Using the X9530 in Fiber Optic Applications

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Author: Joe Ciancio

1 Introduction

Fiber optics are used more and more everyday in the areas of telecommunications, and data networks. Transmitter boards used in such networks as SONET and SDH, commonly use fiber optics to provide high bandwidth telecommunications. System designers are also utilizing *fiber optic* transceiver modules when building high-speed data networks. These make use of fiber optics in such common devices as hubs, switches, routers, and even NICs (Network Interface Cards).

With fiber optics rapidly coming into the mainstream, there is an ever present need to reduce transceiver module size and cost. Engineers therefore, are continuously pressed to look for new and innovative methods to obtain the maximum performance from their designs.

The X9530 from Intersil provides the fiber optic module designer with a key component for increasing the performance of the design, while at the same time reducing overall cost, component count, and required board area.

One requirement of many new fiber optic designs is higher data rate. To accomplish this, designers must compensate and control the various laser characteristics that change over time, such as temperature drift. The X9530 incorporates an on-chip temperature sensor, an A/D converter and a lookup table based method of temperature compensation. This gives the designer a highly flexible tool with which to “tune out” adverse temperature effects of the laser diode. Overall system performance can be increased by the dynamic variation of critical circuit control parameters.

General purpose EEPROM memory is also integrated into the X9530. This allows for board / module parameters or manufacturing data to be stored in the device, without the need for an additional memory IC. All communications to/from the X9530 are conducted over a 2 wire serial bus, compatible with an industry standard I^{2}C™ interface.

These key functions of the X9530 from Intersil, makes the device ideal in for use in applications such as GBIC, SFP, XENPAK, or other high data rate fiber optic modules. This application note illustrates to the reader how the functions of the X9530 may be used in typical fiber optic designs.

2 X9530 Overview

The X9530 integrates all of the functions necessary to manage the temperature variation of laser diodes in fiber optic modules. The key features of the device are summarized below (Note):

- On-chip temperature sensor
- External sensor input (selectable)
- 6-bit A/D converter
- External A/D converter reference input (selectable)
- EEPROM look-up tables
- Dual “Current Generators” (8-bit Current D/A converters)
- General purpose EEPROM memory.

NOTE: Refer to the X9530 Data Sheet for a full and detailed explanation of device operation.

As shown in Figure 1, two current “generators”, realized as current mode D/A converters (DACs), may be independently programmed to either sink or source current (pins I1 and I2). Both current generators have a maximum output of ±1.6 mA, and may be controlled to an absolute resolution of 0.39% (256 steps/8 bit).

Both current generators may be driven using either an on-board temperature sensor, or an external sensor (via pin VSense). The internal temperature sensor operates over a very broad temperature range (-40°C to +100°C). The sensor output (internal temperature sensor, or external) drives a 6-bit A/D Converter(ADC), whose output selects one of 64 rows from an 8-bit wide, non-volatile look-up table (LUT). The content of the selected LUT row (8-bit wide) drives the input of an 8-bit DAC, which generates an output current. In fiber optic applications, the current generator outputs may be used to *control* laser diode (LD) Modulation Current (I_{MOD}) and/or Bias Current (I_{BIAS}) over temperature (see following section).

The full-scale output of the current generators is set by the user by selecting one of three predefined values. These values are selected in software, by writing a specific value to an internal non-volatile control register of the device. Alternatively, instead of using one of the three pre-defined settings, the user may set a custom value by externally connecting programming resistors to pins R1 and R2. This method also has the benefit of enabling the user to set the tolerance of the output current to that of the programming resistor.

A voltage reference is also integrated into the device, and is used as a reference for the ADC and the DACs. By writing a specific value to a non-volatile control register the device may be configured to take an external reference (via pin VRef). This may be useful where the user requires a

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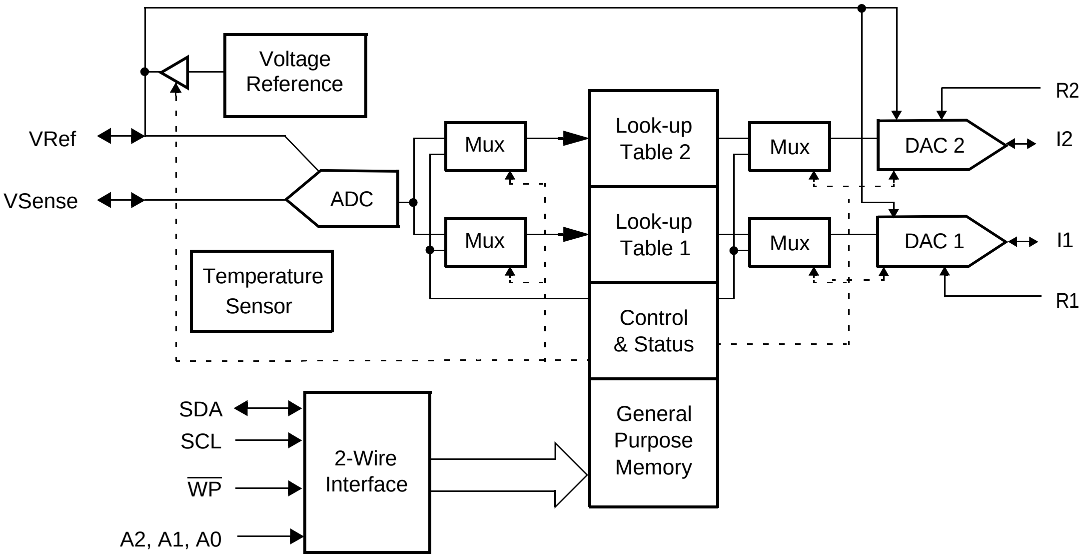

FIGURE 1. X9530 BLOCK DIAGRAM

different reference voltage than that integrated into the device, or if a higher tolerance is required.

A number of software programmable user modes exist in the X9530, which greatly simplify the design, test and set-up. For example, by writing a specific value to an internal non-volatile control register, the device can be configured such that the output of the current generators is controlled directly by a separate register, and not by the temperature sensor (or external VSense pin), ADC, and associated LUT. These modes are not strictly relegated to the tasks of design, test or set-up. Since these modes may be set in a non-volatile fashion, depending upon the particular requirements of the design, they may be useful in the normal operation of a particular circuit.

In addition to the memory dedicated to the functions of the LUTs and Control and Status registers, the X9530 also contains 128 bytes of on-chip general-purpose memory (GPM). This memory may be used to store definition and/or manufacturing data of fiber optic modules such as those conforming to GBIC, SFP, or XENPAK specifications. The integration of the X9530 into such modules is trivial since the memory map of the GPM, and serial data interface of the device are designed specifically for such applications. The inclusion of Intersil's BlockLock™ and other memory data protection mechanisms further make the X9530 ideally suited to such applications.

Now that we have an overview of the main features and functions of the X9530, we shall next look at an example of a fiber optic system, and how the X9530 may be used in such a system.

3 Fiber Optic System Design Considerations

The building blocks of a typical fiber optic module are shown in Figure 2. This block diagram could represent an SFP (Small Form factor, Pluggable) module, but is equally applicable to GBIC (Giga-Bit Interface Converter), or many other fiber optic designs, be they pluggable or otherwise.

