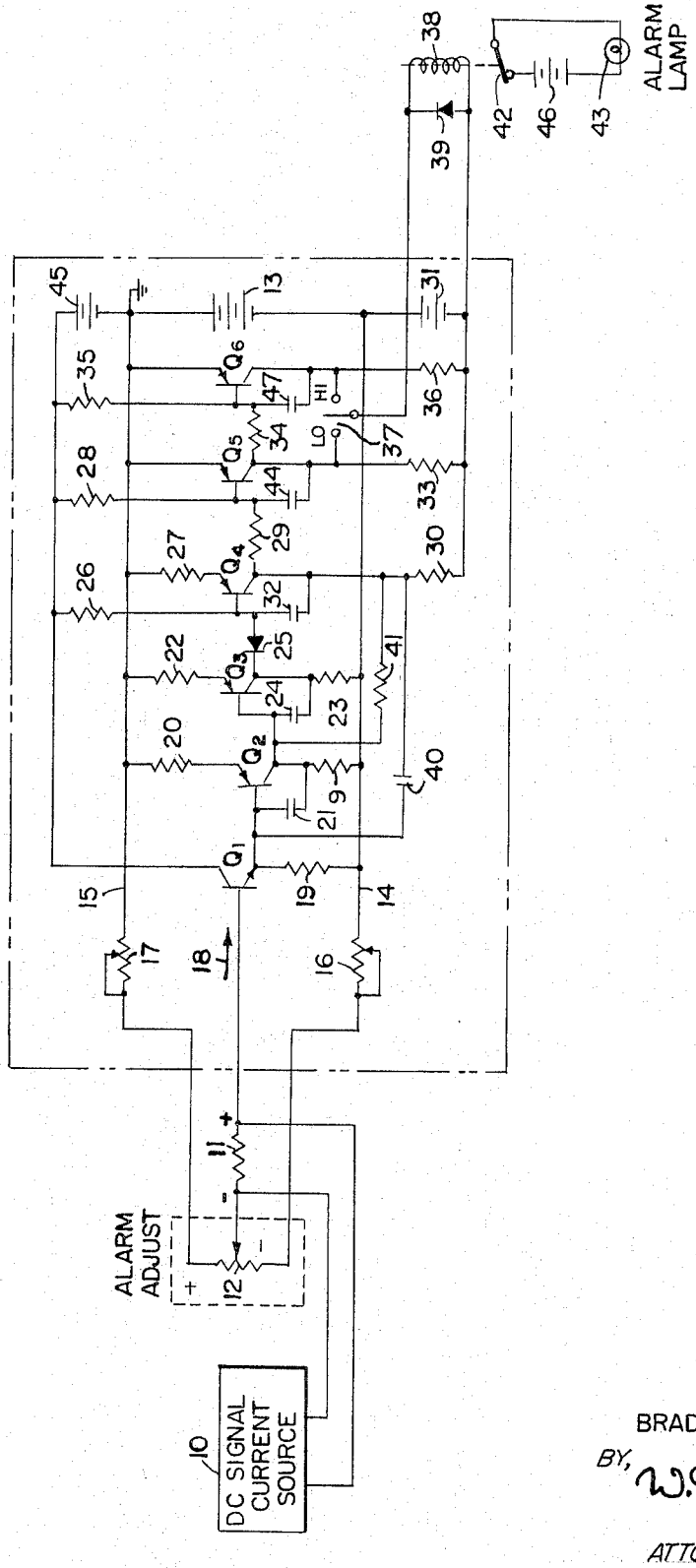
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ALARM SYSTEM HAVING AN AMPLIFIER PROVIDING DEAD-BAND CONTROL

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ALARM SYSTEM HAVING AN AMPLIFIER PROVIDING DEAD-BAND CONTROL

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This invention relates to systems operable to annunciate an alarm condition or perform a control function whenever a signal representative of a variable condition either exceeds or falls below a preselected value. More particularly, this invention relates to an improved alarm system which is characterized by the fact that its dead band may be independently selected without adverse effects upon the accuracy of the system which is conventionally known as system repeatability.

Prior art alarm systems of this type have been found to be useful in process control systems for initiating control functions or operating alarm annunciators whenever the controller output signal deviates far enough from the process set point to arrive at a value, hereinafter referred to as alarm point, which necessitates the institution of a predetermined automatic control procedure or the operation of an alarm so that manual corrective action may be taken.

