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PUSH-BUTTON TUNING

By Garrard Mountjoy*

Push-button tuning at present is accomplished commercially by three systems, namely: motor-drive tuning, mechanical coupling between push-buttons and tuning element, and pre-set circuits controlled by a series of electrical switches. A wide variety of designs is marketed with various distinctive features, but all may be classified under these headings.

Motor-Drive Types

Motor-drive tuning may be divided into two distinct types. The homing type is one in which the mechanism always travels the shortest path to accomplish station selection. For example, if a receiver were tuned to 1000 KC, and a button governing 900 KC were pressed, the mechanism would move to 900 KC through the short path. If a 1100 KC button were pressed the mechanism would move back to 1100 KC.

The second type of motor tuning uses a single direction motor. An example of its method of operation would be to consider a receiver tuned to 1000 KC at the moment of pressing the 900 KC button. The mechanism might travel to the high frequency end of the tuning range, encounter a reversing switch and travel back toward the low frequency spectrum until 900 KC tuning was reached. Half the time this method will first travel in the wrong direction and half the time it will by chance be going in the correct direction for shortest travel.

While the homing type is fundamentally faster in operation, the "electric train" action of motor tuning is intriguing to many individuals and moderate delay in station selection is not necessarily tedious.

An example of homing motor tuning is illustrated schematically in Fig. 1, and photographically in Figs. 2 and 3. Each push-button, when pressed, will make connection through a specific "station setting contact" to one of the two segments of the "selector disc" which govern the direction of the motor through the choice of fields effected by the selector disc segments. The motor will stop when the station setting contact is on the narrow insulated strip between the selector disc segments. An overshoot of the mechanism caused by inertia

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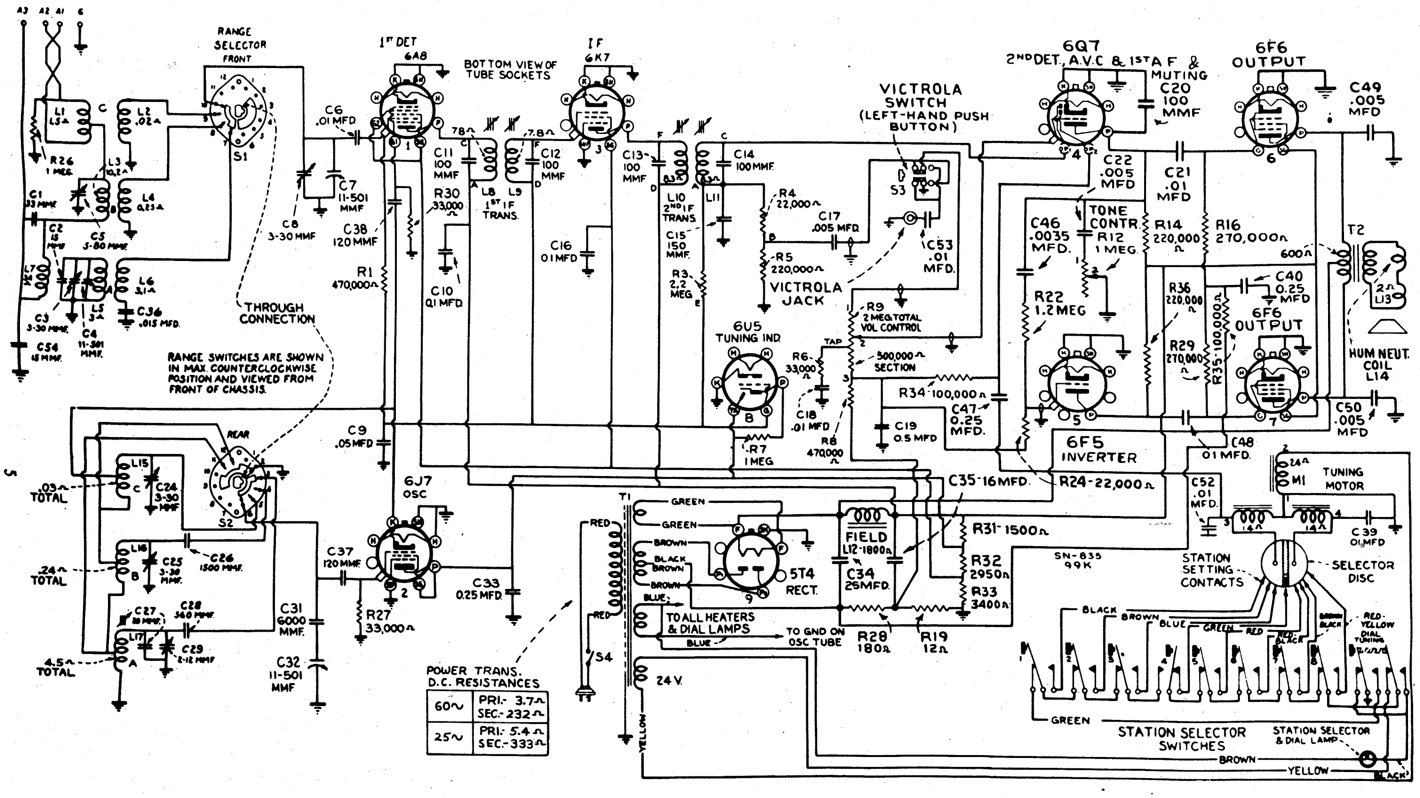

Fig. 1—Homing Motor Tuning—Schematic Diagram.

of the moving parts will bring the station setting contact in contact with another segment of the selector disc and will cause a reversal of the motor. The reverse travel will take place for a minute angular distance, and the resulting momentum being relatively small, will stop at the insulated strip.

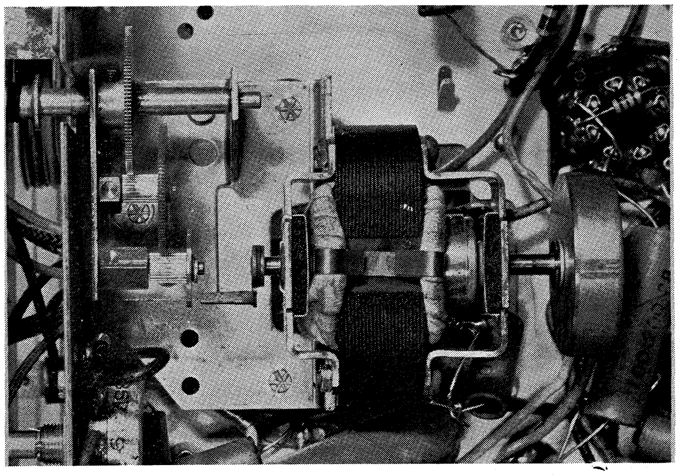

Fig. 2—Homing Motor—Chassis Installation.