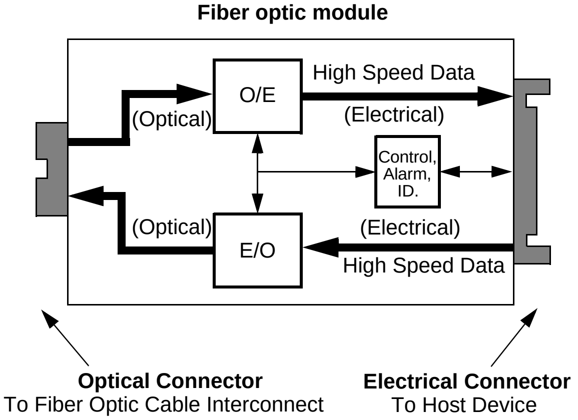

FIGURE 2. FIBER OPTIC MODULE FUNCTIONAL BLOCK DIAGRAM

As show in Figure 2, the fiber optic module may be viewed as a full duplex data transceiver with two data “ports”. One “port” is for optical data, which provides for the reliable, low loss connection of two optic fibers to the module - one for transmitting optical data, and one for receiving optical data. The other “port” is dedicated for electrical signals, and is plugged into the host device. The electrical signals handled over this connector are module fault or alarm, transmit disable, signal detect, module identification, as well as the

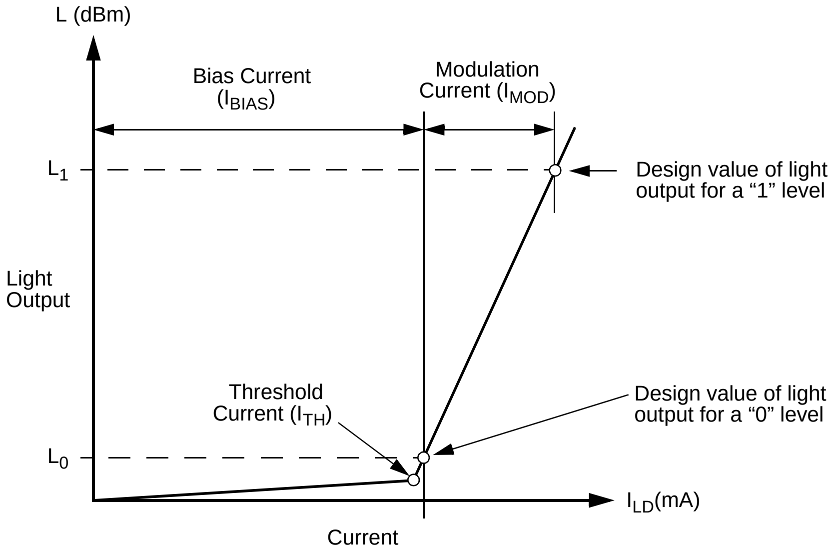

FIGURE 3. LASER DIODE LIGHT-CURRENT (L-I) CHARACTERISTICS

electrical high-speed serial data. Using these two data ports, the module provides the simultaneous Electrical to Optical (E/O) and Optical to Electrical (O/E) conversion of data.

3.1 Laser Diode Driver Circuit Example

We shall now examine the fiber optic transmitter section of the module (i.e. the E/O section of Figure 2.) in more detail. In order to understand the operation of this block however, we will first take a look at the Light versus Current (L-I) characteristics of a typical semiconductor Laser Diode (LD).

3.1.1 Laser Diode L - I Characteristics

Of the many important characteristics of a semiconductor LD, the Light versus Current (L-I) gives the most insight into how a fiber optic transmitter operates, and how the device must be controlled. Typical L-I characteristics of a semiconductor LD, with the main parameters are shown in Figure 3.

Let us first define the current flowing through the laser diode as I_{LD}. As this current is increased from 0 mA, spontaneous emission processes produce light output from the diode, and hence the gradient of the L-I curve in this region of operation is small. The gradient of the L-I curve is known as the *slope efficiency.*

As I_{LD} is further increased, we reach a level at which the LD undergoes *threshold*. Threshold is defined as the point at which the laser diode begins to emit light by sustained, stimulated emission processes. The current at which this occurs is know as the Threshold Current (I_{TH}).

From Figure 3 we can see that above I_{TH} the slope efficiency of the LD increases dramatically, and the light output of the device is linearly proportional $I_{LD.}$

In a DC coupled fiber optic transmitter, the current through the LD that produces a light output corresponding to an electrical digital "0" level, is know as the *Bias Current* (I_{BIAS}).

Similarly, the current through the LD that produces a light output corresponding to an electrical digital "1" level, is know as the *Modulation Current* (I_{MOD}). If we define the light output power at the Bias and Modulation points as L_0 and L_1 respectively, then the Extinction Ratio (E_t) defined as:

$E_t \sim L_1 / L_0$ [dB]

There are a number of important considerations when setting the Bias and Modulation currents in a fiber optic transmitter. Firstly, the Bias Current must be set to a level just above that of the LD Threshold Current (I_{TH}). If the Bias current is set below this point, delays will be introduced to the system, while setting it too high will lower the extinction ratio. Secondly, the Modulation current must be set such that the extinction ratio is maximized, while keeping the current to a level that will prevent the diode from being destroyed.

3.1.2 Example Laser Diode Driver Circuit

In order to set and properly maintain the correct Bias and Modulation current levels of a fiber optic transmitter, many and varied control IC's have been developed. These devices follow a similar philosophy, and a representative circuit topology (at a conceptual level) is shown in Figure 4.

The circuit can be broken down into two main parts. These are Bias and Modulation current generation, and negative feedback control.

The maximum bias current ($I_{BIASMAX}$) is set using the $I_{BIASSET}$ input, while modulation current (I_{MOD}) is set via the I_{MODSET} input. The total current flowing through the laser diode (I_{LD}) is equal to the sum of I_{BIAS} and I_{MOD}. Negative feedback is often realized in the form of an Automatic Power Control (APC) circuit. APC is implemented in order to maintain a constant *average* optical power output. The average optical power output that the APC circuit "tracks", is set using the I_{PINSET} input.

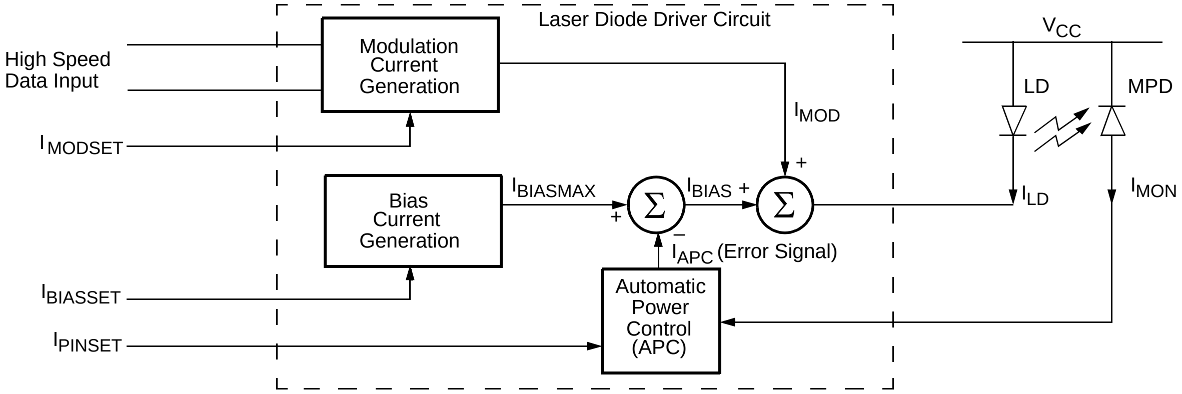

FIGURE 4. EXAMPLE LD DRIVER CIRCUIT TOPOLOGY

3.1.2.1 Bias and Modulation Current Generation

At the simplest level, Electrical to Optical conversion of data in a fiber optic transmitter may be achieved by using a differential transistor pair (Q1, Q2) to modulate the current through the laser diode (See Figure 5).

