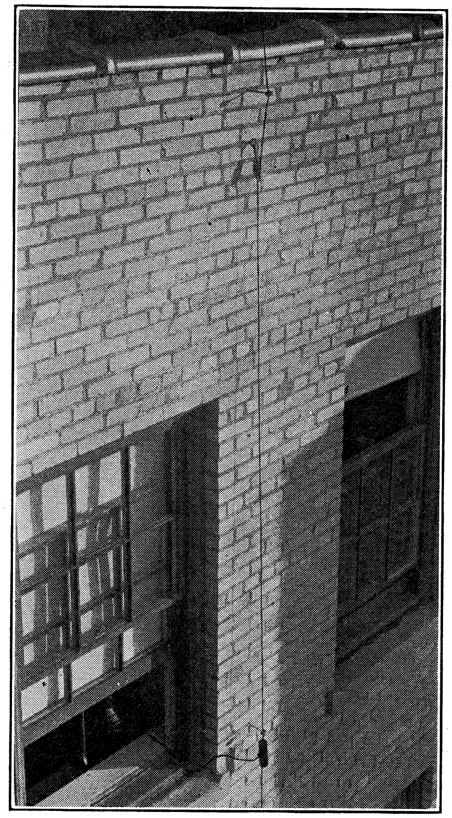
Fig. 2. Generator replaced by an antenna.

$P=\sqrt{(R+j\omega L)\ \ (G+j\omega C)}$ and the terminal impedance will be

$$Z=\sqrt{(R+j\omega L)/(G+j\omega C)}.$$

This line may attenuate the higher frequencies more than the lower ones unless ωL is large in comparison with R, and ωC with respect to G. Let us now replace the generator G by an antenna, and the line by a riser, Fig. 2, then the losses in the line may be considered as made of two components; one due to the series resistance of the conductors R′, and the other due to shunting conductances G representing dielectric losses and the energy consumed by the radio receivers R′.

This schematic representation is only a first approximation. The capacities C represent a combination of distributed capacity along the downlead and the coupling condensers. The conductance G also represents at the same time the losses due to the dielectric, leakage, etc., along the line, as well as the effect of the radio sets. If we make G small compared to ωC, and R small compared to ωL, the line will transmit the e.m.f. without appreciable attenua-



Method of fastening head of downlead.

tion, as previously stated, and the terminating impedance will be sensibly equal to $\sqrt{\frac{L}{C}}$. An approximation of theoretical conditions may be obtained by representing a section of the multicoupler line by means of a series inductance L, Fig. 3; a series resistance $R_1=f(\omega)$, which takes into account ohmic losses, eddy currents and skin effect; a shunt capacity C_1 with leakage resistance $R_2=\varphi(\omega)$, representing the dielectric losses and leakage; another resistance $R_3=\psi(\omega)$, representing a radio set, with the coupling condenser C_2 in series. The three resistances, which are functions of ω, may be expressed approximately as follows: $R_1=K_1\omega$, $R_2=K_2\omega^{.5}$ and $R_3=K_3\omega^{1.5}$. There may be some radio sets in which R_3 is independent of ω and some others in which $R_3=K\omega^2$ with tuned inputs; hence, we may assume $R_3=K_3\omega^{1.5}$ for an approximation.

The equations for the propagation constant per section obtained by introducing these functions of ω in the expression $P=\sqrt{(R+j\omega L)\ \ (G+j\omega C)}$ where $P=\alpha+jb$, from which the at-

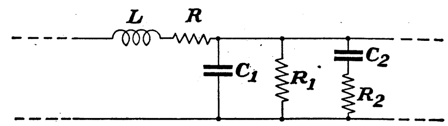


Fig. 3. Section of multicoupler line represented by an inductance.

tenuation α may be obtained are rather complicated, and even after making the calculations the results would not be in close conformity with practice for the following reasons:

In the first place, the radio receivers may have any values of resistance and reactance, which are variable according to the tuning condition.

Second, the shunt capacity is not uniformly distributed along the line and the losses due to eddy current, dielectric hysteresis, skin effect, etc., vary according to local conditions.