The motor is shown in Fig. 2. The armature will be pulled further into the housing when the current is on, and a clutch will engage the first gear in a train of gears driving the tuning mechanism. Several stages of gears are used to permit the use of an economical motor of high rotational speed.

Mechanical Coupling Types

The second type of push-button tuning, or mechanical type, provides that the force of a thrust on the push-button be transmitted to the tuning elements. Many commercial varieties are available which have excellent mechanical construction. It is essential that the entire moving system have adequate balance and freedom from friction to insure station selection without necessitating undue force in pressing the buttons.

One type is illustrated in Fig. 4. A thrust is transmitted by the push-button through cams and other mechanical links to the tuning condenser shaft. Pre-setting the buttons to desired stations may be accomplished from the front of the receiver.

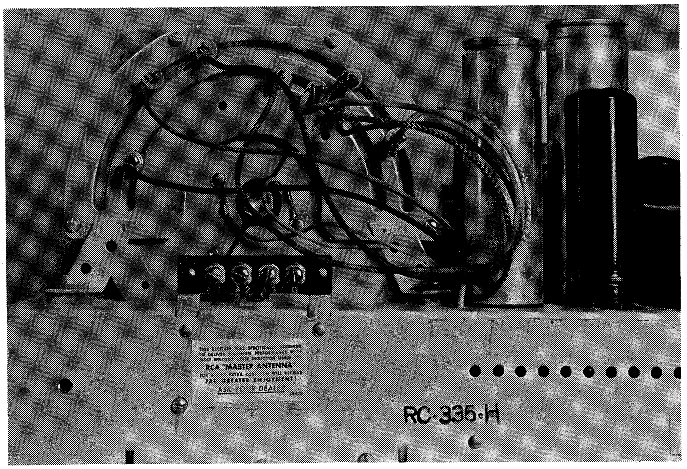

Fig. 3—Homing Motor Selector Disk—Chassis Installation.

This type reflects the trend in mechanical design to simplify the pre-setting of stations.

A type using the same principles but distinctive in that the tuning elements are variable inductors instead of the more widely used gang condenser, is shown in Fig. 5. The motion of the push-button is transmitted through a heart shaped cam and attending links to a magnetic core movable through a coil form. It is required that for every tuned section of the receiver one of these complete mechanisms be used.

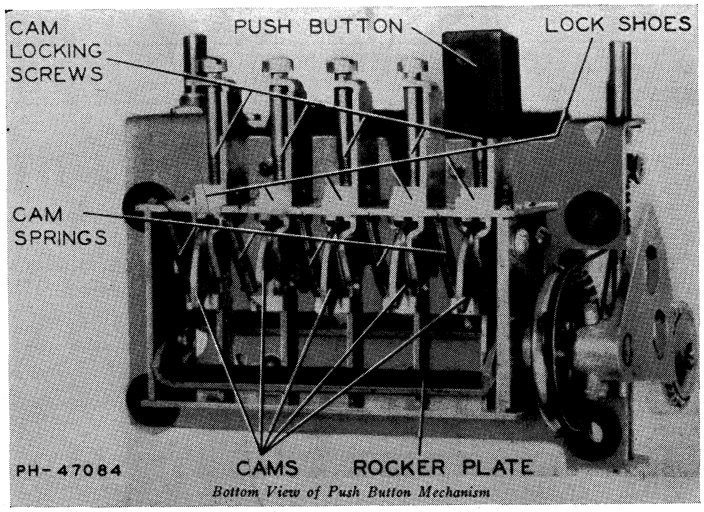

Fig. 4—Mechanical Coupling Type Push-Button Control.

Pre-set Circuit Types

Quite distinct from the foregoing is the third type, or pre-set circuit type. Instead of using the tuning elements available for ordinary manual tuning, this system uses auxiliary circuits, one per station per tuning function. Thus an 8 button receiver, of oscillator, r-f and antenna stage tuning, will require 24 adjustable reactors. The reactors may be separate or ganged.

A good example of ganged reactors is shown in Fig. 6. Oscillator, r-f and antenna inductors are assembled on one form per station. Through the form passes a shaft with three spaced magnetic cores which move simultaneously with the movement of the adjusting screw at the front of the receiver. This greatly simplifies pre-setting. It is not feasible to gang trimming condensers of the mica type because of non-uniformity of commercial products. Air dielectric condensers are not economical in the sizes necessary for frequency band coverage.

An example of pre-set tuning involving two adjustments per station is shown in Fig. 7. Variable capacitors on either side

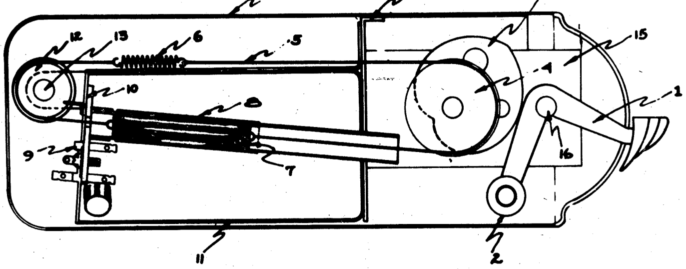

Fig. 5—Mechanical Coupling Type Push-Button Control for Variable Inductor Tuning. Manufactured by Belmont Radio Corporation, Chicago, Ill.

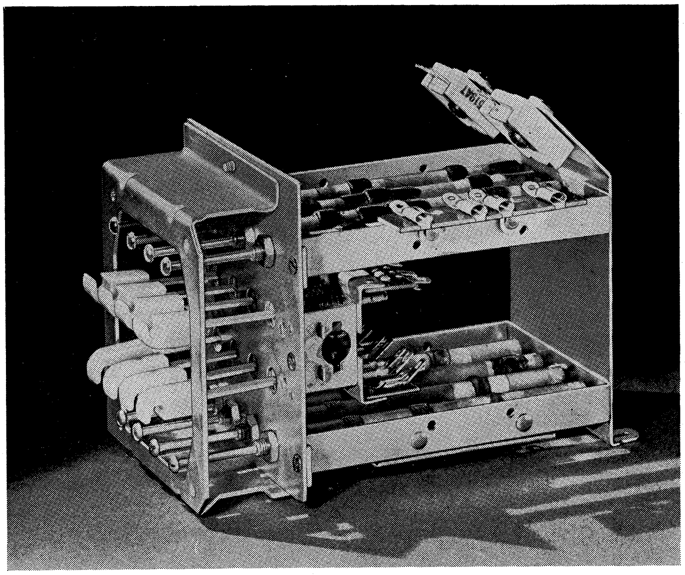

Fig. 6—Pre-Set Circuit Type of Ganged Reactors. Manufactured by Zenith Radio Corporation, Chicago, Ill.

of each electrical switch section are to be adjusted in pairs for each station. This particular example is from a TRF receiver.

