TESTING OF RAILROAD SIGNAL EQUIPMENT FOR POWER LINE INTERFERENCE SUCEPTIBILITY
PART I: THE TEST JIG

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Abstract - A basic need to permit planning of new ac power lines near railroad systems is accurate data for the levels of ac interference that upset the operation of railroad signal components or systems. Such data would help the power system and railroad system design engineer understand the magnitude of the interference problem, investigate alternative mitigation approaches, and select one that is cost-effective and mutually agreeable. Under EPRI research program RP 1902-1, IITRI developed a body of key railroad signal equipment susceptibility data in cooperation with the major U.S. manufacturers of this equipment. This paper describes the innovative test jig developed under RP 1902-1 which has been applied to obtain susceptibility data for track and line relays, electronic track circuits, and grade-crossing warning devices. A companion paper (Part II) describes the results of the tests.

INTRODUCTION

EPRI Research Program RP 1902-1

From February, 1981 to June, 1983, the Electric Power Research Institute (EPRI) funded IIT Research Institute (IITRI) to examine the problem of interference to railroad communications and signal (C&S) systems from high-voltage, overhead, ac power lines. The objective of this project, EPRI RP 1902-1, was to develop mutual design methods and criteria for ac transmission lines and adjacent railroad systems.

Specific program objectives have been:

1. to consolidate known data concerning mutual effects arising from transmission lines and railroads having close sitings;
2. to develop means to accurately forecast whether or not a planned power line to be located near a railroad will cause interference problems;
3. to develop means to perform accurate cost-vs.-benefit trade-off studies for mitigation, if interference is expected to be a problem; and
4. to investigate both existing techniques and possible new techniques to mitigate interference problems.

85 WM 113-6 A paper recommended and approved by the IEEE Power System Communications Committee of the IEEE Power Engineering Society for presentation at the IEEE/PES 1985 Winter Meeting, New York, New York, February 3 - 8, 1985. Manuscript submitted August 31, 1984; made available for printing November 19, 1984.

General Objectives of the Interference Susceptibility Tests

A basic need to permit planning of new power lines near railroad systems is accurate data for the levels of ac interference that upset the operation of railroad components or systems. Such data would help the power system and railroad system design engineer understand the magnitude of the interference problem, investigate alternative mitigation approaches, and select one that is cost-effective and mutually agreeable.

Prior to RP 1902-1, little or no data regarding reliable test procedures and measured ac susceptibility levels for railroad signal equipment was available in the literature. It became apparent to the project team that such data would have to be developed from a negligible base.

As a result, the development of ac interference susceptibility data for key railroad signal equipment became one of the priorities of RP 1902-1. It was strongly desired that this data would be obtained by independent measurements conducted under this program, but with the technical cooperation of the major U.S. manufacturers of railroad signal equipment and systems.

Summary of Accomplishments

A body of key signal equipment susceptibility data has, in fact, been developed with the technical cooperation of four major U.S. manufacturers of railroad signal equipment. Using an innovative test jig developed during RP 1902-1, a series of measurements was conducted at two of the manufacturers' plants under the supervision of the respective chief engineers. The same test jig was used to conduct measurements at IITRI, Chicago, of the other two manufacturers' equipment under the supervision of responsible engineering personnel of the respective firms. The latter two tests were funded by EPRI under a parallel research program, Project RP 1902-2, in connection with a specific right-of-way inductive coordination study.*

Highlights of the four batteries of tests included measurement of upset levels for:

- Nine representative, widely-used, track and line relays;
- Six recent electronic track circuits;
- Five grade-crossing motion detectors and warning devices;
- Steady-state 60-Hz and harmonic interference;
- Simulated fault pulses; and
- Preliminary mitigating devices, such as filters.

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*The latter two tests were performed under subcontract to Science Applications, Inc. Data from these tests have been made available for [1].

Of great interest were the modes of upset of the equipment or systems for specific nominally displayed signal aspects. Careful attention was paid to the possibility of ac interference causing a less restrictive indication to appear than desired. In addition, each relay and electronic track circuit receiver was characterized for input impedance (magnitude and phase) as a function of frequency, through 540 Hz.

Overall, the tests permitted specification of the Thevenin equivalent circuit of each item of signal equipment, as well as the interference threshold level and mode of upset. This permits a "black box" characterization of each item, and easy integration of the device characteristics into the advanced computer programs for modeling ac interference, TRAIN-I and TRAIN-II [1], developed by IITRI under RP 1902-1.

Organization of This Paper

This paper describes the test jig used for the ac susceptibility measurements. Included will be a general description of the capabilities of the jig, the configuration for the continuous wave (cw) tests, and the configuration for the simulated fault-pulse tests.

A companion paper (Part II) details the results of the ac susceptibility tests of relays, electronic track circuits, and grade-crossing motion detectors and warning devices. Previously unsuspected false-clear failure modes for certain vital signal equipment were detected, as well as a very wide range of safe-failure thresholds.

GENERAL DESCRIPTION OF THE CAPABILITIES OF THE JIG

The key to achieving a flexible and consistent test procedure for a wide variety of railroad signal equipment or systems lies in the broad capabilities of the test jig developed during this research program in cooperation with the signal firms involved. The philosophy behind the testing approach is simple. First, generate at low levels a voltage representing the combination of a specific desired signal and a specific undesired (noise) signal. Second, amplify this voltage to a power level sufficient to operate the signal device in question. In this manner, there is great control over both the level of the desired signal and the interference. Signal-to-noise ratios can be adjusted at will over the full operating range of the desired signal at the device in question.

Fig. 1 is a simplified block diagram of the test jig. The low-level signal and noise channels are summed by a Sanborn Type 8875 differential amplifier. Gain controls are provided for each channel. The combined signal is linearly amplified by a Crown M-2000 power amplifier, which feeds the track or line circuit device under test through a nominal source impedance simulating a typical track or line embedding.

Salient features of this system are as follows:

- Signal Channel Capabilities
  - --Can be fed directly by track circuit transmitter;
  - --Handles dc for both positive and negative polarities;
  - --Handles switched or pulsed dc;
  - --Handles ac up to 50 kHz;
  - --Handles switched ac or pulsed ac (tone bursts);
  - --Provides variable gain, zero to maximum.
- Interference Channel Capabilities
  - --Handles dc for both positive and negative polarities;
  - --Handles switched or pulsed dc;
  - --Handles ac up to 50 kHz;
  - --Handles switched ac or pulsed ac (tone bursts);
  - --Can be provided with variable-width and variable-triggering (delay) tone bursts;
  - --Handles lightning-simulation pulses only a few microseconds in duration;
  - --Provides variable gain, zero to maximum.
- Output Capabilities to Device Under Test
  - --Provides for balanced or unbalanced outputs;
  - --Provides up to 140 volts rms steady ac into 8 ohms;
  - --Handles signals from dc to 50 kHz;
  - --Provides arbitrary polarities of voltage and current simultaneously (a full four-quadrant V-I characteristic);
  - --Can handle heavily inductive loads;
  - --Provides ultra-low source impedance and distortion;
  - --Can simultaneously sink amperes of current while sourcing power (therefore, can test track circuit transmitters for blocking, as well as receivers).

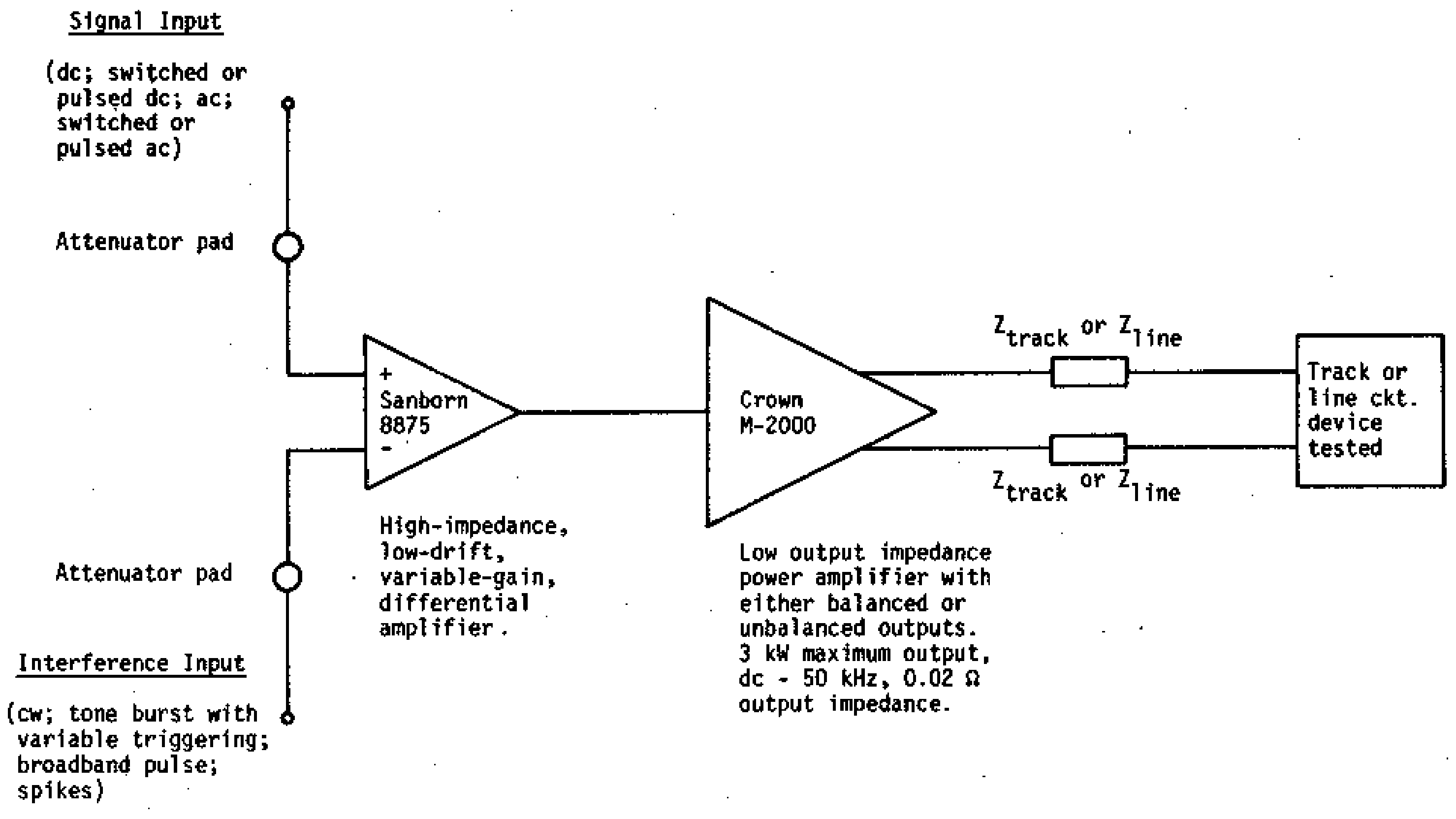


Fig. 1. Simplified block diagram of the test jig used for the signal equipment susceptibility measurements.

In the tests at the manufacturers' plants, the jig of Fig. 1 was used to focus on: (1) cw 60-Hz susceptibility; (2) cw even and odd harmonics of 60 Hz up to 540 Hz; and (3) fault pulses (tone bursts of 60-Hz power) having variable delay 0 - 10 seconds after a signal marker event; variable phase of triggering on the 60-Hz sinusoid from 0°-360°; and variable duration from 3 - 5 cycles at 60 Hz. Additional tests conducted at IITRI in Chicago concerned only the cw 60-Hz and harmonic susceptibility.

No change was required in the test jig to go from the electronic track circuit measurements to the relay measurements. Indeed, this jig permits a common procedure for measuring the interference susceptibility of disparate equipment such as relays, electronic track circuit transmitters and receivers, warning devices, and protectors. In this manner, consistent data can be obtained and a meaningful comparison of ac susceptibility can be made.

CONFIGURATION OF THE JIG FOR THE CONTINUOUS WAVE TESTS

Input Circuit

Fig. 2 is a schematic/block diagram of the input circuit to the Crown M-2000 amplifier of Fig. 1 that was used for the cw susceptibility tests. The signal source (a track circuit transmitter, a line circuit transmitter, or a simple switched dc supply) is connected to the terminals, A and B, which are balanced with respect to ground. If an unbalanced signal source is tested, terminal E can be shorted to terminal G (ground). For track circuit testing, terminals C and D are shorted together, providing a 2.5-ohm input resistance for the source. For line circuit testing, terminals C and D are bridged with a 560-ohm resistor, providing a 510-ohm input resistance for the source.