The control device in the output of such alarm systems is conventionally an electromagnetic relay which exhibits what may be termed an inherent dead band due to its pull-in and its drop-out characteristics. Repeatability of these prior art alarm systems, which is related to the inherent dead band of the control relay, may be made very small in value by utilizing a high gain D-C amplifier in the alarm system. As is well known, repeatability is a measure of system accuracy since it represents the range of input signal variation over which the output relay will operate for any given alarm point setting. This characteristic, which is usually expressed as a percentage, is related to the magnitude of this input signal variation as compared to the total span of input signals. Thus, the lower the repeatability percentage, the better the accuracy of the alarm system.

It may be demonstrated that in alarm systems in which system dead band is solely a function of the inherent dead band of the delay and the finite gain of the amplifier, as is the case in prior art systems, repeatability and dead band are essentially of the same order of magnitude. It will thus be appreciated that no compromise need be made in designing such prior art systems if the dead band is to be minimized since this condition automatically obtains when system repeatability is minimized. However, if a dead band value larger than that obtainable as a result of the inherent dead band of the relay is to be obtained with such prior art systems, it can only be obtained at the sacrifice of repeatability by utilizing an amplifier having less gain.

It is therefore an object of this invention to provide an alarm system in which large system dead band values may be selected without adversely affecting system repeatability.

It is a further object of this invention to provide an alarm system in which magnitude of the dead band may be varied without necessitating a change in system gain.

It is yet another object of this invention to provide an alarm system capable of providing a dead band having percentage values larger in magnitude than its percent repeatability.

These and other objects and advantages of the invention will be pointed out with particularity in conjunction with the following description taken together with the

accompanying drawing which is a schematic diagram of an alarm system in accordance with the invention.

Referring now to the drawing, there is shown an alarm system designed to activate an annunciator system or interlock circuit of a process control system when the monitored input signal; i.e., the controller output signal, either exceeds or goes lower than a preset alarm point. The input signal current, which is provided by D-C SIGNAL CURRENT SOURCE **10**, normally falls within a given range of values, e.g., 10–50 milliamps. The signal current in turn develops a signal voltage across resistor **11** which is connected between the base of transistor Q1 and the slider on ALARM ADJUST potentiometer **12**. Potentiometer **12**, in cooperation with voltage source **13**, conductors **14** and **15**, and rheostats **16** and **17**, provides and adjustable source of D-C reference potential. Conductor **15** will be assumed to be at ground potential for explanatory purposes. The reference potential appearing on the slider of potentiometer **12** is oppositely polarized with respect to the signal voltages developed across resistor **11** so as to develop a difference voltage which will be applied to the base of transistor Q2, through the base-emitter junction of transistor Q1. Transistor Q1, which is connected in emitter follower configuration, is biased so as to be always turned ON. Consequently, its emitter voltage will be substantially the same as its base voltage thereby resulting in the difference voltage being applied to the base of Q2. Transistor Q2 will thus be forward biased, i.e., turned ON when the input signal is less than the reference potential while the opposite will be the case when the input signal is larger.

Q1 and Q2 are connected in the illustrated configuration with the difference voltage connected across their series-connected, base-emitter junctions in order to temperature compensate the amplifier. This temperature compensation is found to be necessary to obtain systems with low repeatability; i.e., less than 1%, since amplifier gains of the order of 10,000 are necessary to obtain such accuracy. It will be appreciated that with amplifier gains of this order of magnitude temperature compensation is essential. This compensation is provided by the configuration of transistors Q1 and Q2 since any change of base to emitter voltage of transistor Q1 due to temperature variations will cause the emitter current of Q1 to vary, thus changing the voltage developed across resistor **19**. Due to the complementary configuration of transistors Q1 and Q2, this change in voltage across resistor **19** is of the correct polarity to tend to hold the base current of Q2 constant. Therefore, the collector current of transistor Q2 will remain constant with changes in ambient temperature.

The signals developed in the collector circuit of Q2 across resistor **9** are degeneratively fed back to the base of Q2 via capacitor **21**, as well as being applied to the base-emitter junction of transistor Q3. The emitter of transistor Q3 is returned to ground through resistor **22**, while the collector is connected to the negative terminal of battery **13** through collector load resistance **23**. Degeneration is also introduced in this stage through feedback capacitor **24** which is connected between the collector and base of Q3. Collector load resistor **23**, diode **25**, and resistor **26**, which are connected between the negative terminal of battery **13** and the positive terminal of battery **45**, provide means for fixing the operating point for the base of transistor Q4 thus establishing the bias upon the base-emitter junction of Q4.

