HANDBOOK OF ELECTRONIC CONTROL CIRCUITS

By JOHN MARKUS

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PREFACE

Significant industrial electronic circuits published during the period 1956–1959 are collected here for quick reference. A busy engineer can find in a few minutes the circuits meriting consideration for a particular industrial electronics application. In this respect the book is a sequel to "Handbook of Industrial Electronic Control Circuits" and "Handbook of Industrial Electronic Circuits," which contain equally useful circuits developed before 1956. The three volumes together can save hours and even days of searching through individual publications. Research and experimentation are cut to a minimum by starting a problem where others left off, rather than from scratch.

For vocational schools and colleges offering electronics courses, this book offers a new tool to instructors who want to emphasize practical circuits as a supplement for basic theory. With this handbook, a graduating student can tackle practically any job in the industrial electronics field with confidence that he is on familiar ground.

The circuits are logically grouped in chapters arranged alphabetically according to function. Any desired type of circuit can generally be found by thumbing through the appropriate chapter or glancing at the article titles under that chapter heading in the table of contents.

Specific circuits can be quickly located in the detailed back-of-the-book index, where each circuit is cross-indexed as many as a dozen times under its various names and categories. Inclusion of index entries for the preceding two volumes, in one alphabetical sequence, is an added feature. This constitutes a cumulative index to the significant electronic control circuits developed during the past twenty years.

Values of all important components are given, since these aid an engineer in reading a circuit and redesigning it for his own uses. With values for one set of operating conditions as a starting point, it becomes much easier to adapt them to a new problem.

Included with each circuit is a concise description giving the general nature of the circuit, its performance characteristics, a detailed explanation of how it works, practical data on critical components, and suggested applications. Following each circuit description is a reference to the original source, where the engineer may obtain more details on related mechanical problems or study graphs of performance characteristics.

All circuits in the handbook are from *Electronics*. To this publication, and particularly to its authors and editors, should go full credit for rendering such a practical contribution to the advancement of the industrial electronic field.

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ALARM CIRCUITS

Balanced-Capacitance Antenna Alarm Protects Barbed-Wire Fence

To SUPPLEMENT the protection provided by barbed-wire fences around electric power generating plants and substations, an electronic system was devised that set off an alarm when anyone approached or touched the barbed wire.

The system corrects for capacitance changes automatically to correct for drift due to changing weather conditions, but at a sufficiently slow rate that it is practically impossible to penetrate by crawling slowly toward the fence antenna. Close to the fence, the slightest movement of a person's body trips the alarm. System sensitivity remains constant at all times, despite changes in antenna capacitance. Changes in antenna loss due to growth of weeds, rain on the wood antenna posts or damp insulation are of no consequence unless extreme, because two separate antennas are used and are connected to oscillators rather than to a tuned receiving circuit whose selectivity depends directly on antenna losses.

The final design, shown in Fig. 1, employs two oscillators, with the lines along the fence serving as part of the tuning capacitance of each oscillator. A mixer produces beats between the harmonics of the two oscillators. A frequency-selective network in the low audio range provides d-c voltages which are used as a bias for sharp-cutoff relay tubes that actuate the alarm through a power relay.

The inductances of the two oscillators are so proportioned that equal capacitance changes on the two halves will be balanced when employing harmonics of the oscillators. If the third harmonic of one oscillator is to beat against the fourth harmonic of the other oscillator and an equal capacitance change takes place on both oscillators, the resulting beat between the two must remain constant.

The method employed for differential correction, shown in Fig. 1, uses a variable capacitor con-

