

A DEVICE AND METHOD FOR RAPID INDIRECT MEASUREMENT OF HUMAN SYSTOLIC AND DIASTOLIC BLOOD PRESSURES

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I. Introduction.

Aeromedical research studies often require the assessment of blood pressure as a reflection of physiological reactivity. In many such studies, measurements of the dynamic blood pressure transients are desirable. Although arterial catheterization provides a direct access to the dynamic measurement of human blood pressure, this procedure carries inherent medical risks which are not warranted for our use¹⁻⁵. A device and method for rapid indirect measurement of blood pressure were therefore sought from commercial sources. Since they were neither available nor forthcoming, it became necessary to develop them ourselves. The complete rationale and evaluation of this device and method have been reported previously⁶. This report will deal mainly with the method of measurement and the components, construction and technical operation of the device.

II. Device and Method.

Figure 1 shows the control panel of the apparatus. In general, it consists of two identical units, each serving one of the two brachial cuffs shown. Each unit is capable of measuring either systolic or diastolic pressure continuously or both pressures alternately, by invoking a manual switchover control. The aneroid gauges shown may be used optionally to calibrate the pressure transducer in each unit or to monitor visually the respective pressures during each measurement cycle. Figure 2 shows an overall view of the internal assemblage. The individual circuit boards were mounted vertically for compactness of design and easy service accessibility. For later reference, note the plastic, low pressure reservoir and, below it, the battery modules for powering field experiments. The remainder of this section will deal mainly with the details of the measurement cycles and their regulation.

The measurement cycles can be described best by viewing a single, rapid tracing of one systolic and one diastolic measurement, as shown in Figure 3. Point A in each tracing marks the initiation of cuff inflation by manual switch activation of each unit. Appropriate valving thereby is opened to provide a constant 6-psi source of compressed air to each cuff via a plastic, low pressure reservoir. Point B in each tracing marks the end of the rapid, cuff inflation portion of each cycle. At this point, a pressure limit switch, which can be set at any desired pressure, activates a relay for the initiation of the next portion of the cycle. For the systolic cycle, this next portion consists of a slow deflation bleed and, for the diastolic cycle, a slow inflation bleed. The bleed rates occurring between Points B and C in each tracing can be set at any desired value commensurate with the measurement accuracy and measurement rate requirements of the particular experiment being conducted at the time. The slow bleed in each tracing is the pressure-seeking portion of the cycle.

Each unit is provided with two sensors to detect the systolic or diastolic pressure in each cycle. A microphone located in each cuff, is positioned over the brachial artery. Its amplifier circuit allows frequencies of 20 to 180 Hz only to be detected. Via this sensor, the standard auscultative criteria of systolic and diastolic pressure levels are utilized⁷. The filtering of all other frequencies offers some protection against environmental and/or body movement noises. A delicate thermistor bead, housed in a rigid metal container in each unit, is able to detect very sensitively in each cuff the "puff" of pressure that occurs with each passing arterial pulsation. As shown in Figure 4, both sensors must be activated simultaneously in order to denote either the systolic or diastolic pressure. Simultaneous activation of both sensors is necessary to trigger the relay for rapid deflation of each cuff.

The delineation of the systolic and diastolic pressures, and the rapid cuff deflation toward zero cuff pressure occur at point C in both tracings.

The next cycle may be initiated by manual switch activation when single measurements only are desired. When fully automatic, maximum rate cycling is desired, the next cycle can be initiated during the deflation portion of the cycle by either of two optional procedures. One option is a low-pressure-limit switch, which can be set at any desired pressure value below that which occurs at point C. Since the cycling rate can be increased by elevating the setting of the low-pressure-limit switch and since the brachial circulatory impedance varies directly as the cycling rate, the use of this option to obtain a maximum measurement rate is desirable only for assessing very short duration physiological transients during which maximum blood pressure changes are expected. Such transients, for instance, might include a 60-second cold pressor exposure, a respiratory "Mueller" maneuver, a 30- to 45-second rapid decompression exposure, or a short duration bout of hyperventilation. The systolic measurement is of prime concern in this regard, since the brachial circulation is cut off completely during some portion of its measuring cycle. As an empirical example of maximum measuring rate, with the low-pressure-limit switch set at 10 mm Hg, we are routinely capable of obtaining 20 to 25 measurements each of systolic and diastolic pressure per minute. Under these conditions, the earliest onset of ischemic "tingling" occurs in the systolic arm only in about 4 minutes. This is more than enough time in which to measure any of the previously mentioned physiological pressure transients. When repeated assessments of these types of transients are necessary in one individual, ample circulatory rest time between assessments should be invoked for maximum subject comfort. When automatic cycling at lesser measurement rates is desired, the second control option can be invoked. This consists of an inter-cycle, automatic time delay, which can be set for any duration up to 20 seconds. The initiation of this delay is triggered by the same relay that initiates cuff deflation at point C of the cycle. Under resting subject conditions, measurement rates of approximately 10 systolic and diastolic pressures each per minute for several hours of continuous measurement

have been tolerated without overt ischemic sensation or discomfort.

Of further interest in Figure 3 are the time segments of the measurement cycle. Segment A-B in each tracing represents the rapid, cuff inflation portion of each cycle. This amounted to 0.7 second for the diastolic cycle and 1.5 seconds for the systolic cycle. In this example, brachial circulation in the systolic arm only was completely cut off (A'-C) for 1.9 seconds. Brachial circulation, of course, is never completely cut off in the diastolic arm. The 1.9-second circulatory cutoff in the systolic arm is much more physiologically desirable than that which occurs during manual, or automatic, single cuff methods of measurement. The circulatory cutoff, as measured from the cycles shown in Figure 5, is approximately 7 seconds in duration. A more detailed analysis of circulatory cutoff during systolic measurement has been reported previously⁶. The slow bleed portion (B-C), as shown in Figure 3, amounted to 2.5 seconds for the diastolic cycle and 1.7 seconds for the systolic cycle. This time segment in both tracings, as well as the total circulatory cutoff segment (A'-C) in the systolic tracing, can be shortened markedly by increasing the bleed rate or increasing the pressure setting of point B in the diastolic cycle and decreasing the pressure setting of point B in the systolic cycle. Resetting point B is more preferable ordinarily, since increasing the bleed rate tends to decrease measurement accuracy. In this example (Figure 3), cuff deflation to 10 mm Hg amounted to 1.7 seconds for the diastolic cycle and 1.8 seconds for the systolic cycle. The relatively short time durations of segments A-B and C-D are somewhat surprising, since the length of the 4.5-mm ID polyvinyl tubing from the compressed air source to the plastic, low pressure reservoir is 8.5 ft and from the reservoir to each cuff is an additional 8.5 ft. These time segments could also be shortened presumably by decreasing the length of this tubing. In this example, the total cycle time (A-D) is 4.9 seconds for the diastolic measurement and 5.0 seconds for the systolic measurement. As shown in Figure 3, when both cycles are initiated simultaneously, both are completed within 5.0 seconds. Under special conditions, it is possible to reduce this cycle time to approximately 2 seconds. The total physiological desirability of obtaining repeated, single determinations of

systolic and diastolic pressures via this two cuff system versus the standard single cuff methods of 20- to 30-second duration should be obvious.

Individual measurements obtained by this system would still be more physiologically desirable in the hypothetical case of the availability of only one arm. This might occur in the case of a one armed person or in operating, and recovery room situations, in which only one arm is available for pressure monitoring because the other arm is being utilized for a simultaneous intravenous infusion. As shown in Figure 6, alternate cycles of systolic and diastolic measurements are readily attainable using only one unit and one brachial cuff. In this example, the alternate cycle was invoked by a manual switch-over procedure. The internal circuitry of each unit was designed to accept the optional addition of a switching circuit that provides fully automatic alteration of individual systolic and diastolic cycles. If this circuit is added, automatic alteration is triggered by the cuff deflation relay. As shown in Figure 6, the total time for both cycles is approximately ten seconds. This duration can be halved by procedures described previously in this paper. However, even at 10 seconds per pair of pressure determinations, this far exceeds the measurement rates available via the standard, single cuff methods and does so with more comfort and significantly less brachial circulatory impedance.

As previously mentioned, both the cuff pressure "puff" detector and microphone auscultative detector must be activated simultaneously in order to trigger the systolic and diastolic pressure readings during the slow bleed portion of each cycle. This is clearly shown in Figure 5, where the activation of both sensors at point C in each cycle triggers the appropriate pressure delineating, cuff deflating relay. The simultaneous activation of both sensors can occur only during the slow bleed portion (B-C) of each cycle due to an "enabling" circuit that is turned on by the relay at point B and turned off by the relay at point C. During the slow inflation portion (B-C) of the diastolic cycle only, one or more "puffs" may be detected prior to the dual sensor, relay triggering that occurs at point C, because of the uninterrupted, pulsatile, brachial blood flow. By the simultaneous use of a standard stethoscope, whose bell is positioned just distal to the cuff microphone, the correct systolic

and diastolic microphone gain settings are empirically adjusted during automatic cycling to agree with the accepted standards of auscultative blood pressure criteria⁷.

By adjusting the rapid inflation pressure limit, the bleed rate, and the recycling low pressure limit, maximum measurement rates approaching those available via an intra-arterial catheter can be achieved. Because of the resulting significant circulatory impedance, this approach should be utilized only for short duration assessment of physiological phenomena during which maximum changes in blood pressure are expected. An example of maximum measurement rate is shown in Figure 7. In the 1 minute delineated in this recording, 33 diastolic and 31 systolic measurements were obtained simultaneously. Since the manually determined pulse rate at this time was 90 beats per minute, approximately one pair of determinations per 3 beats was achieved. The physiological desirability of this relatively benign approach versus the more hazardous intra-arterial catheter method for the assessment of human blood pressure transients should be obvious.

Regarding the pressure sensing element used in this apparatus, most of the commercially available transducers are satisfactory. Pressure calibration is greatly simplified by the linear core type transducer. Furthermore, this linearity will greatly simplify on line, digital printout accessibility in those instances in which data reduction of large numbers of maximum measurement rate records is necessary.

