Temperature Compensation for a Core Memory

A. H. ASHLEY†, E. U. COHLER† AND W. S. HUMPHREY, JR.†

FOR FIXED installation, it is often possible to control the temperature of ferrite core memories within narrow limits. However, in a small mobile computer designed to operate over world-wide conditions, this control is not feasible because of the added weight, volume, and cost encountered. A memory designed for such application has been temperature compensated by the use of temperature sensitive components in the current sources to the X-Y drivers and in the power supplies for the Z drivers. In addition, core derived strobing has provided peaking time compensation for the sense amplifiers as changes in transistor characteristics delay or advance drive current. This compensation permits operation of an 8192 word 38-bit transistorized memory running at an 8 microsecond cycle time in an ambient environment which may vary between −30°C and +55°C.

INTRODUCTION

Most computers use some form of temperature control to maintain the operating temperature of the ferrite cores within very close limits. This precaution is required because of the sensitivity of the ferrite material to ambient temperature variations. When the environmental temperature goes up, the coercive force will go gown and the material then loses some of its squareness, consequently becoming more disturb-sensitive as shown in Fig. 1. Therefore, if the drive current is held constant while the temperature rises, the cores switch faster, giving greater amplitude to the output, and the cores are more sensitive to disturbance by the half-selecting drive pulses. The reverse effect is observed as environmental temperature is lowered. Below 0°C, the drive which has proven satisfactory at +25°C will produce a ONE about half as great as previously observed at normal room temperature. Under this condition, there would not be an output from a conventional sense amplifier. Moreover, a fixed strobe would miss the peak signal-to-noise time if the switching characteristics were changed by such an amount.

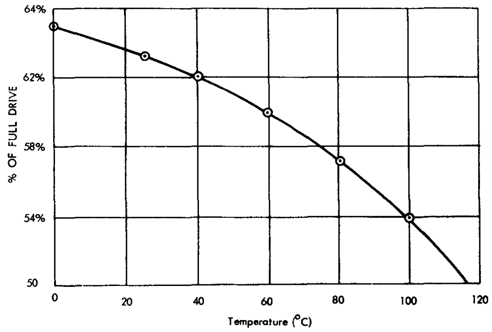

Fig. 1—Percentage of full drive which will disturb stored information *vs.* core temperature.

TEMPERATURE CONTROL

The general solution to the temperature problem has been to control the temperature within the memory enclosure within a few degrees Centrigrade. While at first this appears to be a simple solution to the problem, it has proven unsatisfactory over a large temperature range. To maintain the temperature at 95°C above the ambient (say at 65°C in a −30°C ambient) it will be required to install a rather large insulating oven complete with blowers and high wattage heaters and provisions for creating turbulence for proper mixing. When operating in conjunction with accurate thermostatic equipment, it will suffer from the inherent disadvantages of all mechanical components. The reliability from such components will result in degrees of magnitude lower than that of the memory or the accompanying solid-state circuitry. Moreover, the cost of a good air thermostat is considerably greater than that of the few electrical components required to do the job.

Temperature Compensating the Drive-Currents

Another alternative to control of the temperature of the memory cores is control of the drive-current amplitude. If the drive current is varied with temperature so that half selected cores are not disturbed but the fully selected cores are properly driven for full switching output, satisfactory operation is obtained. From the memory cores of the type used in Sylvania's MOBIDIC it was determined that drive-current compensation aimed solely at maintaining constant switching time resulted in a considerably lower output signal amplitude at the low end of the temperature range. Since the cores are less disturb-sensitive at lower temperatures, it is feasible to compensate for constant output-voltage-amplitude. The constant amplitude compensation below 20°C minimizes sense amplifier problems since no variation in strobe level is required. The overall compensation curve, shown in Fig. 2, results in a constant core output below 20°C and constant switching time above that temperature.

---

† Sylvania Electric Products Inc., Needham, Massachusetts.

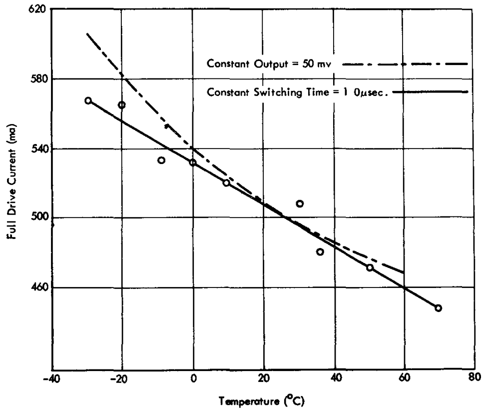

Fig. 2—Core current required *vs.* temperature.