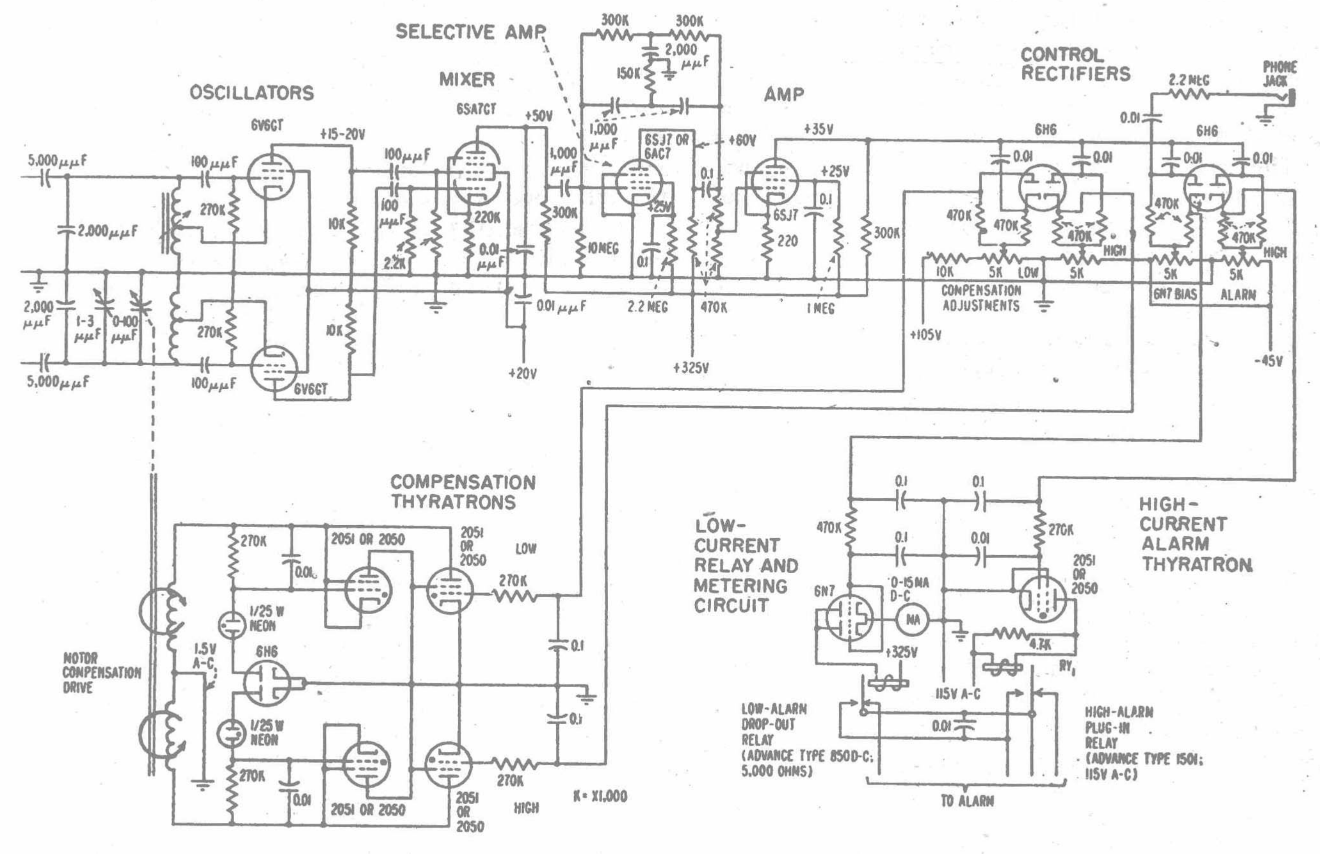


FIG. 1—Complete control circuits of alarm signal system. Power supply is conventional

nected to one oscillator and driven by a reversible Telechron motor which in turn receives its power from four thyratrons. Two of these thyratrons get their control bias from diodes which are adjustable so that compensation can be started at a desired point. The other two thyratrons are connected inverted and fired by a network from the control thyratron, thus operating the motor. One thyratron of the type used had insufficient power to drive the motor.

Adjustable controls permit setting the operating point as well as the high alarm, high compensation and low compensation at the required point.

An alarm must be given should any tube or component in the end equipment fail. Thus, the low-alarm relay is energized under normal operation and drops out when in alarm condition. The filament of the high-alarm thyratron is placed in series with the 6N7 low-alarm tube so that the low-alarm relay will drop out should the high alarm be inactive.

With a two-wire antenna system using insulated wires 2 and 4 feet from the ground on metal supports close to the barbed wire fence, false alarms were common. The capacitance of the antennas was changed by the wind swaying the barbed wire. Rain changed the capacitance materially. Rain drops would collect on the antenna wires and when a gust of wind blew them off, a false alarm resulted. The rain also changed the capacitance to the metal arms supporting the antennas.

When the antennas were placed about 3 feet from the fence, the trouble from the wind on the fence was eliminated and the apparent sensitivity was greatly increased. With 1-$\mu\mu$f equipment sensitivity, the detection range of a person was about 1 foot when the antennas were close to the fence, but with the antennas 3 feet from the fence a person was detected about 4 feet away.

Changing to a powdered mica insulating covering for the antenna wire allowed practically no moisture droplets to collect, but rain still gave false alarms. When porcelain insulators on wooden arms were used to support the antenna wires, the trouble with rain disappeared.

By GLENN H. BROWNING, Balanced-Capacitance Fence Alarm System, *Electronics*, p. 150, April 1956.

Comparator Circuit for Magnetic-Tape Printer Sounds Alarm if Copy Deviates from Master

BEFORE THE ADVENT of magnetic sound tracks, inspection of one optical track on each reel was a relatively simple matter. Since magnetic modulation is not visible a change in control and inspection procedure became a necessity.

The obvious method of actually running all prints in a projection room was considered to be too slow and costly. Development of an automatic electronic method seemed to be most practical.

By adding monitor heads to both the master reproducer and the copying recorder (printer), in the same relative positions, audio signals can be compared and differences indicated.

Details of the comparator are given in Fig. 1.