When there is a logic level “0” present in the electrical high-speed data stream, Q1 is switched OFF, and the current passing through the LD (I_{LD}) is simply equal to the Bias Current (I_{BIAS}). When a logic “1” level is encountered in the data however, Q1 is switched ON causing the Modulation Current (I_{MOD}) to be superimposed on I_{BIAS}. The total current passing through the LD in this case is then equal to $I_{LD} = I_{BIAS} + I_{MOD}$.

By changing the current levels on the control inputs (I_{MODSET} and $I_{BIASSET}$) of the Current Controlled Current Sources (CCCS1, CCCS2), the levels for I_{MOD} and I_{BIAS} may be varied. As mentioned in Section 3.1.1, the precise and correct setting for these quantities is extremely important in all fiber optic designs.

3.1.2.2 Automatic Power Control

By adding negative feedback in the form of Automatic Power Control (APC) to the simple driver in Figure 5, we arrive at the circuit in Figure 6.

As in the previous simple laser diode driver circuit example, the current I_{MODSET} (generated using a resistance R_{MODSET} and a voltage reference) is used to set the Modulation Current (I_{MOD}) via a Current Controlled Current Source (CCS1). Similarly, the resistance $R_{BIASSET}$ is used to set the *maximum* value of the laser diode bias current ($I_{BIASMAX}$), by varying the $I_{BIASSET}$ input of a Current Controlled Current Source (CCS2).

In addition to these controls, we can see that a circuit labelled as “Automatic Power Control (APC)” has been added to the circuit of Figure 5. The APC circuit is essentially a negative feedback control loop.

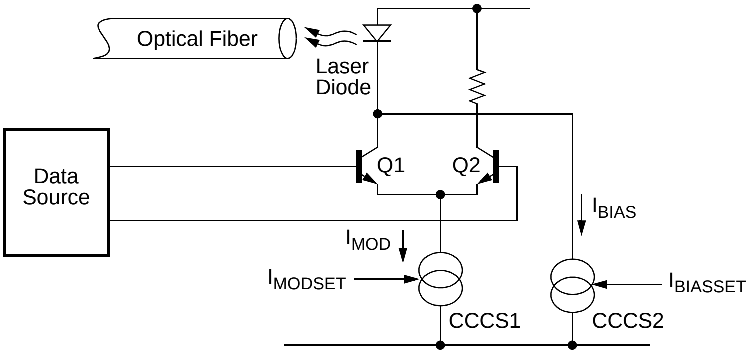

FIGURE 5. BASIC LD DRIVER CIRCUIT

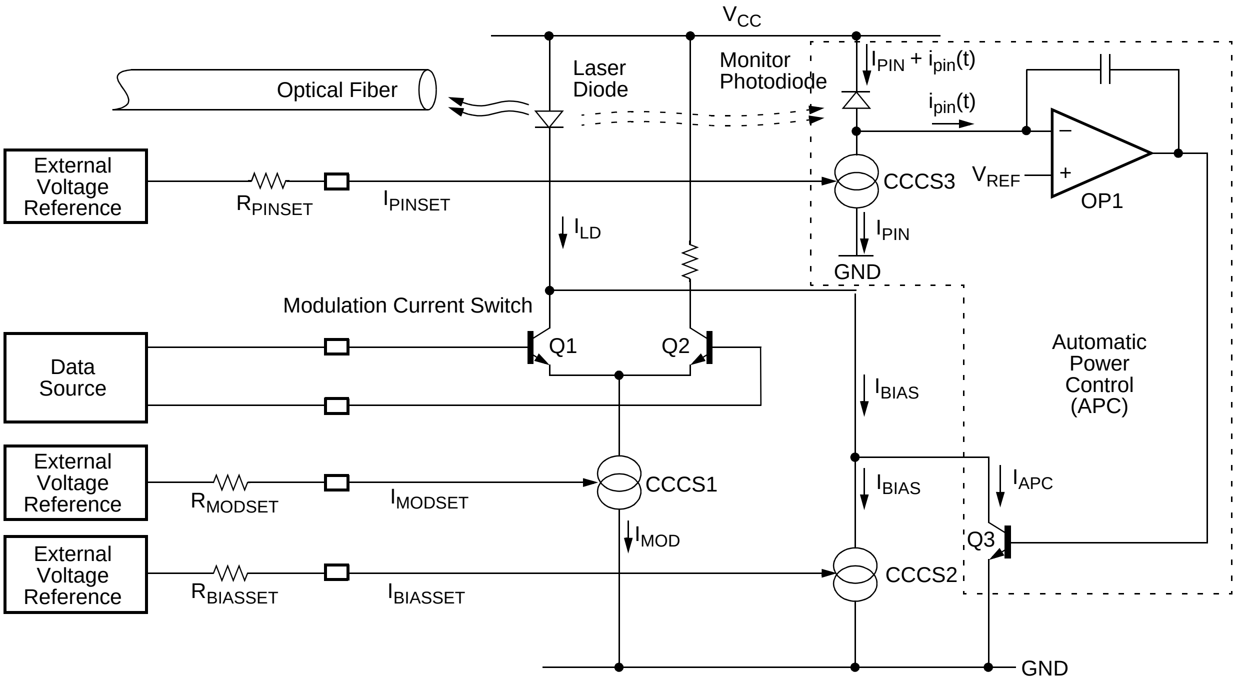

FIGURE 6. EXAMPLE LD DRIVE AND CONTROL CIRCUIT (SIMPLIFIED)

Examining the APC circuit in detail, we can see that it makes use of a p-i-n Monitor Photodiode (MPD). This device is typically built into the same physical package of the laser diode, and a proportion of its' output light power is internally coupled to the MPD. The photodiode is reverse biased using a Current Controlled Current Source (CCCS2), which is controlled by the input I_{PINSET}. When a data signal is applied to the driver circuit, the laser diode light output is modulated, and a time-varying current component ($i_{pin}(t)$) is superimposed upon the MPD bias current (I_{PIN}).

The MPD current time-varying component ($i_{pin}(t)$) is integrated and the output of the integrator drives the base of a transistor (Q3), whose emitter is tied to ground, and collector is tied to a node of the laser diode bias path. The current that flows through the transistor Q3 is defined as the APC error current (I_{APC}), and it is combined with I_{BIASX}. The resulting laser diode bias current (I_{BIAS}) therefore, is equal to $I_{BIASX} + I_{APC}$.

Since the I_{PINSET} controls the MPD (reverse) bias level, varying this quantity has the effect of controlling the *average* optical power maintained by the APC circuit. By using such an APC circuit, the laser diode bias current (I_{BIAS}) is dynamically varied such that the *average* optical output of the laser diode is kept constant, and counteracts against component aging and adverse temperature effects.

3.2 Device Temperature Dependencies

As previously mentioned, the APC circuit can counteract temperature effects of the laser diode driver circuit. As shown in Figure 6a, we can see that without APC, for a fixed I_{BIAS} of about 20 mA, from –25°C to +25°C, the output light power drops from about 2.5 mW to 1.7mW. If the temperature rises to +70°C or above, we then see that the threshold current rises above the set bias current (see Figure 6b), and in this case the laser does not even switch on.

Implementing an APC circuit can overcome this situation. With APC, if we start with an initial value for I_{BIAS}, as the laser diode temperature increases, we see a fall in the output optical power. This corresponds to a decrease in the MPD current, which in turn leads to an increase of the bias current. This negative feedback loop “settles” when the average optical power (as determined by R_{PINSET}) is reached.

The APC circuit overcomes the problem of reduced optical power output, and increased threshold current with higher temperature. However, there are a number of limitations of the APC circuit with regards to temperature compensation.