X-Y Drive-Current Sources

The drive currents for the X-Y coordinates originate from high impedance current sources, each source consisting of a power transistor connected in the common base configuration. The high impedance is required to maintain good current regulation under varying load conditions. The circuit for the current source is shown in Fig. 3. Current is supplied to the emitter of the current-source transistor by a source consisting of a reference voltage V_{REF} applied across a variable resistance network. The resistance is partially variable to compensate for initial differences in transistor parameters. The reference voltage V_{REF} is common to all current sources in the X-Y circuitry.

Choice of Compensation Technique

The output current may be varied with temperature by one of two methods. Either the external emitter resistors may have a positive temperature coefficient, or the Voltage reference may have a negative temperature coefficient. There are no positive temperature coefficient resistors available with sufficient power capability for the first method. Even if they were available they would not be very practical to use because of drive current tolerances. The latter method is considerably better since it employs only one temperature-sensitive network per memory and uses readily available negative temperature coefficient elements. Moreover, the common compensation assures that all drivers vary equally, thus minimizing drive current tolerance problems.

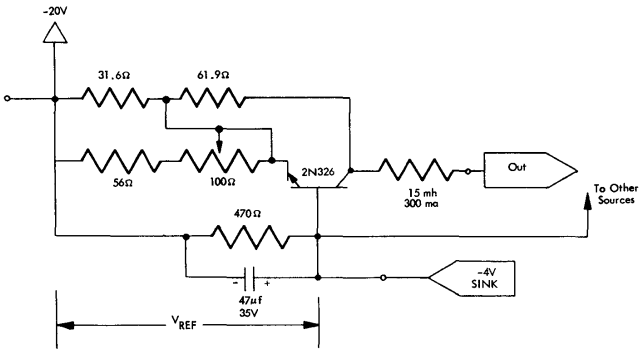

Fig. 3—Current source.

Voltage Reference Design

Thermistors (negative temperature coefficient resistors) have a relatively low dissipation coefficient (watts/°C rise). It is, therefore, advisable to maintain a negligible dissipation within them in order to have their resistance remain a function of true ambient temperature without side effects from internal heating. Consequently, the thermistor net-

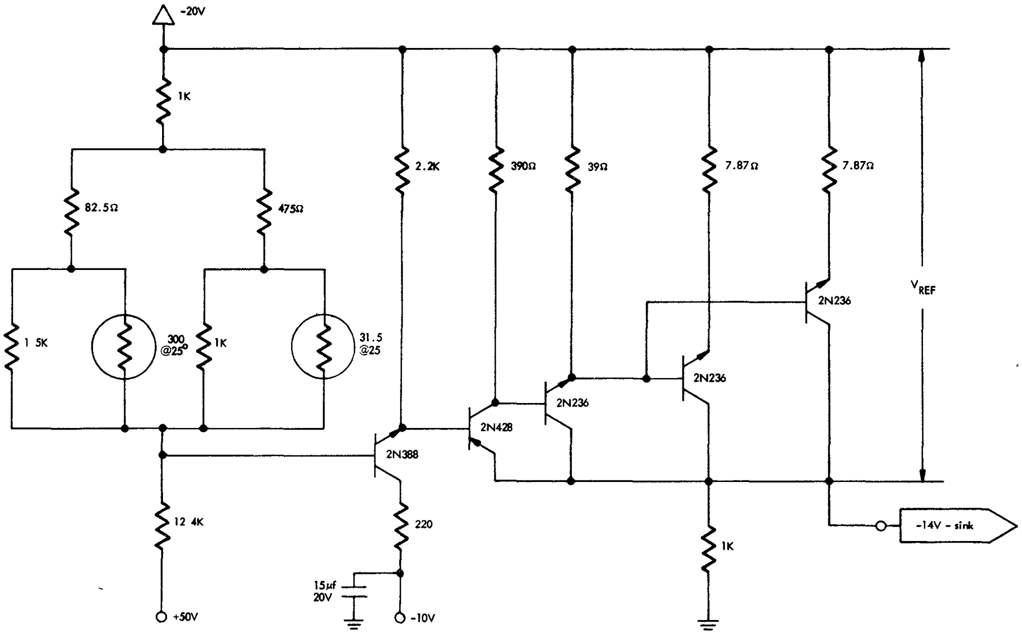

Fig. 4—Temperature compensated voltage reference (X-Y).

work is buffered by a power amplifier with a unity voltage gain and a high input impedance, allowing the use of current as low as 5 ma in the network.