Since simplicity of adjustment imposes restrictions upon the number of tuned circuits, it is common practice with individually tuned reactors to use only one pre-selector and one oscillator adjustment per button.

Since this is the electrical equivalent of two gang tuning, some characteristics of two gang receivers are pertinent and are quoted in Fig. 8 from numerous receiver tests.

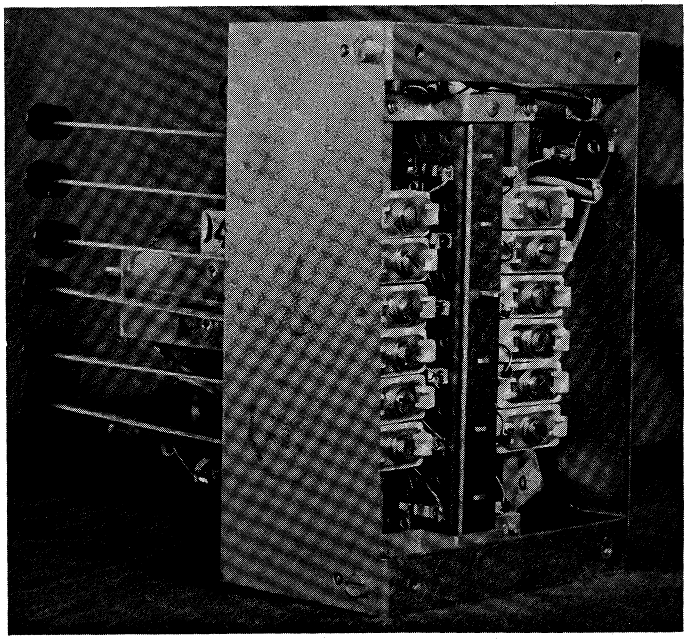

Fig. 7—Pre-Set Tuning—Variable Capacitor Adjustment.

Maximum image ratio	610	344	176
Minimum image ratio	30.4	19.4	14.8
Average image ratio	321	145	88
Max. I.F. response ratio	191	348	507
Min. I.F. response ratio	13	17	30
Av. I.F. response ratio	76	121	212

Fig. 8—Characteristics of Two Gang Receivers.

These figures may be duplicated in push-button receivers with conventional circuits. In many cases they may be adequately high for the nature of the service, particularly when the stations selected for push-button reception have good signal strength.

Higher ratios are obtainable with either of two systems of coupling to be described. These systems retain the single adjustment feature. Their merit may be judged by the following factors:

1. band coverage
2. image ratio
3. i-f ratio
4. signal gain
5. influence of antenna characteristics on circuit resonance
6. noise

The first system is illustrated in Fig. 9. It has a primary circuit of high inductive reactance attached to the high potential end of the secondary tank circuit. No mutual coupling exists. The primary produces a greater attenuation of image than of desired signals. This may be accentuated by the distributed capacity of the primary if the latter is permitted to tune portions of the winding to the higher image frequencies.

TABLE A

L_1 = 600 µh.
L_2 = 3200 µh. (low distributed capacity)
L_3 = 155 µh.
C_1 = 200 µµf.
C_a = 200 µµf.
I.F. = 460 kc.

TABLE B

Frequency	*Image Ratio*	*I. F. Response Ratio*	*Signal Gain*	*Q of L_3*
600 kc.	940	5,000	4	100
1000 kc.	537	6,900	2.8	120
1400 kc.	870	10,000	1.8	143

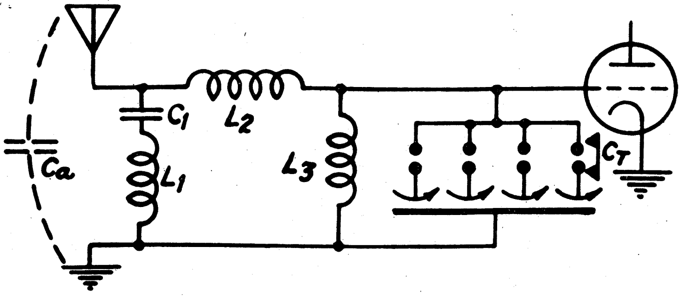

Fig. 9—Antenna Coupling System and Performance Characteristics.

C_1, L_1, form an i-f wave trap. This circuit will exhibit inductive reactance for all desired frequencies and will tend to resonate with the internal capacity of the antenna at some part of the broadcast band. Data were taken with the constants given in Fig. 9. The results are shown in the same figure.

Improved gain may be obtained by reducing L_2 if the design problem requires it. A small antenna gain usually is desirable in the reception of local stations on large receiving antennae. C_T represents a bank of tuning condensers. These will consist of at least two different values of condensers for different tuning ranges. The circuit imposes no unusual restrictions of tuning range, through any peculiarities of coupling.

Some detuning, chiefly at the low frequencies, will result from the substitution of antennae of various capacities. This effect is not seriously detrimental, and may be reduced to a minimum by the use of a small condenser (about 200 micro-microfarads) in series with the antenna.

When the circuit is modified to provide for AVC, a grid coupling condenser and resistor should be used. This will leave intact the hum filtering properties of the circuit and hum pickup will be kept at a negligible level.

A second type of coupling is illustrated in Fig. 10. This inherently possesses better image rejection and less i-f response ratio than the foregoing.

L_1 = 15 mh.
L_2 = 600 μh. (Case A) & 1500 μh. (Case B)
L_3 = 250 μh.
L_4 = 500 μh.
L_5 = 155 μh.
L_6 = 490 μh.

C_1 = 500 μμf.
C_2 = 200 μμf. (Case A) & 80 μμf. (Case B)
C_3 = 15 μμf.
C_p = 1000 μμf.
R = 50,000 ohms.
I.F. = 460 kc.
C_a = 200 μh.

Table D

Case	*Frequency*	*Image Ratio*	*I.F. Response Ratio*	*Coil Used*	*Signal Gain*
A	600 kc.	2440	1120	L_6	4.5
A	1000	2760	2040	L_5	3.56
A	1400	4500	1030	L_5	1.1
B	600	7850	1540	L_6	11.4
B	1000	2150	800	L_5	3.0
B	1400	9000	370	L_5	1.1

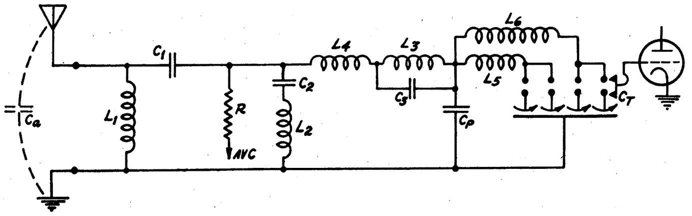

Fig. 10—Antenna Coupling System with Improved Image Ratio.