This circuit accepts the master monitor and print monitor signals through identical channels, each consisting of a constant-sensitivity control ahead of the input transformer, a diode rectifier and an R-C integrating network. The algebraic difference of these integrated voltages is impressed on one grid of the differential amplifier while the other grid is held constant by the voltage drop in its corresponding cathode resistor.

A sensitive relay, together with a zero-center voltmeter in series with a resistance, is connected between the two plates of this amplifier. The meter indicates the sense and amount of error voltage continuously, while the relay operates a buzzer and signal light when the error exceeds a predetermined value.

The constant-sensitivity controls serve the dual purpose of compressing signals above the 3-percent harmonic-distortion point of the magnetic film as well as making the amplitude response approximately a logarithmic function of the output voltage.

The selenium rectifiers, 1.5-v batteries and R_1 and R_2 perform a biased-clipping action that gives the desired logarithmic approximation.

Coupling transformers T_1 and T_2 give a voltage step-up of about 5½ to 1. The outputs of rectifiers V_1 are integrated by C_1 R_3 and C_2 R_4 and their algebraic difference is

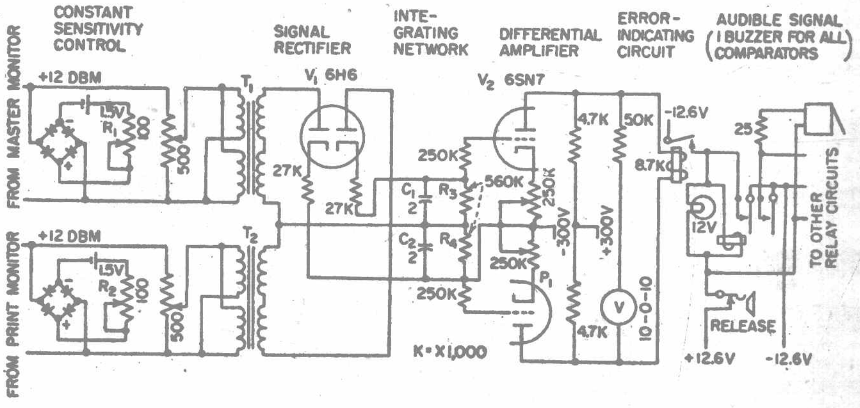


FIG. 1—Comparator and error-indicating circuits. Input level to comparators is +12 dbm when magnetic track is modulated 100 percent

impressed on one grid of V_2, the differential amplifier. The other grid of V_2 is held at a constant value determined by the i-r drop in P_1, its cathode resistance.

A sensitive 8,700-ohm relay, adjusted to operate at roughly a 2.5-volt differential, as well as a zero-center voltmeter in series with a 50,000-ohm resistor, is connected between the two plates of V_2. The meter shows the integrated error continuously, while the relay operates the warning buzzer and signal lamp when the error exceeds 2.5 volts, which corresponds to about 2 db for signals in the upper 15-db-level range. Once the error relay operates, the holding relay continues to hold the warning until released by the push switch.

The differential amplifier operates near unity gain serving as an impedance changer and driver for the indicating system.

By Jerome W. Stafford, Automatic Inspection of Magnetic-Sound Prints, *Electronics*, p. 164, March 1956.

Failure of Picture or Sound Carrier Trips TV Transmitter Alarm

Accurate records of the time and duration of carrier failure at a tv transmitter are required by the Federal Communications Commission. The device described below will obtain this information automatically. An alarm or signal light can also be actuated to warn of failure.

The carriers of picture and sound transmitters that comprise the complete tv transmitter have a separation in frequency of 4.5 mc.

The circuit used works on the superheterodyne principle with the two transmitters acting as the two oscillators. Signals from the two carriers are applied to the grid of V_1. This tube is a remote cutoff type, so the gain of this stage is controlled by the setting of R_1. which adjusts the bias. Since V_1 has a nonlinear characteristic, especially if driven past cutoff, the two signals are mixed in it.

The output of V_1 is fed to T_1, which is tuned to the frequency difference of the two signals. This 4.5-mc signal is further amplified by V_2. Output from V_2 is fed through the tuned circuit T_2 to the detector. The detector consists of two crystal diodes connected in a voltage-doubling circuit.

