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LB-933

MEASUREMENT OF SWEEP AND VIDEO CIRCUIT INTERFERENCE INFLUENCE OF TELEVISION RECEIVERS ON AM RECEIVERS

RADIO CORPORATION OF AMERICA
RCA LABORATORIES DIVISION
INDUSTRY SERVICE LABORATORY

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Approved

Stuart W. Seeley.

Measurement of Sweep and Video Circuit Interference Influence of Television Receivers on AM Receivers

Introduction

The Institute of Radio Engineers has drafted in tentative form a new Test Standard, "53 IRE 17.4 PS1, Methods of Measurement of Sweep Circuit Interference Influence of Television Receivers in the Range of 300 to 10,000 kc", which is based in considerable part on techniques developed and reduced to practice by the Industry Service Laboratory at Princeton, N.J. Enough experience in the use of the tentatively-standardized test methods and the ISL facilities has been accumulated to demonstrate the utility of both, so that it is now possible to present a reasonably comprehensive report on the subject.

The first portion of this bulletin is devoted to an examination of coupling characteristics of AM and television receivers, factors which prescribe the kinds of tests providing the most useful information about the television receiver, and how the test data can be related in at least a quasi-quantitative way to expected field experience. This is followed by a description of the ISL-Princeton test setup, featuring panoramic display of the interference magnitude. Suggestions on interference reduction methods conclude the main discourse. Setup calibration descriptions and data on major design features of the panoramic receiver are appended.

SECTION I. RECEIVER CHARACTERISTICS AND COUPLING MODES

Interference Susceptibility of AM Receivers

The loop-to-ground capacitance of a power-line-operated AM broadcast receiver, together with the loop itself and the power line as a ground return, comprise an incidental auxiliary antenna circuit. Thus, the receiver will respond not only to an r-f magnetic field, but will also respond to an r-f electric field. More significantly, it will respond to a signal introduced at a more or less remote point between ground and the power-circuit conductors considered as one. (This will be called the push-push power-line conduction and receiver coupling mode. Other designations often used are *asymmetrical, unbalanced.*) The typical receiver will also respond in some measure to signals (usually interference) propagating between power-line conductors. (Push-pull mode. Also called *symmetrical, balanced.*) Power-line-to-receiver couplings of both types are illustrated in Fig. 1.

If the sensitivity of the AM receiver to line-conducted interference is defined as the r-f voltage input to the power cord required for a standard output, and the desired-signal sensitivity (in the manner up to now conventional) as the field strength in volts-per-meter of r-f magnetic flux, coupled to the loop, required for standard output, then the

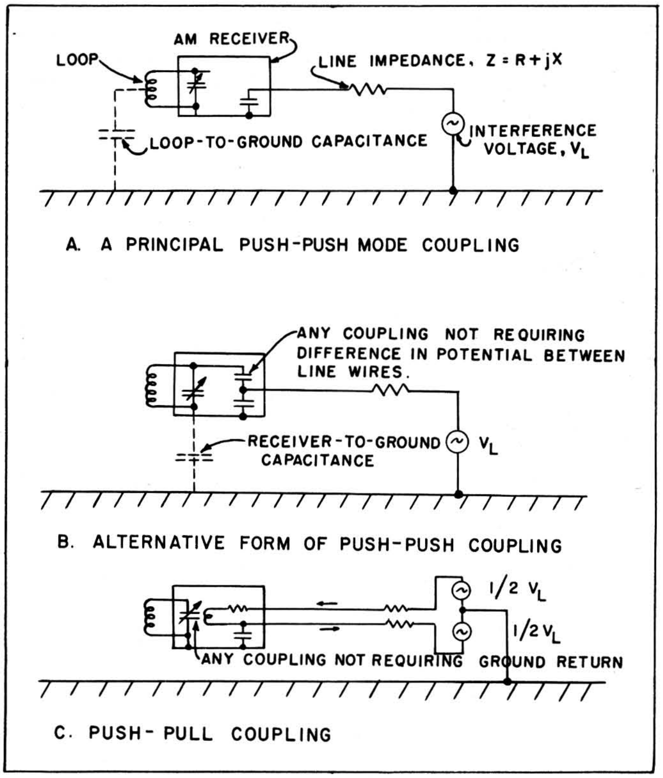


Fig. 1 - AM receiver incidental input modes.

measure of the receiver susceptibility to line-conducted interference is the ratio of line interference-input volts divided by volts-per-meter of desired signal. So expressed, a high ratio indicates low susceptibility. Table I gives such data on two representative table-model receivers, one employing an air-core loop, the other a ferrite-core loop. As might be expected, the ferrite-core-loop receiver has the lower susceptibility to push-push input (it has lower loop-to-ground capacitance), and the power-circuit impedance makes negligible difference in the push-push case (it appears in series with the high impedance of the loop and of the loop-to-ground capacitance), but the line impedance materially affects response to push-pull input (the line is shunted by circuit elements within the receiver).

Continuing on the same basis, the susceptibility ratio of either receiver with respect to an interfering magnetic induction field oriented through the loop is inevitably unity. No analytically useful definition of a receiver's susceptibility to an electric induction field is possible, although it is related to the push-push line susceptibility.

Reference of susceptibility ratios to the magnetic sensitivity of power-line-operated receivers has the merit only of conformance to present practice. The usual AM broadcast receiver receives signal as well as interference via the power line. In Fig. 1a or 1b, if V_L is taken as representing the product of signal field strength and effective height (as an

Table I

AM Receiver Susceptibility Ratios

Line Impedance	Frequency, Kc	V_L/E_M			
		Push-Push		Push-Pull	
		air-core loop rec.	ferrite-core loop rec.	air-core loop rec.	ferrite-core loop rec.
6 ohms	600	1.8	3.3	18.0	5.4
	1000	1.1	2.3	2.3	2.9
	1500	.8	1.5	1.0	5.5
600 ohms	600	1.9	3.7	67	11
	1000	1.1	2.4	56	13
	1500	.8	1.5	32	15

E_M = Signal field strength in microvolts-per-meter required for standard output.

V_L = Input to power cord in microvolts required for standard output.

Note: A high ratio of V_L/E_M indicates low susceptibility to power-line-conducted interference.

antenna) of the power distribution system at the receiver in the push-push mode, it can be seen from data in Table I that response to signal input from the line will usually exceed magnetic response of the loop. Susceptibility ratios measured like those given in Table I are therefore too pessimistic, but their temporary acceptance as valid at least places one on the safe side of error. The Institute of Radio Engineers is currently developing new AM receiver sensitivity test standards which should make more accurate susceptibility definitions possible.

It is evident that use of electrostatically shielded loops and elimination of internal couplings between receiver input and power circuits would greatly reduce the susceptibility of line-operated AM broadcast receivers to line-conducted interference, but that this benefit would be accompanied by a significant reduction in signal sensitivity as well as a possibly undesirable radical increase in directivity of reception.

Interference Sources and Characteristics

Television receiver sweep circuit interference outputs are all harmonics of the line repetition frequency, nominally 15.75 kc. As a rule the sweep outputs are not modulated. Fig. 2 shows a typical distribution with respect to frequency of the harmonic amplitudes. The peaks of vertical displacement of the trace are proportional to the intensity of the receiver's electric induction field at the successive sweep harmonics. The frequency resolution capability of the apparatus used to produce this display is less than would be required to show the harmonics as separated spikes, but it is adequate to show their true relative amplitudes. Major maxima such as are evident in the oscillogram occur at frequency intervals dependent upon retrace time and other resonance effects in the horizontal deflection circuit; 100-110 kc is typical.

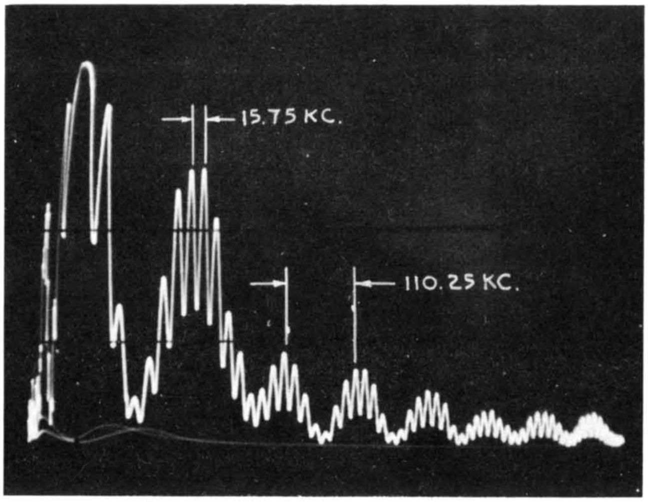


Fig. 2 - Oscillogram of sweep harmonics.

A second LF-MF interference source which may be of some importance is the receiver's video circuit. This interference also peaks up at harmonics of the line-scan frequency. The harmonics are modulated by changing picture content and are accompanied by noise of random frequency composition. Video interference is 60-cycle modulated by the vertical blanking, its distinguishing characteristic, along with variability, in AM reception. In and above the broadcast band, its time-averaged distribution with respect to frequency appears to follow the amplitude response characteristic of the receiver's i-f and v-f sections. Some receivers exhibit a strong intercarrier beat at 4.5 Mc. Interference in the television receiver, such as oscillator radiation from another television receiver, which produces a pattern overlay on the picture, also shows up as a high output in the video interference spectrum.