III. Recordings of Physiological Transients.

To achieve a more integrated assessment of subjects undergoing experimental physiological procedures, other parameters may be recorded with the blood pressure. One example of this is shown in Figure 8, where the blood pressure, respiration, electrocardiogram, and instantaneous heart rate were recorded during a single Mueller maneuver (a sustained negative intrapulmonic pressure with glottis closed). Here we can see the classic response of decreases in both the systolic and diastolic pressures and the biphasic heart rate response of an initial slowing followed by a sustained increase. There was very little body movement during the thoracic muscular strain of this maneuver. This strain was sufficient to produce some noise artifact in the heart

rate recording but none appeared in the blood pressure recordings. The diastolic measurement rate during this Mueller maneuver was 34 per minute.

In Figure 9, a dynamic recording of the effects of a 1-minute tilt to 60° feet downward is shown. Here we can see that the tilt produced some small biphasic changes in the systolic pressure, an initial decrease in the diastolic pressure followed by a typical sustained compensatory vasoconstrictor rise, an increased respiratory amplitude, and a typical sustained compensatory rise in the heart rate. As in the Mueller maneuver, there is little or no body movement during this procedure other than an increased postural tonicity in the leg muscles during the tilt. Some noise appeared in the heart rate recording but, again, none appeared in the blood pressure tracings.

Figure 10 shows a recording of the effects of a rather painful immersion of one bare foot into a bucket of ice and water. Here we can see an initial drop of about 10 mm Hg in the diastolic pressure followed by a marked, sustained rise of approximately 20 mm Hg above control levels, a small sustained rise in the systolic pressure, low-amplitude gasping-type respiration, and a sustained rise in the heart rate of about 15 beats per minute. Following the removal of the foot from the ice and water, the return to preimmersion control values was somewhat delayed due to the slow disappearance of the pain of immersion. The value of dynamic recording of this type should be obvious. As in the two previous procedures, body movement was at a minimum.

Figure 11 shows a recording of the effects of a 45-second bout of hyperventilation. Here we can see the large sustained changes of a decrease in diastolic pressure, an increase in systolic pressure, and an increase in the heart rate. The increased heart rate and widening pulse pressure are most likely related to the invoked exercise level of the hyperventilation. The thoracic movement during this maneuver was quite severe as reflected by the noise in the heart rate recording. With the exception of the short noise artifact in the systolic tracing only, which was

caused by a violent double cough, the blood pressure recordings seem to have been well protected against hyperventilation body-movement artifact.

IV. Conclusions.

The feasibility of the described device for dynamic recording of physiological blood pressure transients in humans under minor body movement conditions has been established. The measurement rates attainable certainly approximate those available via the more hazardous intra-arterial methods. The use of digital printout equipment should keep data reduction within a reasonable processing time. For "steady-state" single measurements the 5-second maximum for one pair of pressure determinations seems to be more physiologically desirable than the 30-second measurement of the standard single cuff methods. Measurement accuracy is at least equal to standard auscultatory methods.

Besides all the obvious possible experimental uses of this system as it now exists several others may be noteworthy in passing. Field studies with this apparatus are quite feasible using smaller capacity compressed-air tanks or motor driven compressors, an already included 2-hour capacity rechargeable battery pack, and a battery-powered, electromagnetic tape recorder. Our projected studies of inflight fatigue assessment of pilots fall in this category. In medical centers, critical blood pressure monitoring with maximum patient comfort during surgical procedures in the operating room, in the post-surgical recovery room, in intensive care wards, and in cardiac and general emergency wards is feasible. The use of this apparatus to measure blood pressure along with adjunct parameters during physiological and pharmacological laboratory demonstrations in medical school teaching activities is also feasible. Finally, the capability for rapid, single determinations and short duration bursts of maximum rate measurements should be of immense value to the physiological assessment of astronauts in space flight experiments.

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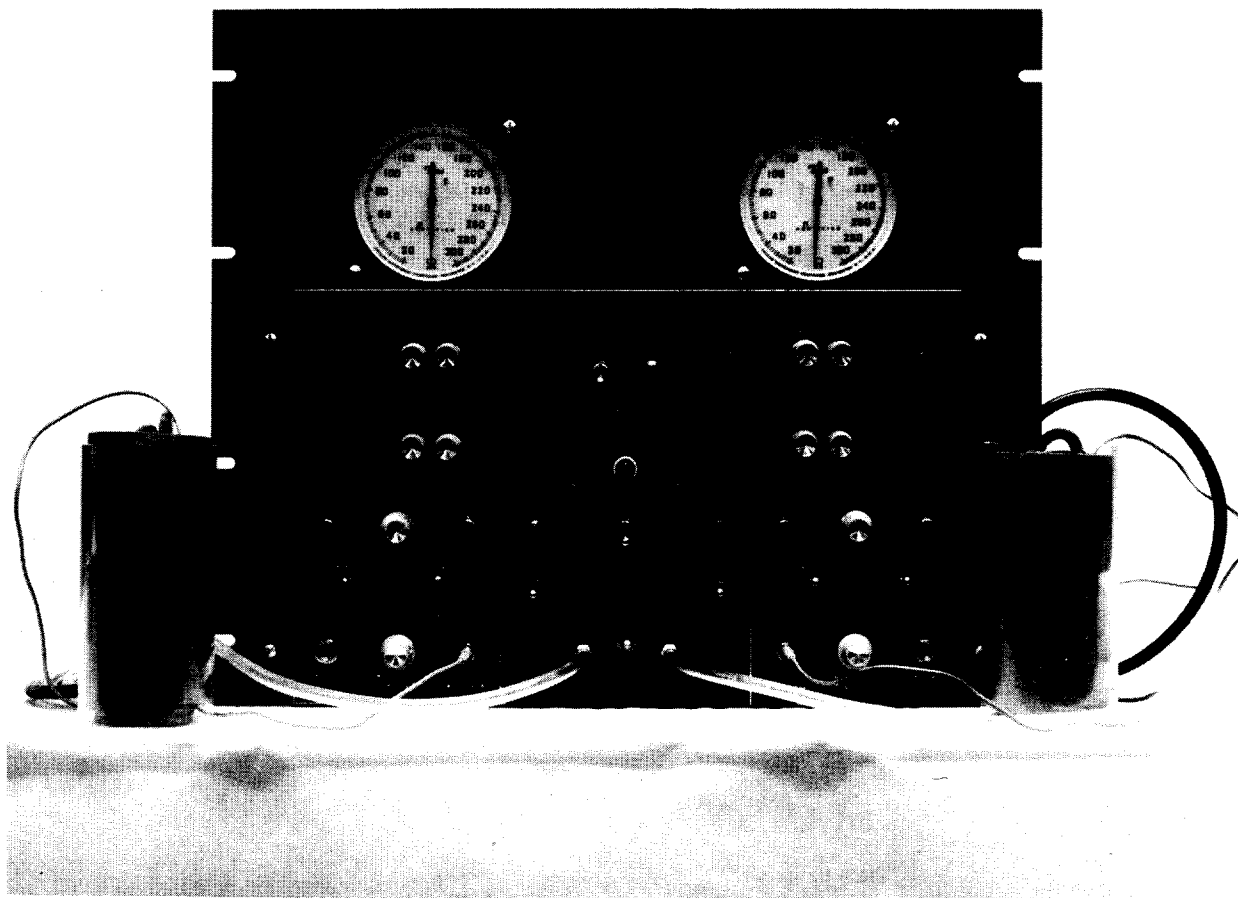


FIGURE 1. Control panel of the automatic blood pressure device.

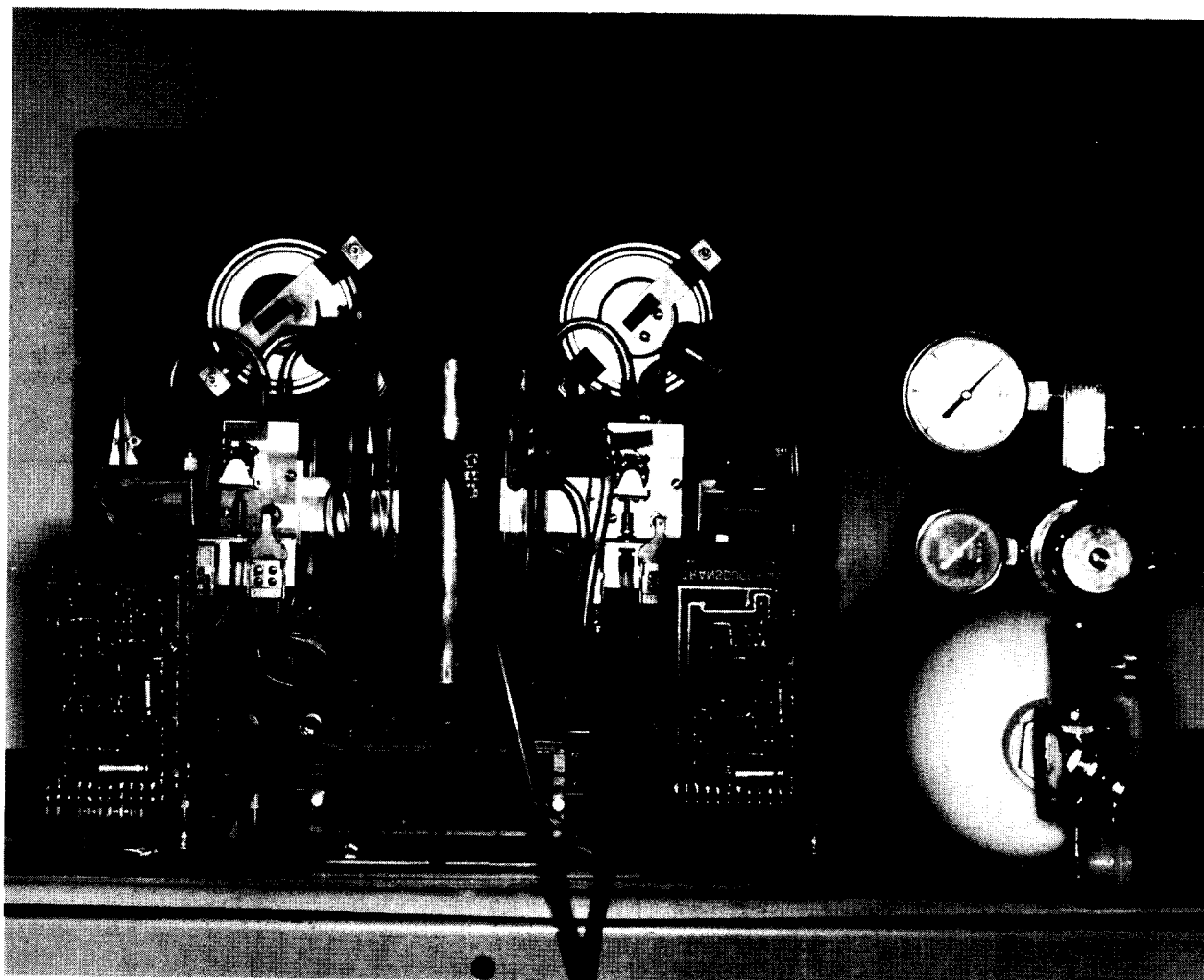


FIGURE 2. Internal view of the automatic blood pressure device.