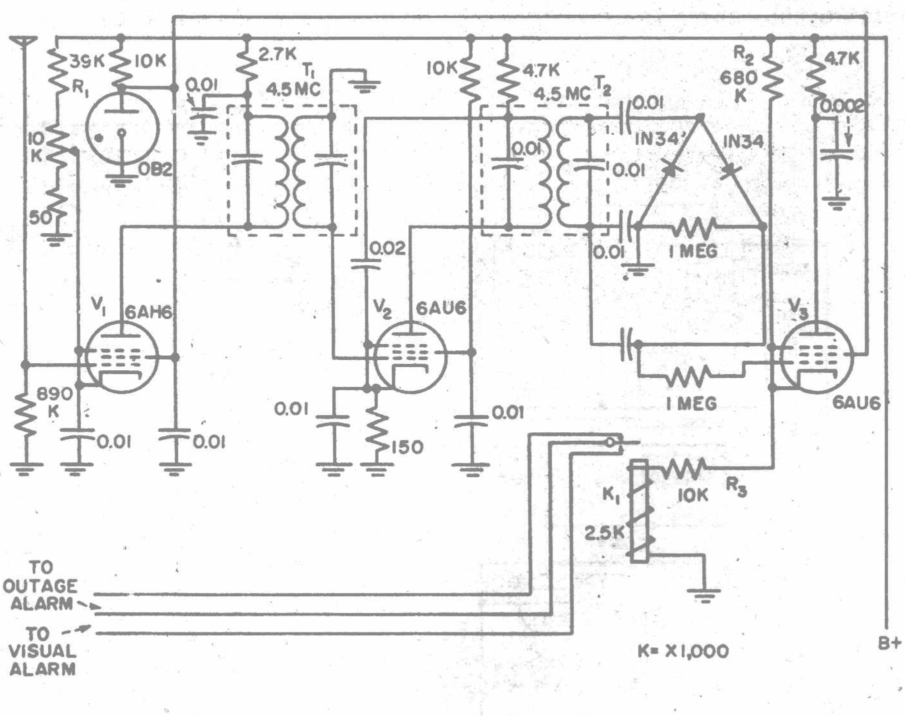
The voltage-regulator tube controls the voltage applied to the screen grids of V_1 and V_2. The pentode cutoff characteristics are sharper if the screen grid is maintained at a constant value.

Tube V_3 is biased to cutoff through the voltage divider action of R_2, R_3 and the coil of K_1. A current of about 0.4 ma flows through K_1 when V_3 is cut off. When a signal is applied to the detector, a positive voltage is produced that raises the voltage on the grid of V_3 to a conducting state. With V_3 conducting, the current through the relay coil is increased to 2.4 ma or more, depending on the strength of 4.5-mc signal received. The relay closes.

The power supply is a conventional choke-input type to keep the B + voltage down to about 200 v.

If either carrier drops out, no 4.5-mc signal is produced and V_3 is cut off. Relay K_1 opens. Loss of a tube or a blown fuse will also allow the relay to open. The circuit will thus give an alarm if part of the circuit itself fails. An outage clock unit is available that gives the time outage occurred and the duration of the outage. This unit must be actuated through the relay contacts by an outside source. The relay is also used to actuate a light circuit or an aural signal such as a bell.

By Kenneth Atwood, Intercarrier Failure Rings Alarm, *Electronics*, p. 188, March 1, 1957.



Circuit diagram of the heterodyne detector with power supply omitted for simplicity

Conelrad Alarm Is Triggered by Loss of Receiver AVC Voltage

THE RADIO OPERATOR at the time of a Conelrad alert is necessarily a busy person, and the alarm system should avoid adding to his burden. The complete alarm should (1) Warn operator of Conelrad, (2) Shut off controlled carrier promptly on alert, or on extended failure of key-station carrier, but not on momentary carrier interruptions, (3) Indicate what is taking place, (4) Fail safe.

To perform these functions certain standarized signals are emitted from the key station. An assemblage to perform all desired functions with optimum fail-safe provisions can be constructed using standard components, and will operate dependably on an avc voltage of as little as 1.5 v.

The warning device turns on an audio system if the avc of the monitor receiver fails for more than 0.5 sec, and turns the alarm off but not the audio when avc resumes. Power controlled by the system is shut off on receipt of a sustained 1,000-cps note or loss of avc for more than 10 sec. The arrangement enables the operator to hear all Conelrad and similar announcements subsequent to a carrier shutoff while relieving him of the necessity of monitoring key-station program continuously.

Referring to Fig. 1, control of this system is by the avc output of almost any receiver. Required voltage excursion from no-signal to full-signal can be anything above 1.5 v and the no-signal voltage need not be exactly zero. Close-differential operation of the alarm is avoided by using amplified avc through control-tube V_{10A}, which is cut off by normal avc voltage but draws plate current when avc fails.

This plate current biases off oscillator V_{11A} with no avc but permits oscillation when avc is normal. The oscillator output is amplified by conventional triode V_{11B}, and its output in turn is rectified by dual germanium diodes. The rectified output is regulated by the NE-51 which also functions as a panel pilot. The amplified avc output is nominally −55 volts whenever the avc input is above a predetermined value such as −1.5 v. A tap on the output voltage divider of the avc amplifier provides −5-v bias for the 1,000-cps amplifier.