Third, it is assumed that the impressed electromotive force is applied to the beginning of the line. In practice, however, additional voltages are induced by the field of the broadcasting stations along the downlead. The manner in which these extra e.m.fs. are induced depends upon the surrounding medium. As there are so many buildings in the vicinity of the downlead, the pickup of both antenna and downlead varies in a very complex way—which cannot be predicted.

All these considerations lead to the experimental, rather than to the treatment a priori of the multicoupler line.

The most important properties of the Multicoupler Antenna System, or, in fact, of any common radio signal system of distribution, to be considered, are:

(1) The propagation of the signal from one end of the line to the other. This means the relative energy level at every outlet.

(2) The lack of interaction, if any, between radio receivers connected to the system.

(3) The actual signal strength at any outlet in comparison with individual signal collectors.

(4) The terminal impedance of the line and the prevention of standing waves along the line.

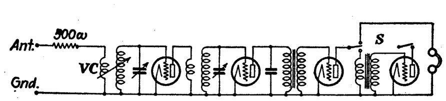


Fig. 4. Receiving system.

TABLE I

780 kc. Set No.	All Sets Tuned to 780 kc.	All Sets Completely Detuned	Detuned +1	Detuned −1
1..........	30	....	....	
2..........	24	....	....	
3..........	29	30.5	28	31
4..........	28	....	....	
5..........	31	....	....	

Potential distribution along line at input — 30
1 — 30.5
2 — 24
3 — 25
4 — 29
R — 28

1100 kc. Set No.	All Sets Tuned to 780 kc.	All Sets Completely Detuned	Detuned +1	Detuned −1
1..........	35	....	....	
2..........	36	....	....	
3..........	37	42	33	29
4..........	34.5	....	....	
5..........	31	....	....	

In connection with the last item, it is well to mention that there are two types of multicoupler lines; the outdoor type and the conduit system. In the latter, additional distributed shunt capacity will be found and the terminal impedance will be found to be lower than in the former, in which case, a suitable impedance-matching transformer is found very advantageous to connect the line in the conduit to the antenna as indicated in Fig. 8.

Propagation of the Signal

Two sets of signal strength measurements will be described:

(A) In the laboratory with a number of multicouplers to which sets are connected.

We have seen that one of the important requirements of the multicoupler line is that it should act as a uniform attenuation conductor for all broadcast frequencies. In order to verify this experimentally, a special receiving set was constructed, the schematic diagram of which is given in Fig. 4. In this set, the volume control VC, which is of the inductive (variable mutual induction) type, was calibrated in dbs. Additional range is obtained by means of a switch S permitting the use of one or two audio stages, the difference amounting to 15 dbs. and the total range about 60 dbs. With an "artificial" signal source made of an r-f. modulated by a single a-f. tone, a meter in place of or in addition to the head phones will permit a more accurate level determination. With actual broadcast signals, the meter will keep moving all the time and it is better to use the vanishing signal as reference level and note how many dbs. are needed to make the signal just inaudible. The more decibels the higher the level, and in the table of results the dbs. have this particular meaning.

Before the Multicoupler Antenna System was put in operation, in actual practice, a number of signal strength tests were made at the laboratory. The general layout is represented diagrammatically in Fig. 5. M, M_1 . . . M_n represent multicouplers all connected to an antenna of about 120 feet in total length at one end, and to a 1000-ohm terminating resistance. To the coupling condensers of the multicouplers were attached a number of radio sets, in many cases just equivalent tuned input circuits, LC, or mere resistances R_2, simulating commercial receivers equipped with or without "coupling tubes."

By means of this signal strength measuring set, the effects of the various radio receivers connected to a multi-

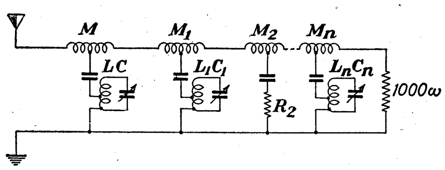


Fig. 5. Laboratory trial of Multicoupler System.

coupler line upon any particular one of them, can be determined experimentally. The actual procedure consisted in connecting to one of the multicouplers a radio set with a vacuum tube voltmeter across the speaker to indicate the volume of the signals received, which during the tests were either regular broad-