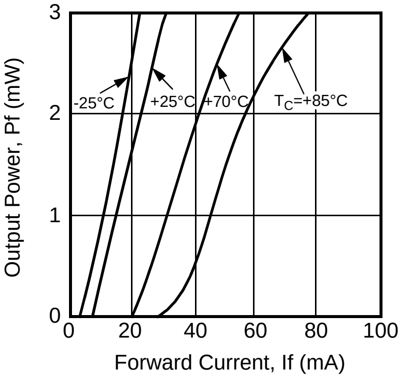

FIGURE 6. LIGHT OUTPUT vs CURRENT (L-I) OVER TEMPERATURE

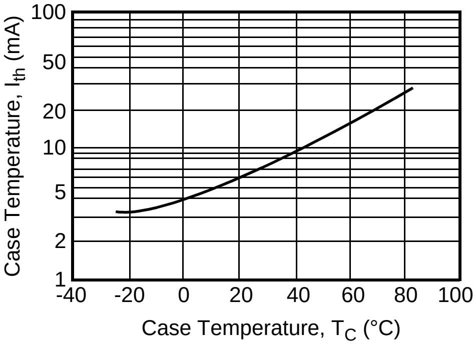

FIGURE 6A. LD THRESHOLD CURRENT vs TEMPERATURE

FIGURE 6A & 6B. TYPICAL LD TEMPERATURE CHARACTERISTICS

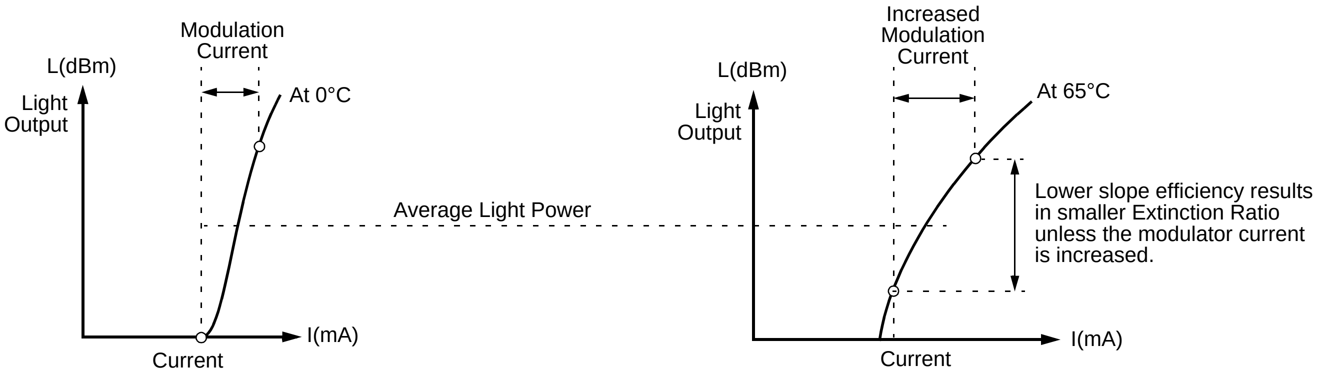

FIGURE 7. EFFECT OF TEMPERATURE ON EXTINCTION RATIO

3.3 APC Temperature Compensation Limitations

One of the main limitations of the APC circuit is that it acts only on the bias current of the circuit, and does not counteract any temperature related effects of the modulation current.

This characteristic in Figure 6a clearly shows that as temperature increases, the slope of the L-I curve decreases. Therefore, for a fixed modulation current, the light output power for a logic level “1” decreases as temperature increases (see Figure 7) and the extinction ratio is reduced. The reduced extinction ratio causes the bit error rate to increase.

A second limitation of the APC circuit is that it doesn’t compensate for temperature variations of the coupling between the laser diode and its companion monitor photo diode, as illustrated.

Figure 8 shows that for a fixed optical output power from the laser diode, the MPD current varies with temperature. This variation manifests itself as an error (variable over temperature) in the APCs’ ability to “track” the desired average optical power output. This is due to the fact that the monitor current that the APC “sees” and the actual optical power emitted from the laser diode will be different, and variable over temperature. The extinction ratio of the system may not be set at its optimal value by the APC.

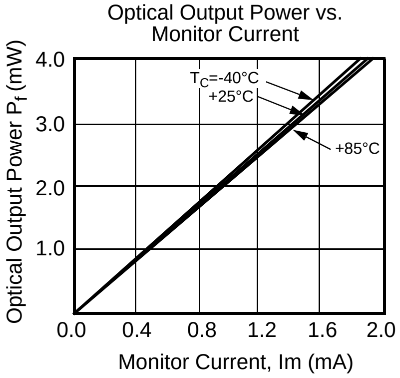

FIGURE 8. TYPICAL MONITOR PHOTODIODE TEMPERATURE CHARACTERISTIC

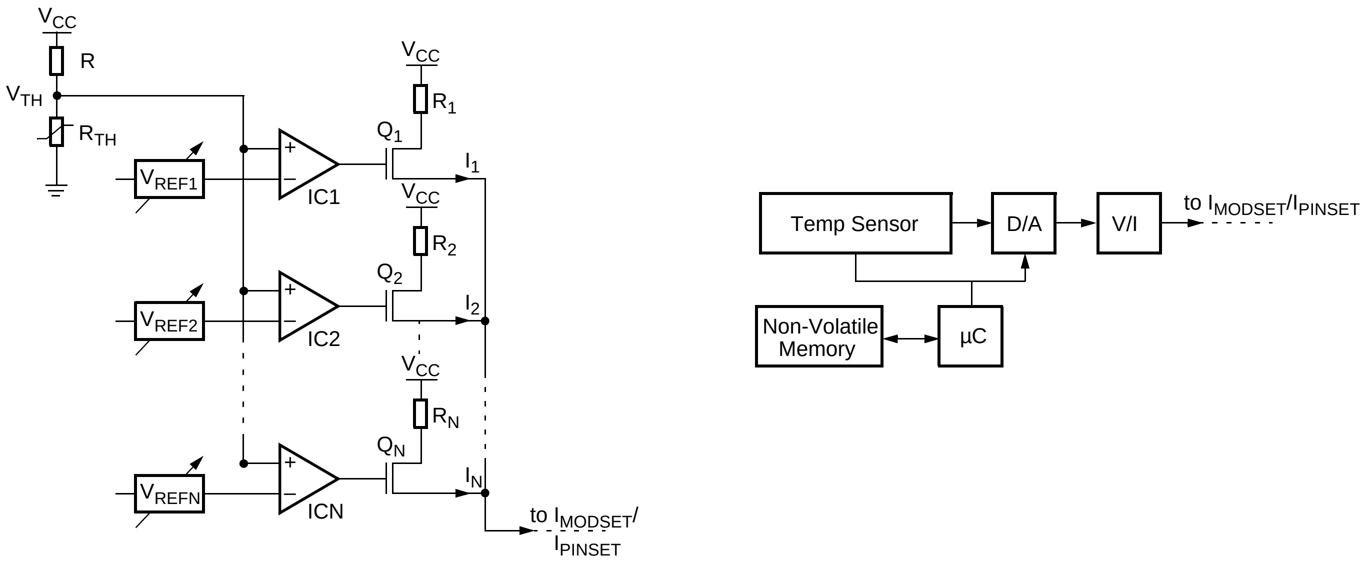

FIGURE 9A. POSSIBLE ANALOG METHOD

FIGURE 9B. POSSIBLE DIGITAL METHOD

FIGURE 9. EXAMPLE OF DISCRETE IMPLEMENTATIONS OF TEMPERATURE COMPENSATION CIRCUIT

3.4 Overcoming Temperature Related APC Limitations

In order to solve either of the temperature compensation limitations mentioned above, it is clear that a dedicated control circuit is needed. This circuit must be able to operate such that the modulation current, and in some cases the average optical power set current, are dynamically varied with temperature.