The thermistor network and buffer amplifier are shown in Fig. 4. Notice that the V_{REF} is derived from the – 20 volt supply as indicated in Fig. 3. This means that variation in the – 20 volt supply will not affect the current source accuracy. Two thermistors are necessary to provide the proper compensation characteristics over the entire temperature range. A constant current of 5 ma through the 1k precision resistor provides a constant drop of five volts. The thermistor network with 5 ma through it will add a voltage drop of 1.0 volt at +25°C, 2.2 volts at – 30°C, and 0.52 volts at +55°C. The overall curve between temperature end points is nearly linear, (note that Fig. 2 is on an expanded scale) in great part due to the constant five volts superimposed on the temperature-sensitive voltage.

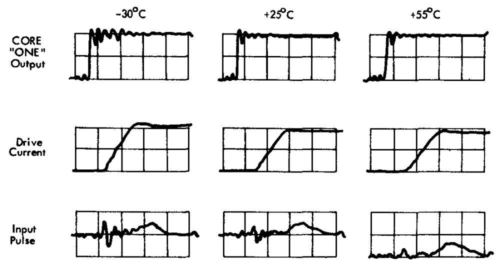

Fig. 5—Temperature compensated outputs.

Results Follow Theoretical Curve

The oscillographs in Fig. 5 were taken from an experimental system consisting of transistor core drivers and a memory core. The drive current varies through the desired pattern, although the compensation at this time was slightly less than that shown in Fig. 2. Even so, the ONE at – 30°C is within 10% of the ONE's at the other temperatures. A subsequent slight revision of the thermistor network was made to increase drive at the lower temperatures, resulting in a higher output at the low end without affecting the drive at other temperatures. The final compensation characteristic is as shown in Fig. 2.

Compensating the Z-Drive Current

The Z-drivers do not employ high impedance transistorized current sources such as those used for the X-Y drivers, because of less stringent current tolerances. The current for each Z winding is determined by the power supply voltage across a fixed resistance in series with the winding, as shown in Fig. 6. In order to vary the current with temperature, either the resistance or the total voltage across the resistance must be varied. The first method was impractical, because resistors with large positive temperature coefficients are not available. To vary the whole supply-voltage with temperature is not practical due to complications in the power supply design. To overcome these problems, one end of the current determining resistance R1 was connected to a fixed close-tolerance power supply (used elsewhere in the memory); and the emitter of the output transistor, (Q3, Fig. 6), was returned to a temperature sensitive supply V_{TEMP}. This supply was designed to vary from +0.5 volts at +55C to +5.0 volts at –30C. Because the maximum voltage swings up to 5 volts, considerably less power is involved in the temperature sensitive control than if the entire 20 volt supply were to vary from –20 volts to –25 volts, and the percentage variation is less critical.

Temperature Sensitive Emitter Supply

Because the thermistor network used in the X-Y coordinate has a quasilinear resistance-temperature characteristic, an identical network was used to derive

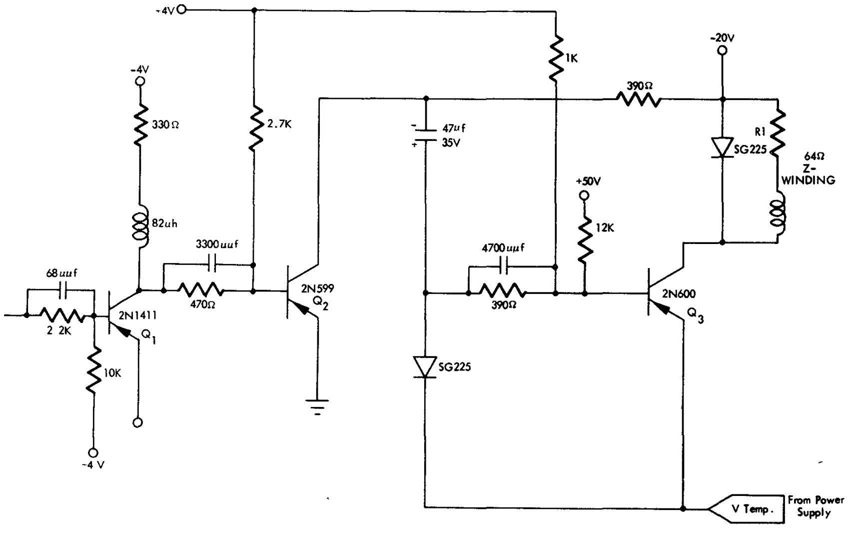

Fig. 6—Circuit for Z-driver.