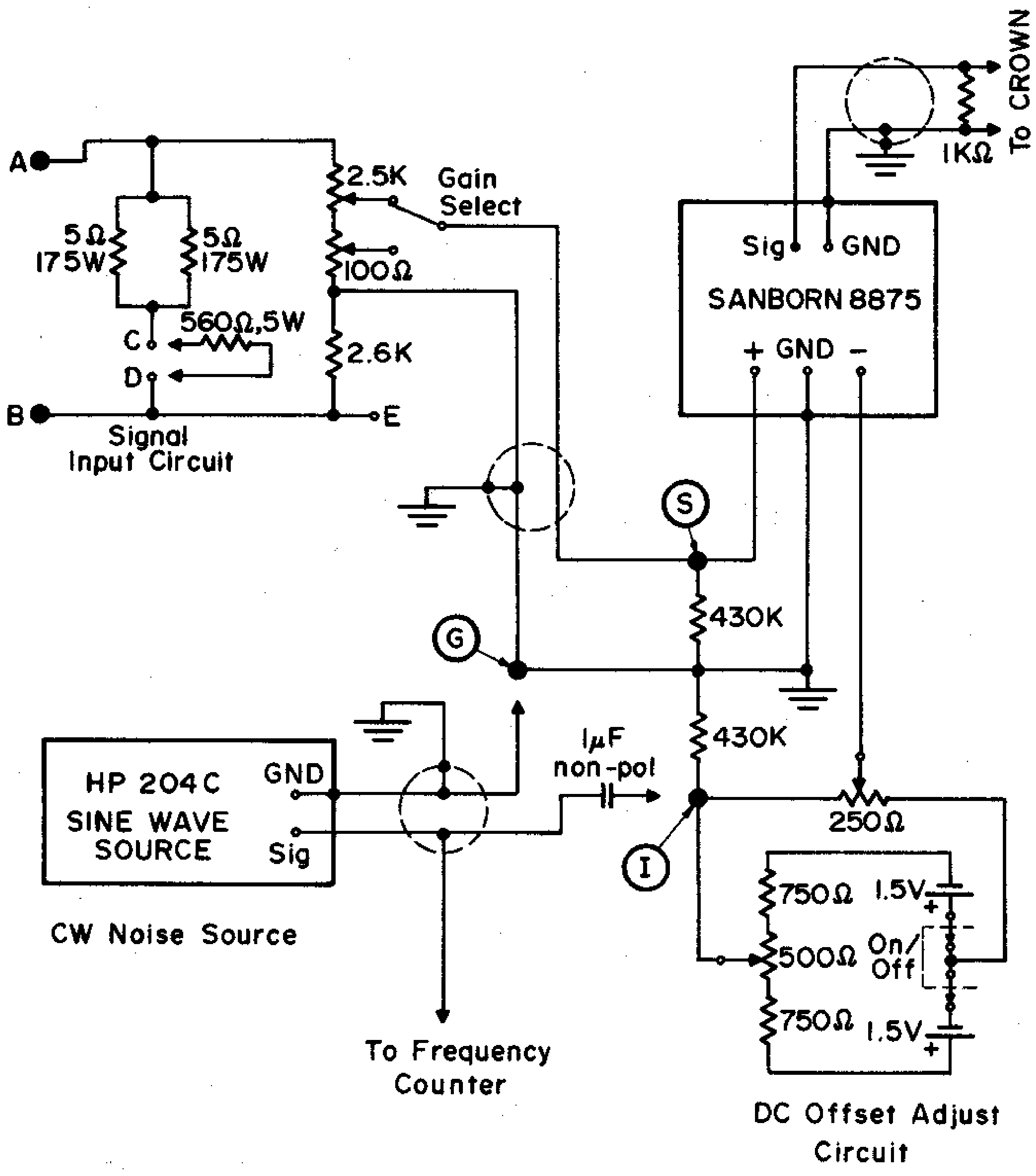


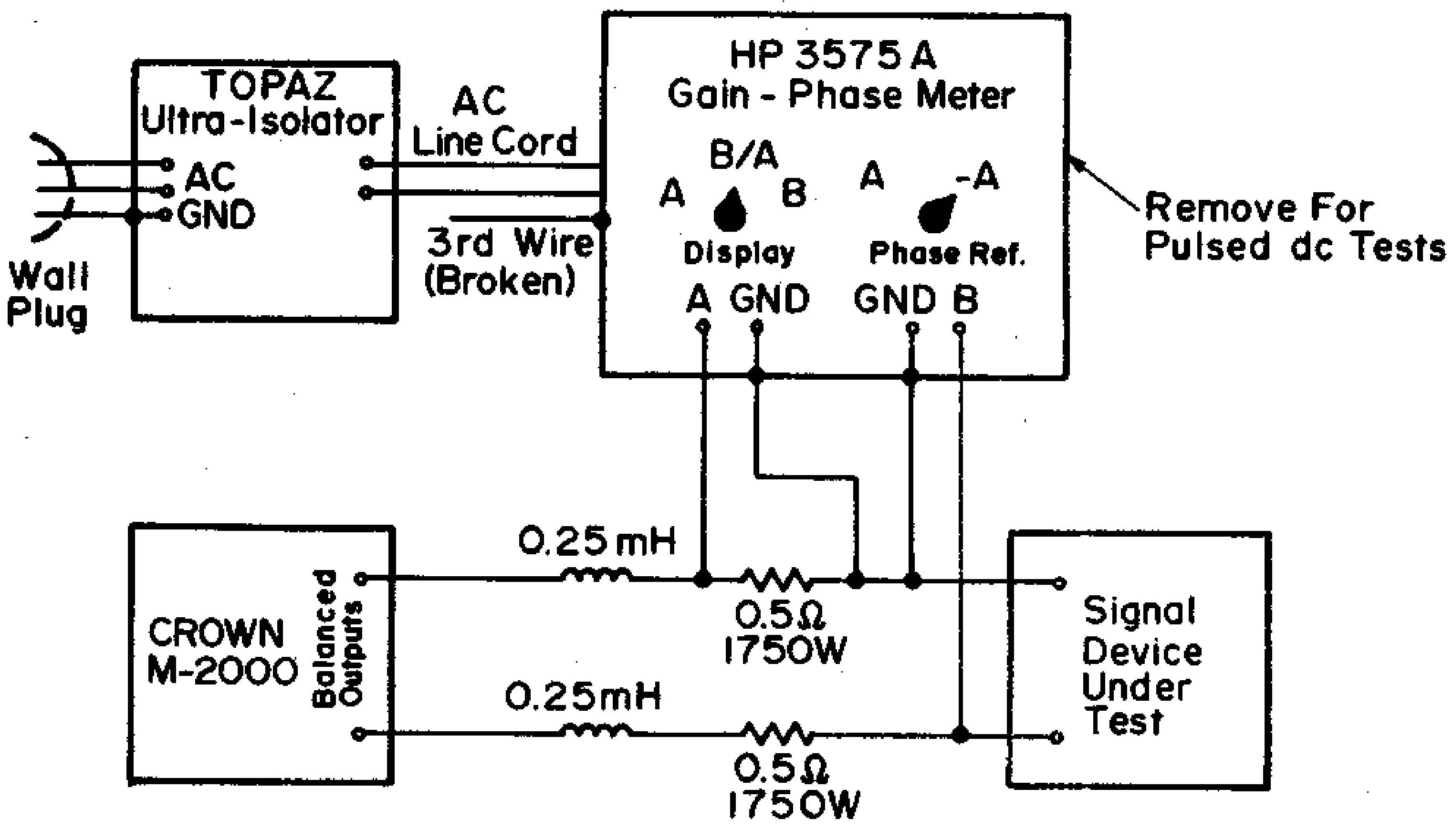
Fig. 2. Input circuit of the test jig for the cw susceptibility tests.

The noise source is a Hewlett-Packard HP-204C audio oscillator, connected in series with a 1-microfarad, non-polarized capacitor to eliminate any residual dc offset of the oscillator. This source is connected to terminals I (interference input) and G (ground).

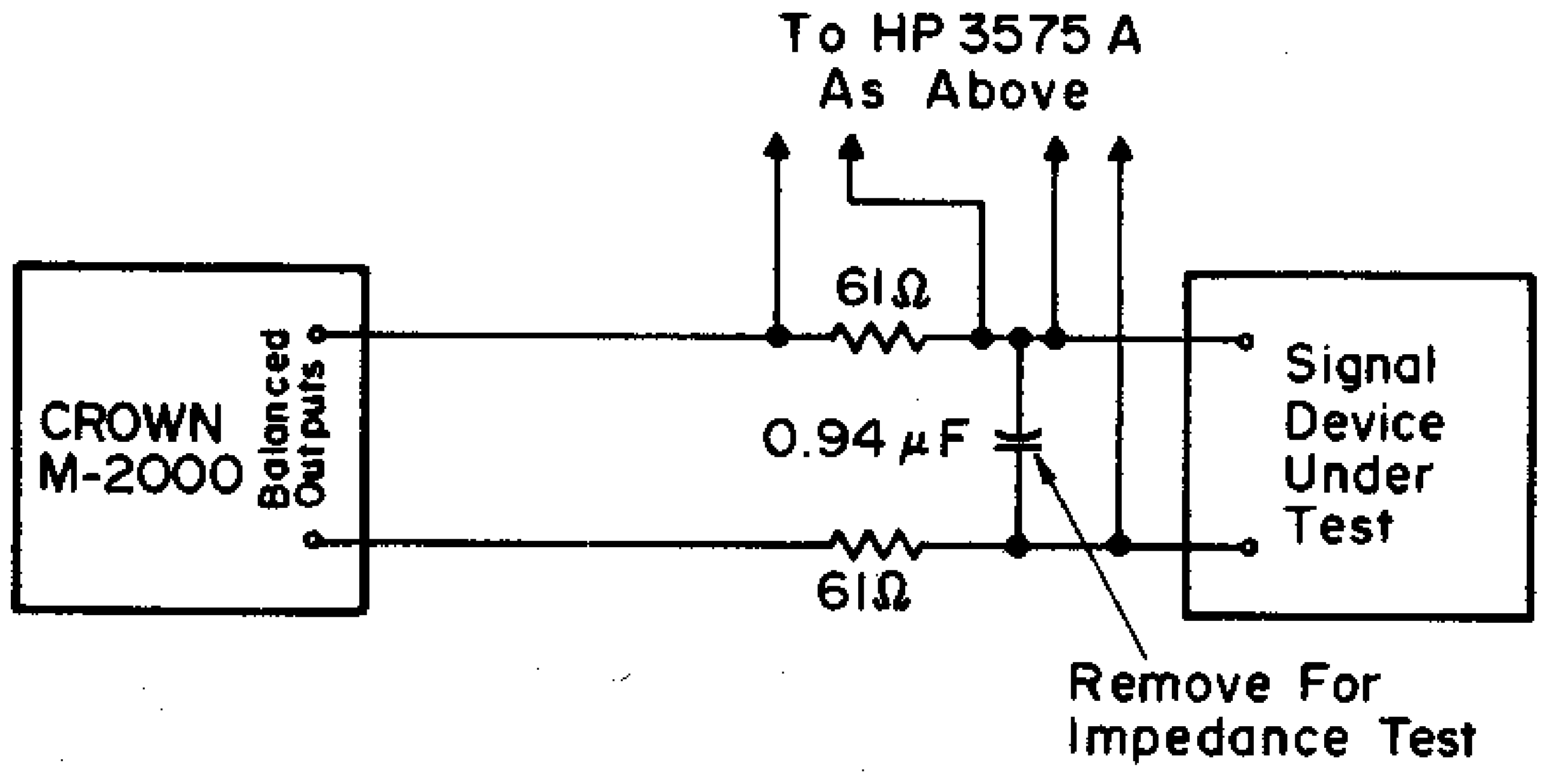
A dc offset adjust circuit is provided in series with the noise source, immediately following terminal I. This permits nulling of the slight residual dc offset of the Sanborn 8875 differential amplifier and the Crown M-2000. This offset-adjust circuit is powered by 1.5-volt flashlight batteries, and, if desired, can be switched out of the circuit.

Output Circuit

Fig. 3 is a schematic/block diagram of the output circuit from the Crown M-2000 amplifier of Fig. 1 that was used for the cw susceptibility tests. The signal device under test (assumed balanced with respect to ground) is connected to the balanced output terminals of the Crown through a simple, balanced impedance. For testing of track circuit devices, the impedance consists of one 0.25-mH air-wound coil and one 0.5-ohm, 1750 W resistor on each side of the Crown amplifier. (The high value of power dissipation is intended to prevent burnout of the resistors under conditions of high voltage being sourced to a low-impedance test device, and to provide some degree of protection to the Crown amplifier.) Note that the air-wound coils should be separated and positioned at a right-angle with respect to each other to minimize mutual coupling.



a) Testing Of Track Circuit Devices



b) Testing Of Line Circuit Devices

Fig. 3. Output circuit of the test jig

For testing of line circuit devices, the balanced series impedance consists of one 61-ohm, 15-watt resistor on each side of the Crown amplifier. A 0.94-microfarad, non-polarized capacitor is connected to shunt the signal device under test. This capacitor is removed for the impedance tests.

The magnitude and phase of the impedance of the signal device being tested is measured using the Hewlett-Packard HP-3575A gain-phase meter, connected as shown in Fig. 3a. This instrument computes the complex value, B/A, where B is the voltage measured across the signal device, and A is the voltage measured across either the 0.5 ohm or 61 ohm resistor on one side of the Crown amplifier. Using Ohm's Law, when the Crown sources current to the signal device, the voltage, A, is proportional to the current flow. Therefore, the impedance of the signal device is simply B/A multiplied by either 0.5 ohm or 61 ohms.