The use of a coupling condenser C_p in the tank circuit restricts the frequency coverage of the adjustable capacities C_T. This would be especially true if only one tuning inductance (L_5) were used. It would be difficult to cover the low frequency spectrum since C_T would more closely approach C_p in value.

A modification to extend the frequency range is to use two or more tuning coils as shown. C_T may then be made of identical units and the coils L_5 and L_6 connected to the switch segments governing a specific tuning zone.

L_2 and C_2 comprise an i-f wave trap. L_3 and C_3 may be non-adjustable units designed to resonate in the image frequency band, preferably at the frequency of 1400 KC plus twice the i.f., since the high frequency end of the broadcast band usually is in most need of improvement in this regard.

L_4 acts in series with L_3, C_3 to form the primary path. Both L_3 and L_4 may be made one inductance and tuned by C_3, but images occurring at harmonics of the oscillator would not be attenuated to the same degree as they are with a separate coil of low distributed capacity.

Particular emphasis should be placed on the construction of L_3 and L_4 to reduce distributed capacity. A pie-wound solid wire construction will be adequate.

C_1 is a d-c blocking condenser, and L_1 is a hum interference filter.

Measurements were made for two magnitudes of C_2 and L_2 the circuit constants used, and results, are listed in Fig. 10.

The data of Tables B and D may be compared. B is materially better for i-f response ratio while D is superior in image ratio. B has greater frequency coverage with capacity tuning and is the more economical to construct.

Oscillator Stability

It is necessary for continued satisfaction in reception that frequency drift in the oscillator circuit be limited to a very low amount. The maximum tolerable drift is dictated by the receiver selectivity and other electrical properties. A test made on a midget receiver of 15 KC band width for 10 times down in response resulted in most observers claiming that ± 8 KC was the maximum variation which they would accept. A more selective and distortionless receiver would require less than ± 8 KC; in some cases ± 2 KC is considered the maximum allowable.

This imposes limits of reactance changes in component parts which can be met only by materials of the greatest excellence. The selection and combination of oscillator components is one of the most important engineering problems in receiver design.

There are four major causes of drift. These are:

1. Effects of temperature change
2. Effects of humidity change
3. Effects of mechanical jarring
4. Variation in voltage

The first is very serious because the chassis with its attending oscillator circuit components usually goes through a wide temperature change from the moment the receiver is tuned on until several hours have elapsed.

Temperature rises usually produce a lowering of tuned frequency. It is possible to test each component individually to discover the degree of drift for which it is responsible. A device such as a hair dryer may be used to blow a blast of air on the unit under question for such testing.

It has been found that mica trimming condensers are one of the chief sources of drift. Variable inductors of the movable core type are much more stable. Both heat and humidity effects are accentuated by the use of mica trimmers.

Fixed condensers of molded bakelite or paper type are potent sources of drift with temperature. A more recent type, consisting of mica sheets sprayed with silver and hermetically sealed, have unusually stable characteristics, and are considered practically ideal.

Temperature and humidity effects on other components may be reduced after careful observation by the use of good ceramic insulating materials, the proper placement of leads, and the moisture proofing of inductors and other parts.

Effects of mechanical jarring warrant tests for this source of drift.

Variation in voltage will usually not be of sufficient magnitude to produce intolerable frequency shift in the broadcast band.

Where it is desired to reduce this phenomenon to minimum effect, the use of a plate tuned oscillator is a good expedient. Since the grid circuit of an oscillator exhibits the greatest impedance change with voltage and oscillator strength variations, the placing of the tuned circuit in the plate circuit of the tube allows the variations of grid impedance to be transmitted through the relatively ineffective "tickler" coil.

Compensating for Frequency Drift

Temperature effects, after being reduced to a minimum, may be studied to establish that the remaining drift will be uniform in all samples of a specific issue of receivers. When this is found to be true, thermostatic compensation may be used. A reactor, controlled by a thermostat, is placed in a discreet location in the chassis so that temperature changes will have a reverse effect on the added reactor. In this way, temperature effects may be reduced to a minimum.

It is necessary that uniformity of receiver production be maintained to insure a cancellation of drift by the thermostatic compensator.

No humidity compensator has as yet had any commercial acceptance. Precautions to reduce humidity effects are the best expedient.

A type of compensation called automatic frequency control (AFC) is one designed to correct for oscillator frequency variations regardless of cause and to re-tune the oscillator to the correct frequency. This type had considerable popularity in 1937, but is now used in about 1% of the models. It served to show the value of constant frequency namely that push-button tuning is thereby possible, and encouraged the improvement of component parts and technique generally to the point where in many cases, AFC is not necessary.

AFC is a system having two functions: a discriminator to produce a d-c voltage of polarity dictated by the direction of departure from exact tuning, and a control circuit to convert the d-c voltage into an oscillator frequency change to compensate for the original inaccuracy of tuning.

A modification of the original method of using a discriminator tube and control tube has been developed. This is called the "Oscillotrol". It uses no separate control tube but combines in the oscillator the dual function of oscillator and frequency control. The oscillator grid capacitor is made small and the discriminator d-c voltage is applied to the oscillator grid causing changes in grid impedance with resulting frequency shift.

Commercial Exploitation

1937 was the first year of wide commercial exploitation of automatic tuning. Data available on 1100 models marketed between January 1st and August 1st of that year revealed the following figures:

Models using "telephone dial" tuning	12%
Models using motor drive push-buttons	1.8%
Models using mechanical and pre-set circuit push-button tuning	0.84%

This makes a formidable entry of automatic tuning. 1938, over the same number of months, showed a marked increase in push-button tuning, at the expense of "telephone dial" types. Of 730 models analyzed, the following data are pertinent to automatic tuning.:

Models using push-button tuning	34%
Models using remote control	2%
Models having optional remote control	2%
Models using "telephone dial" tuning	less than 1%

The push-button types were divided as follows:

Mechanical push-button tuning	51.8%
Pre-set circuit tuning	31.4%
Motor-drive tuning	16.8%

The pre-set circuit types used various types of adjustable reactors. The types and their proportional use are as follows:

All condenser trimming	50%
Inductance and condenser trimming combined	34%
All inductance trimming	16%

The numbers and location of adjustments are shown below.