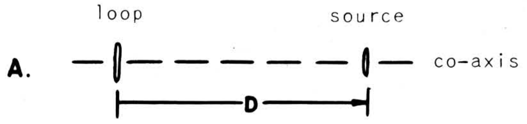
The vertical deflection circuit produces no significant interference. The foregoing sources are the only ones which are presently found to have practical importance at AM broadcast frequencies.

The presence of color information in the received video signal increases the video spectrum energy and frequency content but this increase in interference potential is merely one of degree. However, in color receivers receiving color pictures, the color subcarrier oscillator represents a new potential source of interference at its fundamental and harmonic frequencies.

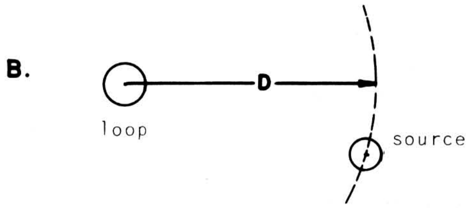
Television to AM Receiver Coupling

Radiation from the television receiver sweep and video circuits is, in general, an insignificant coupling mechanism at broadcast and lower frequencies compared to three other coupling modes:

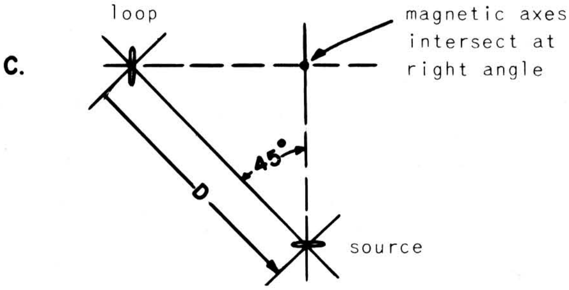
(1) The magnetic induction fields of the yoke and horizontal output transformer will couple to a nearby AM receiver loop. These magnetic field sources have elementary dipole characteristics. For distances up to at least 0.05 wavelength (30 feet at the high-frequency end of the broadcast band) the free-space field strength in any direction from the source can be expected to dwindle as the inverse of distance cubed. This rate of diminution is so rapid that the magnetic fields produced by sweep-circuit components of present-day receivers are perhaps of practical consequence only on a room-to-room or next-apartment basis. Fig. 3 shows the relative coupling coefficients between an elementary magnetic dipole and vertically polarized loop for three orientations of maximized response. The loop represents that of an AM broadcast receiver. The source may be considered to represent a vertically-polarized horizontal-output transformer in Fig. 3a and 3b, and either the horizontal-deflection coils of a yoke or a horizontally or vertically-polarized output transformer in Fig. 3c, but the source is arbitrarily assigned the same value in all cases. It is of interest to note that the coupling between a horizontally-polarized source and vertically-polarized loop (Fig. 3c) can be as much as three-fourths of the maximum possible coupling at the same distance (Fig. 3a). The average coupling for completely random relative orientation of source and loop is 0.28 times the coaxial value at the same distance. This may be used as the coupling probability factor.



A. Co-axial orientation. Coupling coefficient = maximum possible at distance D. Assigned relative coefficient = 1.0.



B. Co-planar orientation. Relative coupling coefficient = 0.5.



C. Mutually perpendicular orientation. Relative coupling coefficient = 0.75. Source loci are circles of radius $D/\sqrt{2}$ in vertical planes $D/\sqrt{2}$ to left and to right of loop plane.

Note: A, B, and C are maximized-response orientations. The distance D, the source diameter, and the loop diameter are common to all cases. D is small with respect to wavelength, but several times the source and loop diameters. The average relative coupling coefficient for completely random relative orientation at distance D is 0.28 times the co-axial value. The locus of random coupling is a sphere of radius D with the loop at the center, with the source assuming every possible orientation in each element of the surface of the sphere.

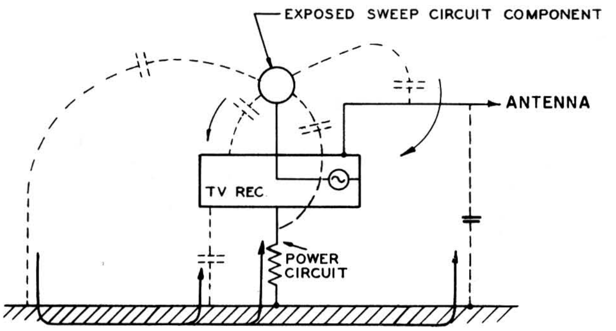
Fig. 3 - Magnetic dipole-to-loop coupling.

(2) Various components of the sweep and video circuits bearing interference voltages usually are imperfectly shielded, and therefore produce an induction electric field. See Fig. 4a. The near-by rate of decrease of intensity of this field would also conform essentially to a $1/D^3$ law were it not for connections from the receiver chassis to an antenna and power line. Portions of the capacitances of the unshielded circuit elements are to ground, to power line, and to antenna. Displacement currents flow through these capacitances and return to chassis via the antenna and power leads. Since these current paths are not necessarily short with respect to wavelength at broadcast frequencies, the electric field intensity declines generally at some rate other than $1/D^3$ at all distances. Furthermore, some portion of the energy thus introduced on the power circui

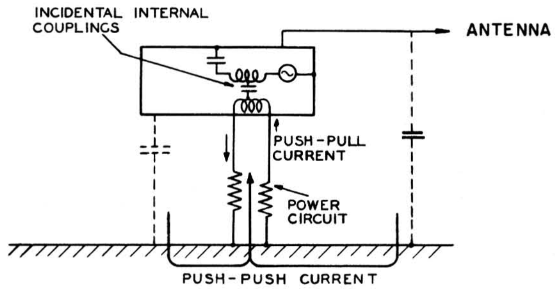
may be conducted or propagated to distances beyond the effective "reach" of either the induction magnetic or electric field, and so interfere with reception in the manner illustrated in Fig. 1. This would be purely a push-push coupling if the impedances to ground of the two line conductors were identical throughout.

(3) The power line may also be, and frequently is, energized with sweep harmonics by couplings within the television receiver chassis. These couplings are usually some combination of push-push and push-pull, the latter usually predominating. See Fig. 4b. Push-pull input to the power line is not affected by other connections to the receiver, but push-push input of the Fig. 4b kind is greatly accentuated by connecting a grounded antenna or one which is series-resonant at the frequency involved. Such an antenna provides a low-impedance connection from chassis to ground as compared to the impedance through the chassis-to-ground capacitance. When the coupling to the line is from a within-the-chassis source, the sweep harmonic outputs are sometimes amplitude modulated at a 120-cycle rate by the B supply rectifiers. This effect is most pronounced at low frequencies (below the broadcast band) and is always largely if not entirely confined to push-pull line input.

Upon entering an AM receiver, one or another of the sweep harmonics beats at an audible frequency, although not necessarily at significant amplitude, with every broadcast signal carrier. The greatest possible separation of a signal from the nearest harmonic being 15.75/2 kc, on the average half the available signals will suffer an interference within the pass band of the usual AM receiver, and also within the range of high auditory sensitivity. Television broadcasters sometimes synchronize their sweeps with the power system rather than with a crystal. Power frequencies are held to good accuracy on the average, but are prone to deviate to appreciable fractions of a per cent from the mean. This discounts the possibility of counting certain signals interference-free as a result of an advantageous frequency relationship.



A. ELECTRIC INDUCTION FIELD AND PUSH-PUSH POWER LINE EXCITATION. DISPLACEMENT CURRENT PATHS SHOWN BY ARROWS.



B. PUSH-PUSH AND PUSH-PULL CURRENTS FROM INTERNAL-TO-CHASSIS COUPLING.

Fig. 4 - TV receiver-to-power-line coupling.

Interference Evaluation

The amount of interference produced can be defined as the amplitude ratio of the sweep harmonic to the AM station carrier at the AM receiver detector. What constitutes just tolerable interference is a matter of individual taste. An instructive idea of the beat ratio which a listener considers border-line in annoyance value can be obtained by a simple experiment. A broadcast receiver is tuned to an interference-free program. An unmodulated standard signal generator connected to a local field source, such as a small loop, is placed near-by, and tuned to interfere. The signal generator output is increased from a low value to the point of loudest beat with the station signal. The signal ratio at the receiver detector is then unity. The generator output is then reduced to a level which the listener considers produces the maximum tolerable interference. Several programs and beat note frequencies should be tried. From the literature on radio noise interference it appears that the interference threshold for appliance and power-

Table II

Sweep Interference Outputs of a 17-inch Television Receiver

(1) Power line input in push-push mode, 25 ohm line.