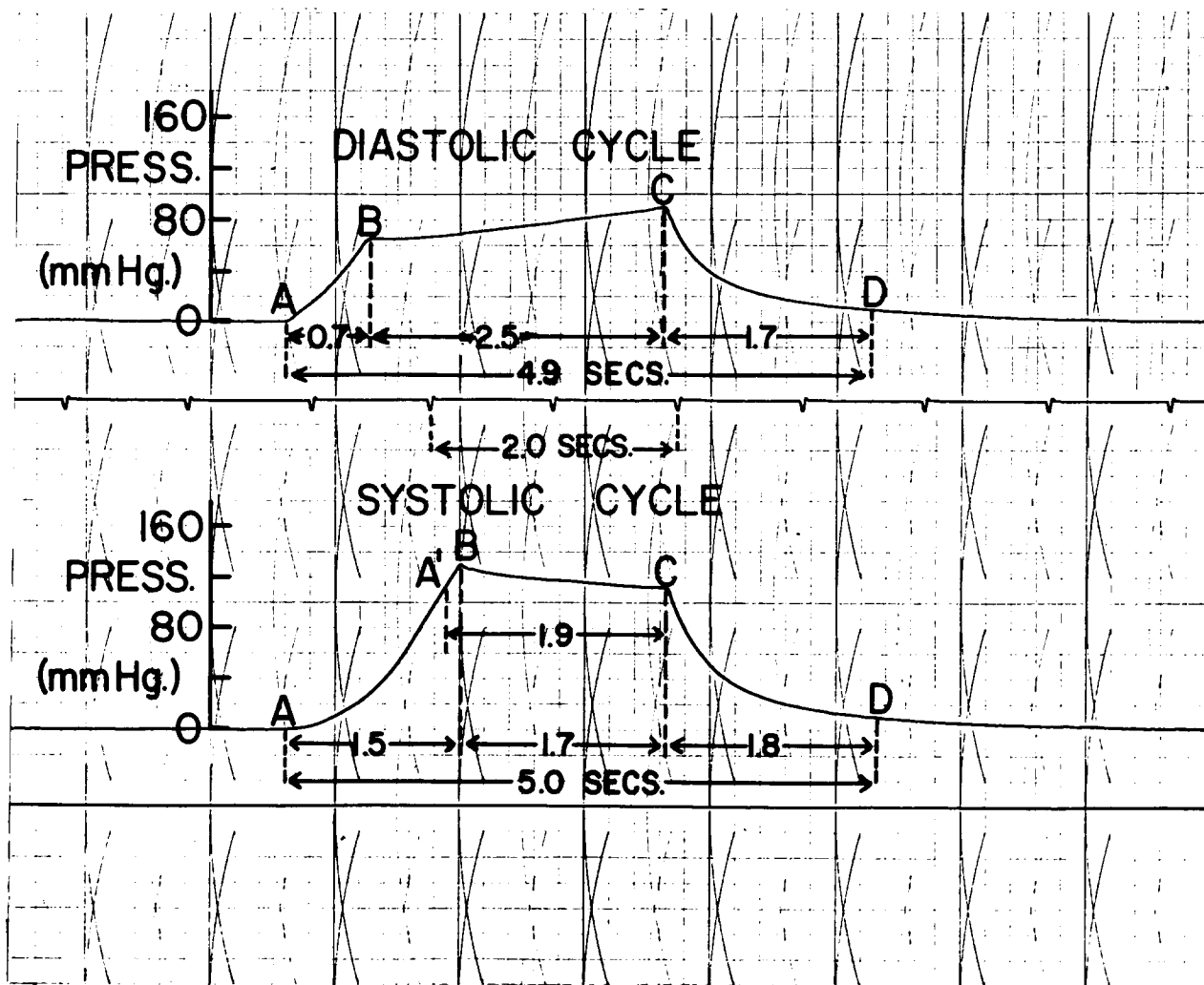


FIGURE 3. Simultaneous recording of one diastolic and one systolic blood pressure measurement.

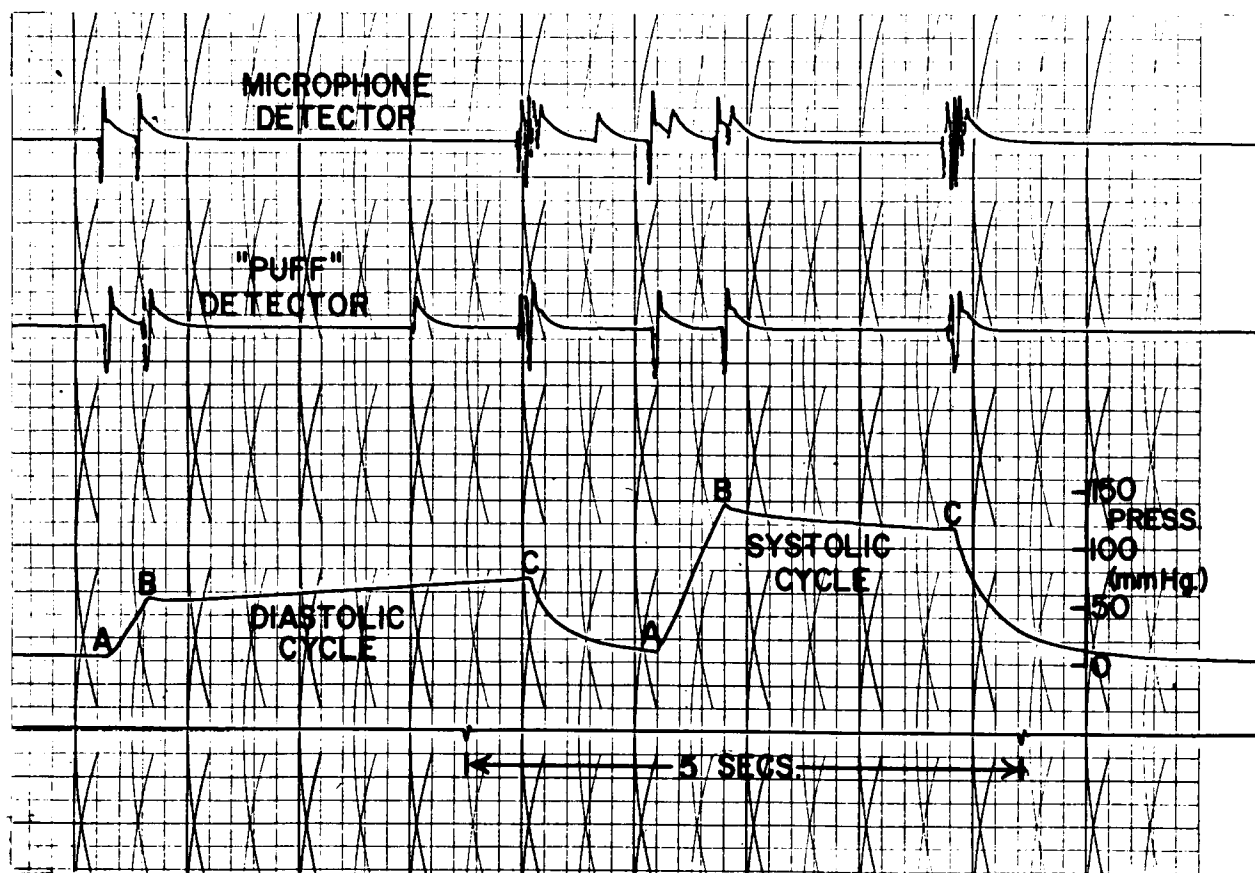


FIGURE 4. Recording of the dual-sensor triggering of diastolic and systolic blood pressure measurements.

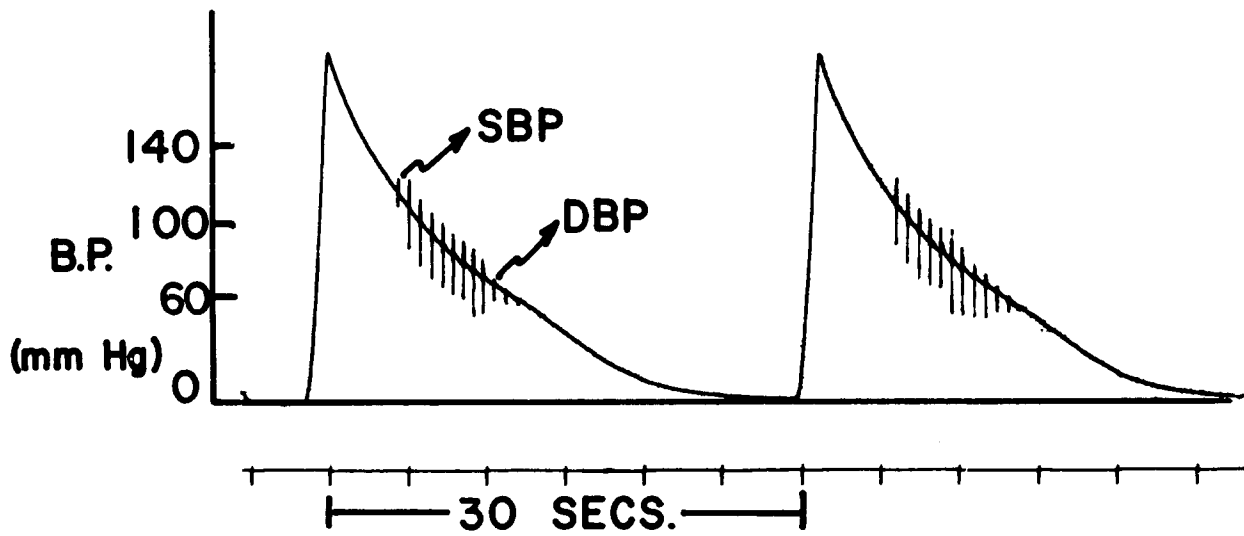


FIGURE 5. Automatic blood pressure measurement using a standard, single-cuff method.