Problems with ground loops will arise if we simply connect a ground-referenced instrument such as the HP-

3575A to the balanced output circuit of the Crown. To prevent these problems, the following two steps are taken:

1. The HP-3575A is floated relative to the ac power lines and to ground by using a Topaz Ultra-Isolator, a high-quality isolation transformer. Note that the third wire (ground lead) of the HP-3575A line cord is not permitted to make contact with the ground of the Ultra-Isolator.
2. The chassis (panel ground) of the HP-3575A is connected to the Crown output circuit at only one point, the junction between the 0.5 ohm or 61 ohm resistor and the signal device being tested.

Note that the latter step means that the sense of positive direction of voltage B is opposite to that of voltage A. To obtain the correct phase of the impedance, therefore, the "Phase Reference" panel switch of the HP-3575A must be set to -A.

CONFIGURATION OF THE JIG FOR THE SIMULATED FAULT PULSE TESTS

Operational Goals

For this case, the major goal of the test jig is to permit the insertion of a simulated fault pulse of arbitrary phasing and duration at an arbitrarily chosen point on the output waveform of an electronic track circuit transmitter. Although in reality fault pulses can occur randomly with respect to the transmitter output coding, it is possible that the decoding process implemented by the track circuit receiver is particularly sensitive to fault pulses that occur at certain times. Therefore, it is desirable to be able to easily shift the point of the simulated fault occurrence with respect to the elements of the transmitted code.

A second goal of the test jig for this case is to permit a simple adjustment of the duration of the simulated fault pulse independent of the time position of the pulse. This is desirable since fault duration can vary with the location of the fault along the power line, and the performance of the power system protective relaying [1]. Fault duration may impact the nature of the interference posed by the fault pulse, under conditions where the pulse can be demodulated by the track circuit receiver and wrongly interpreted as a legitimate signal.

A third goal of the test jig for this case is to permit a simple adjustment of the phase of the simulated fault pulse (both on "make" and "break") independent of the time position of the pulse. This is desirable since the points on the 60-Hz waveform where the fault is initiated and ended can affect the observed average value of the fault waveform (dc offset). This, in turn, may influence the decoding process since switched-dc type of pulses are commonly employed as the desired signal.

Input Circuit

Fig. 4 is a block diagram of the instruments needed to realize a simulated fault pulse (tone burst of 60-Hz power) that is synchronized with respect to one code word of the output of the transmitter of an electronic track circuit. The output of the chain of instruments is simply connected to Points I and G of Fig. 2, replacing the HP-204C. The following discussion will briefly summarize the performance of this instrumentation.

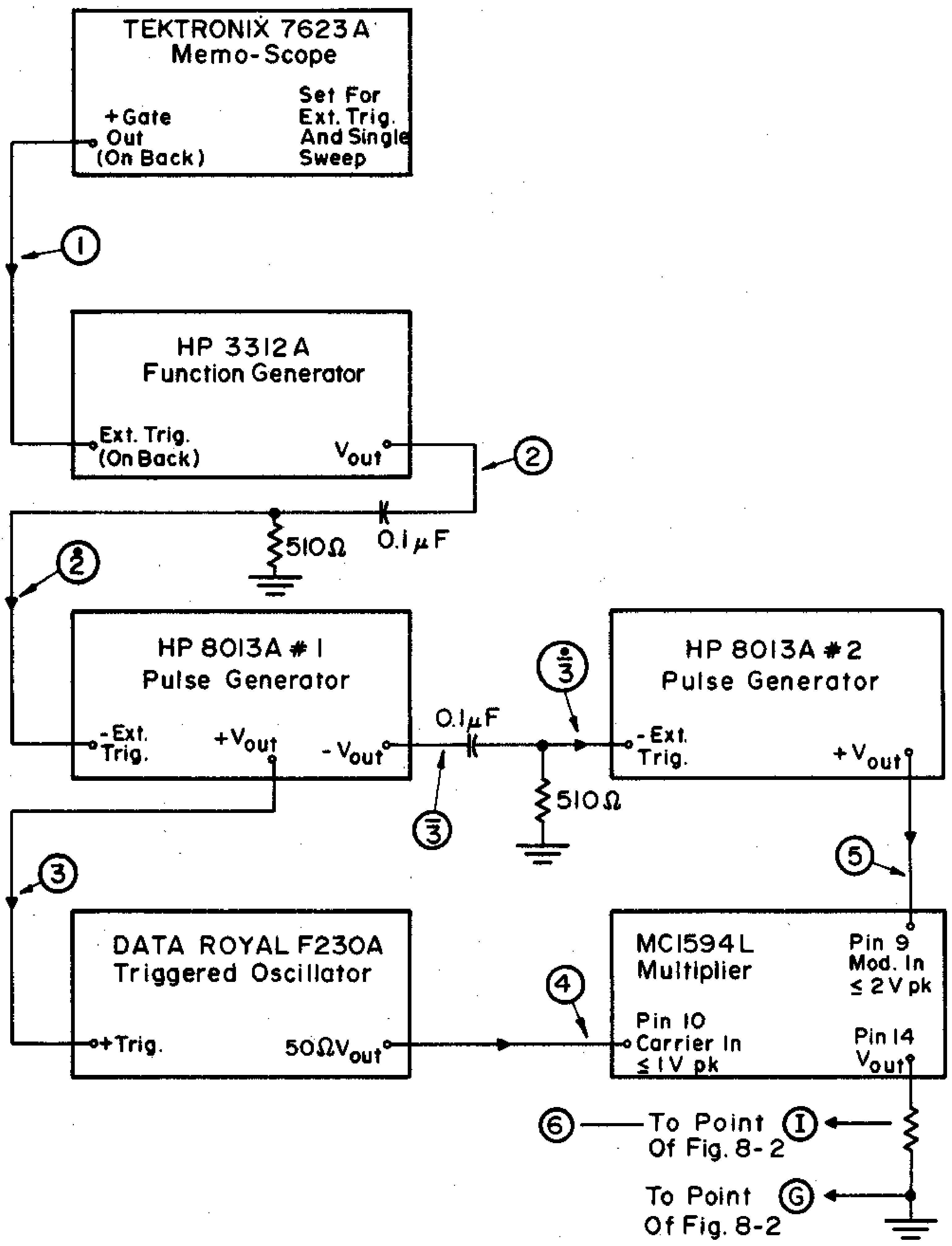


Fig. 4. Input circuit noise source for the simulated fault pulse tests.

Figs. 5 and 6 illustrate how the simulated fault pulse is generated using the instruments of Fig. 4. The circled numbers represent points in the block diagram of Fig. 4 where the sketched waveforms can be observed.

In Fig. 5a, it is planned that the simulated fault pulse begin just at the end of the second desired pulse of Code Word (or Coding Cycle) #N of the track circuit transmitter output. To permit virtually independent adjustment of the position of the fault pulse and its width and phasing, it has been found convenient to split the overall delay between the start of the transmitter code word and the start of the fault pulse into two components. The first delay component, D_A, is the principal delay, which ranges from 0.115 to 10 seconds. D_A serves to position the fault pulse anywhere within the code word or between code words. The second delay component, D_B, ranges from zero to 16.67 msec, and serves to shift the beginning of the fault pulse along the 60-Hz waveform from 0° to 360°.

D_A is realized in the following manner. The Tektronix 7623A memo-scope is set to have a single sweep, and trigger on the leading edge of the first pulse of Code Word #N. The memo-scope then generates a 6V negative-going trigger pulse from its +Gate Out terminal, which is fed to the external trigger of the Hewlett Packard HP-3312A function generator. This instrument is set to provide a 115-msec, 20-V, positive-going pulse from its output terminal, which is delayed from the external trigger pulse by a value adjustable from the front panel. This adjustable delay, called D_A', is considered to be the coarse-delay component of D_A.

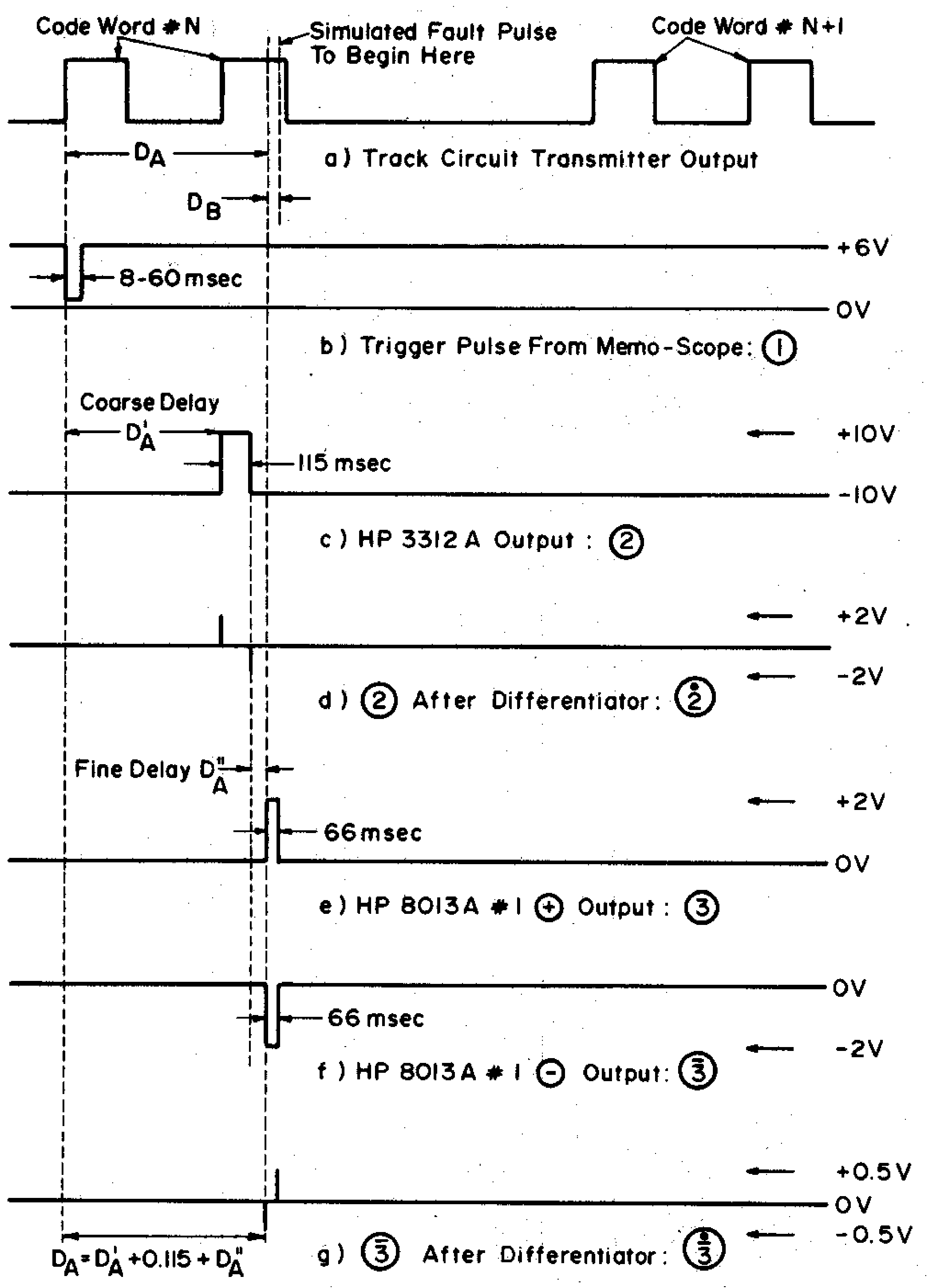


Fig. 5. Initial steps in the generation of the simulated fault pulse waveform.

The output from the HP-3312A is differentiated by a 0.1-microfarad, 510-ohm, L-network, yielding a negative spike at the end of the HP-3312A 115-msec pulse. This negative spike is used to trigger the HP-8013A #1 pulse generator. The HP-8013A #1 unit is set to provide a 66-msec, 2-V, positive-going pulse from its + output terminal, which is delayed from the negative-spike trigger pulse by a value adjustable from the front panel. This adjustable delay, called D_A'', is considered to be the fine-delay component of D_A. Therefore, the total value of D_A equals D_A' + 0.115 second + D_A''.

Two outputs are available from the HP-8013A #1 unit, a positive pulse from $+V_{out}$ and a complementary negative pulse from $-V_{out}$. The positive polarity pulse is fed directly to the Data Royal F230A triggered oscillator. The Data Royal unit immediately begins to generate a tone burst upon triggering, with the carrier frequency of the burst set to be 60 Hz from the front panel. The 60-Hz burst continues for the duration of the 66-msec triggering output from the HP-8013A #1, and then completes one cycle of the 60-Hz waveform after the end of the triggering pulse. Thus, a total of 5 complete cycles of the 60-Hz waveform is produced by the Data Royal. (More cycles can be produced if the triggering pulse from the HP-8013A #1 unit is set to be longer.) The output from the Data Royal is set to be approximately 0.84 V (zero-to-peak), as shown in Fig. 6a.