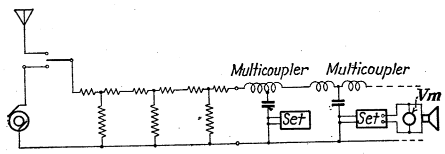


Fig. 6. Signal strength measurement.

cast programs or locally generated modulated signals, the voltage of which was controlled by means of an attenuation resistance network calibrated in dbs. as shown in Fig. 6. When using this source of signal the measurements could be made very accurately and expediently. All that was necessary was to maintain the reading of the vacuum tube meter constant while increasing or reducing the signal voltage by a given number of decibels. The results of the tests made under these conditions are given in Table I, where the first column gives the position of the set, starting from the antenna end. The second column gives the levels in dbs. at the various points along the line when the radio sets were all short-circuited or badly detuned, which has the same effect. The third column gives the same data but with all sets tuned, while the last two columns refer to conditions where the sets were very slightly detuned on each side. The last set of tests shows the effect of tuning at least half of the sets to one station.

The severity of the conditions under which the tests were made will never be found in practice. First of all, there was hardly two feet between outlets;

TABLE II

Floor	Station	Level for vanishing signal: Without transformer	Level for vanishing signal: With impedance matching transformer	Difference in level due to effect of the transformer
15th..............	WMCA...........	42 dbs.	58 dbs.	16 dbs.
	WEAF............	38	50	12
	WABC............	45	60	15
	WOV.............	37	57	20
12th..............	WMCA...........	46	55	9
	WEAF............	40	48	8
	WABC............	44	63	19
	WOV.............	34	54	20
9th...............	WMCA...........	43	55	12
	WEAF............	39	50	11
	WABC............	40	60	20
	WOV.............	37	53	16
6th...............	WMCA...........	43	59	16
	WEAF............	40	52	12
	WABC............	43	65	22
	WOV.............	41	58	17
3rd...............	WMCA...........	38	55	17
	WEAF............	39	45	6
	WABC............	45	60	15
	WOV.............	39	52	13

then all sets were of the tuned input close coupling type with low-loss coils and condensers, and finally, the line was practically devoid of distributed capacity.

(B) In the field, in a building equipped with the Multicoupler Antenna System.

Similar tests were made later on an actual conduit installation at 770 Park Avenue, New York City. The portable set was carried to the third, sixth, ninth, twelfth and fifteenth floors of the seventeen story building and signal strength tests were made at four different frequencies. At the same time, the effect of an impedance matching transformer was determined upon the signal level at the same floors. Using the best ratio, the volume went up by an average of 15 dbs. Table II gives the results obtained.

These results are given in graphical form in Fig. 9. It will be noted how uniformly the propagation of the signal takes place along the line. The effect of the additional capacity due to the conduit lowers the impedance of the line to such extent that the transformer is found to be quite beneficial.

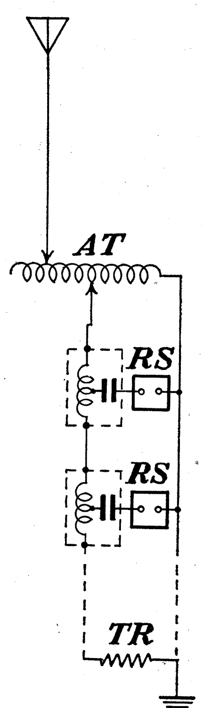


Fig. 8. Impedance matching with conduit system.