A TEST pushbutton disconnects the avc amplifier from the receiver and applies +8 v to the amplifier input. The cathode voltage of V_{11A} and plate voltage of V_7 and V_{10A} is regulated at +108 v by V_{12}, which also supplies regulated voltage to the a-f control tube. The frequency of oscillator V_{11A} is not critical in this application, although its harmonics may interfere with other devices in the vicinity. As the avc amplifier will perform at any frequency from 0.5 to 500 kc, retuning to prevent interference presents no problem.

The input resistor and capacitor of the avc amplifier, plus the 0.1-μf filter capacitor in the rectified output of V_{11B} produce a delay of about 0.5 sec between failure of receiver avc output and failure of amplified avc output. This makes any controlled device immune to short-term interruptions of the carrier as received, whether they are caused at the transmitter, or by switching transients or other power vagaries that are of local origin.

The output of the avc amplifier is fed to a-f control tube V_7, alarm-control tube V_{13} and half of power-control tube V_{14A} through 1-megohm isolating resistors. The audio system will operate from the detector

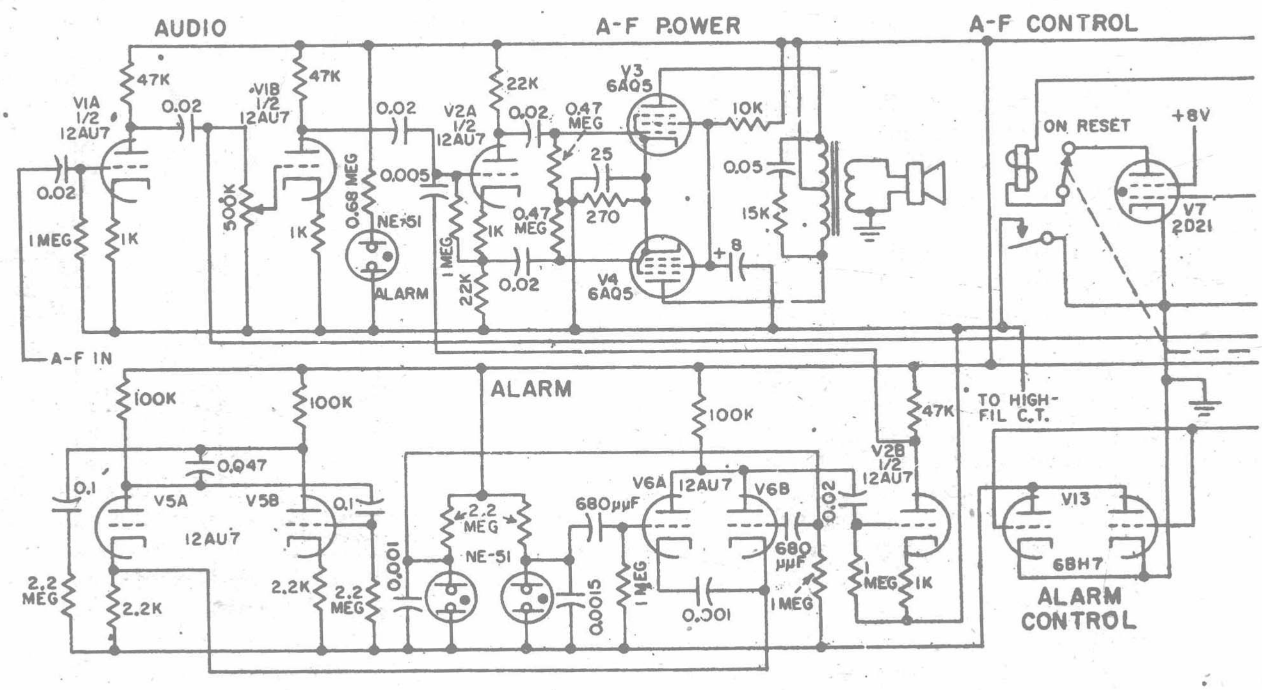


FIG. 1—Schematic of signal-selective Conelrad alarm. Fail-safe provisions are maximized when all tubes are pre-aged in non-

output preceding the volume control of any standard receiver and provide enough output to override room noises up to about 100 dbm. The audio is silent under normal conditions, but turns on and stays on until reset whenever the avc output of the receiver fails for more than 0.5 sec. The main audio amplifier is conventional and capable of 10 w output. Volume control is provided for setting level.

A branch takeoff is provided at the plate of V_{8A} to feed the 1,000-cps amplifier. A secondary input for the alarm signals from V_{2B} ap- tors in addition to those usually present. These make minor changes in the switching rate of the multivibrator but also markedly reduce thumps in the output of the gated amplifier. Other combinations of C, R and L will perform the same process, but usually at considerably higher cost.