Har.	Kc	µv	Har.	Kc	µv	Har.	Kc	µv
5	78.75	4000	38		210	71		220
6		3200	39		290	72		220
7		2100	40	630	400	73		220
8		700	41		440	74		220
9		1100	42		430	75	1181.25	230
10	157.5	2200	43		350	76		230
11		2900	44		230	77		230
12		3200	45	708.75	145	78		230
13		3000	46		200	79		220
14		2300	47		290	80	1260	220
15	236.25	1400	48		340	81		230
16		560	49		350	82		230
17		350	50	787.5	300	83		230
18		1000	51		230	84		230
19		1050	52		160	85	1338.75	220
20	315	1000	53		170	86		210
21		850	54		240	87		200
22		500	55	866.25	290	88		180
23		200	56		310	89		160
24		300	57		290	90	1417.5	140
25	393.75	550	58		250	91		120
26		680	59		200	92		105
27		660	60	945	190	93		85
28		530	61		210	94		80
29		330	62		230	95	1496.25	75
30	472.5	200	63		250	96		70
31		260	64		250	97		64
32		400	65	1023.75	240	98		57
33		460	66		230	99		55
34		540	67		220	100	1575	54
35	551.25	500	68		230	101		50
36		400	69		230	102		48
37		280	70	1102.5	230	103		48

(2) Power line input in push-pull mode, 100 ohm line. (Highest value harmonics only.)

Har.	Kc	µv	Har.	Kc	µv	Har.	Kc	µv
5	78.75	8400	34	535.25	540	62	976.5	230
12	189	7600	41	645.75	400	82	1291.5	140
19	299.25	2500	48	756	480	98	1543.5	105
26	409.5	1100	55	866.25	380			

(3) Free space field intensity of vertically polarized component of receiver's magnetic induction field at 15 feet. (Highest value harmonics in broadcast band.)

Har.	Kc	µv/m
34	535.75	22
43	677.25	19
55	866.25	12
75	1181.25	8

system noise is usually placed at the equivalent of 1 to 3 per cent modulation. This contrasts with 1/3 per cent modulation (noise) allowed by AM broadcasting standards in the transmitted signal. As a basis for further discussion, 2 per cent of signal carrier will be used as the zero level for beat-note interference.

Not enough is known about r-f propagating characteristics of power distribution systems to permit making an accurate estimate of either maximum or average interference probability, but a "guesstimate" may be made along the following lines:

Table II gives broadcast-band sweep harmonic voltages introduced in the push-push mode on a 25 ohms-to-ground power circuit (the impedance specified in the tentative IRE standard) by a representative 17-inch table-model television receiver. From Table I it can be observed that the desired-signal field intensity required by a current-model ferrite-core-loop AM receiver to reduce the interference to the equivalent of 2 per cent modulation varies from 15 times the power-circuit interference voltage at 600 kc to 33 times the interference voltage at 1500 kc. Signals having field intensities ranging up to 2.5 - 6 millivolts-per-meter might therefore suffer interference when these receivers are operated from a common *idealized 25-ohm power line*. The air-core-loop receiver interference levels would be twice as high. In comparison, AM broadcasting primary service field intensity minimum requirements are given as 0.1-1 millivolts-per-meter, country, 2-50 millivolts-per-meter, city.

Table II also shows that for magnetic induction interference, in the low, middle, and high regions of the broadcast band, signal field strengths of up to 1.1 millivolts-per-meter would be required to avoid 2 per cent interference at a 15-foot separation and the most disadvantageous relative orientation of receivers (as in Fig. 3a), with no contribution from a common power circuit and no electric field coupling. Separations as small as 15 feet might be encountered in apartments, closely-spaced houses, etc.

No comparable estimation is practicable of level of interference resulting from direct exposure of the AM receiver to the television receiver electric induction field. The strength of this field is related to the push-push power line input. The coupling depends upon receiver heights above ground and other environmental intangibles. If the television and AM receivers were operated within the *same house*, it can be shown that direct electrostatic coupling might entail greater interference transfer than connection to a common *25-ohm* power line, but the power-line coupling introduces propagating potentialities and thus provides a more realistic basis for evaluation of interference probabilities in the more general case where the receivers are in neighboring houses served by the same power circuit.

Thus, certain kinds of measurements which can be made on a television receiver will provide data capable of being correlated in at least a quasi-quantitative way to AM broadcast interference. The measurements are those of r-f magnetic field intensity in the vicinity of the television receiver, and of r-f voltage input to the power line. These are the measurements tentatively standardized by the IRE. It can be confidently expected that receivers having lowest interference output according to the IRE tests will produce least interference in service.

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SECTION II. TEST SETUP AND PROCEDURE

The ISL-Princeton Setup

The ISL test setup at Princeton incorporates the functional elements called for in the IRE tentative standard. Figs. 5 and 6 show the apparatus installed in the screen room. In Fig. 7, the position shown for the field source is the specified location of the television receiver yoke.

The ISL screen room has interior dimensions of 8 feet high x 8½ feet wide x 11½ feet long. It is of typical double-walled construction and is equipped with the customary power-line entrance filter.

The rotatable stand (Fig. 5) required for receiver orientation in magnetic induction tests is similar to the one described in LB-802, *Open-Field Test Facilities for Measurement of Incidental Receiver Radiation*, except somewhat smaller.

The stationary "hub" around which the turntable base revolves contains the socket portion of a 5-contact tube-socket-type connector, and two 1.0-µf capacitors used to bypass the power-line isolating chokes at the power input end. (See schematic, Fig. 11) The a-c line and two 50-ohm coaxial r-f lines enter the hub at floor level, and connect to the socket terminals. The lines lie on the floor, in a metal conduit for mechanical protection, and are accommodated under the "ball-bearing" by a slot in the lower plywood ring, visible on the floor in Fig. 5.

The power-line impedance unit can be seen just above the turn-table base, plugged into the socket recessed down into the hub. This unit is a 1/16-inch wall copper box, 5½ x 11 x 11 inches in size, with a center partition soldered in, enclosing two r-f chokes connecting the a-c circuit in the lower plug to the television receiver outlet on top. The chokes are two-layer "bank" windings of No. 18 s.s.e. wire, 350 turns each, wound on 1½-inch o.d. bakelite tubes threaded 22 turns per inch. The design criteria for these chokes were (a) sufficiently low series resistance, (b) shunt capacitive reactance high in comparison to 50 ohms at 4.5 Mc, (c) inductive reactance high in comparison to 50 ohms at 75 kc, and (d) negligible mutual coupling. The design described provides an acceptable balance among the conflicting factors. Coupling condensers (0.22-µf) and short sections of 50-ohm coaxial line connect the receiver a-c outlet to the lower plug, whence the 50-ohm lines previously mentioned connect to the 50-ohm load resistances and the input selector switch within the panoramic receiver.

Details of the structure for supporting the receiver under test are visible in Fig. 5. The board upon which the receiver rests is adjustable for height in 3-inch increments, so that the receiver yoke center can be raised to the specified height, one-half way between floor and ceiling. The receiver support and turntable assembly is bolted together so as to be easily knocked down, removed, and later reinstalled.

A television signal coupling transformer and antenna grounding switch are located on the ceiling directly above the turntable center. This unit resembles that illustrated in the IRE standard. No high or band-pass filter is needed with this transformer to exclude AM broadcast signals at Princeton, N. J. The adjustable-height line supports clip onto one of the 2-by-4 uprights of the receiver support structure (see Fig. 5).