Interaction With Individual Antennas

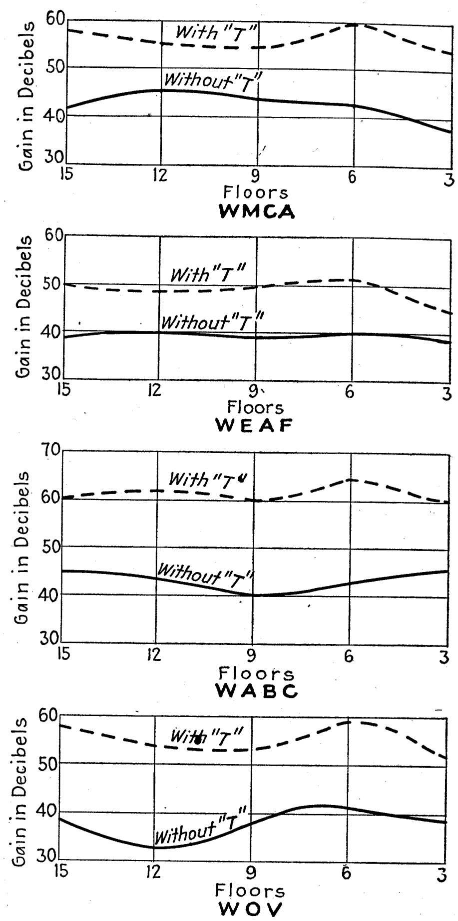
It is very interesting to compare the interaction between two sets when connected to the Multicoupler Antenna System or to individual antennas. For this purpose, two antennas five feet apart were brought down and sets connected to each one of them. The first set was of the tuned input type and the second one had means for measuring the volume in dbs. The two sets were connected successively to the aerial wires five feet apart and then to two consecutive multicouplers. The effects in the case of the multicoupler connection may be studied from data such as given in Table I under extremely adverse conditions. However, when the two sets were connected to individual aerials, the effect of tuning one of them to the station being received by the other was a level difference of between 5 and 20 dbs., according to the frequency and the sharpness of the tuning.

A signal, the strength of which does not vary by more than 1 to 2 dbs., is considered to be of constant volume from the listeners' standpoint. Five dbs. variations are noticeable only in comparative tests. A gradual fading of 5 dbs. can hardly be detected. With these premises in mind, it is possible to judge the performance of a multicoupler layout in the laboratory from tests made as described above. It must be remembered that these tests were made under the severe conditions described before.

TABLE III

Station	Energy Level: Multi-coupler	Energy Level: Test Antenna	Gain in dbs. Multicoupler over Test Antenna
(At the ninth floor)			
WMCA.....	60 dbs.	30 dbs.	30
WEAF.....	60	47	13
WOR.......	60	47	13
WPCH.....	32	20	12
WABC.....	39	32	7
WAAT.....	42	18	26
WOV.......	53	53	0
1500 kc.....	13	58	—43
(At the fourteenth floor)			
WMCA.....	60	43	17
WEAF.....	60	43	17
WOR.......	60	44	16
WOV.......	60	44	16
1500 kc.....	40	14	26

In practice, in any of the buildings equipped with this system, there has not been as yet a single complaint on record of fading due to interference between sets, which may be looked upon as a favorable confirmation of the working theory. How is it then possible to reconcile two apparently mutually conflicting conditions, namely, sufficient signal strength, requiring large coupling condenser, and independence of operation demanding small coupling condenser? The results given above



EFFECT OF IMPEDANCE MATCHING TRANSFORMER UPON A CONDUIT MULTICOUPLER LINE

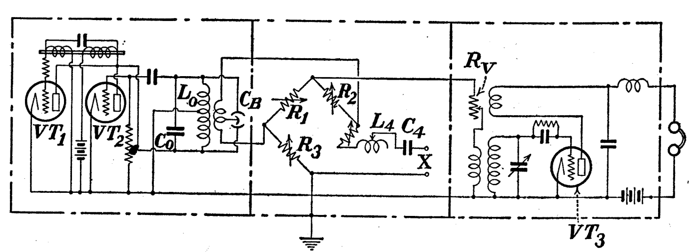
Fig. 9.

offer an answer but not an explanation. One explanation is as follows: The action that takes place with a multicoupler connected to a set is one of phase rotation rather than mere magnitudes of voltages. To make this clear, let us give some numerical values to the quantities involved. Let the multicoupler condenser have a reactance of say 900 ohms at a frequency close to the middle of the broadcast band. Assume the radio set to offer a pure resistance of 300 ohms when tuned to that frequency. The e.m.f. available from the antenna at the junction of the multicoupler condenser to the line will be across both condenser and set in series with each other and let it be of, say, one millivolt. The current supplied to the set would be

$$\frac{.001}{\sqrt{900^2 + 300^2}} = 10^{-6} \text{ amperes.}$$

If the set were detuned, its effective re-

Fig. 7. Bridge method of determining terminal impedance.