There have been a number of attempts to try and implement such circuits in discrete components, using both analog and digitally based techniques. Examples of how such circuits may be implemented are shown in Figure 9.

An analog-based method of temperature compensation shown in Figure 9a uses a resistive divider implemented with a fixed resistance R and a thermistor R_{TH}. The voltage at the node between the resistances is feed to the non-inverting input of a string of N voltage comparators (IC_1 – IC_N). The inverting inputs of the comparators are each connected to a precision, programmable, low temperature co-efficient voltage references (V_{REF1} – V_{REFN}). The output of each of the voltage comparators drives the gate of a FET (Q_1 – Q_N), while the drain is connected to Vcc via a fixed resistor (R_1 – R_N). The source terminals of the FET's are tied together to provide the programming current to the I_{MODSET} or I_{PINSET} inputs of a circuit such as that shown in Figure 5. Each voltage reference (V_{REFx}) must be individually set to correspond to a particular temperature range, while each resistor (R_X) must be individually chosen such that the correct programming current (I_X) is supplied for that particular temperature range.

It is obvious that although this is a *real* technical solution to the problem, it would be commercially unfeasible to implement such a temperature compensation scheme for use in fiber optic modules. Not only are there too many discrete components, but also the labor involved in setting up and calibrating such a circuit would be prohibitively expensive.

The option shown in Figure 9b, uses a digital approach implemented using a discrete high precision temperature sensor, D/A, microcontroller, and non-volatile memory. This implementation uses a look-up table method of temperature compensation, where the temperature characteristics of the laser diode are stored in non-volatile memory.

This digital approach simplifies the test and calibration procedure required over the previous analogue example. The cost of (at least) five integrated circuits, not to mention the large amount of board area would also make this solution impractical for use in small form factor fiber optic modules.

3.5 The X9530 - A Better Way

The X9530 uses the basic idea introduced in the digital solution of Figure 9b. The device provides the same flexibility of a digital look-up table-based method of temperature compensation, while adding other important features useful in fiber optic modules. This solution is made feasible due to the high integration of the device.

One possible manner in which the X9530 may be used in a fiber optic system is illustrated in Figure 10. The block labeled "Laser Diode Driver Circuit" contains the same schematic as that shown in Figure 5. From Figures 6 and 10, we see that the X9530 has replaced the discrete, fixed reference voltages as well as the variable resistors / potentiometers (R_{MODSET}, R_{PINSET}) used to obtain the control currents I_{MODSET} and I_{PINSET}. Not only has the

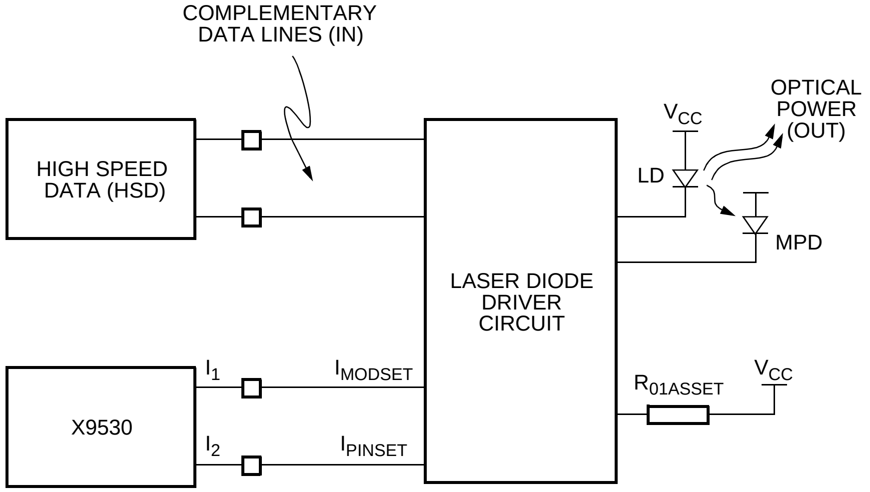

FIGURE 10. EXAMPLE CONFIGURATION OF X9530 WITH LD DRIVER AND CONTROL IC

X9530 replaced four components with one, but it has also added the functionality of temperature compensation, which increases fiber optic system performance.

Compared to any other fiber optic temperature compensation solution, using the X9530 provides the designer with many savings. Not only does the device provide a lower component count when compared to discrete solutions, but also provides lower cost, as well as lowering the cost of inventory management. There are also a number of other technical advantages of the X9530 over competing solutions which use variable resistors to set control parameters such as I_{MODSET} and I_{PINSET}.

When implemented as shown as in Figure 5, the variable resistances R_{MODSET} and R_{PINSET} are typically connected directly to the Vcc voltage rail and their currents are strongly modulated by the fluctuations in Vcc. This problem is eliminated by using the two constant current generators of the X9530. The accuracy of the output current is proportional to the accuracy of the on-chip voltage reference, the precision of the internal or external resistors at pins R1 and R2, and the linearity of the DACs. For example, using external ±1% reference resistors, ±1LSB for the total error of the DAC (±0.4%), and ±0.5% for the accuracy of the voltage reference, the output current for a particular DAC setting can be predicted to within ±1.9%.

The X9530 is also able to provide more accurate absolute control currents (I1, I2) than competing solutions. Using external resistors (R1, R2) and writing a specific value to an internal non-volatile control register, the accuracy of output currents (I1, I2) are related directly to the tolerance of external resistors.

Intersil also provides the user with a LabView™ based software development tool. This software development tool provides the designer with a means to quickly and efficiently get the X9530 up and running in their circuit. In addition to design, this software may be easily integrated into a test, characterization, or manufacturing flow if compatible Automated Test Equipment is used.

4 Application of the X9530 in an Example Fiber Optic System

There are a number of techniques that may be employed when programming the Lookup Tables (LUTs) of the X9530 in order to perform laser diode temperature compensation. We shall now present a few examples of how the X9530 may be commonly used to perform modulation current and / or average optical power temperature compensation.

Throughout the following examples we assume the use of a typical laser diode driver circuit such as the one shown in Figure 5, used in conjunction with the X9530 as per Figure 10.

4.1 Modulation Current Temperature Compensation

There are two main approaches which may be taken when programming the LUTs of the X9530 for modulation current temperature compensation.

The first method involves having pre-determined, well defined temperature characteristics of the laser diode, and programming the device with a temperature compensation curve of the laser diode. The second method involves dynamically testing the whole laser diode driver circuit over temperature, and loading the look-up table with temperature compensation data during automatic testing.

4.1.1 Programming Lookup Table with well defined Laser Diode Characteristics

In some cases the designer may have well defined L-I characteristics for the particular type of laser diode used. This data may be provided by the laser diode manufacturer, or may be obtained by characterising laser diodes on a lot or batch basis. In some specialized cases, devices may even be characterized on a per diode basis. An example of such laser diode characteristics is shown in Figure 11.

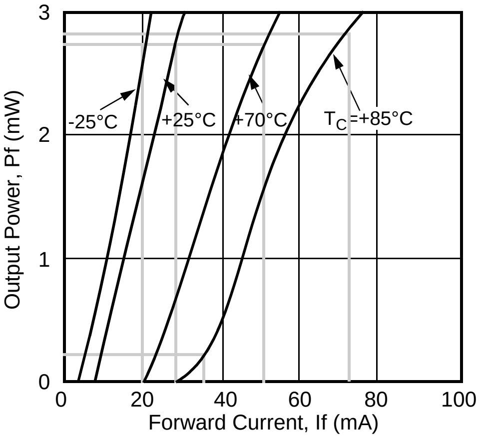

FIGURE 11. EXAMPLE LASER DIODE TEMPERATURE CHARACTERISTICS

We assume that the goal is to keep the average optical output power at 1.35 mW over temperature. Using the characteristic shown in Figure 11, we can deduce the modulation current to maintain the required extinction ratio. The modulation current values at the known temperature points are summarized in Table 1.