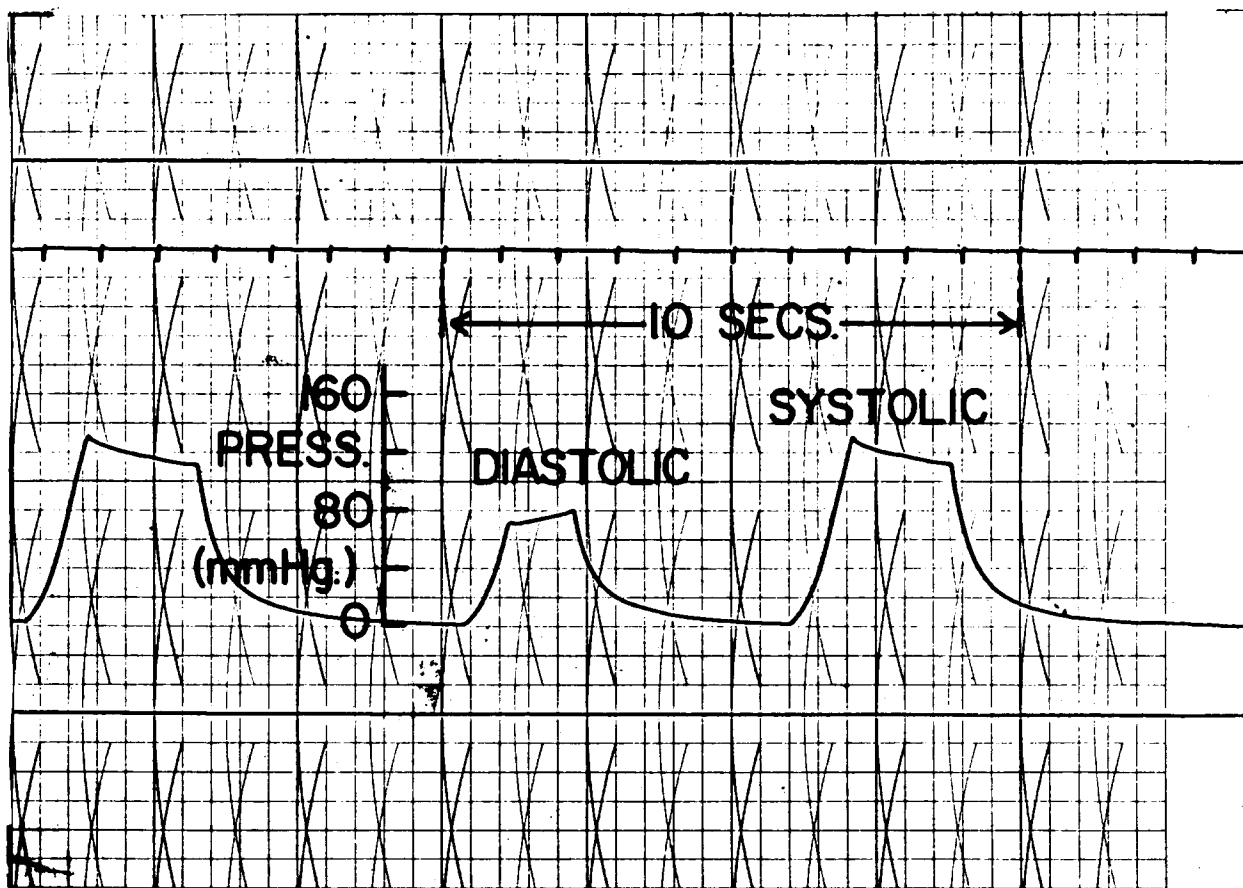


FIGURE 6. Recording of alternating diastolic and systolic blood pressure measurements.

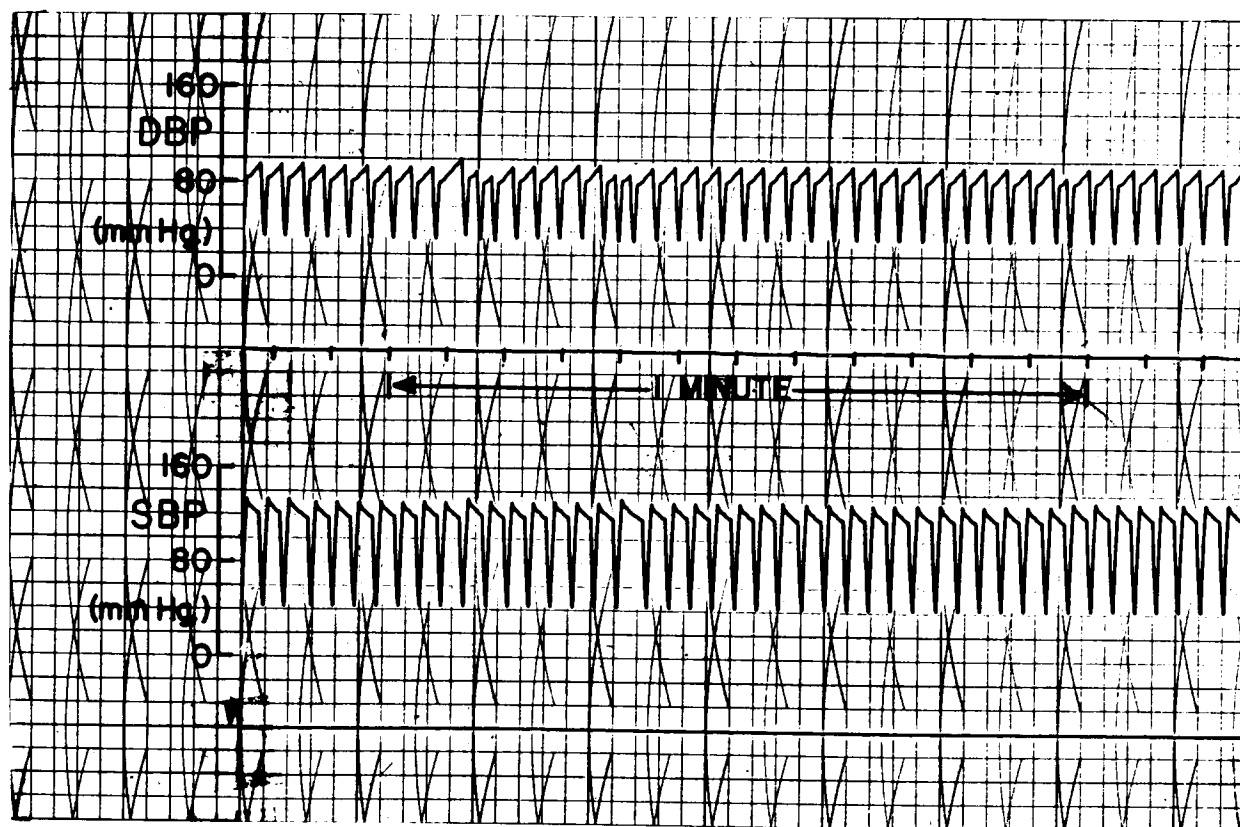


FIGURE 7. Recording of maximum measurement rate of diastolic and systolic blood pressures.

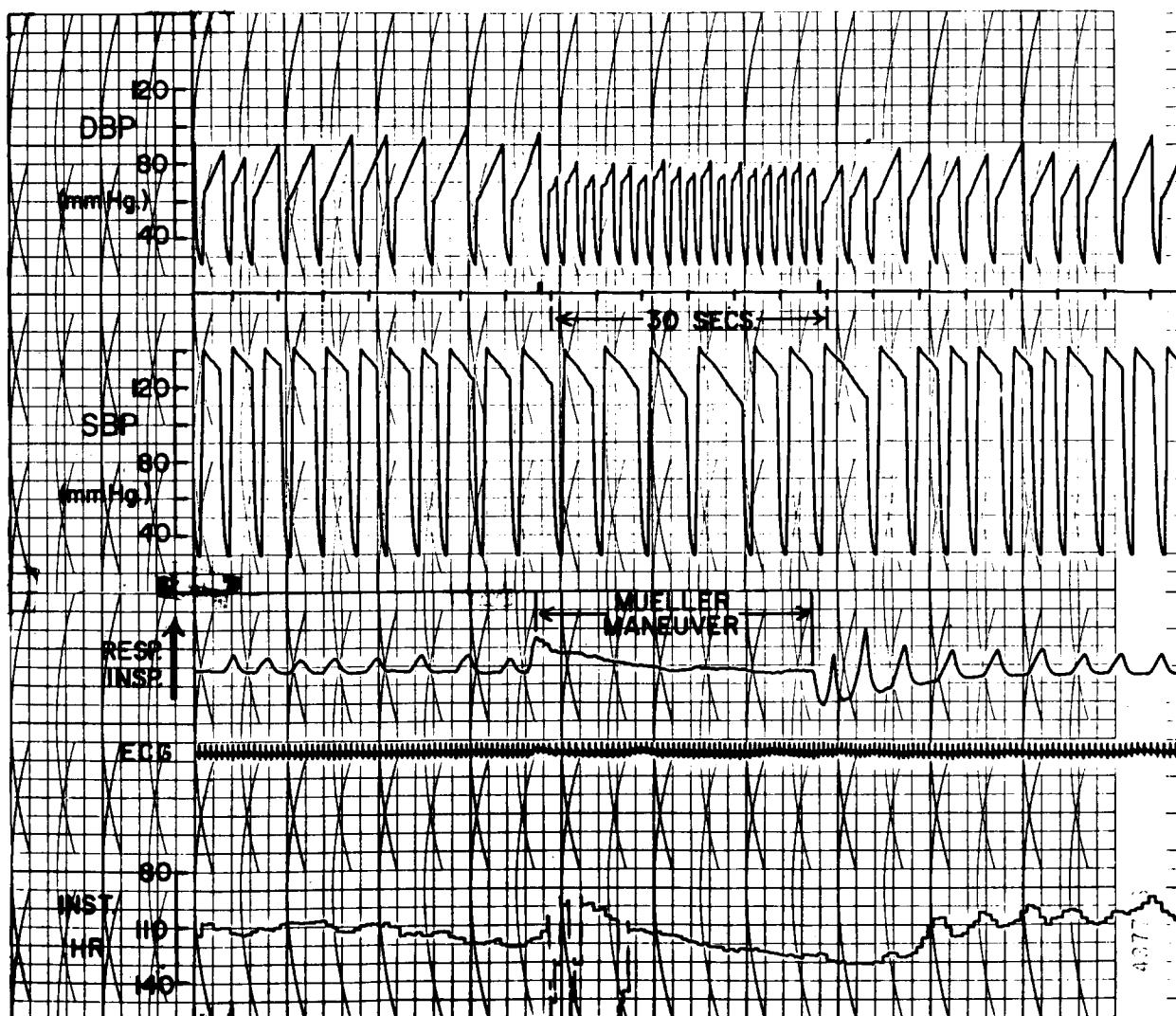


FIGURE 8. Recording of the physiological effects of a single "Mueller" maneuver.