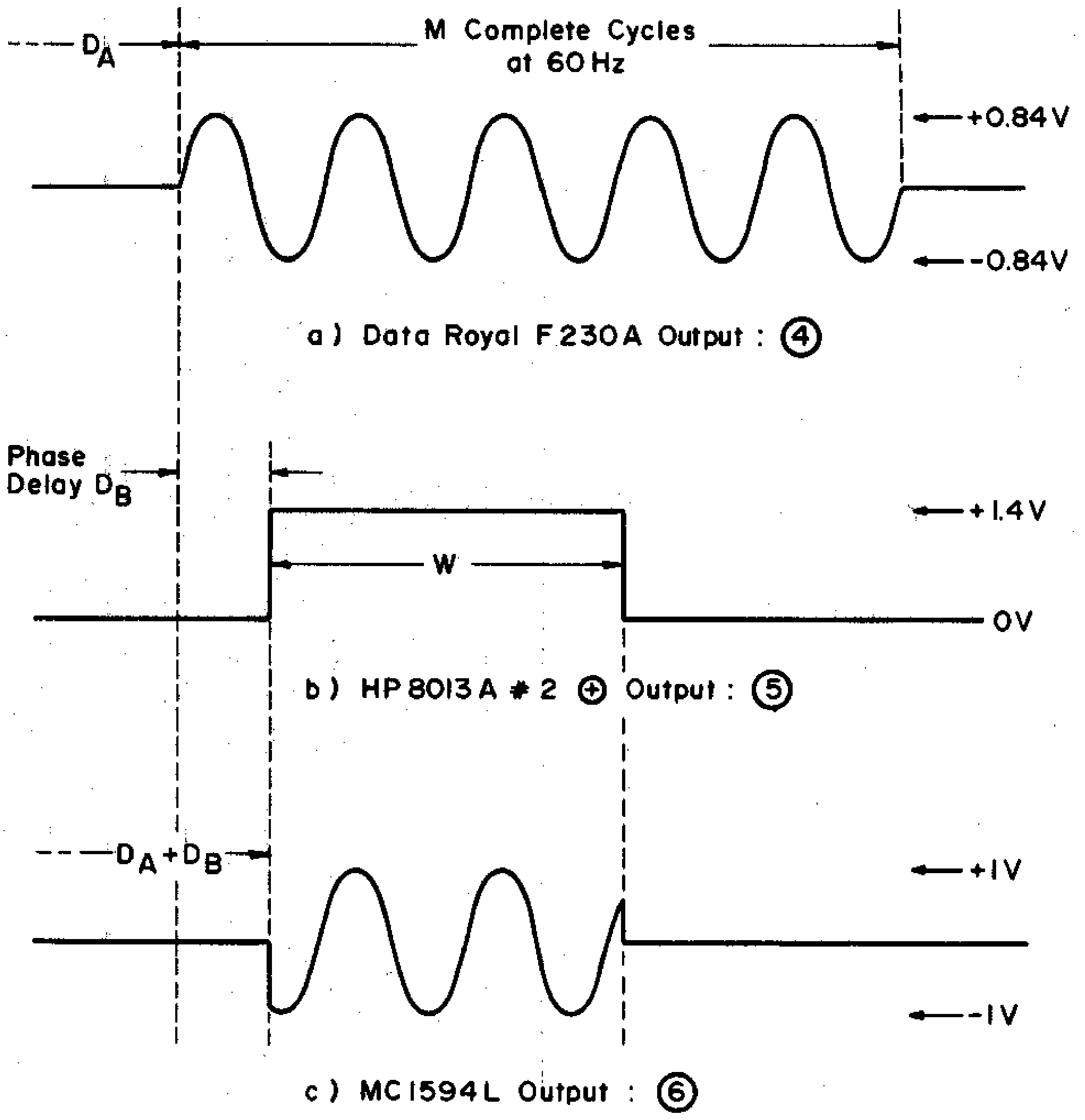


Fig. 6. Final steps in the generation of the simulated fault pulse waveform.

The negative pulse from $-V_{out}$ of the HP-8013A #1 unit is differentiated by another 0.1-microfarad, 510-ohm, L-network, yielding a negative spike at the beginning of the HP-8013A #1 unit's 66-msec pulse. This negative spike is used to trigger the HP-8013A #2 pulse generator. The HP-8013A #2 unit is set to provide a 1.4-V positive-going pulse from its $+V_{out}$ terminal. As shown in Fig. 6b, this pulse is delayed from the negative-spike trigger pulse by a value adjustable from the front panel. This adjustable delay is D_B, which serves to set the point on the 60-Hz waveform where the tone burst begins. Further, the width, w, of the HP-8013A #2 pulse is also adjustable from the front panel, permitting the endpoint of the tone burst to be set.

Now, the tone burst from the Data Royal and the adjustable pulse from the HP-8013A #2 are multiplied together using a Motorola MC-1594L integrated circuit. (The exact circuit is shown in Fig. 7). The output from Pin 14 of the MC-1594L is shown in Fig. 6c. By adjusting D_B and W with the HP-8013A #2, the starting and ending points of the tone burst can be positioned anywhere within the 5-cycle window provided by the Data Royal. This waveform is delayed by a total of $D_A + D_B$ from the leading edge of the first pulse of Code Word #N. The circuit is completed by feeding the output of the MC-1594L to Terminal I of the input circuit of Fig. 2.

The operation of this circuit is shown in Figs. 8 and 9, which are actual oscilloscope photographs. In each photo, the top waveform is the desired signal from the electronic track circuit transmitter, and the bottom waveform is the simulated fault pulse generated as discussed previously. In Fig. 8, the ability of the circuit to position a simulated fault pulse within a coding cycle is shown. Note that the fault pulse position is completely adjustable, and that any intermediate position relative to the code word elements is possible. Note also that the fault pulse is adjusted to simulate 3.5 cycles of the 60-Hz waveform, with beginning and ending points at the zero crossings.

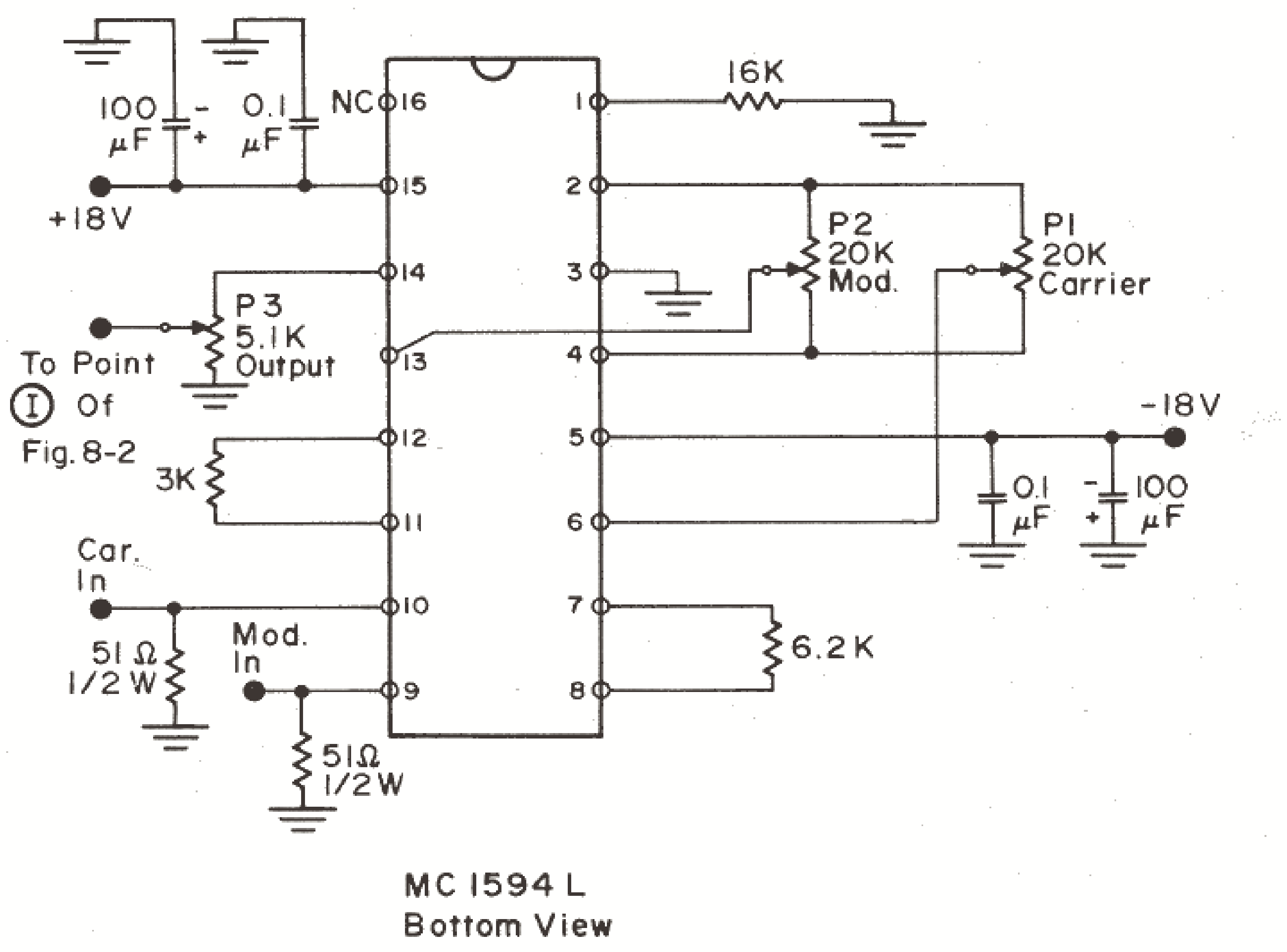


Fig. 7. Circuit diagram of the multiplier.

In Fig. 9, the ability of the circuit to position a simulated fault pulse before a coding cycle is shown. Here, the simulated fault pulse has actually been triggered by the previous coding cycle, but the value of D_A has been lengthened to permit the pulse to appear just before the first element of the new code word. In this manner, it is clear that the circuit of Fig. 4 is capable of testing for fault-pulse susceptibility over the complete range of possible pulse positions with respect to the track circuit coding cycle.

Output Circuit

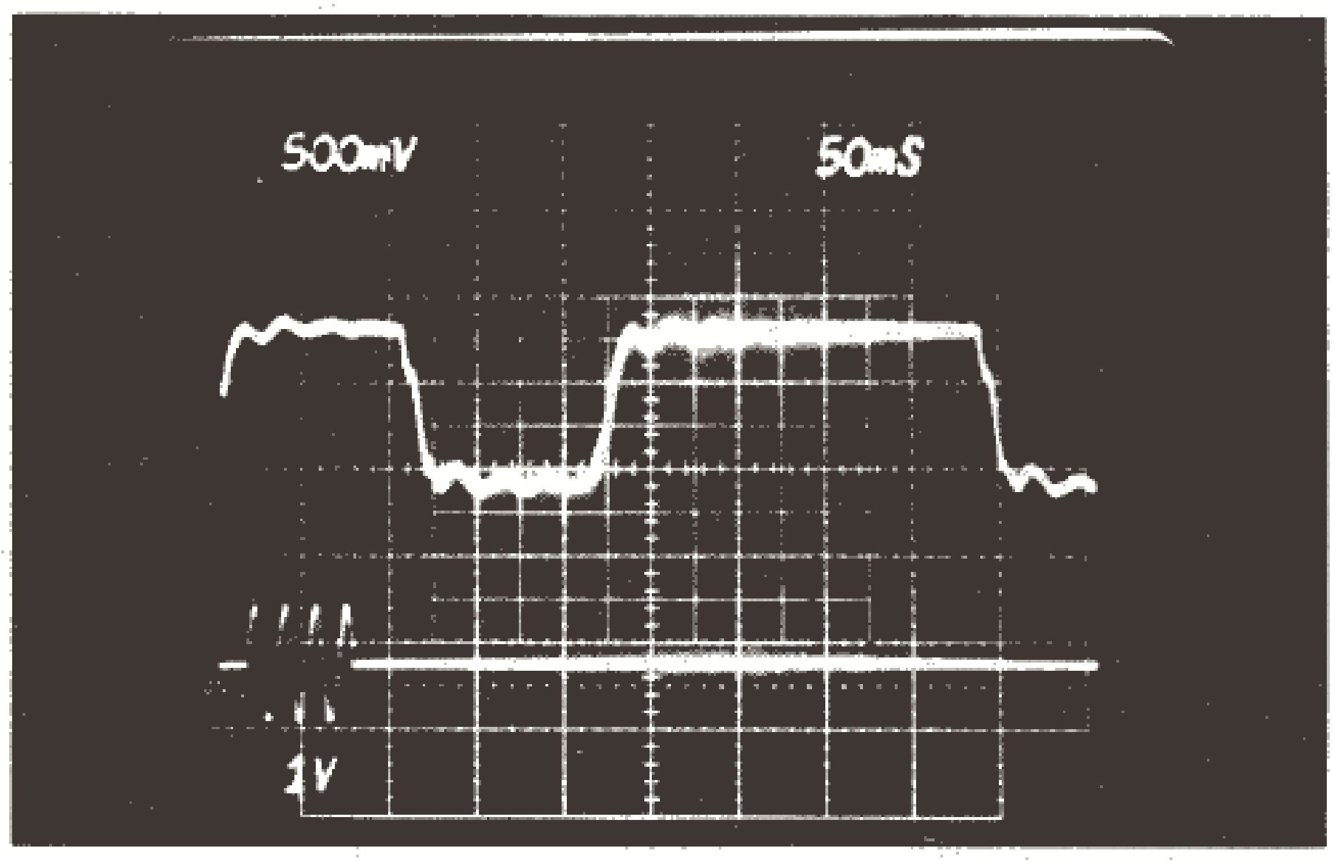
The output circuit of the Crown amplifier is unchanged from that of Fig. 3 used for the cw susceptibility tests. Only the HP-3575A gain-phase meter is removed, because impedance testing is not performed under pulsed conditions.