sistance and reactance would be very small and the current would be practically

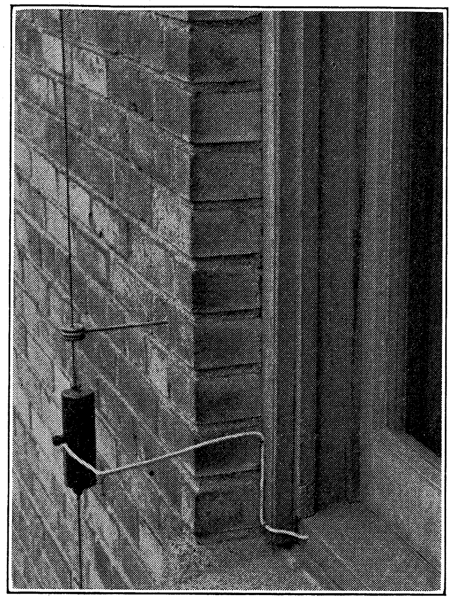
$$\frac{.001}{\sqrt{900^2}} = 1.11 \times 10^{-6}$$

or only 11 per cent greater. Hence, the available voltage will still be substantially the same at all the other points in the line. The average set will offer a higher impedance to the line, so its effect on the signal will be less.

The signal voltage available to the set when tuned will be $10^{-6} \times 300$, or .3 millivolt which is about one-third of the total available potential from the riser. Hence, by cutting down the available voltage to 30 per cent the sets will become independent of each other. The phase rotations in the vector diagram offer the explanations of how the two conditions of sufficiency of signal voltage and freedom from interactions are fulfilled to a practical extent, without resorting to one-way repeaters, or coupling tubes.

Comparison with Individual Antennas

In order to find out experimentally how the signal strength from the multicoupler system compares with that obtained from an individual antenna, experiments were carried out at a 17 story apartment house. At the ninth and fourteenth floors successively, a standard set (Radiola, model 33, a-c.) with



Detail of a multicoupler support outside rear window.

the volume control previously calibrated at the laboratory, was attached by means of a s.p.d.t. switch either to the multicoupler system or to a 40-foot outdoor antenna strung over an open court at the roof (seventeenth floor).

The average gain at the ninth floor was 14 dbs. ignoring the last reading which was no doubt the result of a standing wave formed in the individual aerial. The average gain at the fourteenth floor was 18 dbs.

These observations are typical of a larger number which for the sake of brevity, are not given, but they are enough to illustrate what has been found to be the case in all the Multicoupler Antenna installations — that there is plenty of signal voltage available at the antenna-ground posts of the outlet plates.

Terminal Impedance Measurements

In order to determine experimentally the terminal impedance of a multicoupler line, measurements were made on both laboratory layouts and in actual installations. These measurements were made by means of a portable Wheatstone bridge, the circuit of which is given in Fig. 7. The oscillator tube VT_2 has a balanced coil L_o so that one end is just as high above ground potential as the other end is below ground at the same instant throughout the a-c. cycles. The "figure eight" winding coils make magnetic induction very small. Besides, the aluminum double shield arrests the small leakage field that may be present. The oscillations are modulated by means of the audio frequency oscillator tube VT_1 which gives about 700 cycles. To prevent serious errors, a "Wagner earth" C_B is used to prevent capacity coupling interference in the operation of the bridge.