Adjustment per station	*Location of Adjustments*		
	Front	*Rear*	*Bottom*
1	36.17%	17.44%	0%
2	17	25.22	0.7
3	0	3.47	0

The popularity of number of push-buttons is indicated by the following list:

Number of buttons	*Percentage of Push-button models*
4	12.8%
5	6.6
6	51.6
7	5.2
8	18.7
9	1.03
10	0.34
12	0.68
13	2.71
20	0.34

While it may be observed that push-button tuning is rapidly assuming monumental proportions, it is well to note that it is largely a supplementary form of tuning, and has not yet shown promise of replacing the usual manual controlled dial. It may be considered a "high speed gear shift" for rapid selection of a few usually desired stations, with manual control retained for a more detailed search of the tuning spectrum.

Minor attempts at commercially exploiting push-buttons or other automatic tuning means as the sole method of tuning have not resulted in any widespread abandonment of the dial. There is an increasing demand for automatic tuning, but as an addition to manual tuning. While reluctance to abandon manual may eventually pass, it might be predicted that this will not happen for years to come.

Some tuning methods which have had laboratory consideration only, but which eventually may be considered as marketable ideas, are "frequency dialing," or dialing two numbers corresponding to the desired station's frequency, and "call letter dialing" in which the letters of the station are individually dialed out, much as a telephone dial works on call numbers. These two have the possible advantage that a sufficiently wide number of stations may be selected to render dual tuning (i.e. manual and automatic) unnecessary.

For the present, the combination of manual and push-button tuning is rapidly gaining predominance over all other methods.

ORGANIZATION OF PLANT IN A CENTRAL RADIO TELEGRAPH OFFICE

By R. E. MATHES*

During the past eighteen years, the point-to-point operations of the RCA organization have expanded from just a few long wave circuits to a system using long waves, short waves and ultra-high frequency relay circuits. Transmitter powers now run the entire range from 75 watts to 200 KW. The use of short waves has enabled the establishment and operation of direct circuits to points all over the globe.

The utilization of such a wide frequency spectrum, directed to so many localities, has necessarily given rise to very complex problems of organization, as well as a variety of equipment and systems. To visualize the problems it may be well to follow a typical message through the system.

A large exporter must know the details of a change in the import regulations laid down by England, before he makes a valuable shipment. He dictates his message over a phone which is connected by private wire to a transcribing operator in our phone room at 66 Broad St. . . . Here it is typed and immediately sent on a high speed conveyor belt to the main operating section. It is numbered as it lands and then handed to the transmitting operator who prepares a perforated tape which he feeds through an automatic "Tape Transmitter." This scans the perforations and produces the desired Continental Code signals. By means of a relay, these signals key an audio tone which is carried by phone line to the radio transmitting station at Rocky Point on Long Island. It is there rectified and caused to key the transmitter. The transmitter—of proper frequency and power for the circuit—feeds a directive antenna set in an appropriate direction.

In England two or three correctly located directive antennae feed separate receivers, the outputs of which are combined to give a diversity effect for the purpose of minimizing fading.[1] The combined signal keys a tone which is conveyed, through one of a group of tone filters, on a phone line to the London Office. It is then rectified and operates an ink recorder that produces the characters of the Continental Code on a paper slip,[2] from which an operator transcribes it on to a message blank. Delivery is then made immediately to the addressee. This entire procedure is usually consummated within 10 or 15 minutes, or even quicker if the addressee has a private line connecting with the London Office. A view of the telephone room is shown in Figure (1), and Figure (2) shows the layout of the operating positions for the major European circuits handling much of the important business of the world.

It is well now to look with more detail at the procedures and

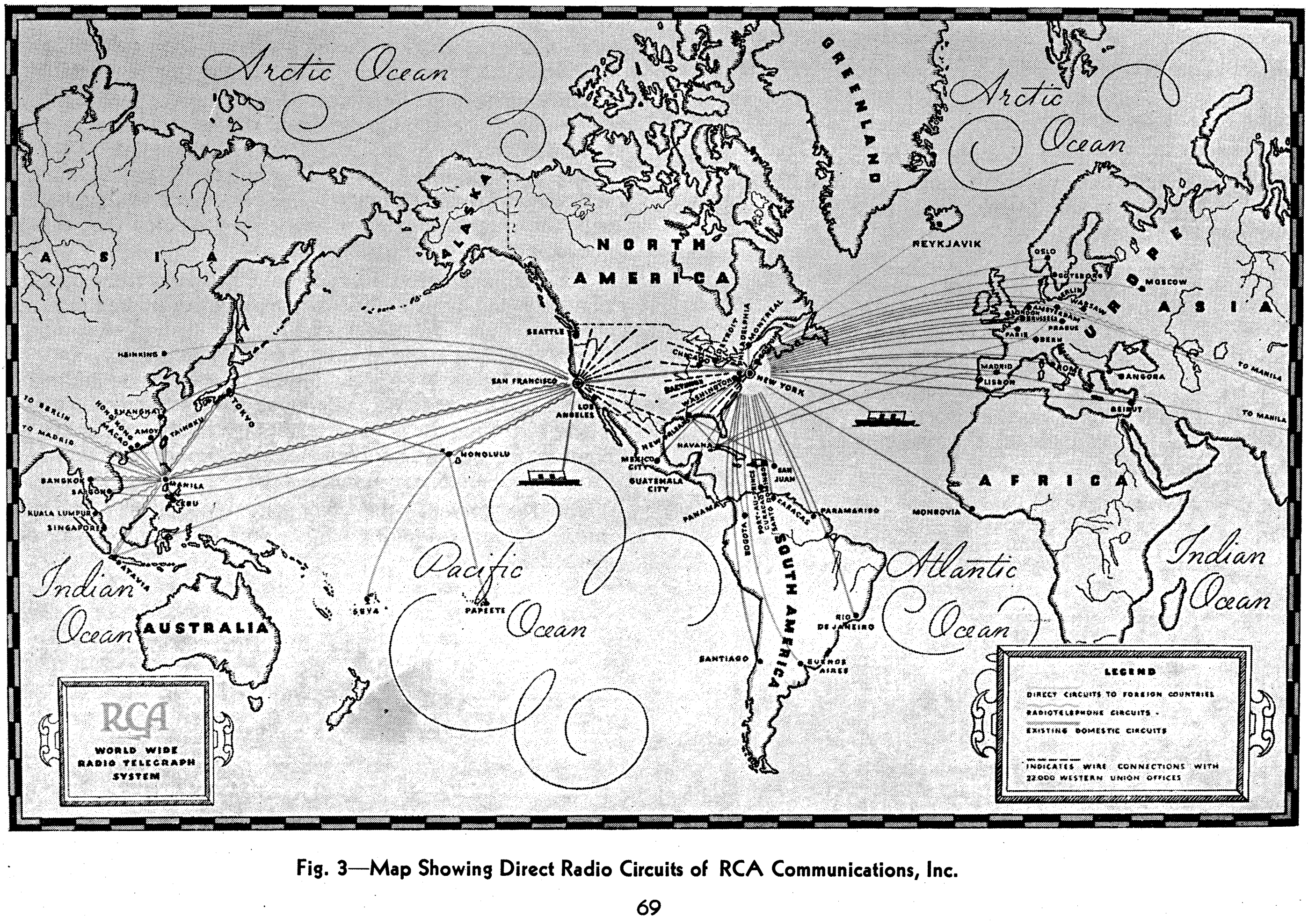

Fig. 3—Map Showing Direct Radio Circuits of RCA Communications, Inc.