SUMMARY

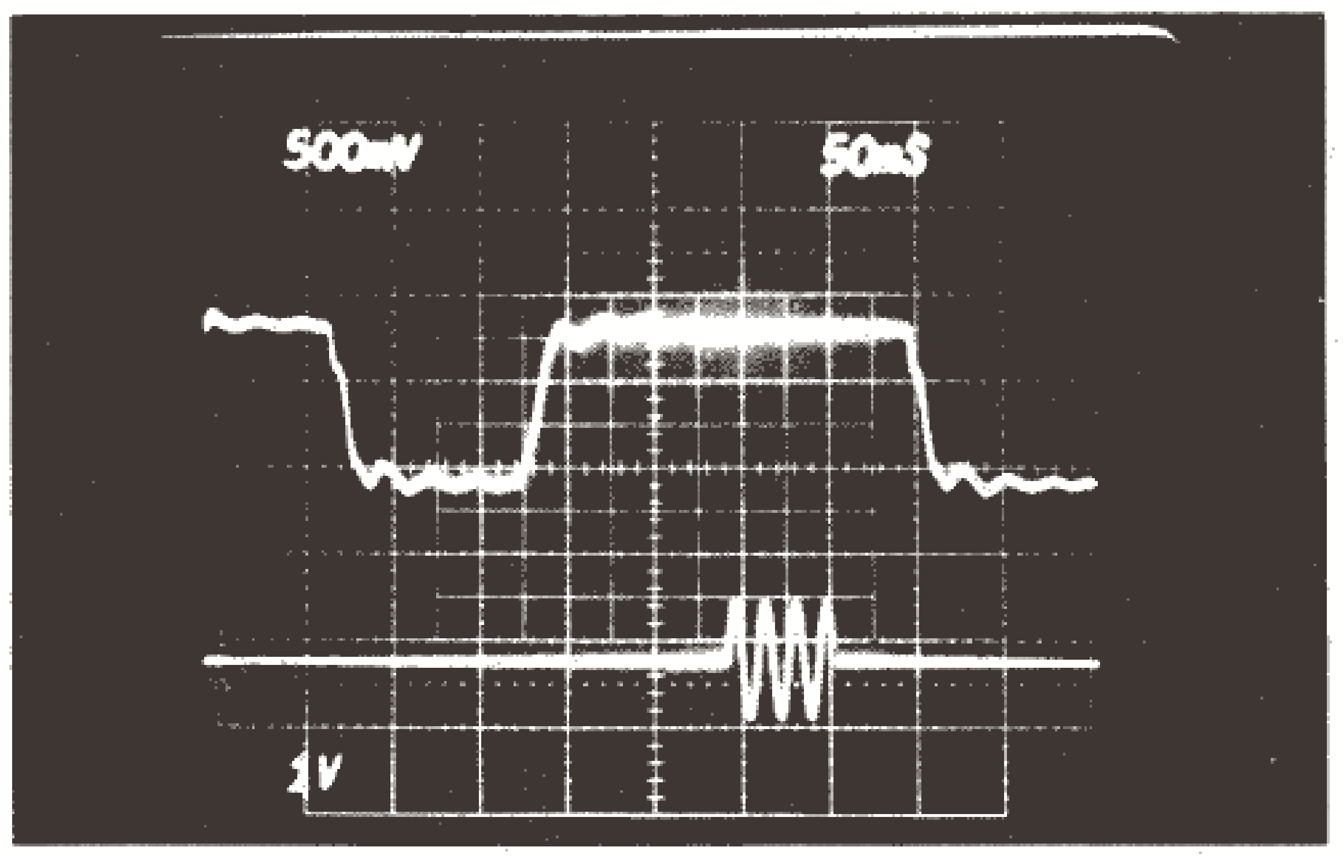
This paper has described an innovative test jig developed under EPRI Program RP 1902-1 which has broad capabilities to test railroad signal equipment for power line interference susceptibility. The test jig has been applied to obtain susceptibility data for track and line relays, electronic track circuits, and grade-crossing warning devices. A companion paper (Part II) describes the results of the tests.

REFERENCE

1) A. Taflove and K. R. Umashankar, Mutual Design of Overhead Transmission Lines and Railroad Communications and Signal Systems. Vol. 1: Engineering Analysis. Vol. 2: Appendixes. Electric Power Research Institute (EPRI) Final Report EL-3301 on Project RP 1902-1, Palo Alto, CA, October 1983.



(a) Within the First Pulse of the Coding Cycle



(b) Within the Second Pulse of the Coding Cycle

Fig. 8. Ability to position a simulated fault pulse within a coding cycle of an electronic track circuit.

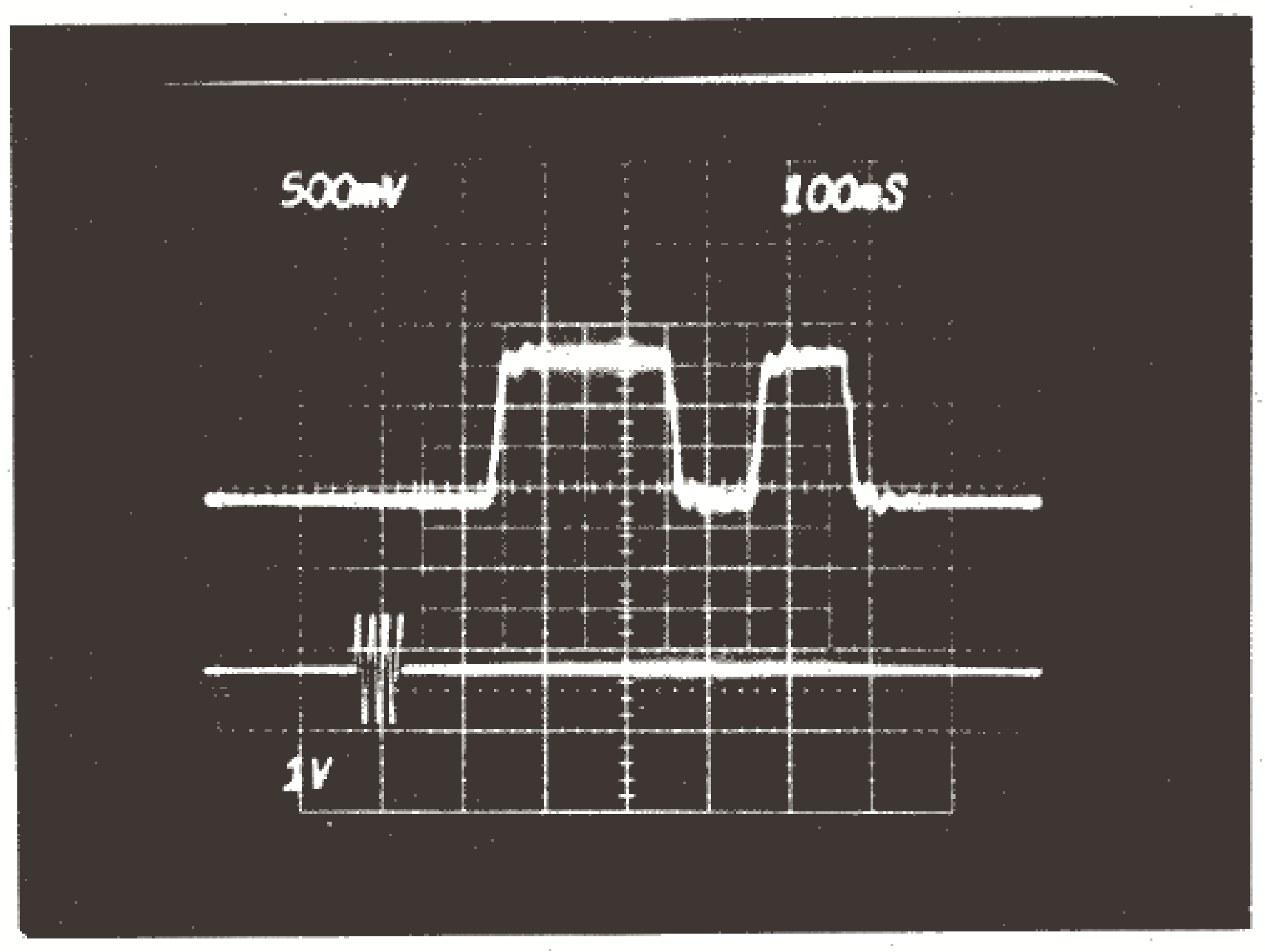


Fig. 9. Ability to position a simulated fault pulse before a coding cycle of an electronic track circuit.

Allen Taflove (M'75, SM'84) was born in Chicago, IL, on June 14, 1949. He received the B.S., M.S., and Ph.D. degrees from Northwestern University, Evanston, IL, in 1971, 1972, and 1975, respectively, all in electrical engineering.

In 1975, he joined IIT Research Institute (IITRI), Chicago, IL. There, his research was concerned with electromagnetic wave penetration and scattering, low-frequency coupling of earth-return transmission-line system, and the development of novel techniques for the recovery of fuels from oil shale and tar sand based upon in situ radio-frequency heating. He was principal investigator on EPRI Program RP 1902-1.

In 1984, he joined Northwestern University, Evanston, IL, as an Associate Professor of Electrical Engineering. At Northwestern, he is continuing his research in electromagnetics, as well as developing a graduate studies program.

Dr. Taflove is a member of Eta Kappa Nu, Tau Beta Pi, Sigma Xi, AAAS, and the New York Academy of Sciences. He has been granted five foreign and two U.S. patents for his in situ fuel recovery inventions. He is senior author of the paper, "Analysis and Modeling of Power Transmission Line Inductive and Ground-Current Coupling to Railroad Communications and Signal Lines," awarded the $500 Best Paper Award at the IEEE 1983 International Symposium on Electromagnetic Compatibility, Washington, D.C.

John H. Dunlap (M'57, SM'83) is a Project Manager in the Overhead Transmission Lines Program, Electrical Systems Division, at the Electric Power Research Institute (EPRI) in Palo Alto, California.

Before joining the Institute in 1979, Mr. Dunlap spent 21 years with Florida Power and Light Company, based in Miami. He was supervisor of Existing Transmission Lines there.

Originally from Chattanooga, Tennessee, Mr. Dunlap received a B.S. degree in Electrical Engineering from the University of Tennessee, Knoxville, in 1957. He was a co-op student with the Tennessee Valley Authority in Chattanooga.

Mr. Dunlap is a senior member of the Institute of Electrical and Electronic Engineers and the Power Engineering Society. He is also a Registered Engineer int he States of California and Florida.

Raymond A. Zalewski (S'59, M'63) received the B.S., M.S., and Ph.D. degrees in electrical engineering from the Illinois Institute of Technology, Chicago, in 1961, 1963, and 1978 respectively.

He joined IIT Research Institute (IITRI), Chicago, Illinois in 1963 and is currently employed there as a Senior Engineer in the Electromagnetic Environmental Effects section. Some of the research areas he has worked in are: interference to railroad electrical systems; electrification of metal objects which are near AC power lines; electromagnetic interference to cardiac pacemakers; EMP protection specifications; and research on various nonlinear effects. Presently, he is involved with predicting and measuring interference to buried pipelines.

Dr. Zalewski is a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi. He is also a registered professional engineer.

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PART II: TEST RESULTS

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Overall, the tests permitted specification of the Thevenin equivalent circuit of each item of signal equipment, as well as the interference threshold level and mode of upset. This permits a "black box" characterization of each item, and easy integration of the device characteristics into the advanced computer programs for modeling ac interference, TRAIN-I and TRAIN-II [1], developed by IITRI under RP 1902-1.

Organization of This Paper

This paper first summarizes the general limitations of the test procedures. Then, the specific test procedures and results for the ac susceptibility behavior of track and line relays, electronic track circuits, and grade-crossing motion detectors and warning devices are presented. Last, recommendations for additional testing to resolve potential safety problems are listed. A companion paper (Part I) describes the test jig used for the ac susceptibility measurements.

GENERAL LIMITATIONS OF THE TEST PROCEDURES

The major limitation of the susceptibility tests is that only a single unit of each type of signal equipment was tested. Therefore, it is not possible at this time to know how the interference threshold and impedance of each type of signal equipment varies because of normal manufacturing tolerances. A study of several samples of each type of equipment would be

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* The latter two tests were performed under subcontract to Science Applications, Inc. Data from these tests have been made available for [1].

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required to obtain a measure of statistical confidence in the results.

A second, and related limitation, is that the signal equipment was tested under normal temperature and humidity conditions in the laboratory. Therefore, it is not possible at this time to know how the interference threshold and impedance of each type of signal equipment varies because of weather conditions.