The bridge is made of four non-reactive variable resistances R_1, R_2, R_3, and

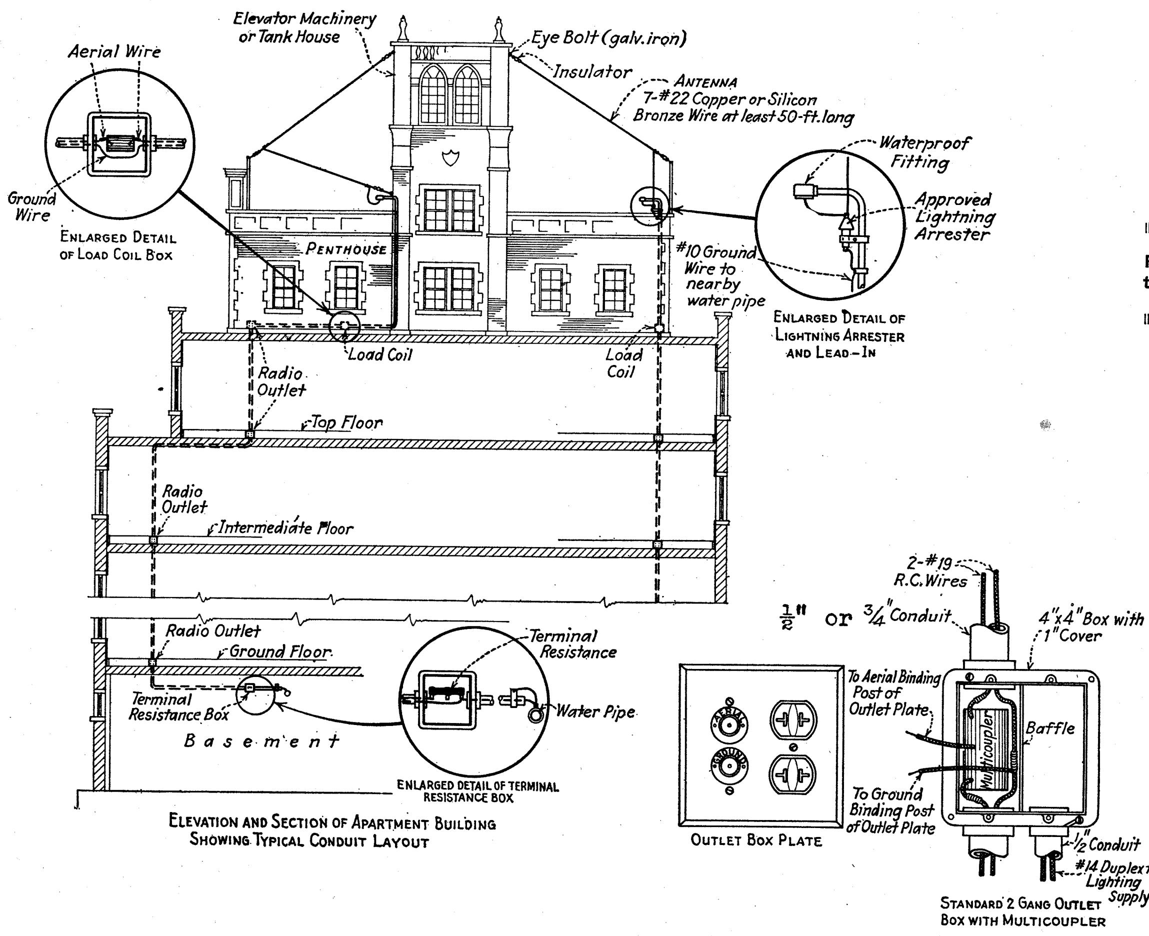


Fig. 10. Conduit type of installation.

R_4 from 0 to 200 ohms. In series with one of them there are; a variable condenser C_4 and a multistep inductor L_4. The condenser at the maximum capacity setting will become short-circuited, and the inductor has four taps the first one of which puts it out; hence, both L_4 and C_4 may be put out of the circuit.

The unknown resistance may be connected between the resistance R_3 and the ground, or between the resistance R_4, condenser and inductor and the ground, so that in the first case the reactance will be balanced by means of a standard reactance of the same sign in the opposite arm, while in the second case the unknown reactance is neutralized by a known reactance of opposite sign in series with it, making the bridge non-reactive in all four arms.

The detector is a regenerative detecting tube with a tickler and a series resistance R_v in the primary to vary the sensitivity and help thereby to find approximately the balance settings. Once located it is easy to obtain an accurate balance by increasing the sensitivity of the regenerative detector. It is enclosed in its shielded compartment, and the tuning condenser has a scale calibrated in megacycles. The measurements with the bridge above described may be relied upon to be within 10 per cent or better.

In Table IV are given the results of the terminal resistance and reactance measurements at various frequencies of a setup of multicouplers with their condensers grounded and the line terminated by 1000 ohms. The same measurements were made on a conduit line in a commercial installation.

It will be noted that the impedances of conduit lines are much lower than those of the laboratory setup. There are several reasons for this which would take too long to enumerate. Better still to repeat that an impedance-matching transformer can raise the energy level by about 15 dbs. as seen before. The schematic arrangement is shown in Fig. 8.