Since we know the amplification factor (β) of the modulation current driver circuit (See Figure 5), we can calculate the current required from the output of the X9530 in order to supply the correct modulation current. From Table 1 we see that the maximum current required is + 0.62 mA at the I1 output – which drives the Imodset input of the laser diode driver circuit (See Figure 10). By setting the I1FSO1 and I1FSO0 bits of the “Control 5” register of the X9530 to “10”, the full scale output at pin I1 is set to + 0.85 mA. Since the current generators of the device have 8 bits of resolution, the smallest resolvable current output (Imin) is :

Imin = +0.85 mA / ($2^{8\ \mathrm{BITS}}$-1)
≅ +3.33 µA

The contents of the look-up tables of the X9530 must be programmed with integer multiples of the smallest resolvable current output (Imin). This integer value can be written to the appropriate LUT1 location after it has been converted to hexadecimal format.

The address of LUT1 to which the current setting is written corresponds to a particular temperature at which the I1 output makes a transition from one current setting to another. The base address of LUT1 is 90h, and corresponds to a temperature of –40°C. Every increment in the address of the LUTs corresponds to a temperature equal to the previous temperature, plus the minimum resolvable temperature increment (Tinc). Since the X9530 has an operating temperature range (assuming the use of the internal, on-chip temperature sensor) of -40°C to +100°C, and an ADC with 6 bits of resolution, Tinc is defined as :

Tinc =(100 – (-40)) / ($2^{6\ \mathrm{BITS}}$ -1) ≅ 2.22 °C

To calculate the temperatures which correspond to the LUT1 addresses directly, the following equation applies:

T °C = -40 + (LUT1 address(decimal) * 2.22)

A table can then be generated with the Temperature values, the decimal values for LUT1 addresses, along with the corresponding Hex values and then finally the Hex values with offset (90h) all in adjacent columns.

To calculate the LUT1 contents directly, the following equation applies:

LUT1 value = INTEGER(Imod(T)/B/Imin) (decimal)
where Imod(T) is the modulation current at a given temperature

Table 1 shows an abbreviated table with the values for this example.

Using the data in Table 1 (see Appendix 7.1 for full listing) we can program the LUT1 of the X9530 to provide the temperature compensation curve for the laser diode modulation current, as shown in Figure 12.

Looking at the temperature characteristics of the laser diode presented in Figure 11, we can see that we only have a limited number of data points. The temperature compensation curve for the modulation current in Figure 12, was created by filling in the unknown temperature points with the last known value. The table values for -40°C were added, and values for +100°C were from adjacent values for completeness.

If only a limited number of temperature data points are known, the designer may wish to implement the compensation curve as a “piece-wise” linear approximation, instead of the “step function” response illustrated in Figure 12.

TABLE 1. EXAMPLE LOOKUP TABLE 1 PROGRAMMING VALUES (SEE APPENDIX 7.1 FOR FULL VERSION OF TABLE.)

T(°C)	Average Lout (mW)	Ild (mA)	Ibias (mA)	Imod (mA)	Imod / B (mA)	Imod/B/Imin (INTEGER)	LUT1 CONTENTS (Hex)	LUT1 ADDRESS (Hex)
-40	1.35			10			0A	90h
-25	1.35	20	4	16	0.2	60	3C	97
26	1.35	28	8	20	0.4	120	78	AE
74	1.35	50	20	30	0.5	150	96	C5
85	1.35	72	35	37	0.62	190	BE	CA
100	1.35			37			BE	CFh

NOTES:

Key to items in the table:

Ild = Total current passing through laser diode for a logic one level. Ild = Ibias + Imod. Values derived from device characterization curve.

B = Amplification factor of laser diode driver IC current control circuit (See Figure 5). B = 60 for this example.

Imin = Smallest resolvable current increment with FSO set to +0.85mA. Imin=0.0033mA for this example.

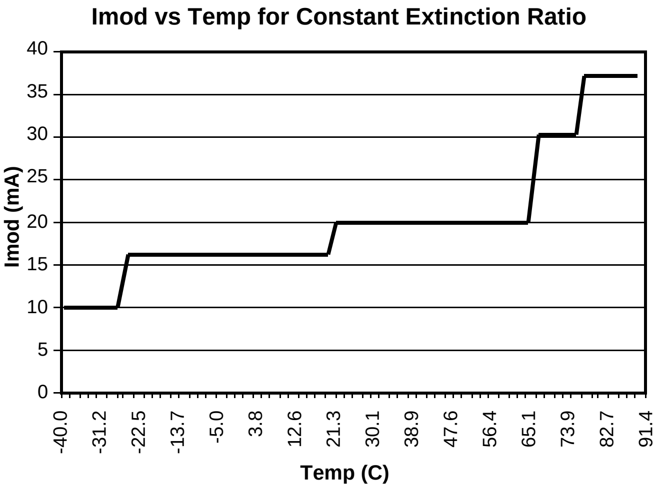

FIGURE 12. EXAMPLE OF MODULATION CURRENT REQUIRED TO MAINTAIN CONSTANT EXTINCTION RATIO OVER TEMPERATURE

4.1.2 Dynamic Programming of Lookup Tables

In the previous section, we looked at an example where the LUTs of the X9530 were programmed on a laser diode batch or lot basis. Programming the LUTs of the X9530 dynamically, however, is performed on a per *board* basis. A possible programming flow is shown in Figure 13.

In this case the whole laser diode driver circuit (board or module), including the X9530 is ramped over temperature, and the device is dynamically programmed. We assume in this example, that the designer is able to communicate and control the X9530 device, read an optical power meter (OPM), switch the APC circuit ON/OFF, and control the temperature or the circuit via ATE (Automated Test Equipment), as depicted in Figure 14.

From Figures 13 and 14, we can see that we begin the dynamic programming process by first setting the maximum bias current level via the Ibiasset pin (at room temperature). This is done by first disabling the APC by opening the feedback loop (eg. opening Ibiasfb in Figure 5). The Pseudo Random Data Generator (PRDG) is then used to generate a data stream of all “0”. Using the OPM the Ibiasset current is adjusted until the desired maximum bias level is reached. This may be achieved using a Intersil Digitally Controlled Potentiometer(XDCP™). See Intersil website at www.intersil.com for additional details on Intersil Digitally Controlled Potentiometers (XDCPs).

The entire circuit may then be brought to a minimum temperature for which the circuit is to be calibrated. The modulation current is first set by using the PRDG to apply a data stream of all “1” to the input of the driver circuit. The Imodset current input is varied from its’ minimum setting (by adjusting the I1 output of the X9530), until the OPM reads the desired optical modulation level. The I1 output current of the X9530 may be easily adjusted by setting the D1DAS (DAC1 Direct Access Select) bit of the Control5 register to “1”. In this mode, the current at the I1 output pin is set to the value written to the Control3 register. Since this register is volatile, it is possible to set the I1 current quickly, without the typical non-volatile write-cycle time delay (twc). Once the correct value of the I1 current output is determined, it may then be written to the appropriate location in the look-up table 1 (LUT1). The location to which the final value is written corresponds to the particular temperature at which the modulation current was set. This operation is always non-volatile.