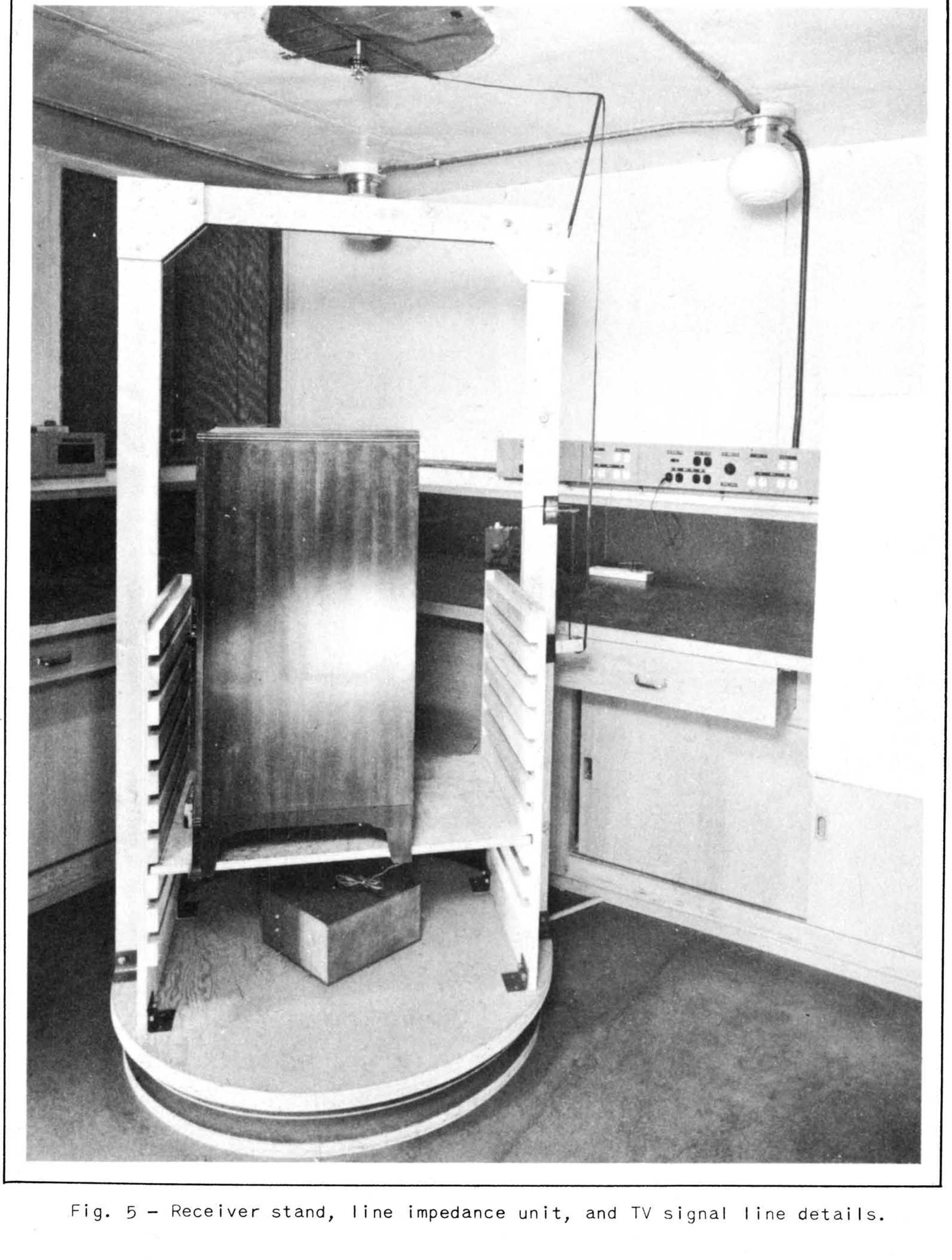

Fig. 5 – Receiver stand, line impedance unit, and TV signal line details.

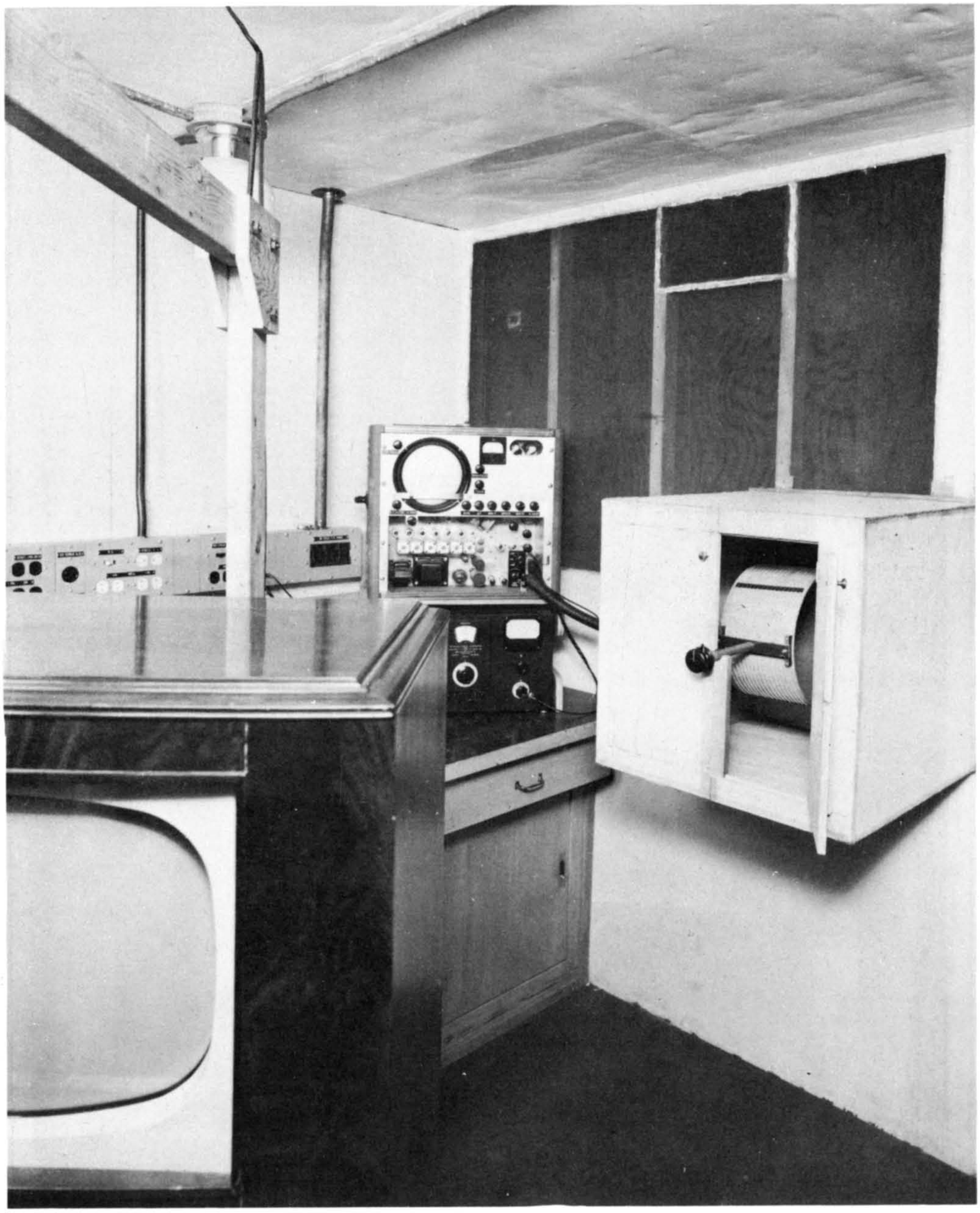

Fig. 6 – Apparatus arrangement and loop details.

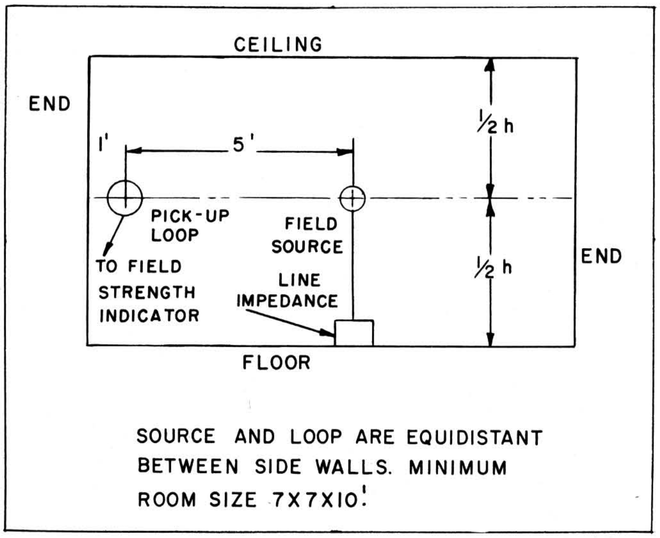

Fig. 7 - IRE standard room arrangement.

The Panoramic Receiver

The panoramic receiver (to be abbreviated PR) shown in Figs. 8 to 11, was designed for the one specific job of measuring television receiver interference outputs. While a commercial field intensity meter can be used for the IRE tests, it was anticipated that a considerable volume of receiver testing might have to be handled at ISL. A dynamic presentation of the spectrum of interference provides the most expeditious means of selecting frequencies appropriate for measurements, and instantly supplies a comprehensive answer to the "better, worse, or unchanged" question occurring during experimentation on receivers. The PR is used in conjunction with a standard signal generator having motor-driven tuning. The generator serves as a frequency marker and input calibrator. Present discussion concerning the PR will be limited to operational features. Additional data concerning its major design characteristics are provided in Appendix B.

The PR is shown in block diagram form in Fig. 10.

The principal operating controls are:

a. Input Selector. This switch has eight positions:

(1) Loop, tuned.
(2) Loop, untuned.
(3) Loop calibration. This connects the signal generator to the input amplifier grid.
(4) Line input calibration. Functionally like (3).
(5) Input from line conductor "A" (arbitrary designation) measured to ground.
(6) Input from line conductor "B" measured to ground.
(7) Line input in push-push mode (A and B in parallel).
(8) Line input in push-pull mode (A and B in series).

b. Loop tuning. This is a manually-tuned variable condenser.

c. MIN-F. This sets the low frequency limit of frequency sweep, substantially independent of sweep width.

d. Δ-F. This sets the sweep width, substantially independent of setting of 3, except that the upper limit of sweep does not exceed about 4.7 Mc for any combination of settings of 3 and 4.

e. Gain (i-f). This controls vertical deflection of the oscilloscope.

Measurement Procedure

Only one measurement will be fully described, as the procedure varies only in minor detail. Assume that measurements of interference input to one of the two line conductors are to be made in the broadcast band, in the low, middle and high frequency regions. The following operations are performed.