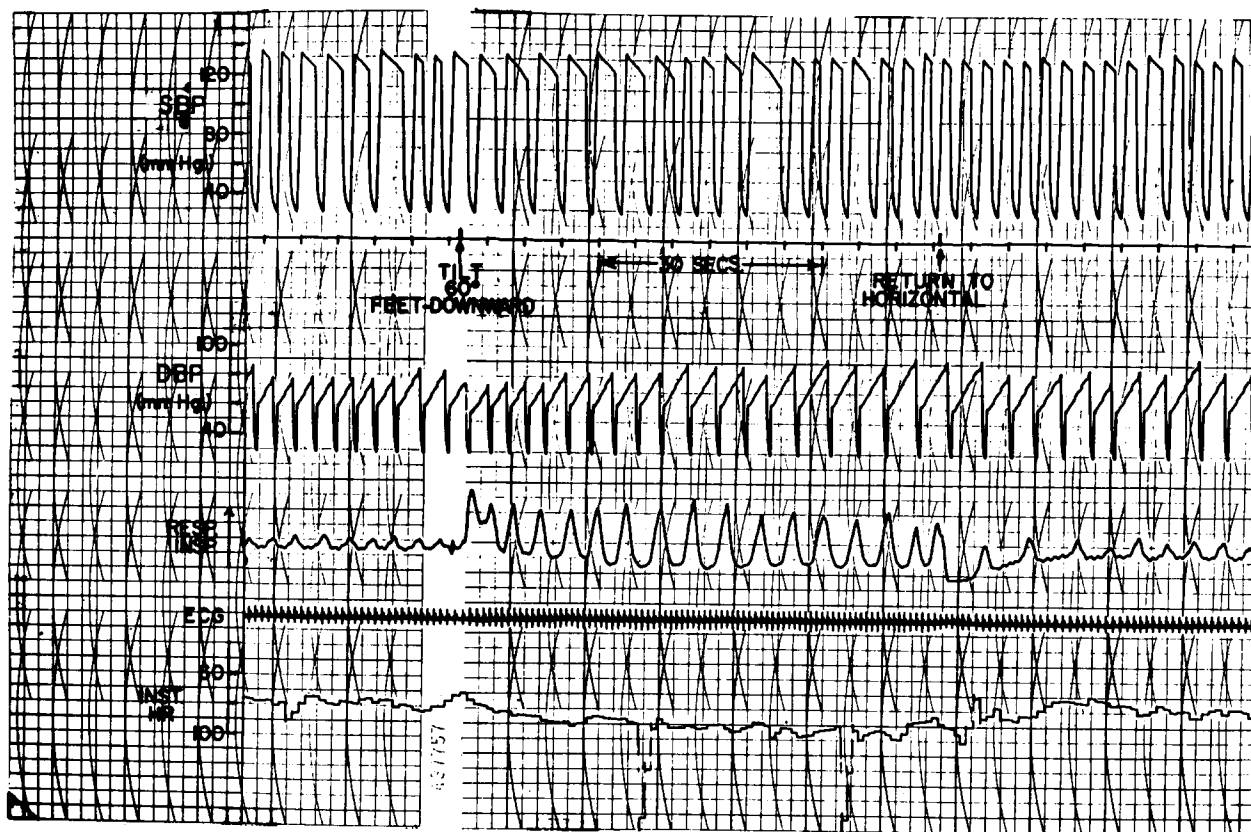


FIGURE 9. Recording of the physiological effects of a feet downward 60° tilt for a duration of one minute.

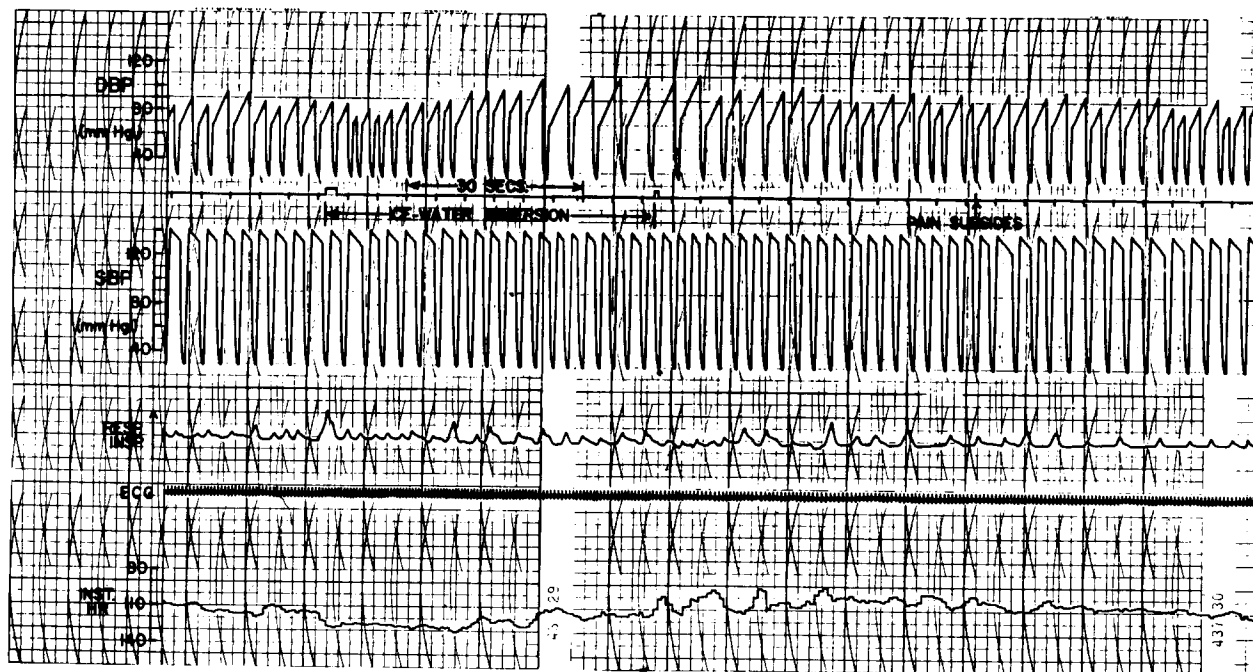


FIGURE 10. Recording of the physiological effects of a one minute, barefoot immersion in ice and water.

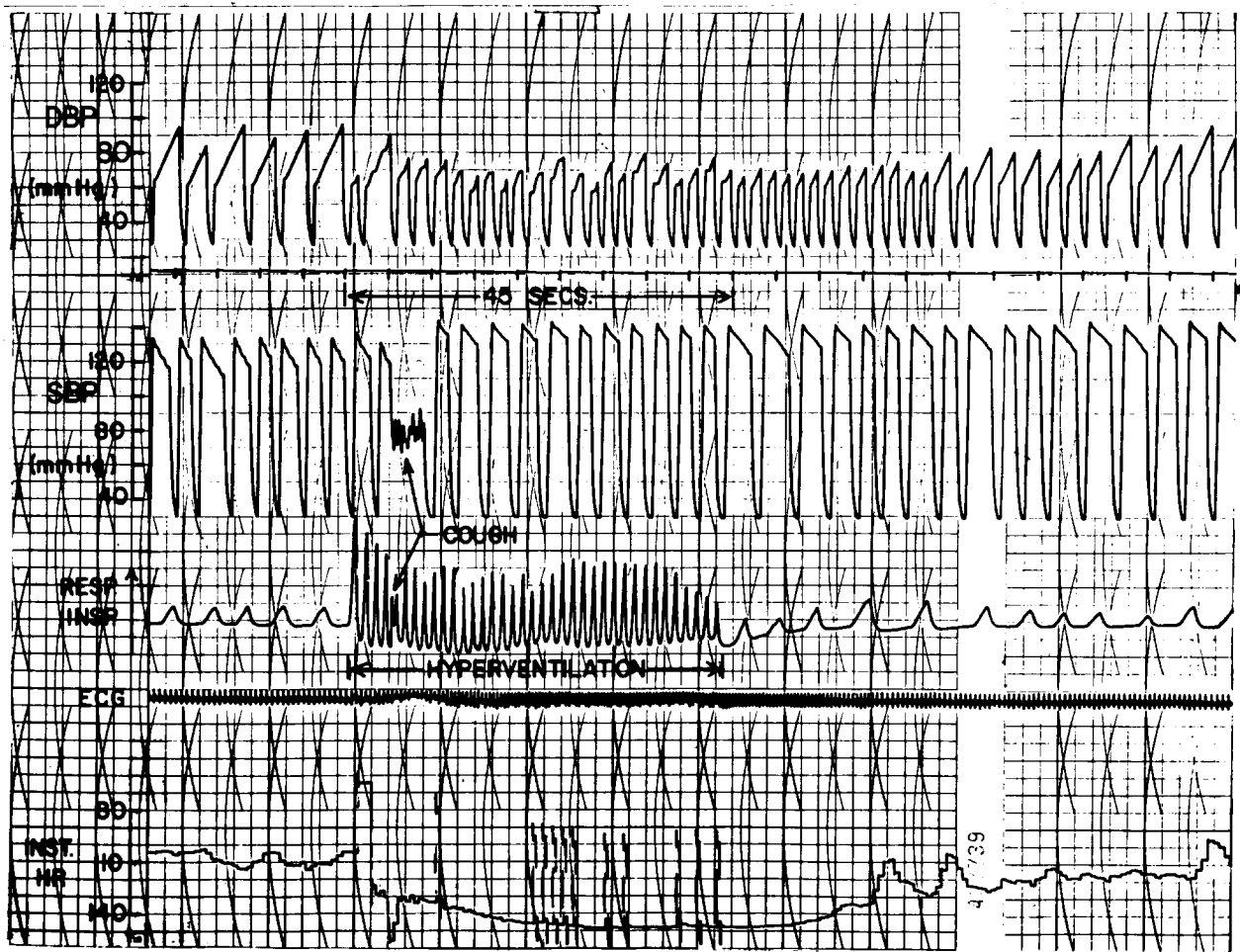


FIGURE 11. Recording of the physiological effects of a 45 second bout of voluntary hyperventilation.