A third, and related limitation, is that the signal equipment tested was brand new, except for several relays. Therefore, it is not possible at this time to know how the interference threshold and impedance of each type of signal equipment varies because of aging processes when installed in railroad lines.

A fourth limitation is that the signal equipment may have inherent properties which: (1) cause the measured impedance to vary with the applied voltage; and (2) cause the measured susceptibility to vary with the test jig source impedance. Number 1 above results from nonlinearities of the input circuit of the signal equipment, due either to magnetization effects of ferrous-core devices or saturation/clipping effects of semiconductor devices. Number 2 above results from distortion of received pulses due to charging of capacitors or excitation of inductors in the input circuit of the signal equipment. This distortion can vary with the source resistance of the test jig, and can affect the proper decoding of the pulses under noise conditions.

It should be noted by the reader that the four limitations of the susceptibility tests summarized above also apply to real-world installations of signal equipment. There, the effects of manufacturing tolerances, weather, aging, and variable track noise voltages and source impedances also serve to prevent complete uniformity of the equipment operation.

However it is clear that substantial additional testing is required to address the four limitations summarized above. The reader is cautioned that the results obtained to date are of a preliminary nature, and that any conclusions drawn from these results must therefore be considered tentative.

TESTS OF TRACK AND LINE RELAYS

Two generic types of relays were tested, which can be classified as follows: (1) Static relays, which normally remain in one state for substantial periods of time; and (2) Coding relays, which normally change states many times per minute to follow a coding signal. The test procedures and results for these two types of relays are now summarized.

Test Procedures

Static Relays: The basic test procedure was to measure the pick-up and drop-out values of dc relay current under conditions of additive 60-Hz (and harmonic) ac interference ranging from zero to some maximum level. In this manner, it was learned what effect the interfering ac current has on the static relay characteristics. A safe failure was defined to occur when the ac interference caused unacceptably-high measured resistance of the relay front contacts on pick-up, or of the back contacts on drop-out, in the judgment of the signal company representative present. (The increase in the effective contact resistance was caused by vibration of the contacts trying to follow the ac current. At higher levels of ac current, the vibration would become observable in the form of motion, as seen through a magnifying glass; and sound, as heard by the ear. A quite appropriate name for this sound is "chatter.")

An unsafe (false-clear) failure was defined to occur when the ac interference caused the relay front contacts to pick up, even though the normal dc signal current was either zero or reduced to a level substantially below the relay drop-out level. Testing for the false-clear condition was done only at 60 Hz.

Concurrently with the above tests, impedance measurements of the relay were made at 60 Hz and power harmonic frequencies through 540 Hz. Both magnitude and phase angle of the impedance were recorded.

Coding Relays: Here, the basic test procedure was to operate the relay at 75, 120, or 180 times per minute under conditions of additive 60-Hz (and harmonic) ac interference ranging from zero to some maximum level. With the relay coding, the relay contacts were used to chop the output voltage of a small dc supply at the coding rate. This chopped voltage was then applied to the input of an adjustable band-pass filter (the Krohn-Hite 330-M) which was tuned to approximate the response of the actual frequency-selective circuit following the relay.* With the ac interference introduced, the filter output was observed on an oscilloscope.

A safe failure was defined to occur when the ac interference caused the filter output to diminish below the detection level. A second type of safe failure was defined to occur when the ac interference caused a more restrictive filter output to appear (say 120 when a 180 code was being sent to the relay). An unsafe (false-clear) failure was defined to occur when the ac interference caused a less restrictive filter output to appear than desired. In all cases of judgment, the signal company representative present was called upon for his assessment of the magnitude of the filter output.

Test Results

Table I lists the test results for the ac interference susceptibility thresholds of nine track and line relays. Each relay is identified by its generic, engineering description. This generic data reporting is in accord with agreements reached by EPRI, IITRI, and the four signal equipment firms to permit their involvement in EPRI Program RP 1902-1.

This table shows the nominal values of relay pick-up current, I(pu), and drop-out current, I(do), that were measured. Interference thresholds for safe failures are shown at the power-related frequencies through the ninth harmonic. The false-clear threshold appears in the last column. Where the symbol > appears before a voltage threshold, it means that voltage levels beyond that point were not tested due to concerns about the survivability of the relay coil at the high ac levels. All voltages shown are given in rms volts. Finally, the symbol N/A stands for "not available," which means simply that the data for a given frequency or other condition was not taken.

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*A Hewlett-Packard HP-3312A function generator was connected to Terminals S and G of Fig. 2 of Part I to provide square pulses at 75, 120, or 180 per minute (1.25 Hz, 2.0 Hz, or 3.0 Hz, respectively). The pulsing current through the relay coil was adjusted to be either the assured operating value or the assured drop-out level. The filter characteristics were adjusted by the signal company represntative present. For example, the filter was set to have a passband from 102 to 145 per minute (1.7 Hz to 2.4 Hz) for the case of a relay coding at 120 per minute (2.0 Hz).

Table I. Rail-to-Rail or Line-to-Line Voltages for Malfunction of Track and Line Relays

	Relay Type*	I(pu) I(do)	60 Hz	120 Hz	180 Hz	240 Hz	300 Hz	360 Hz	420 Hz	480 Hz	540 Hz	60 Hz F. C.
1.	2-ohm neutral track relay. Shelf-type, 2 Form C contacts	85 mA 66 mA	2.0 V	6.0 V	>16 V	>16 V	>16 V	>16 V	>16 V	>16 V	>16 V	32 V
2.	2-ohm neutral track relay. Shelf-type, 4 Form C contacts	96 mA 60 mA	9.0 V	>16 V	>16 V	>16 V	>16 V	>16 V	>16 V	>16 V	>16 V	>50 V
3.	4-ohm neutral track relay. Shelf-type, 4 Form C contacts	74 mA 51 mA	14.0 V	>16 V	>16 V	>16 V	>16 V	>16 V	>16 V	>16 V	>16 V	>50 V
4.	500-ohm neutral line relay. Shelf-type, 4 Form C contacts	7.5 mA 5.0 mA	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V
5.	500-ohm neutral line relay. Shelf-type, 6 Form C contacts	11 mA 7 mA	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V
6.	500-ohm neutral line relay. Plug-in type, 6 Form C contacts	12 mA 9 mA	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V	>90 V
7.	0.3-ohm polar track relay. 2 Form C contacts	380 mA 200 mA	0.3 V	0.6 V	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8.	1.8-ohm neutral track relay Rack mount, 4 Form C contacts	103 mA 72 mA	7.0 V	10 V	19 V	14 V	25 V	>50 V	>50 V	>50 V	>50 V	>50 V
9.	200-ohm code responsive relay. Plug-in type	19 mA 8 mA	40 V	>50 V	>50 V	N/A	N/A	N/A	N/A	N/A	N/A	>50 V

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*Data obtained for EPRI Project RP-1902-2 under subcontract to Science Applications, Inc.

Comments

Thresholds for a safe failure of neutral track relays ranged from 2.0 V (Relay #1) to 14 V (Relay #3). This range of susceptibility levels indicates that replacement of one neutral track relay with another can help to mitigate a signal system interference problem. One neutral track relay (Relay #1) exhibited a false-clear failure, which required 32 V. The reader should note that such a large rail-to-rail voltage is possible under broken-rail conditions, as discussed in Section 10 of [1].

Thresholds for a safe failure of neutral line relays were all in excess of 90 V. Similarly, thresholds for false-clear failures were all in excess of 90 V. These relays seem to be quite immune to ac interference under conditions of substantial voltages impressed across their operating coils.

Relay #7 was very susceptible to safe failure, requiring only 300 mV. This relay is an apt candidate for replacement in situations of moderate or even low levels of ac interference. However, replacement may require substantial redesign of the track circuit system to accomodate less susceptible relays employing higher operating signal levels.

The code-responsive relay (Relay #9) proved to be quite immune to ac interference, when operated with a simulated code-rate bandpass filter following the relay. This may be a good substitute for other relays in a rather severe case of ac interference. Again, redesign of portions of the signaling system may be needed to permit such a substitution. Also, space for the addition of decoding filters may require additional wayside housings at locations having too little spare room in existing enclosures.

TESTS OF ELECTRONIC TRACK CIRCUITS

Four different dc pulse-coded electronic track circuits, and two audio-frequency pulse-coded electronic track circuits, were tested for ac interference susceptibility and receiver impedance. These track circuits are currently sold by four different U.S. manufacturers, to be designated "Q", "X", "J", and "V". (This generic data reporting is in accord with agreements reached by EPRI, IITRI, and the four signal suppliers to permit their involvement in EPRI Program RP 1902-1.) The test procedures and results for this equipment are now summarized.

Test Procedures

The track circuit to be tested was first set up for normal operation by the signal company representative present. In this case, this means that the track circuit transmitter was used to provide a desired signal voltage to the track circuit receiver through the Sanborn 8875/Crown M-2000 amplifier chain. The gain of the amplifier chain was adjusted to provide nominal levels of signal current or voltage at the receiver terminals. One or more codes could then be transmitted, received, and decoded to demonstrate proper operation of the system.

For the continuous wave (cw) interference tests, 60-Hz or pure harmonic interference (from 120 Hz to 540 Hz) was added gradually to the desired signal. A safe failure was defined to occur when the ac interference caused the decoded signal to drop to red. A second type of safe failure was defined to occur when the ac interference caused a more restrictive code to appear on the receiver output than was transmitted. An unsafe (false-clear) failure was defined to occur when the ac interference caused a less restrictive receiver indication than was transmitted. False-clear tests were done with either no desired signal at the receiver, or the desired signal reduced to a level at least 3 dB below the minimum operating threshold of the receiver. (The latter approximated the condition of a broken rail, a partially-contacting switch, etc., which could reduce the desired signal at the receiver and should result in a red indication.) The cw interference tests were repeated for the case of front-end interference filters used at the receiver, if such filters were made available by the manufacturer involved.

For the simulated fault-pulse tests, a 60-Hz tone burst of variable phasing and width was added to the desired signal at various points during the coding cycle. The position of the simulated fault pulse was changed to see if there was any effect. Only limited testing in this regard was done because there are so many possibilities for phasing, width, time position, and amplitude of the simulated fault pulse.

Test Results

Table II lists the test results for the cw interference susceptibility of the six track circuits. Since each manufacturer provides specific, unique features, this table is divided into four parts which permit specification of these unique attributes. As for the relay tests, all voltages are rms; the symbol > indicates that voltages above the given level were not tested; and N/A indicates that the test was not performed. Additional relevant data for each track circuit test is provided in the footnotes.

Fig. 1 shows the position of the simulated fault pulse for a momentary decoding error of the electronic track circuit of Manufacturer "J". As shown in Fig. 2, the effect of randomly positioning the pulse in this manner was to cause the nominal detector output at the receiver to briefly "glitch" downward. This caused the nominal long-short pulse output to be interpreted as a long-short-short pulse output. The effect on the signal aspect displayed by the receiver was a transition to a less-restrictive state than transmitted. However, this less-restrictive state continued only until the next coding cycle (a few seconds), when the proper aspect was again displayed.

Table II. Rail-to-Rail Voltages for Malfunction of Electronic Track Circuits

Manufacturer "Q"[*]	60 Hz	120 Hz	180 Hz	240 Hz	300 Hz	360 Hz	420 Hz	480 Hz	540 Hz
Safe-failure susceptibility:[a]									
For system as received	0.1 V	0.5 V	0.6 V	0.9 V	N/A	N/A	N/A	N/A	N/A
Input capacitor removed	0.5 V	0.4 V	0.3 V	0.3 V	0.2 V	0.2 V	0.2 V	0.2 V	0.2 V
With supplied filter	23 V	0.7 V	0.4 V	0.3 V	0.2 V	0.2 V	0.2 V	0.1 V	0.1 V
False-clear susceptibility:[b]									
Lower threshold	>6 V	0.1 V	0.1 V	N/A	N/A	N/A	N/A	N/A	0.1 V
Upper threshold	>6 V	0.2 V	0.2 V	N/A	N/A	N/A	N/A	N/A	0.2 V
Composite interference[c] for no false clear	0.1 V		0.15 V						

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[*] Data obtained for EPRI Project RP-1902-2 under subcontract to Science Applications, Inc.

[a] Nominal received signal = 1.5 V_{pk-pk}; minimum received signal = 0.65 V_{pk-pk}. Received signal set for nominal here.

[b] Received signal set at 0.3 V_{pk-pk} (6.7 dB below operating threshold). Input capacitor removed; no filter used.

[c] Power line interference is almost never a pure harmonic. Thus, it is reasonable to test the effect of a 60-Hz + harmonic composite interference voltage.

Manufacturer "X"[*]	60 Hz	120 Hz	180 Hz	240 Hz	300 Hz	360 Hz	420 Hz	480 Hz	540 Hz
Safe failure susceptibility:[a]									
For system as received	1.4 V	3.8 V	>4 V	>4 V	>4 V	>4 V	>4 V	>4 V	>4 V
With supplied filter	21 V	15 V	>8.4 V	>6.5 V	>5.5 V	>4.9 V	>4.9 V	>4.7 V	>4.6 V
False-clear susceptibility:[b]	>5 V	>4 V	>4 V	>4 V	>4 V	>4 V	>4 V	>4 V	>4 V

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[*] Data obtained for EPRI Project RP-1902-2 under subcontract to Science Applications, Inc.