The impedance of the multicoupler measured from the antenna and ground outlet to the radio set is approximately that of a .0003 mf. condenser. Thus it is evident that a set which will align properly on an antenna of this capacity, which is not much greater than that of an average antenna, will not be adversely affected by the impedance of the multicoupler.

The inductance of the multicoupler units is small enough so that the capacity of the downlead to ground furnishes enough capacity to make the operation satisfactory when only a few of the multicouplers in a long downlead are connected to receiving sets which are also connected to ground in the usual manner.

Practical Conclusions and Advantages

A large number of apartment houses in New York and other cities have already been equipped with the Multicoupler Antenna System and owners have been quick to realize that their radio antenna problem has been solved by this simple and inexpensive system, which may be installed by the average electrician or radio man.

The finished installation is neat, inconspicuous and exceedingly convenient for the apartment house tenant, as shown in the accompanying photograph of an outside installation in buildings already erected. The advantages extend to the set owner, since there are several benefits from this group antenna system and the multicoupler. First, each multicoupler is so designed that it serves to pass all the broadcast frequencies to reach the receiver. All interfering noises, such

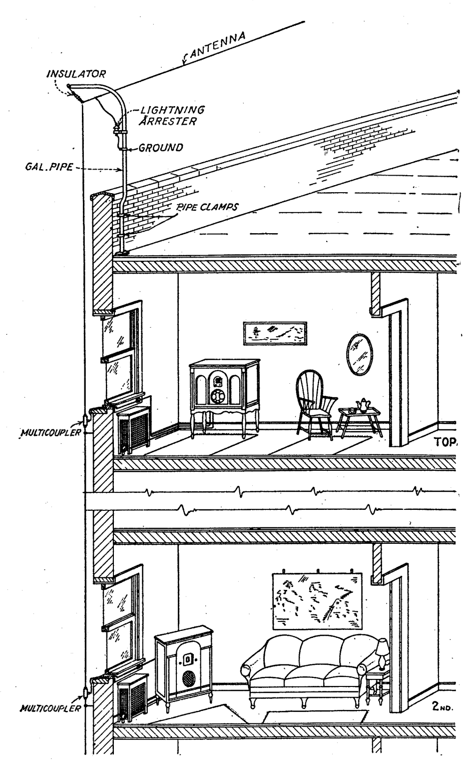


Fig. 11. Outside type of installation used on completed buildings.

as electric motors, elevator contacts and so on, are reduced, resulting in a minimum of background noise. This arrangement also stands for greater selectivity and a much better quality of reception. Nevertheless, although adjusted primarily for broadcast frequencies, short-wave fans and television experimenters are not neglected in an installation of this sort. By connecting a small series condenser .0003 mf. to the main downlead, a few inches above the multicoupler, each tenant simultaneously secures the benefits of an excellent outdoor antenna for short-wave reception.

The multicoupler, with its coils and coupling condenser properly protected by a weatherproof case, contains nothing that can wear out. There are no tubes or other parts to replace. There is no further expense to this system once it is installed.

The installation of the system in conduit in new buildings has proved equally as satisfactory as the outside system. Architects and consulting engineers are specifying the system as a standard feature in plans for new apartment buildings, apartment hotels, hospitals and dormitories.

TABLE IV

Effective resistance of a Multicoupler line containing 10 multicouplers with the condensers grounded and terminated by a 600 ohm resistance.

Frequency in megacycles	.6	.7	.8	.9	1.0	1.1	1.2
Effective resistance in ohms	640	525	453	420	400	385	375

Effective Reactance Negligible

Effective Resistance and Reactance of a Conduit Multicoupler Line with 17 outlets.

Frequency	.6	.7	.8	.9	1.0	1.1	1.2	1.3
Resistance	196	44	36	34	31	30	26	17
Reactance	—4	8	0	—6	3	—10	5	11

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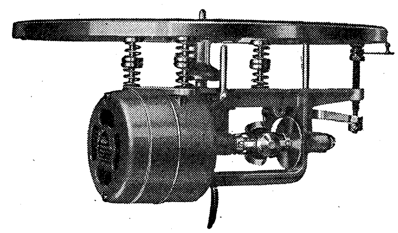

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