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*Central Office Engineering Laboratory, RCA Communications, Inc., N.Y.C.

system through which this message passed so hurriedly and efficiently.

The exporter's phone connection direct to RCA-C is but one of many methods of getting the messages to and from the operating room of RCA-C. It is provided for all types of customers whose volume of Radiogram business is sufficient to justify the maintenance and depreciation charges of this equipment.

Other methods include the old-time Morse wires,—sounder, "tobacco can resonator" and all—connecting RCA-C with many business houses who use this scheme by preference. These Morse wires terminate on the operating floor immediately adjacent to the main operating positions.

Fig. 1—General View of Telephone Room.

In proximity to another side of the main section is a large telephone room with special switchboards, positions and operators to copy down messages received over the phone from customers of all classes throughout New York City, and to deliver messages in like manner. All private telephone lines from the customers' offices terminate in this room. These facilities are arranged so that 20 messages can be copied down or delivered simultaneously. RCA-C will also accept messages by phone from any customers having telephone service in their own names.

Teletype printer connections are provided with the Press Associations, large banks and other business houses. In fact, many customers who use the private line phone for filing messages with us, prefer that we deliver to them by printer instead.

We maintain 11 RCA-C branch offices located at strategic spots throughout New York City. These are all connected to the operating room by Teletype printers terminating in the "Branch Office Printer" section. Each such office, as well as the main Central Radio Office at 66 Broad St., is provided with a staff of messengers who pick up and deliver messages within the area of their respective offices. Regular customers are equipped with call boxes so they may obtain a messenger by merely twisting a knob.

In addition to the above methods, customers may file messages with us through any of the Western Union facilities merely by stipulating "Via RCA." We also use these facilities for all deliveries outside the service areas of our various city and branch offices.

Upon arrival in the CRO, all messages for transmittal are marked with a serial number and with the number of chargeable words in the message. This number is then used throughout the system to keep track of its passage and to guard against loss or delay, as well as to ensure that it will be transmitted in its proper rate class and order of filing. It is then carried to the proper transmitting operator and sent in its order as above described.

Incoming messages, after being transcribed by the operator, are checked off on a serial-number sheet and are carefully scrutinized for apparent correctness. Any occasional letters or words which are the least bit questionable are immediately referred back to the transmitting office for confirmation or correction before such messages are released for delivery, thus safeguarding their accuracy.

Delivery to the customer is effected through the appropriate facilities of the same type as are used for pick-up.

The circuits operated by RCA-C extend from its main offices at New York City and at San Francisco to some 40 different countries throughout the world. In addition, 11 circuits are operated to as many key cities of the United States. All these circuits are indicated on the map of Figure (3).

Some of the circuits are to small countries which have low volumes of traffic and also radiate low quality signals which must be copied aurally. Others are to countries having greater business and better equipment. Ink recorders may be used on these circuits to permit more efficient and rapid operation.

Still other circuits with the major countries or cities have immense volumes of business, some of which is "urgent" traffic, and require the use of several radio circuits operating simultaneously in order to ensure sufficiently expeditious handling of this class of traffic.

The standard equipment on these circuits is, of course, the automatic tape transmitter and the ink recorder. However,

Fig. 2—View of Operating Positions for Major European Circuits.

these circuits have, in the last few years, become so reliable and the signals of such high quality that various types of quasi-automatic machine operations are now being applied to them. These types are comprised of multiplex systems and of printers of various types and in varying combinations to suit the particular case.

As a traffic experiment we are also operating a two-way ultra high frequency circuit between New York and Philadelphia[3],[4] which provides printer operation with Philadelphia, Camden, Baltimore and Washington. The circuits to the latter three are extended from Philadelphia by wire lines.

It is obvious that the operating requirements for all these classes of circuits, coupled with the limitations of radio propagation imposed by such factors as diurnal and seasonal variations, distance and occurrence of abnormal propagation conditions, combine to form a highly complex problem. For reliable operation of a public service in the face of such a problem, it is essential that many frequencies and a highly flexible plant be at the disposal of the traffic supervisors.

For this purpose there is, at the various transmitting stations controlled from the New York office, a combined plant totalling 51 transmitters distributed as follows:

36 transmitters on 60 freqs. at Rocky Point, Long Island
10 transmitters on 14 freqs. at New Brunswick, New Jersey
2 transmitters on 2 freqs. at Tuckerton, New Jersey
3 transmitters on 3 UHF freqs. at 30 Broad St., New York City

The comparable receiving plant comprises:

39 comb. telephone and telegraph shortwave receivers, mostly used in diversity groups of 3, at Riverhead, Long Island.
126 telegraph shortwave receivers, mostly used in diversity groups of 3, also at Riverhead, Long Island.
16 telegraph longwave receivers at Riverhead and
1 UHF receiver at Exchange Place, New York City.[2]

An idea of the vast antenna plant required may be obtained from the Figure (4), which shows a partial view of the antenna field surrounding the main shortwave receiving building at Riverhead.

To properly manipulate such a system, a dispatching center, termed the control room, is provided at one end of the main operating room.[5] Here a control operator, seated at a console, directs the technical operations and controls the equipment in use both in New York and at the outlying stations. He has direct communication with the supervisors at all these stations.

The console is equipped with volume controls and monitor meters on all the incoming signals fed to the standard operating position. Arranged closely around the console are racks containing jacks terminating the incoming and outgoing control lines for the stations as well as jacks to and from the various operating positions in the rooms. Additional jacks on filters, amplifiers, etc., provide full flexibility of equipment as well as assignment of signals to any desired position in the rooms.

Control equipment for the ultra high frequency circuits is also adjacent to the console. Some of the amplifiers are mounted behind it, and the tone filters are in an alley-way just off the control room. The rest of the amplifiers as well as the racks containing the multiplex equipment are in a special room just above the control room.