The collector of transistor Q4, as well as the base of Q5, have their operating points fixed by being connected to the current path comprising resistors **28**, **29**, and **30** which are connected in the order named between the positive terminal of battery **45** and the negative terminal of

battery 31. Capacitor 32 and resistor 29 provide means for coupling the signal appearing across collector load resistance 30 to the base of Q4 and the base of Q5, respectively. The signal applied through resistor 29 to the base-emitter junction of Q5 appears in an amplified form across collector load resistor 33 which is returned to the negative terminal of battery 31. Resistors 34 and 35 are provided to cooperate with collector load resistor 33 to fix the operating point for the collector of transistor Q5, as well as the base of transistor Q6. Resistor 36, which is connected between the collector of Q6 and the negative terminal of battery 31, serves as the collector load resistance of transistor Q6. Degeneration is introduced in stages Q5 and Q6 by feedback capacitors 44 and 47, respectively.

Means is provided by single-pole, double-throw switch 37 to selectively connect relay winding 38 in parallel with collector load resistors 33 or 36 to provide the desired LOW or HIGH alarm operation, respectively. Diode 39, which is connected in shunt with relay 38, is provided to protect transistors Q5 and Q6 from the application of high voltages induced in winding 38 when it is de-energized.

Normally closed contacts 42 provide means for controlling ALARM LAMP 43 so as to perform the annunciating function in those applications where operators will be in attendance. Of course, it will be recognized that relay contacts 42 can also be utilized to perform an interlocking control function in the process control system if predetermined programs are to be instituted when the input signal current either exceeds or goes lower than the alarm point which is preset by ALARM ADJUST potentiometer 12.

Capacitor 40, which is connected between the collector of Q4 and the base of Q2, provides means for introducing additional degeneration into the amplifier for stabilization purposes to prevent high frequency transients from operating the alarm. Dead band resistor 41, which is connected between the collector of Q4 and the base of Q3, is utilized to provide, in accordance with the invention, a true and stable dead band for those applications in which dead band is desired. The manner in which this is accomplished will hereinafter be described after the operation of the alarm is first explained assuming that resistor 41 is disconnected.

The operation of the alarm of the invention will now be described with reference to an alarm system having the following assumed values:

9		9.1K
11	ohms	20
12	do	300
16		4K
17	ohms	150
19		4.3K
20	ohms	51
Q1		2N1306
Q2		2N1175
Battery 13	volts	8.5
Battery 31	do	11.5
Battery 45	do	15

It can be seen that with the value assumed for resistor 11 the voltage generated across resistor 11 varies from .2 to 1.0 volt as the input current varies from 10 to 50 milliamps. Adjustment of the span of the system, which is provided by rheostat 16, provides means for adjusting the current flowing through potentiometer 12 so as to provide a voltage drop across potentiometer 12 which is equal to the drop appearing across resistor 11; i.e., .8 volt. Means is provided by zero adjust rheostat 17 to permit the cancellation of the negative offset voltage appearing upon the base of Q1. It has been found that, with the previously noted components, this offset voltage is normally of the order of 40 millivolts. Thus, assuming such an offset voltage, the potential of the point common to potentiometer 12 and rheostat 17 should be set to .24 volt by manipulating zero adjust 17 in order to cancel the effect of the offset voltage. In this case, the point common to potentiometer 12 and span adjust rheostat 16 will be −1.04 volts.

Assuming now that the difference voltage applied to the base of Q2 is positive enough so as to turn transistor Q2 OFF, transistors Q3 and Q5 will be in their conductive or ON condition while transistors Q4 and Q6 will each be rendered nonconductive due to the bias placed upon their base-emitter junction by the positive signal generated in the collector circuit of the preceding stage. Assuming now that the input signal from source 10 starts decreasing in value, the signal applied to the base of Q2 will start going in a negative direction and eventually reach the point at which Q2 will be turned ON. This will cause stages Q5 and Q6 to switch from their previous conditions so that Q5 will go OFF while Q6 will be turned ON. It has been found that with the following representative component values this switching will occur, still assuming dead band resistor 41 is disconnected, when the net signal on the base of Q1 decreases to approximately +8 millivolts:

22	ohms	100
23		5.6K
24	microfarads	.1
25		1N645
26		22K
27	ohms	82
28		82K
29		8.2K
30		5.6K
32	microfarads	.1
33		3.9K
34		15K
35		82K
44	microfarads	1
47	do	1
Q3 and Q4		2N1175
Q5 and Q6		2N1926

It will also be appreciated that once Q5 is switched OFF and Q6 is turned ON they will remain in their respective conditions until the input signal from source 10 increases until the potential of the base of Q1 again exceeds +8 millivolts. Switching of Q5 and Q6 will thus take place whenever the potential of the base of Q1 falls below or exceeds +8 millivolts.