To use the sustained 1,000-cps tone which is in integral part of the Conelrad alarm signal sequence, a selective amplifier is employed. This consists of series amplifier V_8, the upper grid of which is the signal input, and the lower grid the feedback input. Feedback is negative for all frequencies except the fundamental of the twin-T network, and zero at that frequency. A cathode follower, V_{9A}, fed from the plate of V_{8A} reduces circuit loading. The other half of twin triode V_9 is part of the full-wave output rectifier along with V_{10B}. The other half of V_{10} is the avc amplifier control tube.

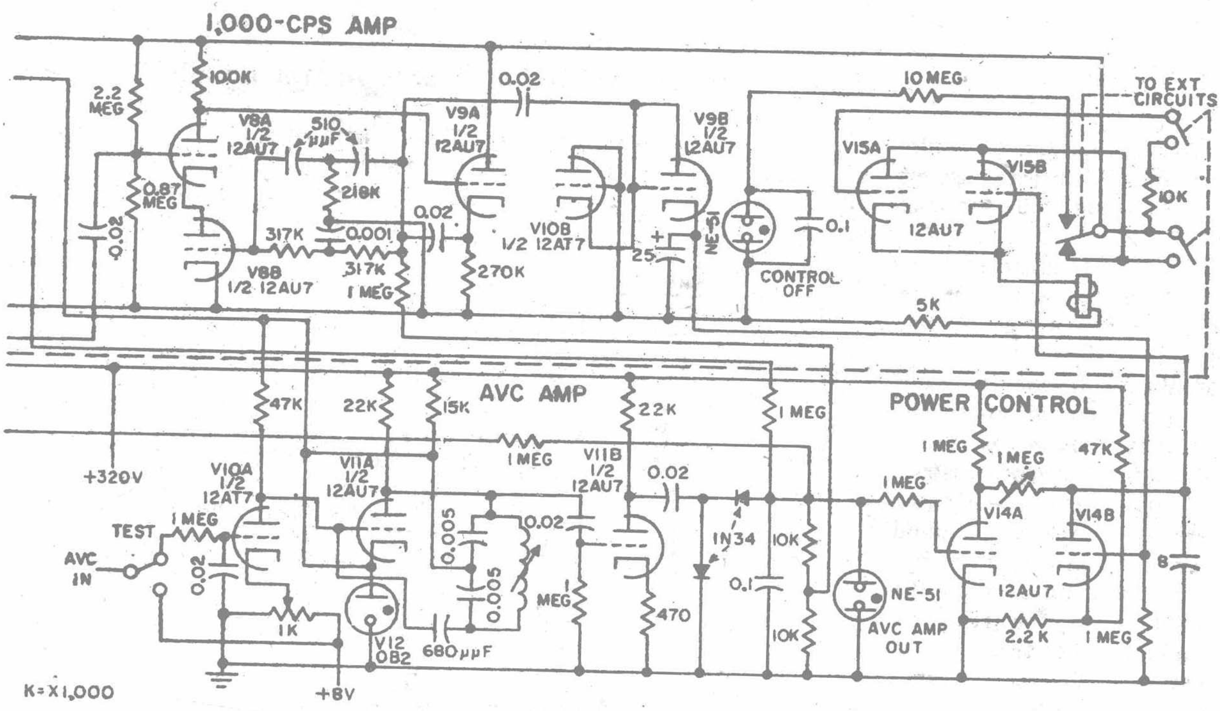
With a 0.5-v tone input to the main audio system, output of the tuned amplifier after rectification is +25 v when the input frequency is from 950 to 1,050 cps, +1 v at 900 and 1,100 cps, and negligible at all other frequencies. Bias for this audio amplifier V_6 which in turn feeds a straight audio amplifier V_{2B}. Signals are generated by two neon oscillators tuned to around 400 and 600 cps but having no common factor. They are capacitively coupled to the gated amplifier so that the tones are alternately fed into V_{2B} and thence into the audio power stage. This generator is controlled by the amplified avc through ground-return gate V_{13}. Whenever the avc from the receiver fails, and only then, the alarm is operative. When the avc voltage is restored the alarm stops, but the thyratron-controlled main audio system remains in operation so that announcements can be heard.

The multivibrator has plate-to-plate and cathode-to-cathode capaci- or has aged nearly to the replacement point. The relay is essential because the series thyratron introduces a roar into the audio system and tends to sputter and cut off when strong a-f signals are received. Capacitive filters adequate to eliminate this also cause strong R-C oscillation in the control-tube circuit.

The audible alarm must not be confused with anything else in the environment. Steady tones are therefore ruled out in most instances, as there are too many of them already present in industrial areas. Intermittent beeps are better, but resemble too closely the fire-alarm signals in many rural areas as well as a number of aeronautical stall alarms. The simplest alarm seems to be a two-tone warble, and the hearing response of most of the population indicates that both tones should be below 1,000 cps. A number of experiments indicate that the two tones will be a more effective alarm if their frequencies do not have a common factor.