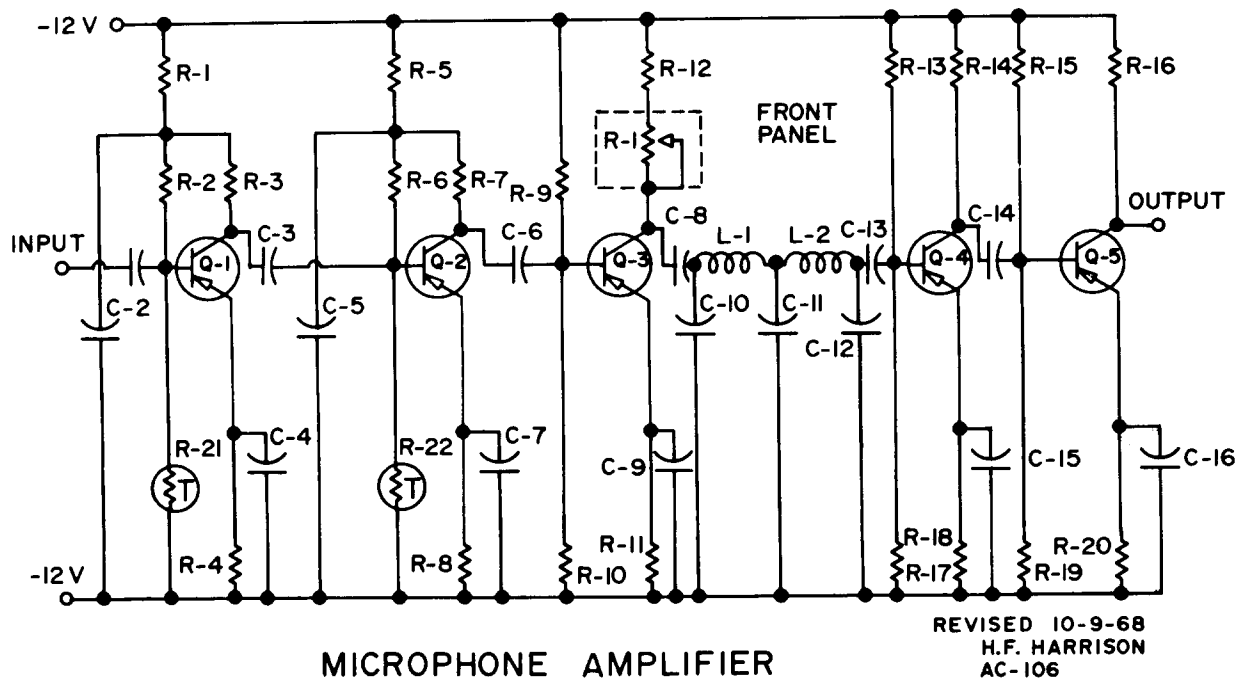


FIGURE 14. Microphone amplifier circuit diagram.

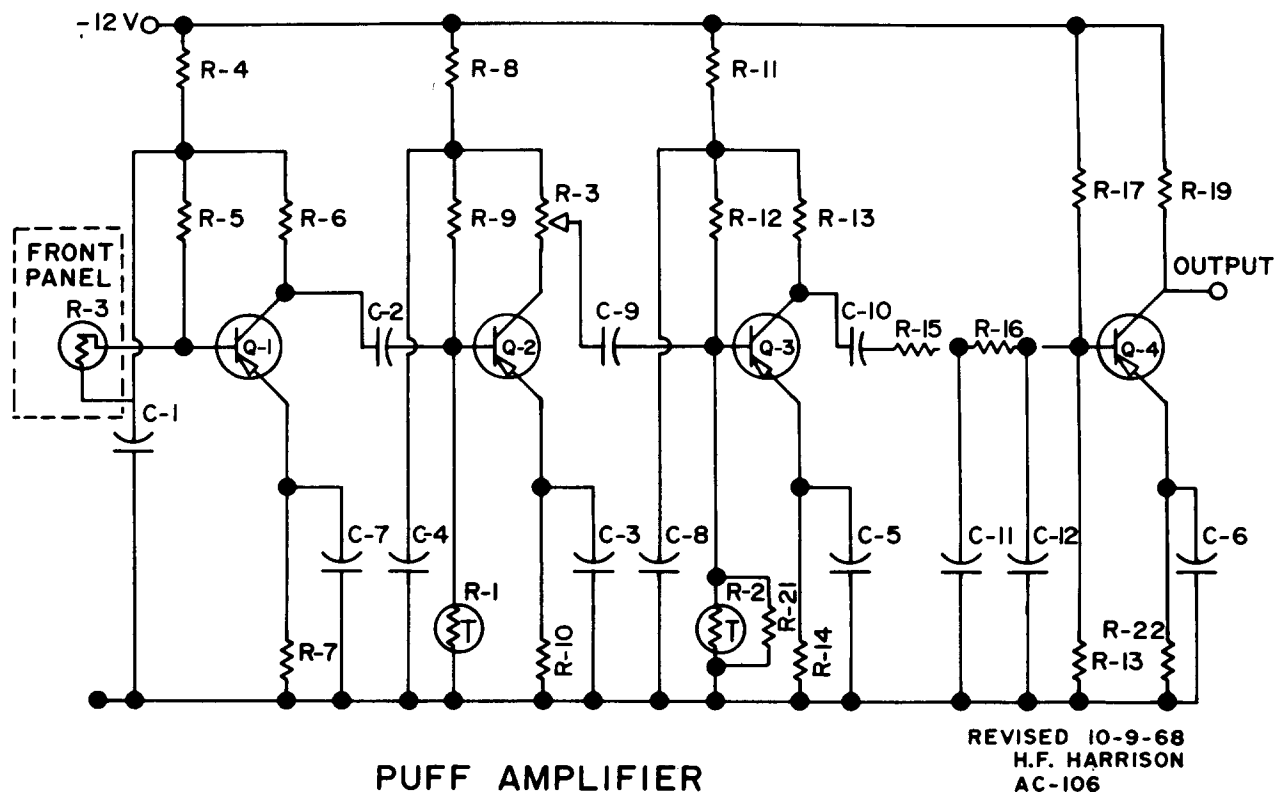
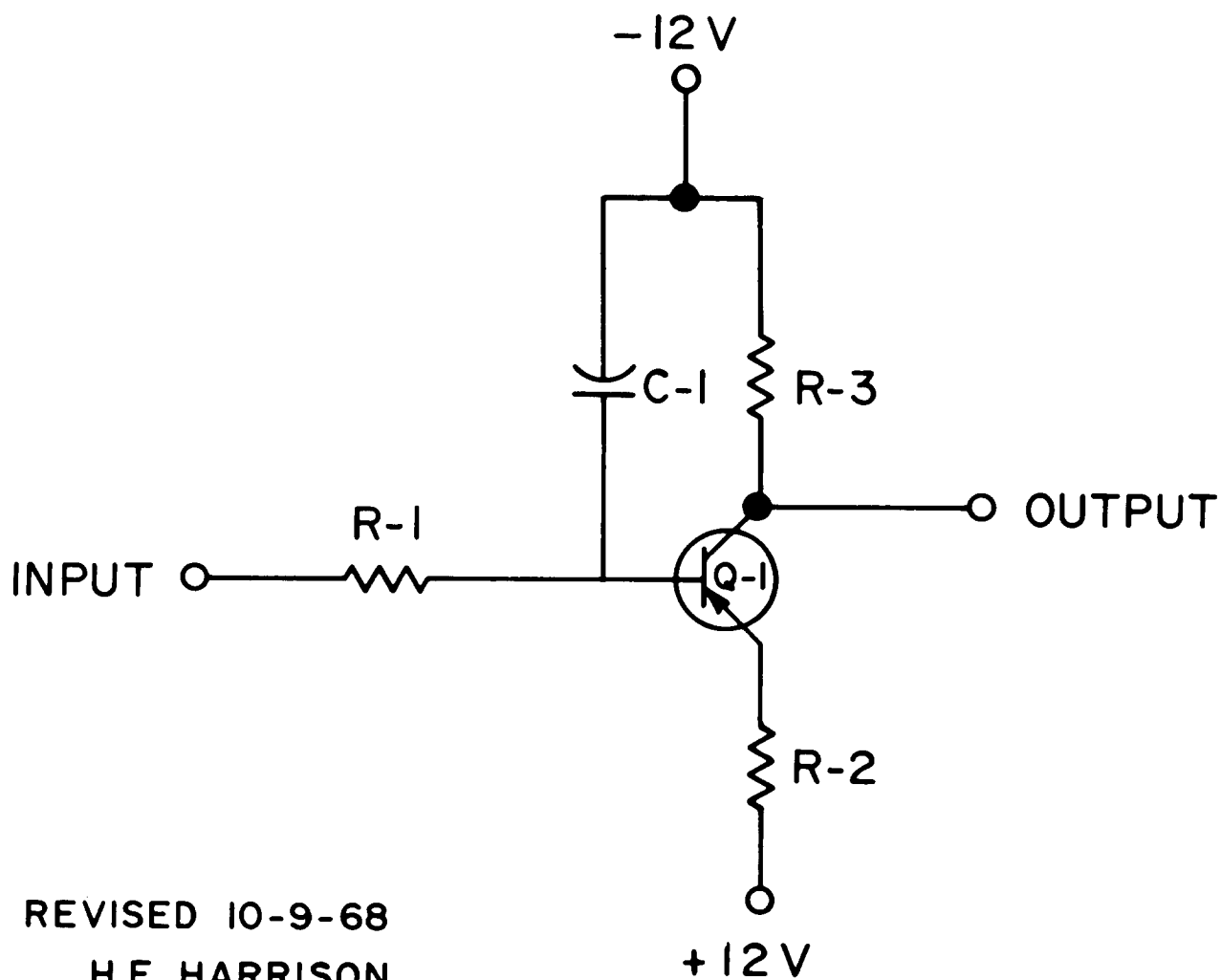