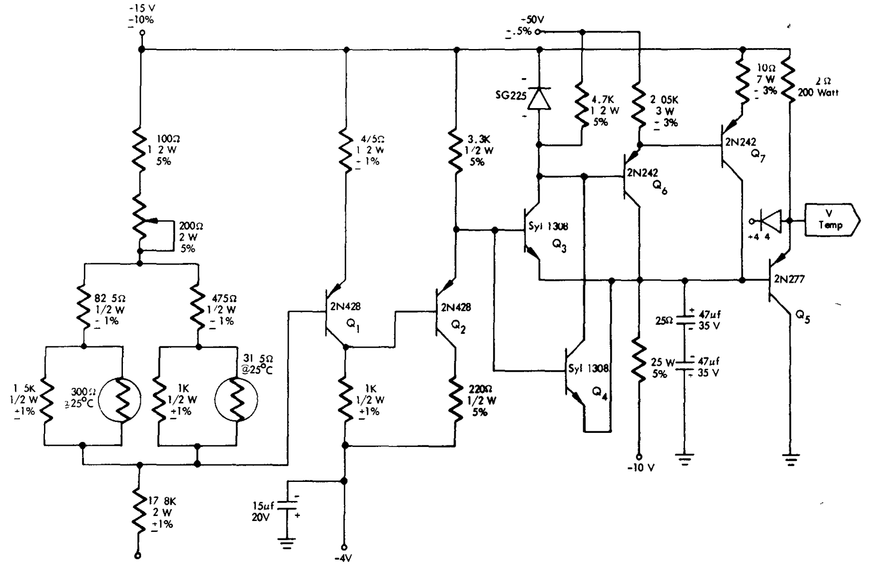

Fig. 7—Temperature controlled voltage source.

the emitter supply for the Z-drivers as shown in the circuit of Fig. 7. A stage of inversion with a voltage gain of 2 is interposed between the thermistor network and the power amplifier in order to provide the proper phase and amplitude to the variation. The output is clamped to ground on the low end by the transistor and to +5 volts (+4.4 plus diode drop) on the high end by a diode. This clamping insures against overvoltages on the Z-driver transistors. When none of the Z-drivers are in operation, 7.5 amps. are conducted to ground by the output transistor (Q5 of Fig. 7) of the V_{TEMP} circuit. When Z-drivers are being pulsed, the V_{TEMP} output conducts the difference between 7.5 amps and the average Z-driver drain.

Compensation with Core-Derived Strobe

The compensation of the drive currents still allows some variation in the peaking time of the core output, even for perfect amplitude compensation. Moreover, temperature affects the drive circuit delay. These effects can be observed in Fig. 5. The compensation for this variation is made completely and simply by the use of a core-derived strobe pulse. The time-discriminating-strobe is derived from a standard core receiving the same current as the selected cores in the memory. That core is essentially wired to receive a full read and full write from the x and y drivers selected to supply the rest of the memory. The output of the core is therefore a standard ONE produced at the same time as all other ONE's being read out. This output is then properly shaped and suitably delayed to supply a strobe pulse for the memory sense amplifiers. The block-schematic in Fig. 8 gives the outline of the method employed. Experimental results in a full memory show that variations in the sense amplifier output of 0.8 microseconds may occur and are compensated by the core-derived strobing even when ZERO's are larger than ONE's (under virgin-checkerboard test).

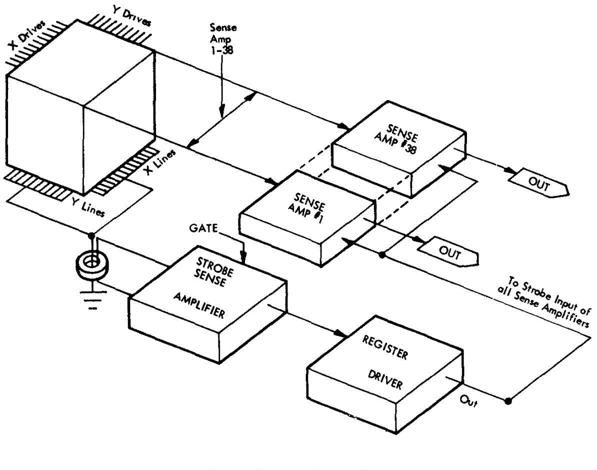

Fig. 8—Core-derived strobe system.