[a] Nominal received signal = 1.0 V_{pk-pk} (1.0 A_{pk-pk}); minimum received signal = 0.65 V_{pk-pk}. Received signal set for nominal here.

[b] Received signal set for 0.46 V_{pk-pk} (0.46 A_{pk-pk}), a level 3.0 dB below operating threshold. No filter was used.

Table II (continued). Rail-to-Rail Voltages for Malfunction of Electronic Track Circuits

Manufacturer "V"	60 Hz	120 Hz	180 Hz	240 Hz	300 Hz	360 Hz	420 Hz	480 Hz	540 Hz
Solid-state dc-coded track circuit									
Safe-failure susceptibility:[a]	15 V	7.3 V	21 V	46 V	>50 V	>50 V	>50 V	>50 V	>50 V
False-clear susceptibility:[b]	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V
Audio-frequency pulse-coded track circuit (operating freq. ≈ 160 Hz)									
Safe-failure susceptibility:[c]	>50 V	24 V	3.7 V	16 V	>50 V	>50 V	>50 V	>50 V	>50 V
False-clear susceptibility:	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V
Audio-frequency pulse-coded track circuit (operating freq. ≈ 210 Hz)									
Safe-failure susceptibility:[c]	>50 V	>50 V	33 V	7.3 V	32 V	39 V	>50 V	>50 V	>50 V
False-clear susceptibility:	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V

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[a] Received signal set for nominal level of 1.0 A_{pk-pk}. No interference filters were provided by the manufacturer.

[b] Received signal set for 0.2 A_{pk-pk}, a level approximately 6 dB below operating threshold.

[c] Received signal set for nominal detector output of 17 V (zero-to-peak)

Manufacturer "J"	60 Hz	120 Hz	180 Hz	240 Hz	300 Hz	360 Hz	420 Hz	480 Hz	540 Hz
Safe failure susceptibility:[a]									
For system as received	18 V	7.7 V	12 V	17 V	21 V	24 V	30 V	33 V	35 V
With filter "A" (60 Hz)	56 V	5.2 V	11 V	14 V	18 V	23 V	25 V	31 V	33 V
With filter "B" (60/120 Hz)	56 V	34 V	7.4 V	13 V	18 V	23 V	25 V	28 V	31 V
With filter "C" (choke)	40 V	17 V	25 V	30 V	36 V	44 V	49 V	54 V	54 V
With filter "D" (harmonics)	15 V	38 V	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V	>50 V
Test for improper operation:[b]									
For system as received[c]	43 V	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
With filter "B" (60/120 Hz)[d]	56 V	34 V	6.4 V	10 V	14 V	N/A	N/A	N/A	N/A

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[a] Nominal received signal = 1.0 A_{pk-pk}; minimum received signal = 0.6 A_{pk-pk}. Received signal set for nominal here.

[b] Received signal set for 0.2 A_{pk-pk}, a level approximately 10 dB below operating threshold.

[c] Track fuse blew; no improper signal resulted.

[d] Receiver operated two codes that should not have operated.

Comments

Safe Failures: Thresholds for a safe failure of dc-coded electronic track circuits for the unfiltered case at 60 Hz ranged from 0.1 V (Manufacturer "Q") to 18 V (Manufacturer "J"). This is almost a 200:1 range. Similarly, the availability and usefulness of front-end filters supplied by the manufacturers was widely variable. Manufacturer "V" provided no filters at the time of testing. Manufacturers "Q" and "X" provided filters only for 60-Hz interference. On the other hand, Manufacturer "J" provided a full line of filters for both 60 Hz and harmonics.

The susceptibility of the dc-coded electronic track circuits to harmonic energy was also widely variable. Safe failures were noted at levels of less than 1 V of harmonic energy for Manufacturer "Q", with or without the supplied 60-Hz filter. The overall best harmonic rejection without using front-end filters was achieved by the equipment of Manufacturer "V". With the application of front-end filters, the best overall harmonic rejection was achieved by the equipment of Manufacturer "J".

The thresholds for safe failure of the audio-frequency pulse-coded track circuits of Manufacturer "V" were very high at 60 Hz, exceeding 50 V. However, sharp dips (vulnerable points) in the frequency spectrum were noted at 180 Hz and 240 Hz, near the respective carrier frequencies of the equipment.

False Clears: In the susceptibility testing of the electronic track circuits, there were two cases of decoding errors possibly leading to false clears. Since these findings have potential implications for railroad safety, these two cases will now be discussed in some detail.

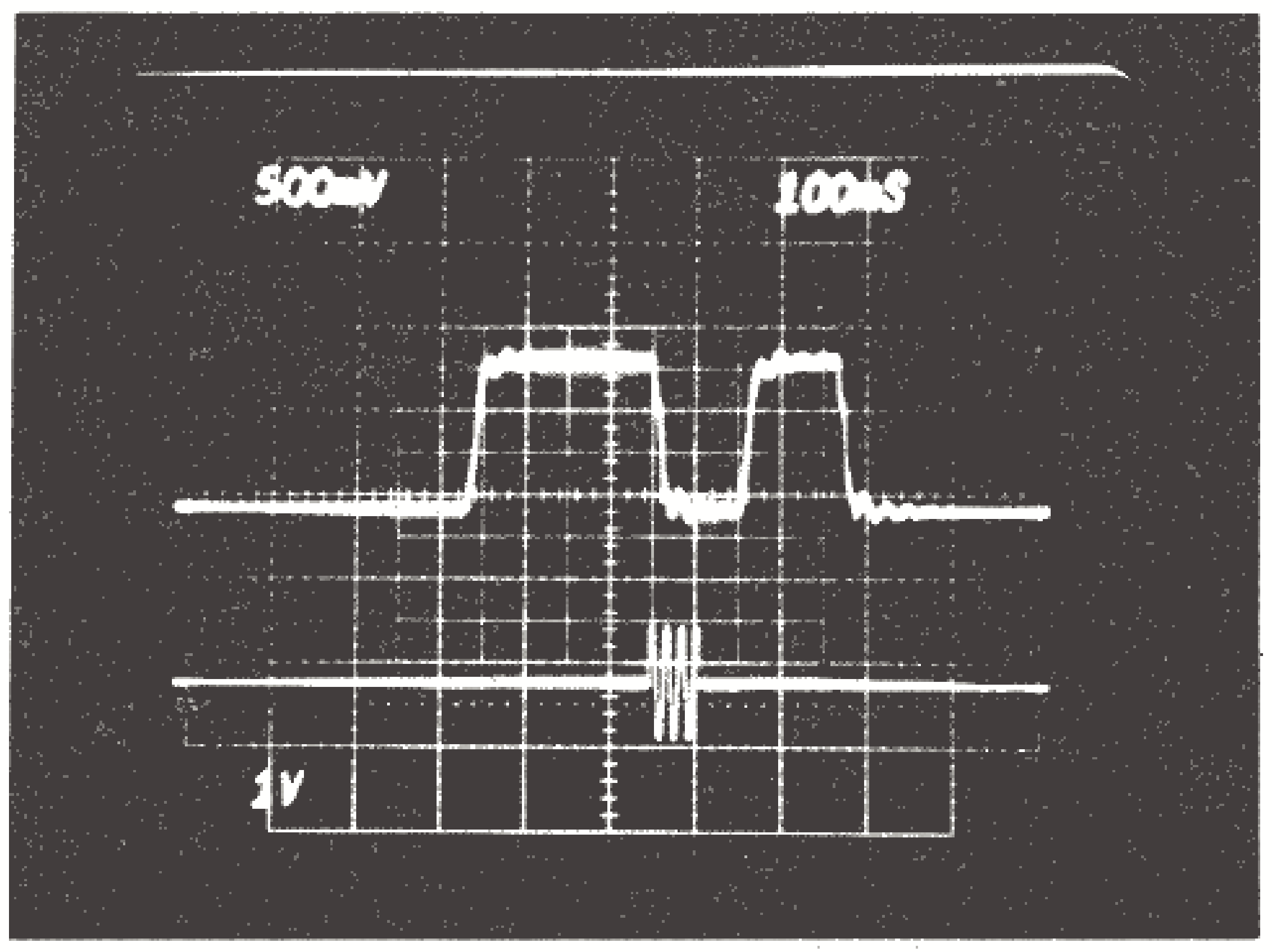
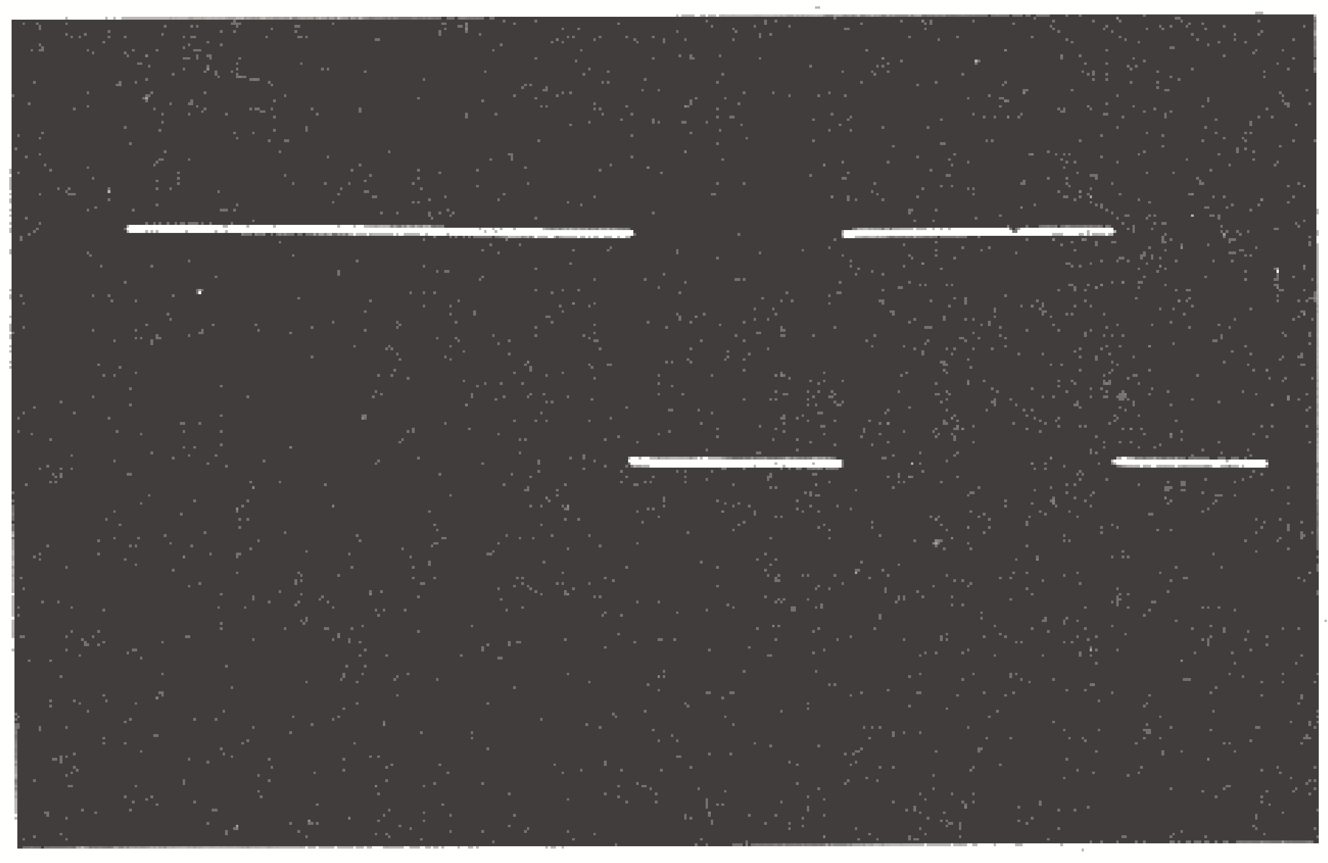
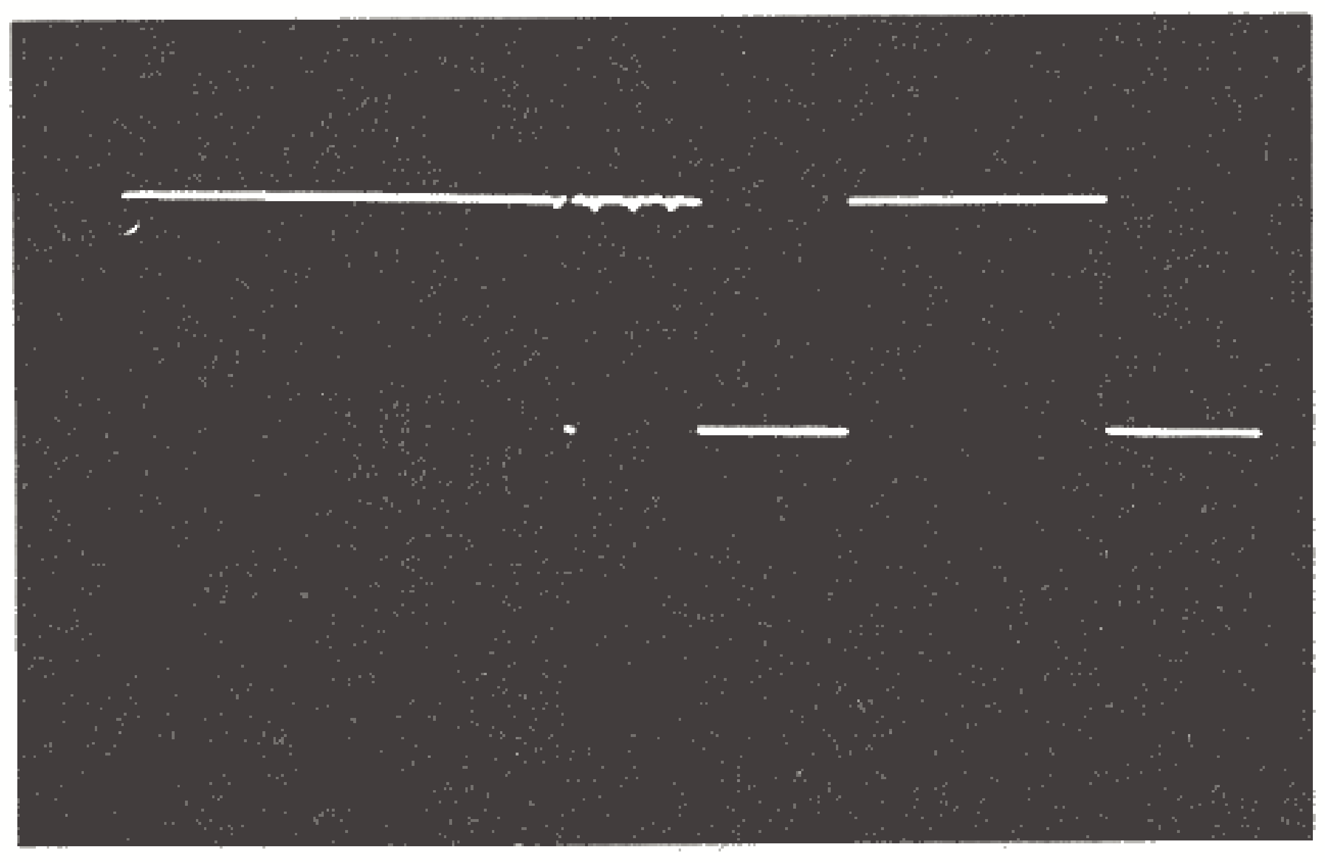