1. The a-c line input to the television receiver is set at 117 volts.
2. The PR Input Selector is turned to Line Cal.
3. The PR MIN-F and Δ-F controls are set for wide range of sweep.
4. The signal generator (SG) is tuned to 540 kc and its output is increased to such a high value that overload of the PR converter tube manufactures visible harmonics at 1080, 1620, etc. kc, in addition to the fundamental indication at 540 kc.
5. The PR sweep range is narrowed to bracket the broadcast band, i.e., the 540 and 1620 kc responses.
6. The PR Input Selector is turned to

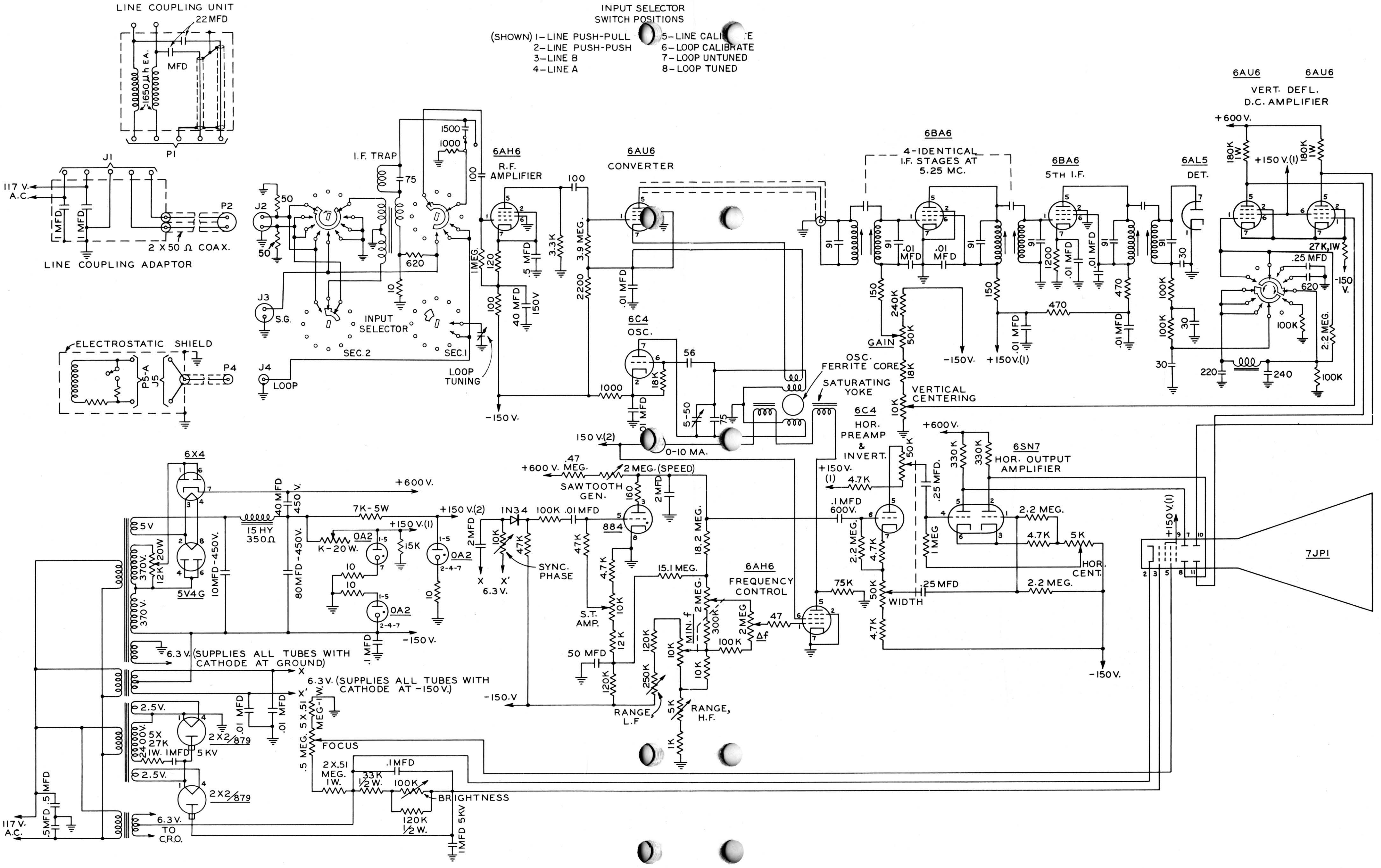

Fig. 11 - Schematic of 75 kc to 4.5 Mc panoramic receiver.

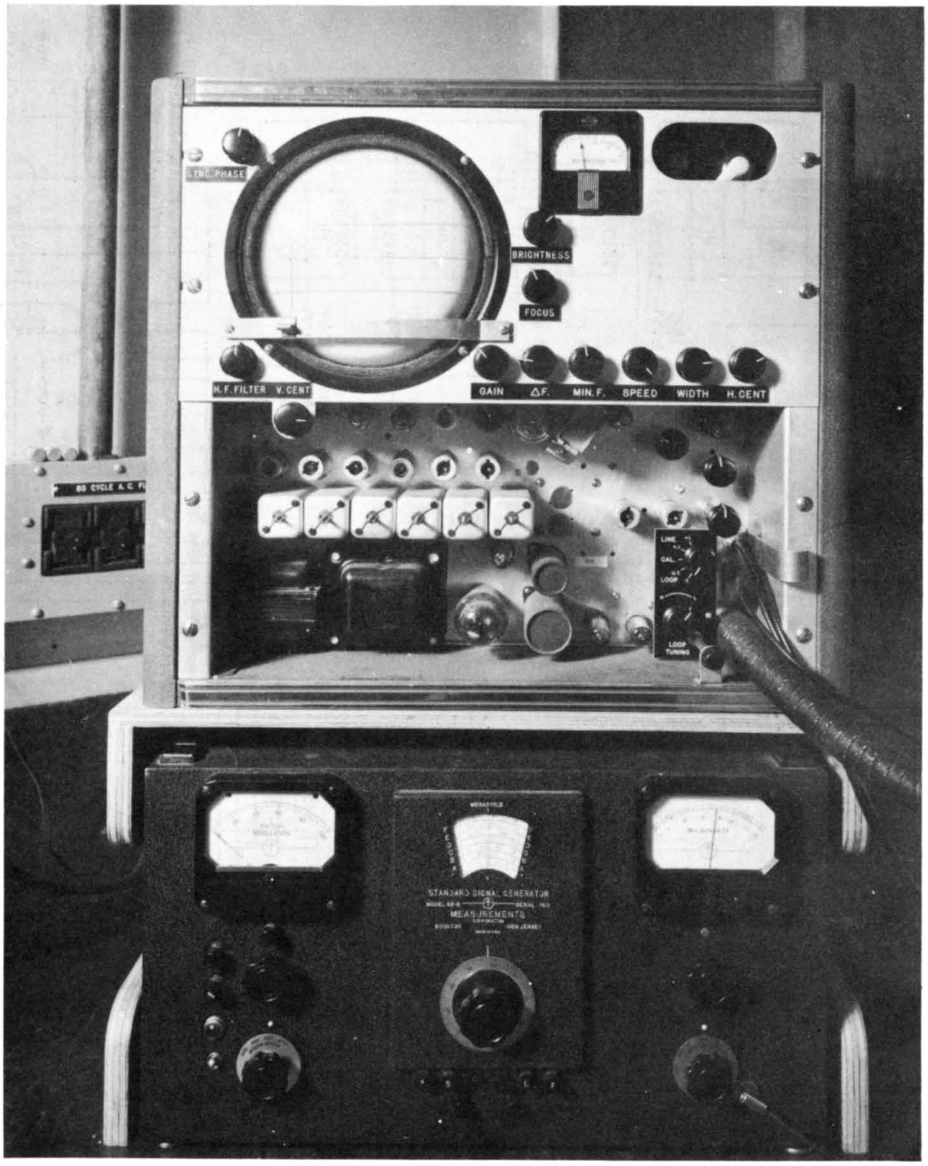

Fig. 8 - Panoramic receiver with input connections from calibrating generator, loop, and line impedance unit.