It will be appreciated that, since relay 38 has an inherent dead band due to the difference between the power necessary to lock up the relay and the power level at which the relay will drop out, switching will not occur at exactly +8 millivolts. This inherent dead band, as well as other factors, is responsible for the repeatability error of the system which may be kept considerably below 1% of the total span by utilizing high gain amplifiers and carefully selected relays; e.g., in the preferred embodiment of my invention, minimum repeatability is equal to +.1% while maximum repeatability is about +.05%.

Fail-safe alarm action is provided by defining what will hereinafter be referred to as the "alarm" condition as occurring whenever winding 38 is de-energized to cause its armature to drop out and complete the annunciator circuit through normally closed contacts 42. It can be seen that, when selector switch 37 is in its LOW alarm position, relay winding 38 is connected in parallel with collector load resistor 33 of transistor Q5 and, consequently, the circuit will assume its "alarm" condition whenever the potential of the base of Q1 falls below +8 millivolts causing transistor Q5 to be turned OFF. In other words, the LOW alarm will be energized whenever the signal produced by source 10 falls below the alarm point selected by the setting of potentiometer 12. The "alarm" condition will be indicated in like manner when the system is in its HIGH alarm configuration by

the de-energization of winding 38 which causes ALARM LAMP 43 to be energized. Thus, the HIGH alarm will be energized whenever the signal produced across resistor 11 exceeds the preset alarm point.

Low alarm configuration

In accordance with the invention, if dead band is desired, resistor 41 may be selected to create the desired amount of dead band without affecting the magnitude of the repeatability error. The action of feedback resistor 41 may best be explained by assuming that the input signal is larger than the alarm point and that switch 37 is in its LOW alarm position. Under such conditions, transistor Q2 will have a positive potential upon its base causing it to assume its OFF condition. Transistors Q3 and Q5 will thus be ON and, in view of this fact, the system will be considered to be in its "normal" condition since coil 38 will be energized. When in this condition, transistors Q2 and Q4 are OFF thus permitting their collector voltages to assume values controlled by the currents flowing in bleeder networks to which their collectors are connected.

The network controlling the collector voltage of Q2 may be traced from the positive terminal of battery 31 through resistor 9, dead band resistor 41, and resistor 30 to the negative terminal of battery 31. The network controlling the collector voltage of Q4, which comprises resistors 28, 29, and 30, is connected between the positive terminal of battery 45 and the negative terminal of battery 31. The later network thus has 35 volts across it while 11.5 volts appear across the network connected to the collector of Q2. This results in a current flow through resistor 9 which is of a polarity to make the base of transistor Q3 more negative than the −8.5 volts potential present at the negative terminal of battery 13. It can thus be seen that a larger signal will have to be developed in the collector circuit of Q2 in order to turn OFF transistor Q3 and thus switch the circuit to its "alarm" condition since the current flowing in dead band resistor 41 places a greater forward bias on Q3. It has been found that with the previously noted component values the drop across resistor 9 prevents Q3 from switching OFF when the input signal on the base of Q1 decreases to +8 millivolts and delays it until the base reaches approximately ground potential. Thus, the circuit will not assume its "alarm" condition to indicate the input signal is less than the alarm point until the base of Q1 is at ground.

Once the circuit is in its LOW alarm condition, it will not switch back to its "normal" condition when the base of Q1 arrives at ground potential since the presence of dead band resistor 41 has no effect under these conditions. This result obtains since both Q2 and Q4 are ON and therefore both ends of resistor 41 are at substantially the same potential due to the conduction of transistors Q2 and Q4. This means that no bleeder current will flow through the network comprising resistors 9, 41, and 30 when the circuit is in its LOW "alarm" condition. Consequently, the circuit will switch to its "normal" condition at the same potential that would cause such switching if resistor 41 were disconnected. Thus, transistor Q3 will turn ON again to return the circuit to its "normal" condition only when the potential on the base of Q1 reaches +8 millivolts. It will thus be appreciated that an 8 millivolt dead band; i.e., a 1% dead band, is provided due to the current flow through dead band resistor 41. It will thus be apparent that the amount of dead band can be adjusted by adjusting the magnitude of the bleeder current flowing in resistor 41 when the circuit is in its "normal" condition.