Fig. 1. Position of the simulated fault pulse for a decoding error of the electronic track circuit of Manufacturer "J".



(a) Nominal Detector Output



(b) Detector Output During Interference by the Simulated Fault Pulse

Fig. 2. Detector output of the electronic track circuit receiver of Manufacturer "J" during the simulated fault pulse of Fig. 1.

We first consider the decoding error obtained during the cw testing of the dc-coded electronic track circuit of Manufacturer "Q". This occurred when pure harmonic interference at either 120 Hz, 180 Hz, 240 Hz, 300 Hz, 360 Hz, 420 Hz, 480 Hz, or 540 Hz was adjusted to be in the range 0.1 V to 0.2 V; and the desired coding signal was adjusted to be about 7 dB below the operating threshold of the receiver. The result was the display of a yellow signal aspect or a green aspect (possibly intermittent), instead of the required red aspect. It was noted that the sum of the peak-to-peak harmonic voltage plus the peak-to-peak desired coding signal equaled the minimum receiver decoding threshold. Adjustment of the harmonic voltage to either a lower or higher level caused the false-clear indication to disappear.

A concern was expressed by the representative of the manufacturer (who witnessed this test) that the pure harmonic interference case is not at all realistic for a 60-Hz power line; and that some 60-Hz component should properly be added to the interference. It was agreed that this should be tried. It was found that the false-clear indication disappeared when the 60-Hz component was approximately equal to or greater than the harmonic component.

Therefore, it was concluded that this particular false-clear is unlikely to occur, unless a 60-Hz rejection filter is placed ahead of the receiver so that only harmonic energy comes through. (This is a curious situation where the presence of the 60-Hz energy on the track would serve to mitigate a potentially serious decoding problem.) In this case, it is essential to employ a front-end filter that has approximately uniform suppression of 60-Hz energy as well as the principal power line harmonics.

We next consider the decoding error obtained during the simulated fault-pulse testing of the dc-coded electronic track circuit of Manufacturer "J". This occurred when a 3.5-cycle tone burst at 60 Hz was positioned at the trailing edge of the long pulse of the code word, as shown in Fig. 1. The amplitude of the tone burst was 58 amperes peak going into the receiver chassis, with 140 V peak rail-to-rail.

At this time, there are many unresolved questions regarding the potential for this type of malfunction, and the effects of this malfunction even if it occurs, for the electronic track circuits of the various manufacturers. (At this point, only the equipment of Manufacturer "J" has had testing for fault-pulse susceptibility.) First, the probability of a randomly-occurring fault pulse appearing at a vulnerable point in the coding cycle is unknown. Detailed studies are needed to resolve the sensitivity of the decoding process to fault pulses having variable width, phasing, timing, and amplitude, for the equipment of the various manufacturers. Second, the probability of a momentary decoding error which could result in a false-clear aspect causing an engineman to respond in an unsafe manner is unknown. The false-clear indication due to a fault pulse lasts only until the next coding cycle of the track circuit, which may be an interval too brief to allow an incorrect train operation to occur. However, this question must be resolved, for the sake of safety.

TESTS OF MOTION-SENSING AND GRADE-CROSSING WARNING DEVICES

Three motion-sensitive devices and two grade-crossing constant-warning time devices of Manufacturer "V" were tested for ac interference susceptibility and impedance. The test procedures and results for this equipment are now summarized.

Test Procedures

The motion-sensitive device or grade-crossing constant-warning time device was first set up for normal operation by the signal company representative present. Similar to the tests of the electronic track circuits, the Sanborn 8875/Crown M-2000 amplifier chain was placed in the loop between the transmitter and receiver units. The gain of the amplifier chain was adjusted to provide nominal levels of signal current or voltage at the receiver. With the test jig set up only for continuous wave (cw) measurements, 60-Hz or pure harmonic interference (from 120 Hz to 540 Hz) was added gradually to the desired signal. A safe failure was defined to occur when the ac interference caused the receiver to issue a gate-down command. An unsafe (false-clear) failure was defined to occur when the ac interference caused the receiver to issue a gate-up command. No front-end filters were provided by the manufacturer to test.

Results

Table III lists the test results for the cw interference susceptibility of the motion-sensing and grade-crossing warning devices. Additional relevant data is provided in the footnotes.

Comments

Thresholds for a safe failure of the motion-sensitive devices ranged from 0.24 V to 1.7 V at 60 Hz. The higher thresholds were exhibited by Model "A" having an operating frequency near 160 Hz, and by Model "B". Model "B" also exhibited improved performance relative to harmonic susceptibility, especially at 180 Hz and above. It may be desirable for front-end filters to be designed for such units to improve both the poor 60-Hz and harmonic performance, since the measured levels may be marginal with respect to real-world rail-to-rail interference voltages.

Table III. Rail-to-Rail Voltages for Malfunction of Motion-Sensing and Grade-Crossing Warning Devices

Manufacturer "V"	60 Hz	120 Hz	180 Hz	240 Hz	300 Hz	360 Hz	420 Hz	480 Hz	540 Hz
Motion-sensitive device, Model "A" (operating freq. ≈ 90 Hz)									
Safe-failure susceptibility:[a]	0.24 V	0.24 V	0.60 V	0.84 V	1.1 V	1.5 V	1.7 V	1.8 V	2.1 V
Gate-up failure (unsafe):	>50 V	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Motion-sensitive device, Model "A" (operating freq. ≈ 160 Hz)									
Safe-failure susceptibility:[a]	1.7 V	1.5 V	0.32 V	2.0 V	2.9 V	4.0 V	4.9 V	5.4 V	6.0 V
Gate-up failure (unsafe):	>50 V	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Motion-sensitive device, Model "B" (operating freq. ≈ 90 Hz)									
Safe-failure susceptibility:[b]	1.3 V	1.3 V	3.2 V	4.3 V	5.4 V	6.6 V	8.5 V	9.4 V	10 V
Gate-up failure (unsafe):[c]	>50 V	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

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[a] Received desired signal set to the nominal operating level of 50 mV. Safe failure means a gate-down failure.

[b] Received desired signal set to the nominal operating level of 300 mV.

[c] Received desired signal set to a sub-operating level of 7 mV, just at the AGC threshold.

Manufacturer "V"	60 Hz	120 Hz	180 Hz	240 Hz	300 Hz	360 Hz	420 Hz	480 Hz	540 Hz
Grade-crossing constant-warning time device (operating freq. ≈ 90 Hz)									
Safe-failure susceptibility, low-current test (110 mV desired signal at receiver)	0.25 V	0.32 V	3.2 V	20 V	>40 V	N/A	N/A	N/A	N/A
Safe-failure susceptibility, high-current test (330 mV desired signal at receiver)	0.79 V	0.89 V	9.4 V	36 V[a]	N/A	N/A	N/A	N/A	N/A
Grade-crossing constant-warning time device (operating freq. ≈ 160 Hz)									
Safe-failure susceptibility, low-current test (260 mV desired signal at receiver)	19 V	0.37 V	0.36 V	1.3 V	4.9 V	15 V	35 V	N/A	N/A
Safe-failure susceptibility, high-current test (605 mV desired signal at receiver)	43 V	3.8 V	0.85 V	3.1 V	12 V	35 V	N/A	N/A	N/A

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[a] Receiver giving off smoke.

None of the units tested gave an indication of a gate-up (unsafe) failure at levels up to 50 V at 60 Hz. This is very encouraging.

Thresholds for a safe failure of the grade-crossing constant-warning time devices ranged from 0.25 V to 43 V at 60 Hz. The higher thresholds were exhibited by a device operating near 160 Hz, especially when adjusted to provide a high level of desired signal at the receiver. However, the usefulness of this device is degraded by its poor susceptibility threshold at the harmonics 120 Hz, 180 Hz, and 240 Hz. A properly-designed harmonic filter would seem to provide a potential benefit here.

SUMMARY AND RECOMMENDATIONS

This paper has described the results of ac interference susceptibility tests of several important types of railroad signal equipment. These tests were performed under EPRI Programs RP 1902-1 and RP 1902-2. A companion paper (Part I) describes the innovative test jig developed under RP 1902-1 which was used to perform the tests.

Apparently, the ac interference susceptibility testing described in this paper represents the first concerted effort to obtain such data for a broad range of recent railroad signal equipment. The greater than 100 to 1 variability of the measured safe-failure levels found during these tests indicates an absence of standardization of ac susceptibility levels in the railroad signal industry.

A key result of the lack of susceptibility data and standards is the present uncertainty concerning the vulnerability of railroad signal equipment to a false-clear condition caused by ac interference. This condition was found outright in one track relay. Further, two electronic track circuits evidenced decoding errors which might lead to false clears under certain conditions. For example, one of the electronic track circuits gave a false clear (red-to-green) failure with as little as 0.10 V rms of harmonic voltage across its rail-to-rail input terminals, if the 60-Hz voltage was limited to less than this level via filtering, and if a sub-operating-level green signal was also received.

Recommendations to the Utilities

In the absence of railroad industry susceptibility data and standards, utilities are advised to work with the railroads to set up measurement procedures (or procurement standards) to test each item of vital railroad signal equipment that may be subjected to ac interference. Both safe failures and false-clear failures should be tested. In this manner, equipment with relatively good interference behavior, such as certain conventional electromechanical relays, could be specified for installation. Equipment with relatively poor or unsafe interference behavior could be pinpointed.

If electronic track circuits are considered, a careful check of the following possible decoding-error modes should be made.

- Mode 1: Low-level 60-Hz and harmonic interference voltages adding to a sub-operating level of signal voltage to generate a detector output when no output should be obtained;
- Mode 2: High-level 60-Hz and harmonic interference voltages causing a brute-force change of the detector output to a less restrictive state than desired;
- Mode 3: Fault-pulse interference causing splitting of signal code pulses to temporarily shift the detector output to a less restrictive state than desired.

The present EPRI research programs have conducted insufficient tests of Modes 1 and 3 above to resolve all uncertainty. More detailed tests are called for, in addition to tests of a number of devices of each type to obtain a level of statistical confidence in the results. In addition, the effects of equipment aging, exposure to extreme environmental conditions, and variable track source impedances should be tested.

Recommendations to the Railroads and Their Signal Suppliers

Sound measurement procedures and standards for the susceptibility of vital railroad signal equipment to ac interference are clearly needed. Observed possibilities for decoding errors suggest that all electronic track circuits on the market should be thoroughly tested for vulnerability to such errors.

REFERENCE

1) A. Taflove and K. R. Umashankar, Mutual Design of Overhead Transmission Lines and Railroad Communications and Signal Systems. Vol. 1: Engineering Analysis. Vol. 2: Appendixes. Electric Power Research Institute (EPRI) Final Report EL-3301 on Project RP 1902-1, Palo Alto, CA, October 1983.