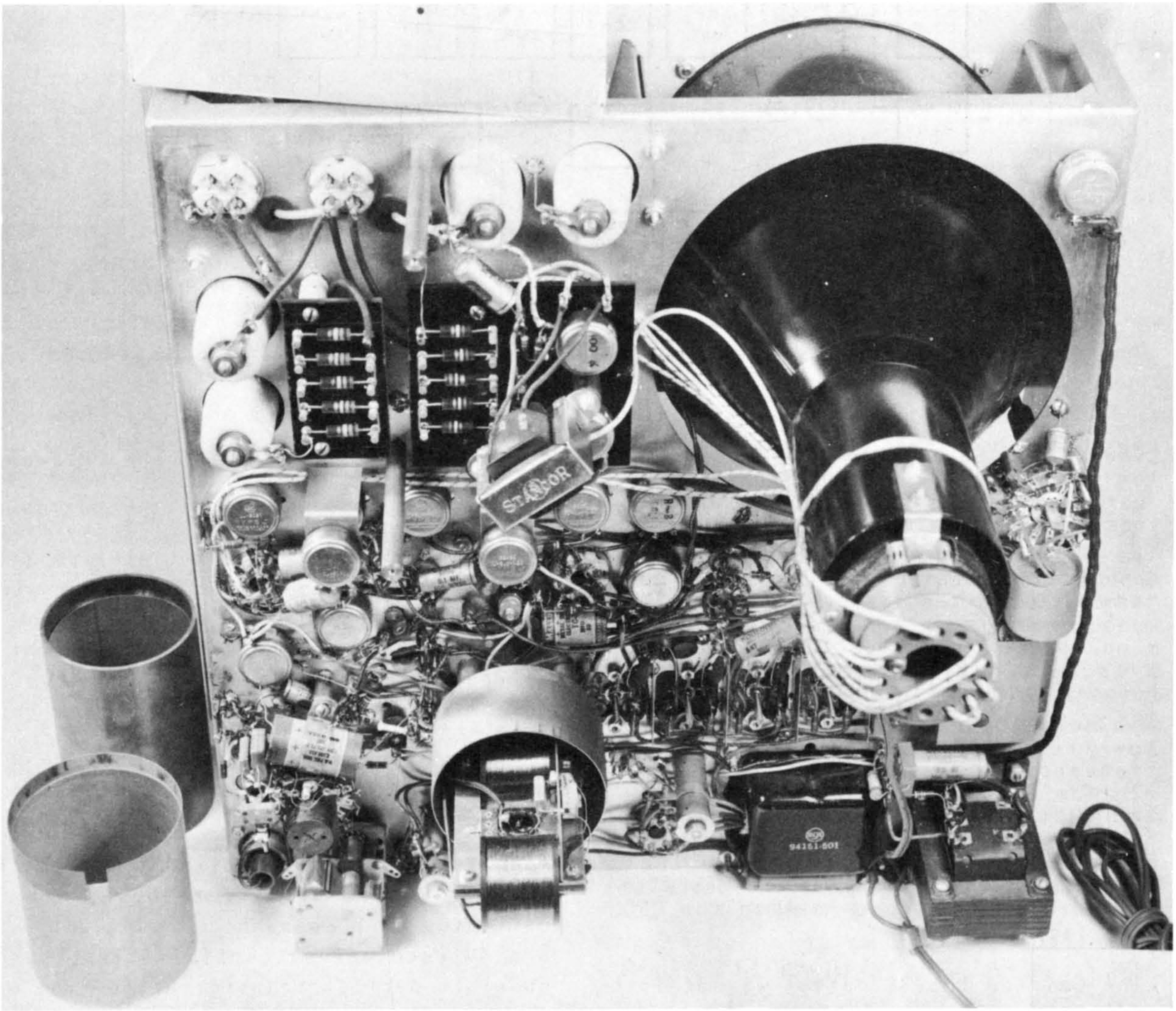

Fig. 9 - Panoramic receiver with high voltage compartment cover and oscillator magnetic shield removed.

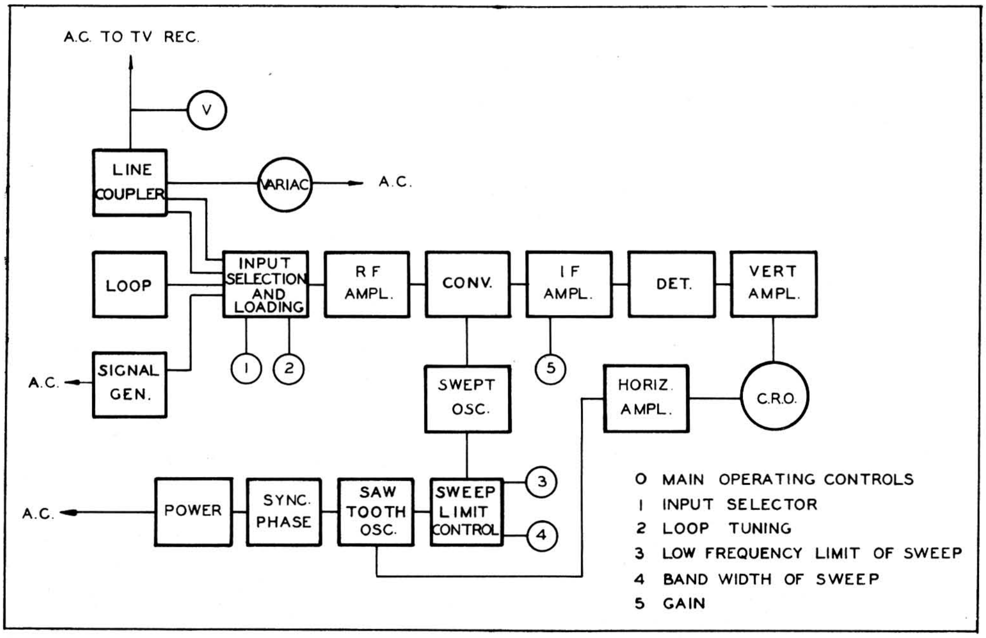

Fig. 10 - Block diagram of panoramic receiver.

Line A, the SG output is reduced to a low value, the PR Gain control is adjusted, and the receiver's interference spectrum is visually surveyed.

7. The SG output is increased until it appears as a beat on the nearest sweep harmonic, and the frequencies at which measurements are to be made are determined by motor-tuning the SG to beat with selected high-amplitude sweep harmonics.
8. The SG marker is placed on the selected low-frequency-region harmonic, the frequency sweep width is reduced to minimum (about 150 kc) and bracketed around the marked harmonic, the SG output is reduced to eliminate the marker, and the PR Gain is adjusted so that response to the harmonic coincides with a reference amplitude mark on the CRO tube face.
9. The PR Input Selector is turned to Line Cal and the SG output is set for reference mark CRO response. The frequency and SG μv output are noted in the "A" column of the data sheet.
10. The SG is tuned to the next higher selected frequency, and the essential steps in operations 8 and 9 are repeated. Etc....

While there are numerous motions involved in this procedure, the pace is rapid, the measurements are accurate, and there is no uncertainty as to whether or not the most appropriate data have been obtained. A, B, push-push and push-pull line-input readings are usually taken in one run, to avoid unnecessary shifting back and forth of the PR sweep range and SG tuning.

Push-push and push-pull measurements are not stipulated in the IRE tentative standard; only the measurements on the line wires individually. Although this avoids the necessity for a balance-to-unbalance transformation required for push-pull measurements using commercial field strength meters, the resulting data do not appear to be as readily interpretable. Voltages to ground on the individual line conductors may be composed of push-push and push-pull components having any relative magnitude and phase. While it may not be particularly more orderly to base interference estimates on push-push and push-pull voltages and AM receiver susceptibilities, because of possible partial transformation from one mode to the other enroute from the television to the AM receiver, the push-push and push-pull data are more useful for locating the sources of power-line input coupling in the television receiver. Consequently, the ISL practice is to measure and report push-push and push-pull line input voltages in addition to the IRE-specified individual-line-wire-to-ground voltages.

Measurements of television receiver magnetic induction field strength follow much the same pattern as line input measurements except that an orientation procedure is involved both in selecting the frequencies and in the field strength measurements. Frequency selection is easier using an untuned loop, but advantage may be taken of the signal-to-noise ratio improvement afforded by loop tuning when the measurements are made. The tuned loop is always used with narrow-band sweep, so that its addition to selectivity, which is considerable at low frequencies, does not result in suppressed response (explained in Appendix B). Measurements of push-push line input are required at the same frequencies where loop measurements are made. These are not ordinarily the same frequencies as those where line input maximizes. The ratio of the loop input to the PR to the push-push line input at the same frequency provides a means of determining, with the aid of a screen-room calibration, whether (a) the loop input results primarily from a magnetic dipole source within the receiver, or whether (b) it is excessively "contaminated" by flux due to displacement current induced in the room space and walls by the receiver's electric field. In the latter event, the data are discarded as being inapplicable. A second room calibration supplies the ratio between the loop voltages and free-space field strengths at 15-feet distance. Derivation of the two room calibrations by experimental procedure is described in Appendix A.

In measurement of video interference, the visual impression given by the PR is somewhat at variance with observations made with an ordinary AM receiver. With an AM receiver, monochrome video interference is plainly localized around the harmonics of line-scan frequency, and plainly modulated by the vertical blanking. In the panoramic display the interference more nearly resembles random noise, and the blanking-interval suppression is less marked. With an ordinary field-strength meter, an average or quasi-peak indication is obtained at one frequency for the entire picture. With the PR the indication obtained is that of the energy present at all frequencies included in the portion of the video spectrum for which the frequency sweep is set, but the information for the indication at any particular frequency is extracted from only a small segment of the vertical expanse of the picture. With either equipment, the indication at any frequency varies as picture content varies, but not necessarily in the same way. However, the band-average indication of the PR is in acceptable agreement with the band-average indication of a hand-tuned field-strength meter over the same band of frequencies. Thus far, no receiver tested has had video interference output equivalent to sweep output in the broadcast band, although the video interference frequently is paramount above 2 Mc. This interference occurs principally in the push-push mode. It is measured in the same manner as input to the power line except on a band-average rather than individual-frequency basis. No magnetic field measurements are required on video interference.