CONCLUSION

The operational limits of the memory were extended by the combination of core-derived strobing and temperature compensated drive currents, as shown in Fig. 9, which is a "shmoo" plot of temperature versus discrimination level limits of the sense amplifiers. The smaller area with cross-hatching shows the limit with core-derived strobe but without temperature compensation; the larger encompassing area shows extension of those limits by the temperature compensation. With neither core-derived strobing nor temperature compensation, the limits are reached at +10°C and +45°C.

Because the MOBIDIC computer in which this memory is being used is intended for battlefield operations, provision is made for retention of the information in the memory even after the computer

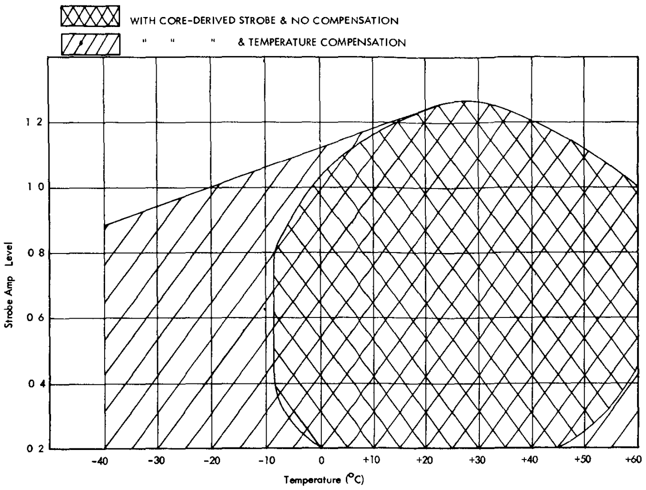

Fig. 9—Operation Shmoo for sense amplifiers.

is shut down. Conceivably the information could be read into the memory at one temperature and later read out at another. Tests performed on the cores showed no measurable difference between ONE's read out at a given temperature regardless of the core's temperature when the information was stored in it. Thus retention of memory is possible even if the machine is shut down and restarted in a new and widely different environment.

Discussion

W. N. Papian: I wonder if you could give us a very rough estimate of the percentage that has to be added as an increment to do this compensation?

Mr. Ashley: The biggest single item that has to be added is power supply capability because we have to increase this drive. We are using 32 current sources, each a quarter of an amp at 20 volts, and we have to have capability of power that the Z drivers might draw if the whole 38 drew at once. This increases by 20 percent the power requirements. There is an unregulated power that is required of 9 or 10 per cent regulation of 100 watts to effect this Z driver compensation, but beyond this the cost alone of the necessary additional parts is very slight.

W. Lawrence, Jr. (IBM): How do you regulate against temperature differences of memory locations receiving different interrogation rates?

Mr. Ashley: I assume that refers to whether or not the core is being self-heated by the application of the drive current. This particular memory is not working at a high enough power and speed to cause any appreciable heating, since the speed that is required is 8 microseconds cycle time. A total of 20 watts maximum occurs within the enclosure for which we have capable blowers to ensure that the air is circulated.

S. B. Yochelson (Goodyear Aircraft): Will you comment on the effects of local heating in the plane, such as might occur if a particular core is repeatedly interrogated?

Mr. Ashley: With the speed and power we have, we don't have that problem. We don't need to drive the cores for the real fast switching time that would require the high current. So the self-heating is rather minimized.

P. Barek (Lincoln Lab.): What is the variation in memory access and rewrite cycle time as function of temperature?

Mr. Ashley: The access time actually doesn't change much because we have a constant slope to the drive current. With increasing temperatures, although the circuit delay is more with a resultant later start for the current, the rise time between 10 per cent and 90 per cent of the current is faster. The two effects tend to cancel each other in access time. Except for the change in delay in the sense amplifiers and the external circuitry (registers, timing flip-flops, etc.) it is not much different. I would guess maybe 0.2 microsecond slower at the high temperature than at minus 30° C.

J. E. Veal (RCA): How much effect does low temperature have on core switching times?

Mr. Ashley: It has a great effect on it but the idea of compensation is to increase the drive current to overcome the effect.

G. N. West (IBM): What limitation do you impose on temperature variation between write and read on a given core to eliminate distrub on half select?

Mr. Ashley: To maintain the accurate write and read current? That is in line with what has to be done for the inhibit drivers. The inhibit current actually varies. Of course, the full select write current is kept the same as the read because it is derived from the same voltage reference. The inhibit current can vary as much as 8 to 10 per cent on either side of the nominal value of the read for that temperature with no harmful effect. Actually this is really conservative also, because I think it could be 10 or 12 per cent without any great harm.