The alarm signal generator consists of multivibrator V_5, operating at about 2 cps, controlling gated

Control of the audio system is by thyratron V_7 and its associated re-



critical service 2' ... -d six months only and finally replaced by another similar batch lay. Under normal conditions the avc amplifier provides more than adequate hold-off voltage for the tube. Failure of the avc allows the tube to fire, closing the relay contacts and completing the ground return of the entire audio system. Resumption of avc output thereafter has no effect on this circuit, which must be manually reset before it can be silenced.

Panel indication of alarm operation is provided by a neon bulb connected between the audio system plate supply and return. When the system is inoperative voltage across this bulb is zero. As soon as the system becomes operative, voltage across the bulb and resistor is about 200 v, giving visual indication of the condition.

To guard against the effects of tube aging, the screen of the thyratron is biased at +8 v. This insures firing even when the tube has operated cut off for extended periods frequency-selective amplifier is provided by a tap on the avc amplifier bleeder. In consequence the selective amplifier is out of operation when the key station carrier is off due to saturation of triode V_{8B}. The system is therefore immune to background heterodynes and other extraneous tones. Voltage output of this amplifier is nearly constant through a wide range of inputs, so the signal produced by the 1,000-cps tone is substantially immune to fading and similar troubles.

Power control is accomplished by two tubes. In the first a relay is held closed by the cathode current of dual triode V_{15}, whose two halves are paralleled and whose grids are normally held positive. One set of relay contacts is in series with the plate supply, so if the circuit is broken power will not be restored until the control is manually reset. Release of the relay armature switches on a front-panel flashing neon indicator, giving clear indication that external power is off.

The grid of this tube is connected to the plates of control tube V_{14}, both halves of which are normally cut off. Any sustained positive d-c output from the 1,000-cps amplifier causes V_{14B} to draw plate current, discharging the 8-μf plate capacitor and drawing down the grid voltage to cut off V_{15} in about 3 sec. This time can be altered by changing the capacitance from cathode to ground of V_{8B}.

Continued failure of the avc likewise shuts off the power control circuit through a time-delay system. When the grid of V_{14A} falls to ground potential the tube draws plate current, immediately lowering its plate voltage and slowly discharging the 8-μf plate capacitor of V_{14B} through the 1-megohm variable resistor. After a definite time lapse (here set at 10 sec) the grid voltage of V_{15} is reduced to cutoff value, the cathode relay drops out, and external power circuits are opened. As all of these circuits will operate with relatively great voltage differentials, minor shifts in tube sensitivities have little effect.

The power supply is conventional as to plate voltage, but the filament supply is dual. The high-filament circuit is connected through its center tap to the return of the audio system so that heater voltage is always within safe limits. The low-filament circuit is biased at about +80 v with respect to ground for the same reason.

Failure of any tube filament will immediately light one of the two filament-alarm lights on the main panel and also the interior light adjacent to the failed tube. Failures of main power-control tube V_{15} or of main avc amplifier tube V_{11} will immediately shut off the controlled power, as will a power-supply failure. Other failures will be apparent through routine test procedures.

By Ronald L. Ives, Alarm System Uses Gated Neon Warbler, *Electronics*, p. 74, May 23, 1958.

Crystal Transducers in Acoustic Chamber Detect Breaks in Moving Film

DETECTION of the end of a film strip in the processing of black and white and color film can prevent a tedious job. If undetected, the machine unthreads, requiring rethreading sprockets in the dark through a series of wet processing tanks.

Film breakage presents an even worse problem. In addition to rethreading, film footage is often spoiled because of overprocessing.

Transmitting and receiving transducers in a resonant sound chamber are used in a system that is simple, reliable and easy on the film. A change in the resonant chamber affects the transfer of energy between the two transducers.

The acoustic detector can also be applied as a control in a variety of other applications ranging from position detection to finding air bubbles during transfusions.

The acoustic detector consists of two crystal transducers, a transmitter and a receiver-detector, facing each other at opposite ends of

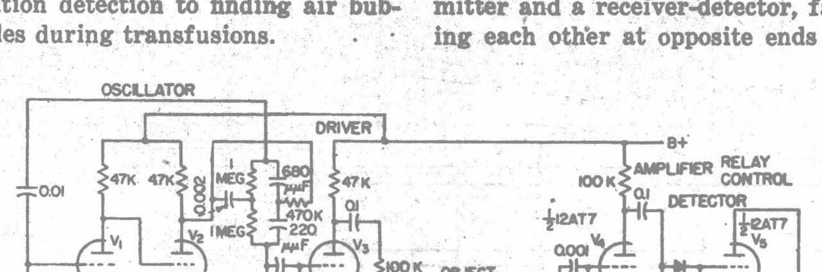


FIG. 1—Oscillator and amplifier drive one crystal transducer and other transducer receives energy that controls relay through amplifier and detector

a resonant chamber. A gap is provided in the center of the chamber for introducing the element to be controlled—in this case film. The transmitting transducer is driven at the resonant frequency of the crystal-chamber combination and the receiver output is used to control a relay.