From a practical standpoint, the interference spectrum of either black-and-white or color television receivers terminates in the intercarrier beat at 4.5 Mc. Sweep and video outputs above 4.5 Mc are trivial as compared to those at lower frequencies. The only noteworthy exception to this rule thus far observed within the frequency range embraced by the recently-extended tentative IRE Standard (up to 10.0 Mc) is the second harmonic of a color subcarrier reinsertion oscillator. A commercial field strength meter is used at ISL to search the 4.5 - 10.0 Mc region for power line input in tests on color receivers. Modifications to provide additional frequency range in the panormaic receiver can be made if the need becomes evident.

* * *

SECTION III. INTERFERENCE REDUCTION

Since the generation of potential interference by the sweep and video circuits of a television receiver is inherent to the receiver functions, the only available approach to reduction of the interference potential at the source is to contain the generated fields within shielding. The extent of applicability of this solution is a matter of economics, but there can be little question about technical possibilities of interference reduction to any desired level.

For reduction of the receiver magnetic-induction field intensity, consideration may first be given to most effective use of the shielding properties of magnetic cores of the yoke and horizontal output transformers. It was found experimentally that increasing a yoke core permeability from 50 to 350 decreased the yoke's external field strength by four times, with only a small effect on yoke inductance. Increase in permeability reduces the core reluctance as a return path for the flux without appreciably changing the reluctance for the magnetic circuit, which includes the high-reluctance air gap through the kinescope neck. The disparity in ratio of field reduction to permeability increase is due to leakage flux from the winding ends. Thus, a second sevenfold increase in μ above 350 (if available) could not be expected to be nearly as beneficial.

The field from a horizontal-output transformer of the most common type can be somewhat reduced when an air gap is employed in the core, by putting all the air gap in the core leg which mounts the coil, thus reducing the flux-return-path reluctance without appreciably changing the reluctance of the magnetic circuit. The measured reduction in field intensity at a distance was two-to-one when two 25-mil air gaps in opposite legs of a 300-μ core were replaced by a single 50-mil gap in the coil leg of the core, using the largest diameter coil the core would accommodate. Transformer designs employing no air gap can be improved with respect to *core* flux leakage by increasing the core *intrinsic* μ, and introducing such length of air gap in the coil leg as restores the effective μ to the original value. When the core μ has a value typical of ferrites, the leakage field from the exposed winding ends may equal or exceed the core leakage field, hence use of the smallest diameter winding which will safely withstand the peak pulse voltage to be developed is indicated. Design modifications which require increase in *effective* μ of the core soon run into limitations due to increased core losses. Thus, increasing the core μ by four times would enable reduction in turns to one-half for the same inductance, current, pulse voltage, etc. This would reduce the coil leakage field strength to one-half, but the flux density in the core would be doubled. The characteristic increase in losses in ferrites for doubled flux density is five times.

The alternative and perhaps more fruitful approach to magnetic field strength reduction, at least in the case of the horizontal output transformer, is use of improved shielding. Measurements show that, of the two types of transformer enclosures most commonly used, viz., boxes assembled with screws from sheet-iron stampings, and "tin" cans, the cans provide better magnetic shielding. Although thinner-walled, the cans are more nearly seamless, a factor of more importance than either the kind or thickness of metal used. No measurement data are available at present on the efficacy of currently-used types of yoke mounts as magnetic shields.

Practical shields for electric field containment are also of the conducting variety, but the required conductivity is much lower than for magnetic shielding at AM broadcast and lower frequencies. While an electrostatic shield must be essentially complete in area of coverage to be *fully* effective, it does not have to be continuous. The shield is merely one "plate" of a condenser of which the other plate is the surface of the field source. The conductance of the active area of the shield (and of its return connection to ground) need only greatly exceed the condenser susceptance, so that the voltage drop between the field source and ground occurs in the dielectric space rather than in the shield. Materials having much higher resistivity than metals, very thin metallic films, wire grids, etc., usually answer the requirements fully as well as does sheet metal.

Incompletely shielded electric fields in the television receiver are the source of power-line input of the Fig. 4a kind. The predominant source is usually the kinescope, energized by electrostatic coupling from the yoke, and by connection to the high-voltage rectifier. Thus, to minimize this field, it is necessary to employ adequate filtering in the high-voltage supply *and* electrostatic shielding of the kinescope neck and funnel from the yoke winding. The first expedient is not successful without the second. One form a yoke shield may take is a grounded film, such as Aquadag, deposited on the exterior of the tube neck and funnel, the film having a resistivity high enough to limit deflection-flux eddy-current losses to an acceptable value, but low enough to answer the requirements for electrostatic shielding, as defined previously. The tolerance range on film conductivity is improved by using a material combining high dielectric strength with low dielectric constant to insulate the shield from the yoke winding, so as to minimize the capacitance between yoke and shield.

Electric field shielding possibilities already available in television receiver designs are not always fully utilized. For example, the electrostatic shielding effect of even the simplest internal cabinet-top antenna is often great enough to be worth using. When this antenna is in use for reception, it is usually grounded to chassis insofar as AM broadcast frequencies are concerned. An additional terminal grounded to chassis would enable use of its shielding properties when operating on an external antenna. Many cabinet-top antennas could be considerably improved for electric field shielding purposes without diminishing their signal pick-up efficiencies. Similarly, all the hardware used in mounting the kinescope and yoke should be grounded. Grounding the focusing device and ion trap usually makes a noticeable reduction in the electric field intensity of unshielded receivers.

The benefits obtainable by such simple expedients as minimization of exposed length of yoke and video leads, enclosure of horizontal output and damper tubes in some kind of electrostatic shield, etc., may be appreciable.

The concept of containing the generated interference within shielding implies not only a unipotential shield, but also effective by-passing of outgoing leads where they leave the shield. Power-line-to-chassis by-passes must be limited in capacitance to about 0.01 µf because of shock hazard, but there is no limit except one of economics on capacitance of a line-to-line by-pass for reducing push-pull line input. Capacitors of 0.01 µf are not large enough to prevent excessive line input in either the push-push or push-pull mode unless the power circuit is carefully isolated within the chassis. Inductive loops in the leads connecting the power cord, a-c switch, line by-passes, and power transformer may need be avoided. If the circuit passes close to a major interference-bearing item, such as the damper tube socket, enclosure in electrostatic shielding (such as braid) may be necessary.

Magnetic coupling of interference through the power transformer decreases quite rapidly with increasing frequency, but it may be quite large at frequencies of the order 100-200 kc. This is a push-pull coupling (Fig. 4b) characterized by 120-cycle modulation imposed by loading by the B supply rectifiers. It occurs, for instance, when the damper-tube heater winding is connected to a tap on the horizontal-output transformer. With respect to push-push coupling of the Fig. 4b kind, the transformer primary is usually electrostatically shielded by other windings from the damper heater winding, but power-transformer leads are customarily all brought out in a single bundle, and the resulting capacitive coupling to the power circuit might be excessive if the damper-tube heater were connected into the sweep circuit.

In interference reduction work on receivers, it will be obvious that the interference leaks must be found and eliminated in descending order of importance until the desired output level is reached. Hand capacity effects are of use in gauging the relative importance of the electric fields of various receiver components, although it must be kept in mind that the sum-total field from a large item bearing a low interference voltage can exceed the field from a small item having a much higher interference voltage, hence showing a greater reaction to hand capacity. The push-push line input will be observed to increase

An electric field source having directional properties simulating those of a television receiver is constructed, consisting of a metal rod a foot or so long mounted perpendicularly on, but insulated from, the center of a metal sheet about two feet square. This source is connected by a short, flexible cable to a standard signal generator, and located at the approximate normal position for a receiver under test, with the signal generator placed just below. The signal generator is plugged into the a-c outlet provided for the receiver in the line impedance unit, but it is not otherwise grounded to the room. The signal generator output is increased to the point where a measurable "false" magnetic field is produced, and the electric field source is then oriented in all degrees of freedom to whatever direction maximizes the magnetic field strength indication. The push-push input to the power line is then measured with the field source position and input unchanged. The ratio of the indicated magnetic field strength (or loop voltage) divided by the push-push line input voltage is a criterion by means of which magnetic field measurement data on television receivers can be judged for degree of freedom from electric field contamination, provided supplementary push-push line input measurements are made on the television receiver at the same frequencies where magnetic field measurements are made.

If the ratio so measured in calibration is called R, and the corresponding ratio measured on a television receiver at the same frequency and loop polarization is called R′, it can be shown that the error in magnetic field strength measurement resulting from presence of an electric field from the receiver will not exceed 3 db if R/R′ is less than 0.3.

The described calibration must be made separately for horizontal and vertical pick-up loop polarizations, and at enough frequencies to enable construction of interpolation plots. This calibration is not included in the IRE tentative standard.

Appendix B

Panoramic Receiver Design Data

The receiver is shown in block diagram form in Fig. 10, and schematically in Fig. 11. Figs. 8 and 9 give some idea of the layout of parts. The major design objectives were:

1. Simultaneous display of all interference components present between 75 kc and 4.5 Mc, or in any selected segment of this range.
2. Uniform sweep rate in cps/s whether over a wide or narrow frequency range.
3. Lowest feasible noise level, and enough gain to operate at the noise level.
4. Independent responses to successive harmonics of 15.75 kc.
5. Freedom from spurious responses.
6. Fast recovery from overload.