An extensive system of intercommunicating loud speakers is provided between the console and the various supervisors on the floor, as well as to the multiplex room. Thus the technical operators in the control room can be informed of circuit or signal conditions the instant they affect operations to the slightest degree, without depending upon the necessity of simultaneously watching over 50 monitor indicators. Thus the personnel who must use the facilities for the movement of traffic are responsible for reporting any occurrence which may hinder their operations, and the technical operators are responsible for checking these reports and applying proper remedial measures—either themselves or through the medium of the operating engineers at the stations.

The exact lay-out of this control room is more adequately described in a paper soon to be published.[5]

Besides its main business of point-to-point radiogram service, RCA-C also operates a point-to-point Program Service for interconnecting the American broadcast networks with various international centers. Such business must necessarily be handled on pre-arranged schedules. In doing so satisfactorily, some very interesting results have been obtained in applying present knowledge to the practical prediction of radio propagation conditions. Though not perfect as yet it has been quite generally successful and has been a large factor in the establishment and acceptance of this service. The reliability of such prediction is about 85%.

Another major factor contributing to the success of this service is the careful organization of the programs prior to their transmittal. A 2-way telephone circuit is established between our control office at Broad Street and the foreign point of origin, at least 15 minutes prior to the scheduled broadcast. Time ticks are exchanged, modulation and noise levels checked, exact time of entry of the foreign program into the broadcast network stated, and cues explained to the distant announcer. The network program is fed back to the foreign studio so that the announcer may actually hear the program on the network in this country and get his cue therefrom.

Another special service offered is that of transmitting pictures and facsimile matter by radiophoto. The apparatus and method for this has been previously published.[6] Direct service is now offered between New York and San Francisco, London, Berlin and Beunos Aires with telephoto extensions to many other countries. During the recent European disturbances, news pictures received via this service have been printed in the major newspapers almost daily.

Those who have seen these pictures have probably wondered about the streaks sometimes appearing in them. These are caused mainly by multipath effects and are almost a direct picturization of such phenomena. Development work is, of course, still in progress looking toward elimination of these streaks.

Because we use so many radio channels it is necessary that we take more than ordinary precautions to maintain all of our transmitters within legal limits of their assigned frequencies. For this purpose, we have provided two special frequency measuring laboratories,[7] one at Riverhead and the other at Point Reyes, Cal. These stations are equipped to measure transmitter frequencies to within 0.0003% at 20 MC against a standard frequency source having a constancy of better than 1 part per million. They can also measure any parasitic or other spurious emanations. These measurements were of such great value to our own operations that we now offer it as a public service to all stations. Broadcasting stations all over the country regularly avail themselves of it.

Facilities of generally similar type to those above described are also provided on the West Coast for operation of Trans-Pacific circuits.

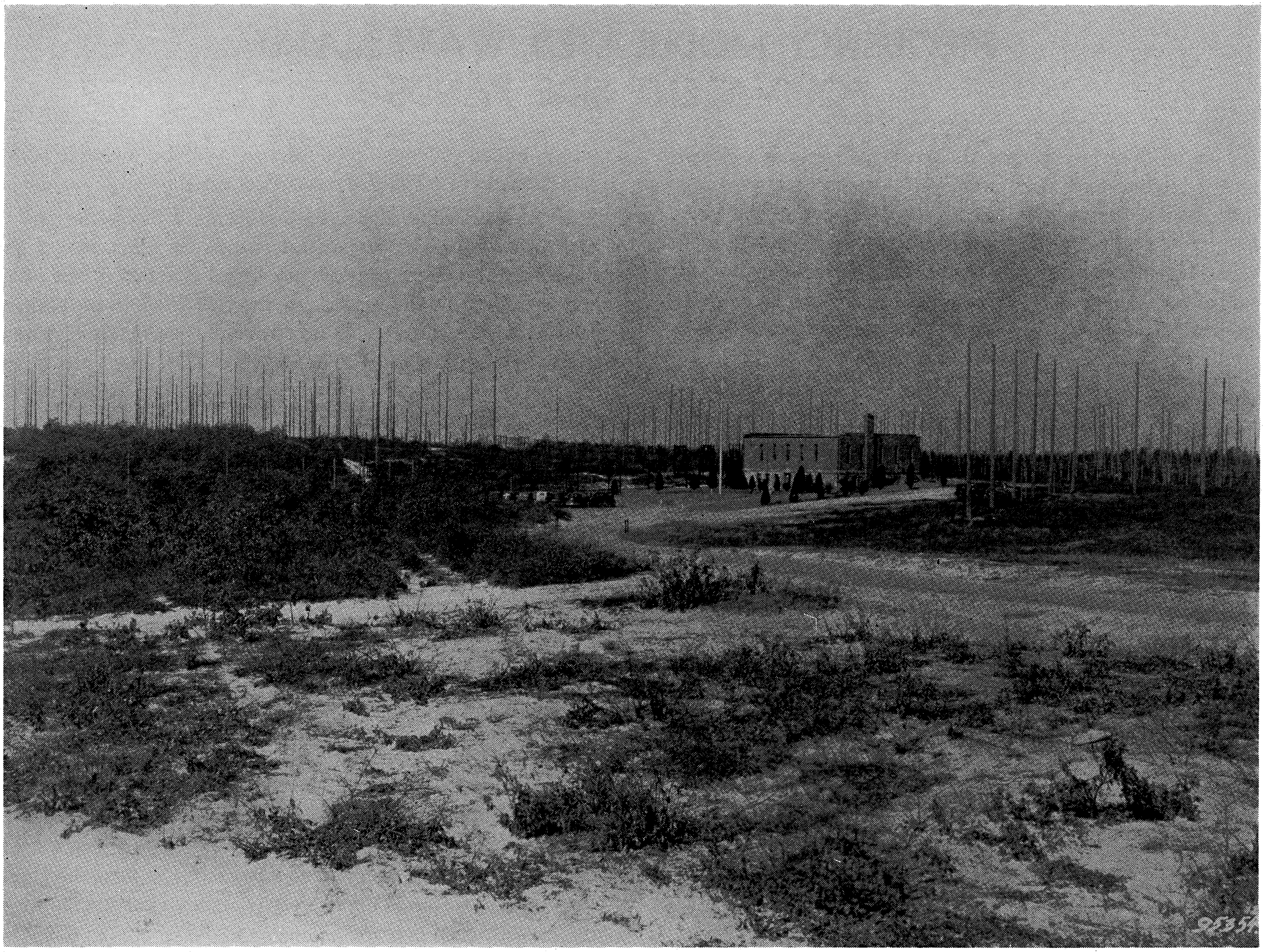

Fig. 4—General View of Receiving Station and Antenna Field.