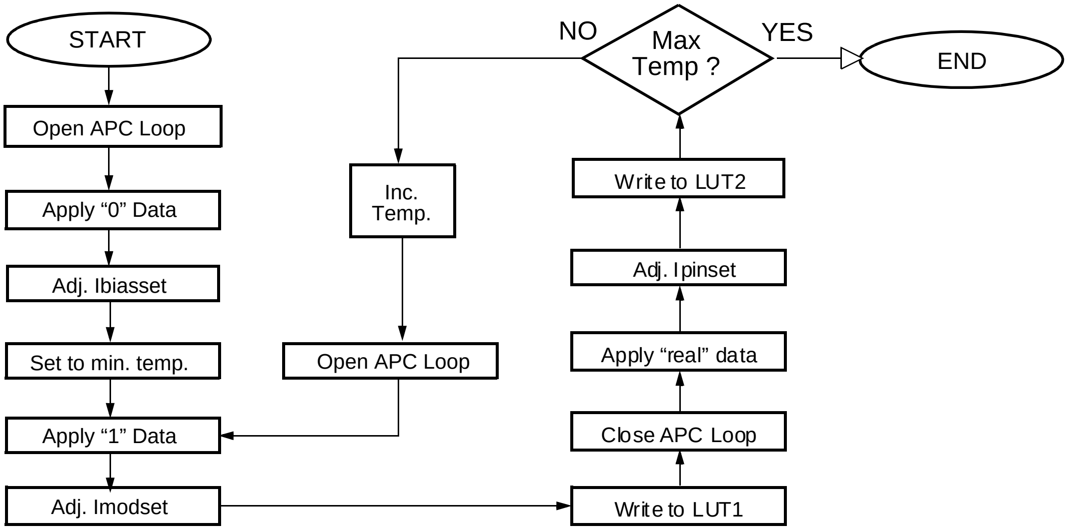

FIGURE 13. EXAMPLE FLOW-CHART FOR DYNAMIC LOOK-UP TABLE PROGRAMMING PROCESS

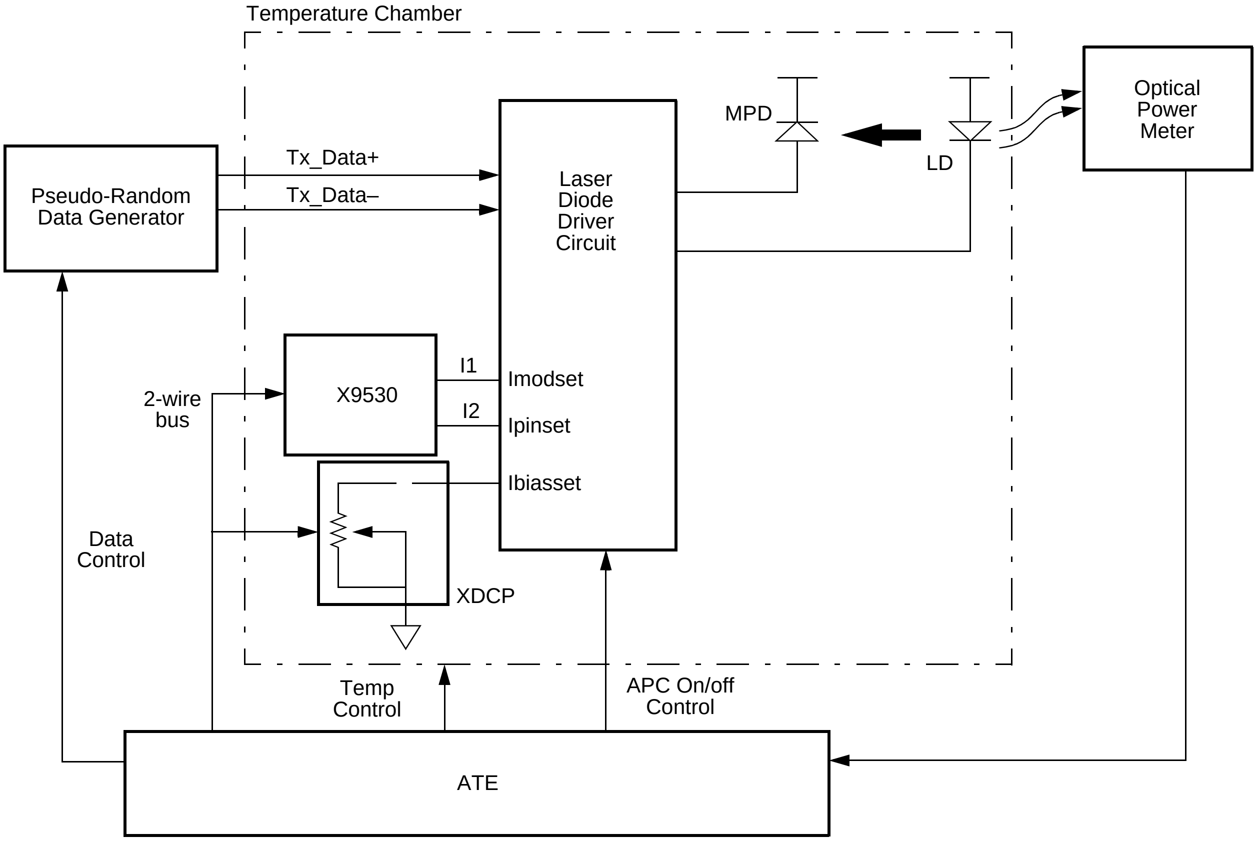

FIGURE 14. EXAMPLE TEST SET-UP FOR DYNAMIC LOOK-UP TABLE PROGRAMMING

Next, the average optical power level of the circuit is set. First, the ATE engages the APC loop (eg. re-connecting the Ibiasfb in Figure 5). A “real” data stream is then applied to the input of the driver circuit. The data should be appropriately coded, and at a data rate close to that of “real life” circuit operation. With the Ipinset input (i.e. the I2 output of the X9530) set to a minimum value, the ATE may then increase the current until the OPM reads the desired average optical power. Identical to I1, the I2 output current may be set directly via a volatile data register (Control4 register) by setting the D2DAS (DAC2 Direct Access Select) bit to “1”. Once the desired average optical power level is determined, the value for I2 can be written to the location in LUT2 (look-up table 2) corresponding the particular temperature at which Ipinset was determined. Once again, this is always a non-volatile operation.

After having checked if the maximum temperature has not been reached, the temperature of the circuit may be increased by some incremental value, and the process of setting the Imodset and Ipinset currents begin once again. This is performed only after having opened the APC loop. The temperature increment used will determine the performance of the temperature compensation scheme. Since the input ADC of the X9530 has 6 bits of resolution, the designer may calibrate the circuit to a maximum of 64 temperature points over the range of -40 °C to +100 °C.

While the initial set-up of the test scheme may be more involved that described in Section 4.1.1, it has the benefit of temperature compensating for temperature dependencies of ***all devices in the circuit – not only those of the laser diode and monitor photodiode.***

4.2 Average Optical Power Temperature Compensation

The need for the temperature compensation of the average optical power may arise due to the temperature dependencies of the monitor photodiode in the APC loop. There are two main approaches which may be taken when programming the LUTs of the X9530 for average optical power temperature compensation.

4.2.1 Dynamic Programming of Lookup Tables

When the process as detailed in Section 4.1.2 is employed, the laser diode characteristics *and* the average optical power of the driver circuit are both temperature compensated by definition.

4.2.2 Programming Lookup Table with well defined Monitor Photodiode Temperature Characteristics

This method also assumes that monitor photo-diode temperature characteristics are well known and definable on repeatable basis.

If the LD characteristics are well known and the modulation current is temperature compensated to maintain a theoretical constant average optical power level (as per Section 4.1.1) – then there will be an error due to the temperature dependencies of the MPD. Looking at Figure 15, we can see that at a particular received optical power level, over the temperature range of -40 °C to + 85 °C, the monitor photodiode current increases.