A panoramic presentation of signals existing within a given frequency range is obtained by (a) sweeping the frequency of the receiver conversion oscillator, (b) direct-coupling the detector output to the vertical deflection plates of an oscilloscope, and (c) applying a voltage synchronized with oscillator frequency deviation to the horizontal CRO deflection plates.

A critical problem is selection of a method of sweeping the oscillator frequency. A sawtooth sweep in which frequencies spaced by equal kc increments are spaced by equal horizontal displacements in the display is desirable. When the sweep-bandwidth is to be varied over a wide range, mechanical control of the oscillator frequency is impractical in the case of sawtooth sweep. The development of r-f grade ferrites combining relatively high μ and easy saturability has made possible new forms of electronic reactance control circuits giving many times the range of older circuits based on phase shifters, thus permitting wider range of sweep at comparatively low oscillator frequencies.

In a panoramic receiver, it can be visualized that the signal is tuned past the i-f pass band exactly as though this were done by turning the tuning knob on a conventional receiver at an appropriate rate. A practical method of estimating the maximum frequency sweep rate which will allow full build-up of the output signal is to equate the time required to pass between 3-db-down points on the selectivity characteristic to the time interval of one cycle of amplitude modulation at the highest frequency which would be passed by the receiver with 3-db sideband suppression, with the carrier held at the center of the pass band. Thus, if the total bandwidth at 3 db down is 10 kc, the swept signal must "dwell" within this pass band for at least 1/5000th second to reach full amplitude. In other words, the frequency sweep rate must not exceed 10 kc per 1/5000th second, or 50 Mc per second. For a 0 to 4.5 Mc sweep at uniform rate, the maximum permissible sawtooth frequency is thus 11 cps. These figures apply approximately to the present case.

In the ISL receiver, the frequency sweep is accomplished by varying the saturation of a ferrite ring core on which the frequency conversion oscillator coil is wound, in accordance with the amplitude of the sawtooth voltage which performs the horizontal deflection of the oscillograph. The sawtooth of saturating current is superimposed on a d-c "bias" current which establishes the highest value of core permeability, hence low limit of frequency sweep. The current sawtooth is pre-distorted by grid-voltage plate-current curvature in the frequency control tube to suit the incremental saturation characteristic of the ferrite, so that the frequency sweep rate is essentially constant throughout the sweep. Because of hysteresis effects the frequency retrace lags a bit behind spot retrace, but the only disadvantage is loss of a small portion of the beginning of the time axis (see Fig. 2). No return-trace blanking is needed.

The oscillator coil ferrite core has an O.D. of 3/4-inch, 3/32-inch square cross-section, with an initial μ of 60. The coil Q with the core under partial saturation, as used, is in the range 40-70, considerably in excess of the Q in the absence of the magnetic bias. The core occupies a gap in the center leg of a 1/8-inch stack of modified "E" transformer laminations, as shown in Fig. 8. The saturating coils, in series, occupy the outer legs of the laminations. They are polarized to add their fluxes in the center leg. The saturating coils are each 20,000 turns of No. 37 Formex wire, random wound in turned bakelite spools. The oscillator tank winding is split between sides of the ferrite ring in the manner shown in the schematic diagram, Fig. 11. The ferrite ring is cushioned in the laminations by 20-mil paper spacers, and cemented in place.

In spite of the self-shielding type of construction, this magnetic structure is extremely sensitive to hum fields from the power supply. To eliminate hum effects on the rate of frequency sweep, the oscillator assembly was enclosed in a three-layer shield consisting of a mu-metal sleeve, a copper sleeve, and a mu-metal can. This unit was mounted away from the steel chassis on non-magnetic spacers. A separate voltage regulator tube was provided for the frequency control tube screen and plate supply, to filter out hum and to isolate the frequency sweep from minor voltage variations resulting from i-f gain control and the like.

The functioning of the frequency control circuit can be understood by noting the following effects: The input signal selected by the i-f amplifier increases in frequency with oscillator frequency. The oscillator frequency increases with degree of core saturation; i.e., with increase of plate current in the control tube. The input to the control tube consists of a direct-coupled positive-going sawtooth voltage superimposed upon a d-c negative bias which always exceeds the peak-to-peak sawtooth amplitude. When the Δ-F control setting is increased (upward in the schematic) the sawtooth input is increased, and the average bias is decreased by approximately one-half the peak-to-peak increase in sawtooth amplitude, so that the maximum negative grid voltage, which determines the low limit of frequency sweep, is not much changed. With the Δ-F control at maximum, when the MIN-F control setting is increased (downward in the schematic--a dual control) the negative d-c bias is decreased, and the sawtooth peak-to-peak amplitude is decreased similarly, so that the minimum negative grid voltage, which determines the high limit of frequency sweep, is little affected. With the Δ-F control at minimum, as the MIN-F control is advanced the d-c bias and sawtooth input are both decreased, and the lowest frequency reached by the sweep is increased, but the sweep width remains nearly constant up to about 2 Mc because of the compensatory increase in control tube g_m. The sawtooth amplitude, LF range and HF range controls so identified in Fig. 11 are set-up controls.

The sawtooth sync control permits shifting the time at which a particular frequency is observed with respect to the 60-cycle phase, so that sweep interference outputs which are hum-modulated by rectifier loading can be observed at their maximum amplitude without shifting the section of frequency spectrum under observation.

An intermediate frequency just above the input frequency range eases the i-f selectivity problem. At 5.25 Mc i-f, the oscillator sweep range is 5.325 to 9.75 Mc, a range easily obtainable with a saturable ferrite core, and the image range is 10.575 to 15 Mc, a region in which little output need be expected from television receivers. The i-f selectivity required is less than would be required in an ordinary AM receiver. Assuming proper detector characteristics (to be discussed later), partial response to a signal adjacent to the pass band merely results in superimposition of a beat on the signal in the pass band, and the beat can be filtered out after detection. Nevertheless, the selectivity required to differentiate successive sweep harmonics is not easily obtained at 5.25 Mc. The transformer windings used have an in-can Q in excess of 175. The couplings are below critical except for the final transformer driving the detector, which is critically coupled. Couplings were adjusted by putting decoupling rings between windings in the cans, adding fractional-μμf capacitors made of twin polyethylene-insulated wire between plate and grid terminals externally, and clipping these capacitors a little at a time while monitoring the transformer voltage transfer ratio. The over-all bandwidth of the six transformers at 3 db down is 9.75 kc, at 20 db down, 25 kc, just adequate selectivity. Successive 15.75-kc harmonics having an amplitude ratio up to four-to-one show as separate peaks having the correct relative amplitude. Three-to-one is about the maximum amplitude ratio observed between successive harmonics in sweep outputs. High i-f gain with high stability was obtained by using five stages (required primarily for selectivity) with low gain per stage, using tubes with low plate-to-gri capacitance, individually filtering +B and bias inputs with short time-constant RC filters, and shielding the connections to the transformers and detector socket. Manual gain control of the first four stages provides vertical deflection control for the oscilloscope.

To improve the signal-to-noise ratio the converter was preceded by an untuned r-f amplifier. A pentode was used to avoid excessive feedback when operating with a tuned loop. Stage gain was limited by use of a low valu plate load resistor to the amount needed to obtain optimum signal-to-noise ratio. R-f gain in excess of this amount would needlessly lower the input voltage level at which overload would occur in the converter, with consequent generation of spurious products of the input signals. With 0.1-volt input to the r-f amplifier grid, the relative amplitude of the second harmonic generated in the converter is -17 db. This decreases to -26 db below 40 millivolt input, and to -40 db below 10 millivolt input.

The coupling transformer which is switched into the receiver input circuit when measuring power-line interference is a tri-filar winding in a high-μ ferrite cup-and-core shell. The response through this transformer is essentially "flat" between 75 kc and 4.5 Mc, and its loading effect on the input is negligible. The CR coupling between the transformer and input grid introduces a 6-db-per-octave loss at low frequencies. with the inflection point at 1 Mc. This prevents the 15.75 kc input and its high-amplitude low-frequency harmonics from overloading the converter and producing spurious indications of a magnitude comparable to that of the legitimate indications at higher frequencies.

Three plug-in loops cover the range from 100 kc to 4.5 Mc, tuned. A fourth brackets the AM broadcast band. When the loops are used untuned they are shunted by resistance equal to the inductive reactance at the frequencies where the loops resonate with the incidenta capacitance. This makes response to fields of a given intensity approximately proportional to frequency up to the loop resonance frequency.

A panoramic receiver needs a "high fidelity" detector; a linear AM detector capabl of following the highest envelope frequency component. In measurement of sweep interference, the rectified envelope contains (a) d.c., (b) low-frequency transients, (c) a low frequency resulting from cyclic variation in the sweep harmonic amplitudes as harmonic number increases, (d) a frequency corresponding to time-recurrence rate of the sweep harmonics, 3200 cps at 50 Mc/s maximum sweep rate, and (e) 15.75 kc beats. The desired information is contained in the first four. Component (e) is merely obscuring, and is removed by a 6400-cps cut-off low-pass filter. A long-time-constant averaging type of RC filter (slow charge, slow discharge) can be switched in to provide a band-average indication on video interference.

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