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FREQUENCY MODULATED WAVES AND EQUIVALENT SIDE BANDS

In order that the concepts, the analytical methods and design practices which have been developed in connection with amplitude modulation may be directly applied to the problems of frequency modulation it is highly desirable to have available a simple method by which the characteristics of a frequency modulated wave may be expressed, as in the case of amplitude modulated waves, in terms of carrier and side bands. Such a method is available and is here pointed out.

Basically, it is the result of the fact that analysis shows that any phase or frequency modulated wave may be expressed as a series of side bands and a carrier and so treated in the design of apparatus and the solution of other problems to be faced in this relatively new art. While the basic analysis shows that for complete equivalence of a frequency modulated wave a carrier and an infinite number of side bands all separated from one another by the modulating frequency is required, under practical conditions only a portion of these side bands need be considered and the problem of dealing with the frequency modulated wave is thus reduced to not much more than would be involved in the case of the transmission by amplitude modulation in which a tone rich in harmonics is involved.

There remains, then, only the determination of the amplitudes of the several side bands. Here again analysis results in an infinite series in the expression of the amplitude of each side band. Happily, however, this type of series has long since been recognized as of general importance, and tables of its values prepared under the title of Bessel's Functions. Such a table provides all that is essential for expressing the frequency modulated wave as an equivalent carrier and side bands. To further simply this process and to encourage the use of the method there is given a graph of Bessel's Functions, prepared by Mr. M. G. Crosby and here published with his permission, which under ordinary circumstances will be found a useful substitute for a table of Bessel's Functions.

More specifically, then, the amplitude of the carrier and of each pair of the symmetrical side bands on either side of the carrier is given by a value of the Bessel function of the order corresponding to the number of the side band in its position relative to the carrier. Thus, the amplitude of the carrier is given by the zero order function, J_o. The amplitude of the side bands immediately adjacent to the carrier is given by the first order function, J_1; the next by the J_2, etc.

The values of the zero to the tenth order of Bessel functions are given in Mr. Crosby's graph. These have been plotted against the ratio of the peak frequency deviation i.e. one half of the total frequency swing employed in the process of frequency modulation, to the modulating frequency, i.e., $\frac{f_d}{f_m}$ as the argument, X.

To use the graph it is only necessary to know, first, the deviation of frequency which constitutes the frequency modulation and, second, the modulating frequency. From these the ratio or argument, X, may then by computed. With this and by reference to the graph the value of the amplitude of any side band may then be taken directly by reference to that one of the several curves labelled by the J of such a subscript as corresponds to the number of the side bands of interest.

The value of the function so determined is then the amplitude of the side band of interest relative to the amplitude of the unmodulated carrier.

It is hoped that the compact form in which Mr. Crosby has presented this material will not only encourage the use of Bessel's functions for this and other purposes but will encourage the study of the many interesting and important problems of frequency modulation.

BESSEL FUNCTIONS
FOR THE
FIRST TEN ORDERS

M. G. CROSBY

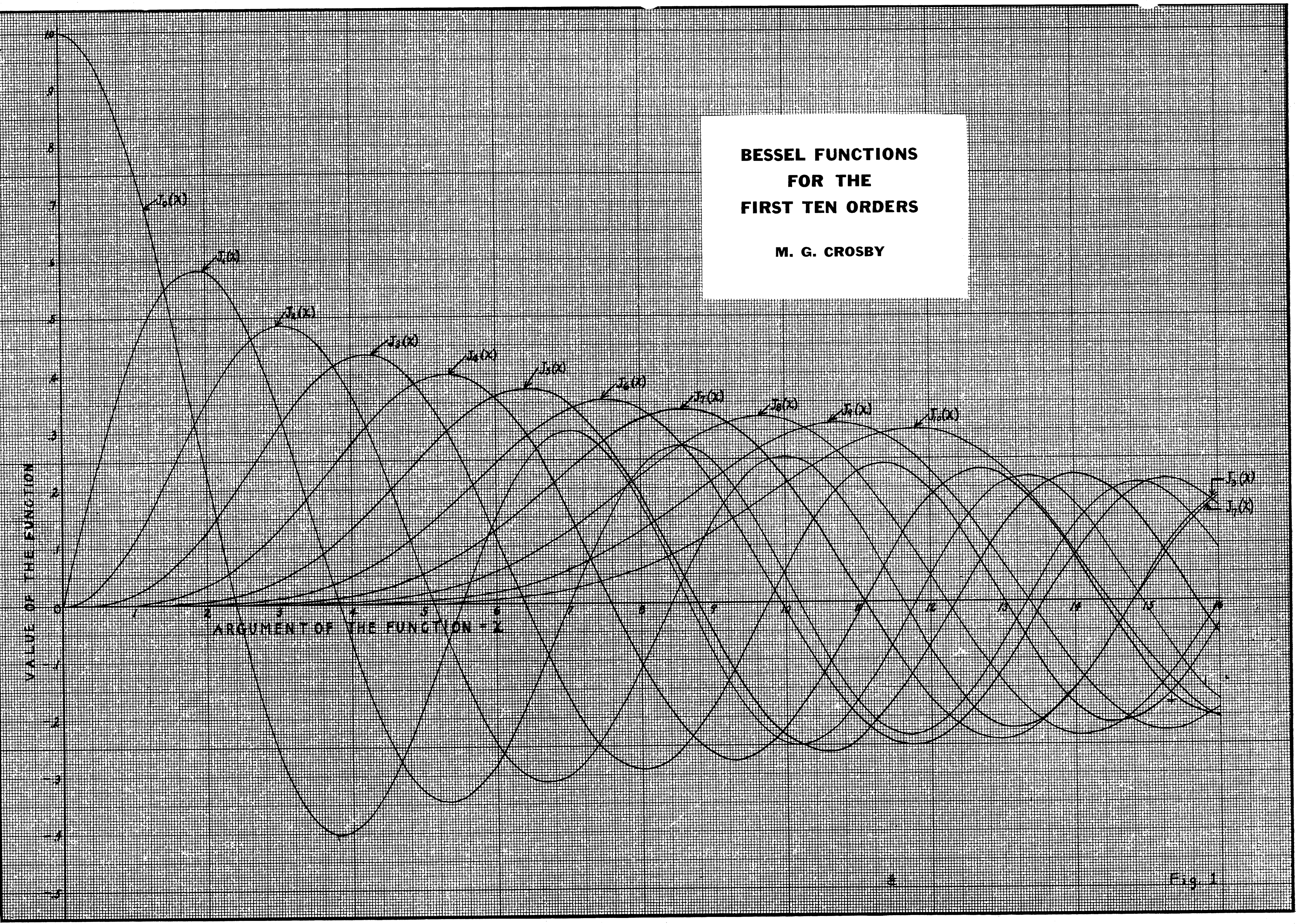

Fig. 1