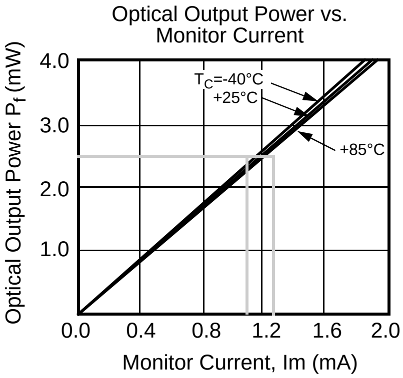

FIGURE 15. TYPICAL MONITOR PHOTODIODE TEMPERATURE CHARACTERISTIC

We now assume we have a system which has the modulation current temperature compensation table correctly calibrated (as per Section 4.1.1), and the average optical power control (Ipinset) kept at a constant level. As temperature increases, the monitor photodiode current seen by the APC circuitry at elevated temperatures is higher than what should actually be generated at a particular received optical power level. The APC therefore, will reduce the bias current to try and reduce the optical power output. This leads to the scenario where the APC will cause the average optical power output to settle to a value lower than the desired value (as set per the Ipinset control current).

In order to compensate for this effect, the average optical power set current (Ipinset) may also be increased over temperature - the net effect being that the *actual* average optical power output is maintained at a constant level. The programming of the look-up table for the temperature compensation of the Ipinset current, would follow a similar procedure to that detailed in Section 4.1.1.

4.3 Other Configurations

The descriptions detailed in Sections 4.1 and 4.2, are representative examples of how the X9530 might be used in real designs. As previously mentioned however, the topologies and details of laser diode driver and associated control circuits are many and varied. There will be countless other configurations in which the X9530 may be used to provide temperature compensation functionality in an actual design.

One situation that may be encountered is where a larger bias current is required than available at the I1 or I2 outputs. A current mirror can be implemented with emitter degeneration to provide current multiplication. The accuracy of such a circuit is not tight, and there is temperature dependence, but these factors can be adjusted out using the temperature calibration procedure described in 4.1.2. See figure 16 for an example circuit.

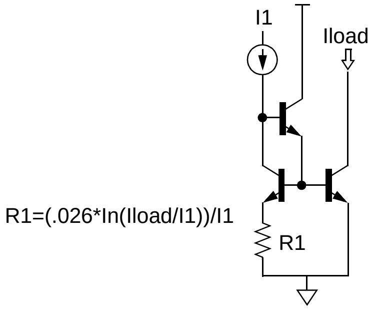

FIGURE 16. CURRENT MIRROR MULTIPLIER CIRCUIT

In another example, the representative circuit used throughout this Application Note (Figure 5), employs three control parameters: Imodset, Ibiasset, and Ipinset. Other laser diode driver circuits may have different control parameters, some of which (like Ibiasset) may not require temperature compensation. In the case that there is a “spare” current generator output of the X9530 available, then this output may also be used to provide temperature *independent* control of a particular parameter. This could be achieved by simply filling the look-up table of the particular current generator with the same value corresponding to the required current output.

5 Conclusion

From the details reviewed in this Application Note, we can see that the X9530 from Intersil provides a flexible and powerful solution to the problem of temperature compensation in fiber optic control circuits. By providing an integrated, look-up table-based method of temperature compensation; designers are able to compensate for the adverse effects of temperature on such parameters as optical modulation power, and average optical power. The features of the X9530 provide a tool for increasing the performance of the fiber optic designs, while at the same time reducing overall cost, component count, and required board area.

6 Bibliography

Intersil X9530 Data Sheet

Intersil Application Note:
AN140 - Fiber Optic Reference Design

Intersil Application Note:
AN137 - X9520 Application Note

Intersil X9530 LabView™ Evalution Kit

7 APPENDICIES

Complete table of data for example modulation current temperature compensation.

T(°C)	AVERAGE Lout (mW)	Ild (mA)	Ibias (mA)	Imod (mA)	Imod/B (mA)	Imod/B/ Imin (INTEGER)	LUT1 CONTENTS (HEX)	LUT1 ADDRESS (HEX)
-40	1.35			10			0A	90h
-37.8	1.35			10			0A	91
-35.6	1.35			10			0A	92
-33.3	1.35			10			0A	93
-31.1	1.35			10			0A	94
-28.9	1.35			10			0A	95
-26.7	1.35			10			0A	96
-24.5	1.35	20	8	12	0.2	60	3C	97
-22.2	1.35			12			3C	98
-20.0	1.35			12			3C	99
-17.8	1.35			12			3C	9A
-15.6	1.35			12			3C	9B
-13.4	1.35			12			3C	9C
-11.1	1.35			12			3C	9D
-8.9	1.35			12			3C	9E
-6.7	1.35			12			3C	9F
-4.5	1.35			12			3C	A0
-2.3	1.35			12			3C	A1
0.0	1.35			12			3C	A2
2.2	1.35			12			3C	A3
4.4	1.35			12			3C	A4
6.6	1.35			12			3C	A5
8.8	1.35			12			3C	A6
11.1	1.35			12			3C	A7
13.3	1.35			12			3C	A8
15.5	1.35			12			3C	A9
17.7	1.35			12			3C	AA
19.9	1.35			12			3C	AB
22.2	1.35			12			3C	AC
24.4	1.35			12			3C	AD
26.6	1.35	28	4	24	0.4	120	78	AE
28.8	1.35			24			78	AF
31.0	1.35			24			78	B0
33.3	1.35			24			78	B1
35.5	1.35			24			78	B2
37.7	1.35			24			78	B3
39.9	1.35			24			78	B4

T(°C)	AVERAGE Lout (mW)	Ild (mA)	Ibias (mA)	Imod (mA)	Imod/B (mA)	Imod/B/ Imin (INTEGER)	LUT1 CONTENTS (HEX)	LUT1 ADDRESS (HEX)
42.1	1.35			24			78	B5
44.4	1.35			24			78	B6
46.6	1.35			24			78	B7
48.8	1.35			24			78	B8
51.0	1.35			24			78	B9
53.2	1.35			24			78	BA
55.5	1.35			24			78	BB
57.7	1.35			24			78	BC
59.9	1.35			24			78	BD
62.1	1.35			24			78	BE
64.3	1.35			24			78	BF
66.6	1.35			24			78	C0
68.8	1.35			24			78	C1
71.0	1.35			24			78	C2
73.2	1.35			24			78	C3
75.4	1.35			24			78	C4
77.7	1.35	50	20	30	0.5	150	96	C5
79.9	1.35			30			96	C5
82.1	1.35			30			96	C7
84.3	1.35			30			96	C8
86.5	1.35			30			96	C9
88.8	1.35	72	35	37	0.62	190	BE	CA
91.0	1.35			44			BE	CB
93.2	1.35			44			BE	CC
95.4	1.35			44			BE	CD
97.6	1.35			44			BE	CE
99.9	1.35			44			BE	CF

NOTES:

Imin = Smallest resolvable current increment with FSO set to +0.85mA. Imin = (0.85 / 255) mA.
Ild = Total current passing through laser diode. Ild = Ibias + Imod.
B = Amplification factor of laser diode driver IC control circuit (See Figure 5).
T is in multiples of the minimum resolvable temperature increments of the X9530. Minimum resolvable temperature increment (Tinc) is : Tinc = | -40° - 100° | / ((2 ** 6 bits) - 1) = 2.22 °C.

Intersil Corporation reserves the right to make changes in circuit design, software and/or specifications at any time without notice. Accordingly, the reader is cautioned to verify that the Application Note or Technical Brief is current before proceeding.

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