Normally, the system is adjusted so that there is sufficient energy transfer between the transducers to hold the relay closed. Interposition of an absorber in the gap destroys the acoustic resonance and the relay opens.

The circuit shown in Fig. 1 consists of a twin-T feedback oscillator and a detector. The twin-T network, which is designed for 1,700 cps, the resonant frequency of the system, provides a positive feedback path between V_1 and V_2, permitting oscillation. Tube V_3, the driver, functions as an amplifier.

Energy from the receiving transducer is fed through a simple high-pass filter, which attenuates 60-cycle pickup and low-frequency mechanical vibrations, to the grid of V_4. Such a filter is adequate for the present application, however, a tuned amplifier may be used, with the pass band centered on the oscillator frequency. Stage V_4 amplifies the signal and feeds it to the half-wave voltage doubler, which drives the grid of relay control tube V_5.

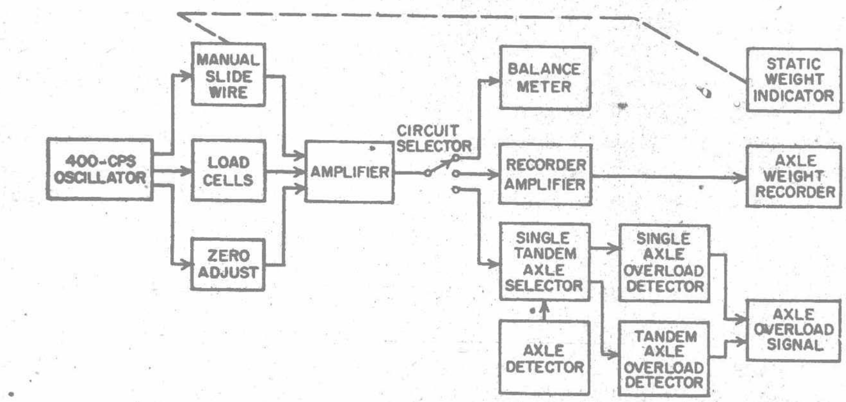
A sensitivity control is provided in the cathode circuit of V_5 to adjust the relay operating point. One contact of the double-pole double-throw plate relay is wired in a lock-up circuit so the relay will stay energized until released manually or by an external control circuit.

By Edward L. Withey and Richard G. Seed, Acoustic Cavity Detects Breaks in Film, *Electronics*, p. 50, March 28, 1958.

Electronic Highway Scale Trips Alarm if Moving Truck is Overweight

An electronic highway scale detects overloaded trucks while they are in motion, recording the weight of all passing trucks and accurately weighing stationary trucks.

The scale operates at 400 cycles. Power is fed into the load cells, the zero-adjust potentiometer and the slide-wire circuit as shown in the block diagram. The voltage into the slide wire circuit and the zero-adjust potentiometer are in opposite phase to that fed to the load cells. The zero-adjust potentiometer is used to counterbalance load cell output owing to the dead weight of the scale platform.



Elements of highway scale that indicates static weight or signals and records overweight on basis of preset alarm

When this equipment is used for static weighing, the circuit selector is connected to the balance meter, which is a zero-center, 100-microampere meter. With no load on the scale and the weight indicator dial at zero, there is no input to the amplifier and the meter shows a zero balance. When a load is placed on the platform, unbalancing the bridge network in the load-cell circuit, a voltage is applied to the amplifier and the meter goes off balance.

By turning the weight indicator dial, a voltage of opposite phase is introduced into the amplifier and this voltage is adjusted until its magnitude is equal to the load-cell output. The resulting amplifier input is zero and the meter returns to zero balance. The actual weight on the scale is indicated by graduations of the weight indicator dial on the shaft of the slide-wire control used to develop the balancing voltage.

When the scale is recording moving weights, the circuit selector switch is turned to the record position. The slide wire is not used and the weight indicator dial remains at zero. In this case, any load placed on the platform develops from the cells an output that is amplified and fed into the paper-tape recorder.

This recorder uses a heated stylus and sensitized paper for low-inertia, high-speed operation. To save tape, because it is used at the rate of 50 millimeters per second, a roadway treadle is placed just ahead of the scale to start the paper drive as a vehicle approaches the weighing platform. A second treadle shuts off the drive after the platform is cleared.

As an overload detector, the manual slide wire is set to the predetermined limit over which excess weights are to be detected. For a signal to trip the overload detector circuit, a voltage must be developed by load cells in excess of that voltage introduced by the slide wire. Any slight excess will trip the detector circuit and set off the alarm signal. In addition to the alarm, there would normally be a sign along the roadway to indicate to the driver of the overloaded truck that he is to pull off the highway and be weighed at a static scale operated by enforcement personnel.

As most states allow less weight on a tandem axle arrangement than on two single axles, two treadles are