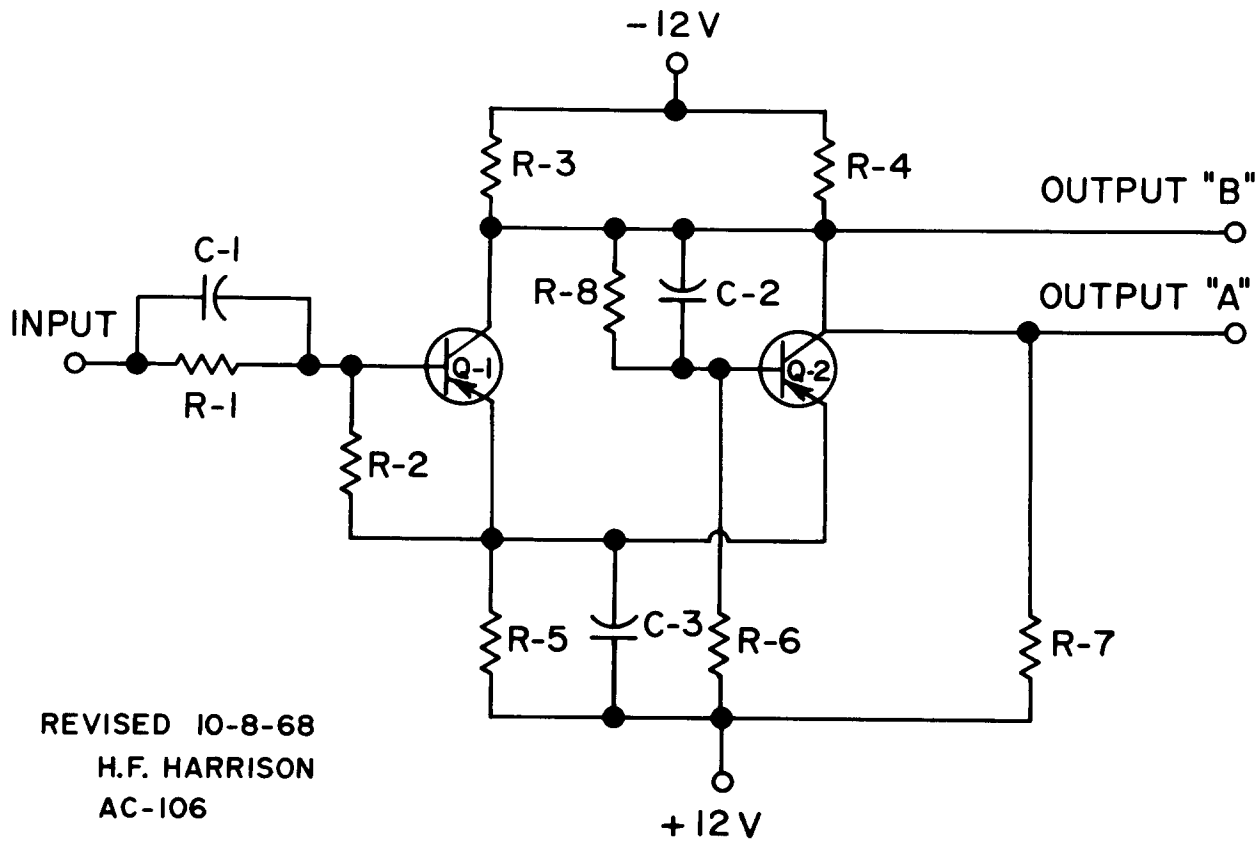
FIGURE 15. Puff amplifier circuit diagram.



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ENABLE CIRCUIT

FIGURE 16. Enable circuit diagram.



SQUARING AMPLIFIER

FIGURE 17. Squaring amplifier circuit diagram.

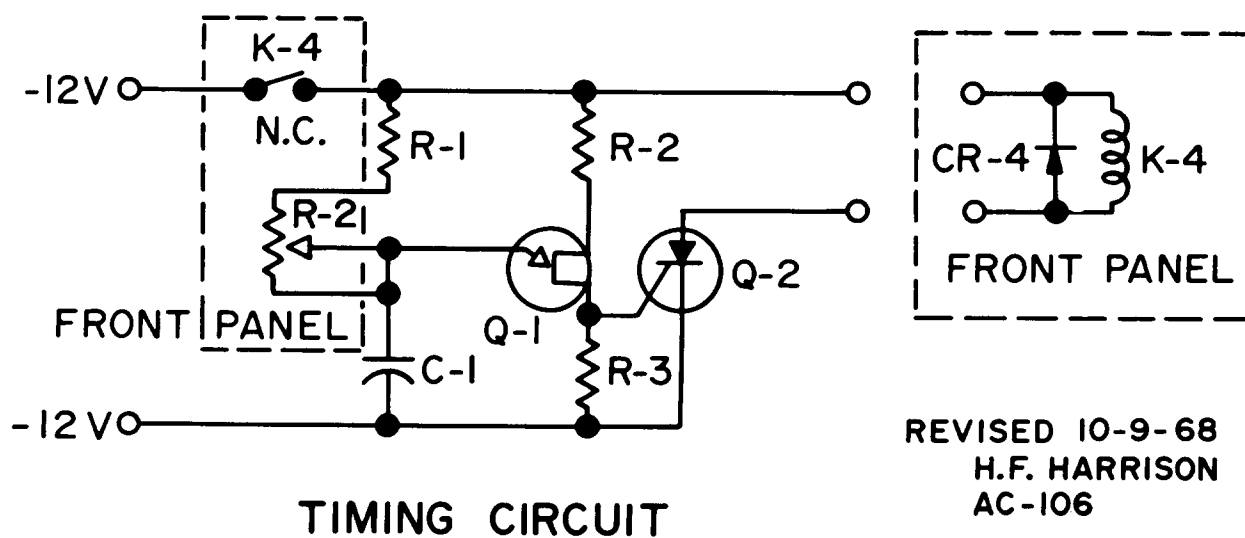
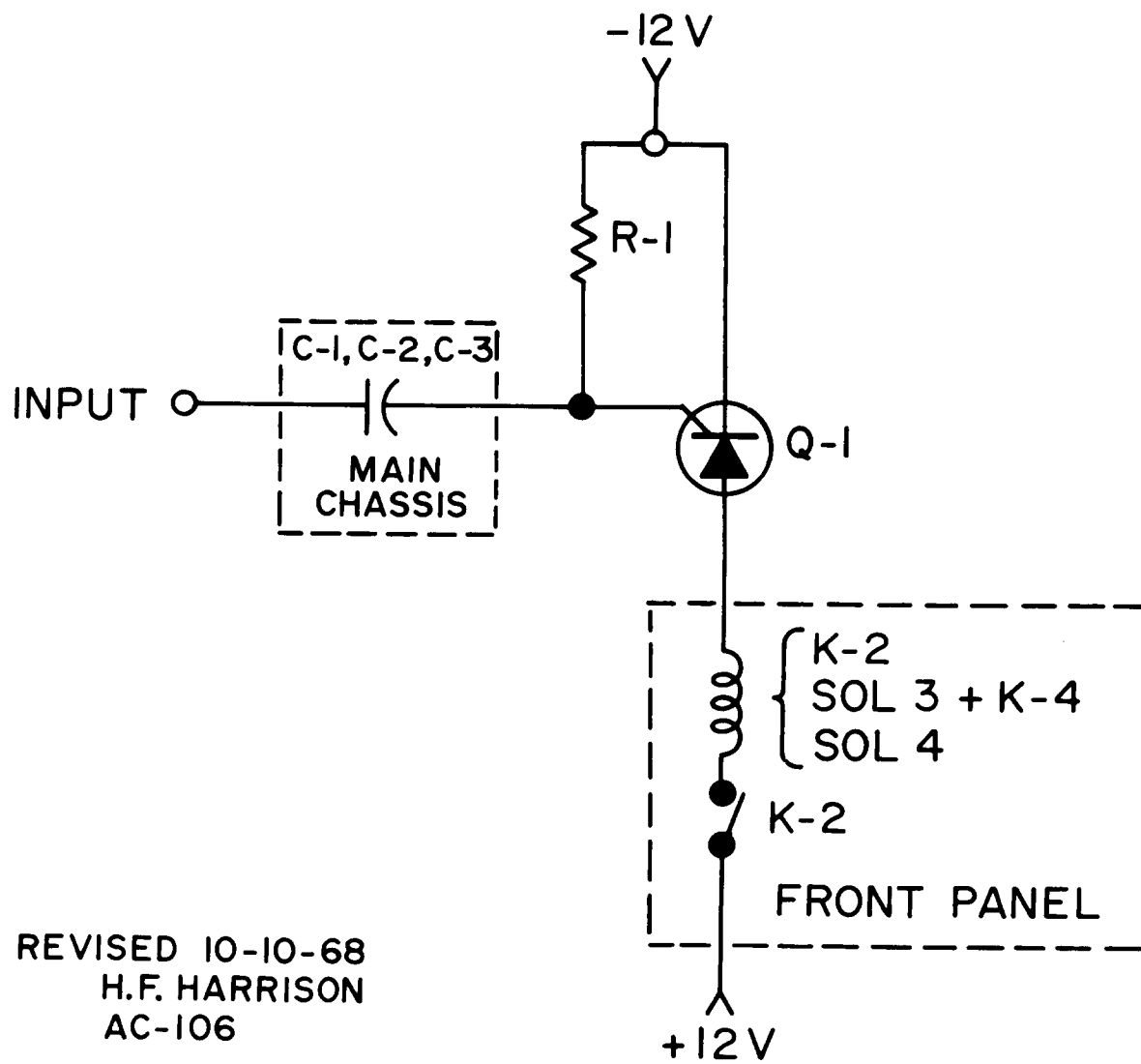