High alarm configuration

It will be clear from the preceding discussion that, when the circuit is in its HIGH alarm configuration, current will flow in resistor 41 only when the circuit is in its "alarm" condition to thus delay its switching to its "normal" condition until the base of Q1 arrives at ground. The circuit will, of course, switch back to its "alarm" condition only after the input signal increases beyond the alarm point to drive the base of Q1 to +8 millivolts.

To summarize, dead band control is very simply provided, in accordance with the invention, by resistively connecting the collectors of two in-phase stages of the system amplifier so that an additional forward bias is placed upon the base-emitter junction of the stage following the first of the two in-phase stages when the circuit is in one condition only so as to delay its switching to the other condition and thus provide the desired dead band. Dead band may thus be introduced without necessitating any change in the gain of the circuit and thus no change in circuit repeatability would be involved.

While I have shown and described a particular embodiment of my invention, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from the invention and I therefore intend in the appended claims to cover all such changes and modifications as fall within the spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a control system having a source of D-C signals, an adjustable source of D-C reference potential.
   - means for obtaining a current equal to the difference between the D-C signals and said reference potential,
   - means for amplifying said D-C difference current,
   - a control relay and means for coupling said relay to an output of said amplifying means,
   - the improvement for providing a true and stable dead band comprising means coupled between the outputs of two in-phase stages of said amplifying means for feeding back a signal of the proper polarity when both of said stages are OFF to tend to increase the forward bias on the stage succeeding the first of said two stages so that the switching of said succeeding stage from ON to OFF requires said first stage to pass a current larger than a predetermined value, said predetermined value being the current value that would cause said succeeding stage to turn OFF in the absence of said feedback current.

2. The combination of claim 1 in which the outputs of said two stages when they are both ON are at potentials such that said feedback means has substantially no effect upon the forward bias of said succeeding stage whereby said succeeding stage will be turned ON when said first stage passes current equal to said predetermined value whereby a true and stable dead band is obtained.

3. The combination of claim 2 in which said two stages and said succeeding stage each comprise a conductive device having input, common, and output electrodes,
   - said devices being rendered conductive whenever a forward bias of a given magnitude is applied between said input and common electrodes, and
   - said feedback means comprises a resistance connected between the output electrode of said second stage and a point common to the output electrode of said first stage and the input electrode of said succeeding stage,
   - the output electrodes of said first and second stages being respectively returned to first and second sources of D-C potential of the same polarity as said forward bias,
   - said second source providing a larger potential than said first source whereby the current flow through said resistance, when said first and second stages are OFF, is in a direction to increase the forward bias on said succeeding stage.

4. The combination of claim 3 in which said coupling means is selectively operable to connect said control relay to two out-of-phase stages of said amplifying means, said two out-of-phase stages being the output stage of said

amplifying means and the immediately preceding stage whereby said control relay may be selectively connected to operate whenever the D-C signals from said source either fall below a given value or exceed a given value, said value being controlled by the setting of said source of D-C reference potential.

5. The combination of claim 4 in which each of said stages comprises a conductive device having input, common, and output electrodes,

each of said output electrodes of said output and immediately preceding stages being returned to said second source of potential through corresponding load resistors,

said coupling means comprising a switch for selectively connecting said relay in parallel with either of said load resistors to provide the desired control action.

6. The combination of claim 5 in which the output of said second stage is connected to the input of said preceding stage,

said combination further comprising an alarm annunciator controlled by said relay,

said annunciator being operable to its alarm condition when said relay is de-energized.

7. The combination of claim 6 in which said conductive devices are transistors, and said amplifying means further comprises means for coupling said difference current to the input of said first stage, said input coupling means serving to compensate said amplifying means for ambient temperature changes.

8. The combination of claim 7 in which the transistor of said first stage is of a given conducting type, and

said input coupling means comprises a transistor of conductivity type opposite to said given conductivity type,

means for connecting the base-emitter junctions of the two transistors in series across the output of the difference current source with the emitter of said coupling transistor being connected to the base of said first stage transistor,

and a resistance coupled between the point common to said two transistors and said first source of D-C potential whereby the change in potential across the resistance due to change in emitter current of said coupling transistor with temperature change is of the correct polarity and magnitude to counteract the tendency of the base current of said first stage transistor to change with temperature and thus keep the collector current of the first stage transistor constant with temperature changes.

9. The combination of claim 8 further comprising means for capacitively feeding back a signal from the collector of the transistor of said second stage to the base of said first stage transistor to stabilize said amplifying means.

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