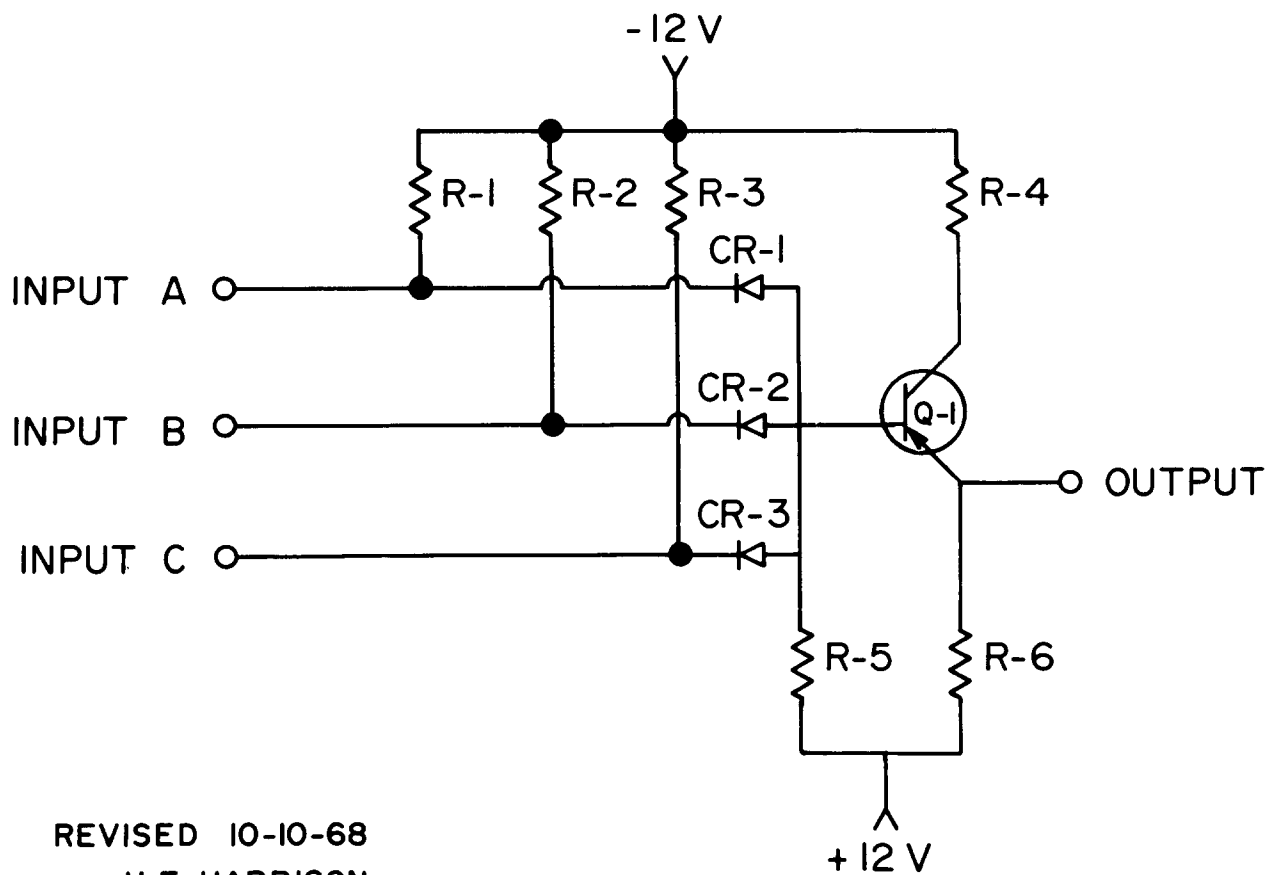
FIGURE 18. Timing circuit diagram.



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SOLID STATE SWITCH

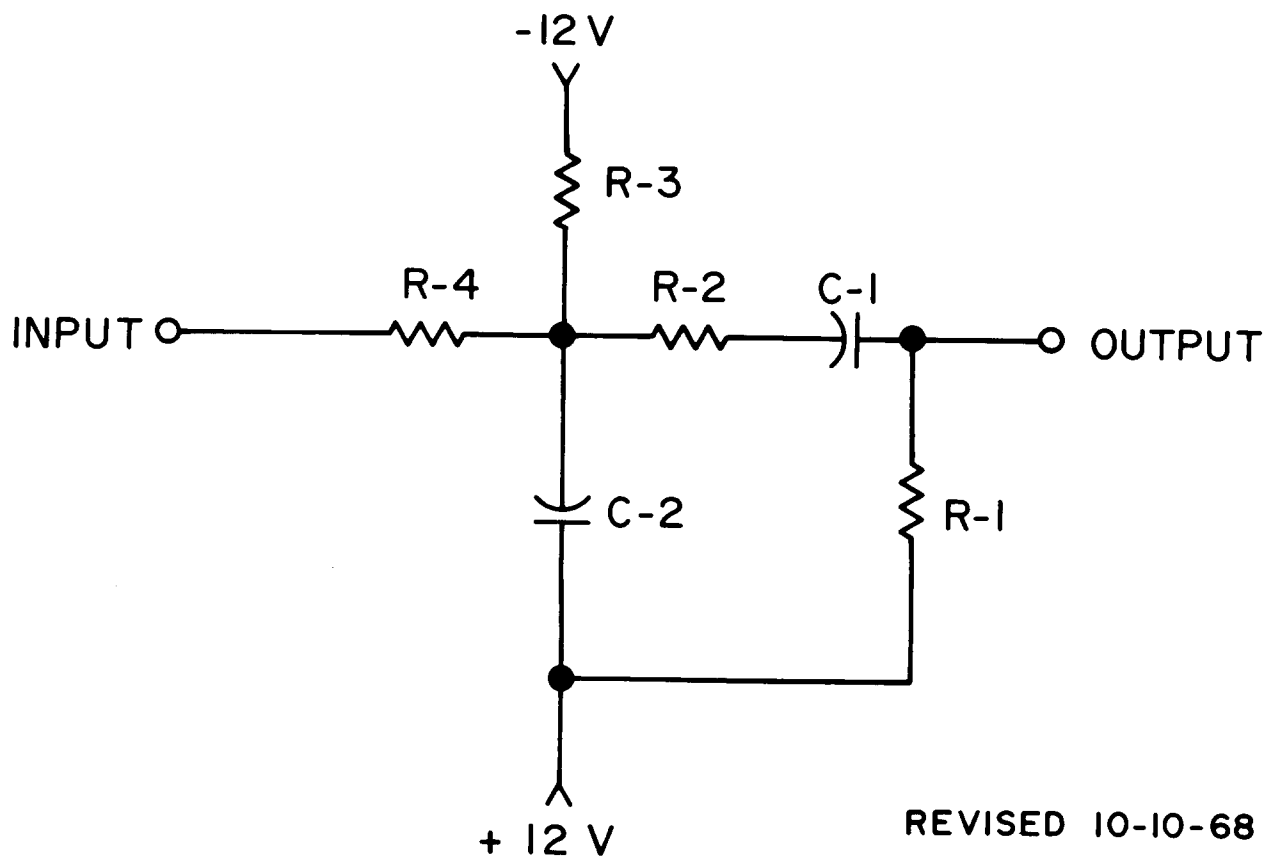
FIGURE 19. Solid state switch circuit diagram.



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"AND" CIRCUIT

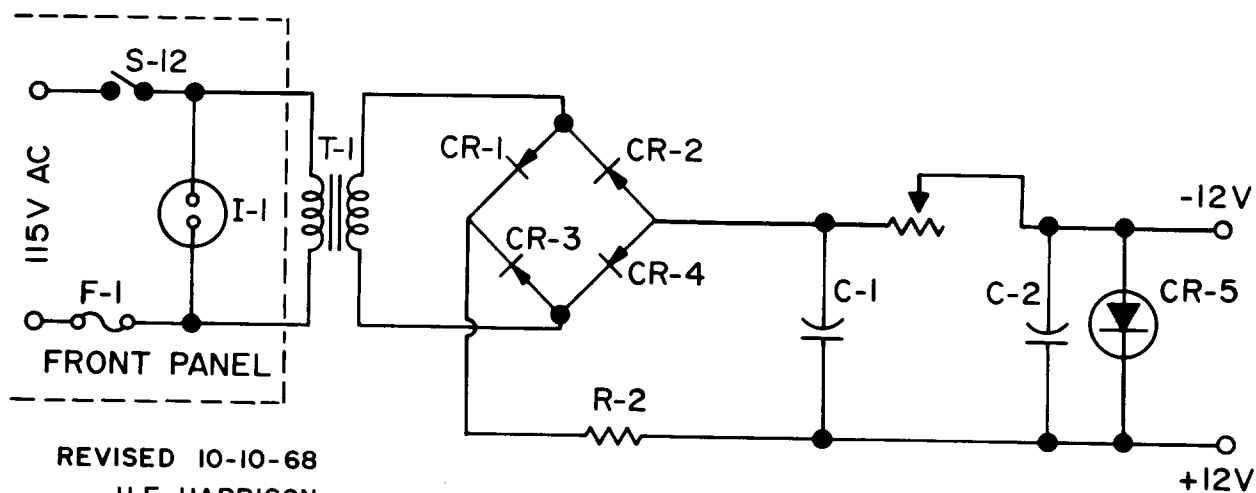
FIGURE 20. And circuit diagram.



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PULSE CIRCUIT

FIGURE 21. Pulse circuit diagram.



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POWER SUPPLY

FIGURE 22. Power supply circuit diagram.

