A Hewlett Packard Infrared Signal Decoder

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Several Hewlett Packard pocket calculators are able to send printer output via Infra-Red (IR) signals to a small portable printer. They use an HP-specific transmission protocol which is also called “Red Eye”. This protocol is different from the better known IrDA protocol. This document gives a brief overview of the format and describes hard- and software to build a decoder system for this protocol. This system allows receiving the “Red Eye” signals with a computer via a serial or an USB interface.

Printers with IR Interface

In 1987 HP introduced the small IR printer 82240A (replaced later by the improved variant 82240B). The ON/OFF switch of the printer shows a red dot when in the ON position and the IR receiver is mounted behind a transparent red window. Therefore protocol has been given the nickname “Red Eye”. HP has long discontinued the production of this printer but even today in 2015 you can find still many dealers offering their stock at relatively high prices. There is also at least one manufacturer who offers similar printers with improved technology but still understanding the “Red Eye” protocol. Several rather expensive measuring systems are still in use in automotive and heating system diagnosis so that there seems to be a market for replacement printers. On the other hand you can find used but working printers on eBay for less than 20€, if you are lucky.

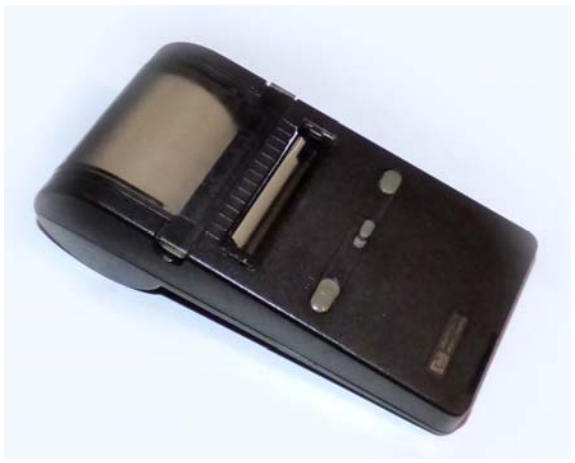
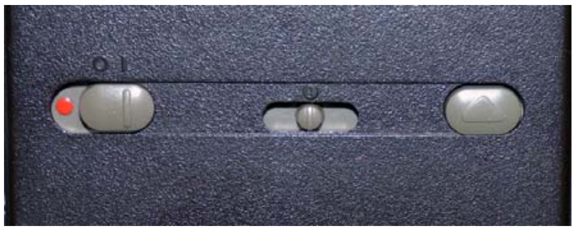



Figure 1: The HP 82240B printer with its “Red Eye” on/off, darkness and paper advance controls.

While the printer is small and portable, it also has some drawbacks: first, it uses a unidirectional interface so that it cannot signal a problem, e.g. “paper out”, to the sending device. Second, a line of sight between sender and receiver is needed, requiring proper alignment of both units. Finally, the range depends on the strength of the sender signal. While ranges of 20 meters and more are possible, most calculators have a very limited range. This was a design decision by HP to minimize energy consumption and to avoid cheating in classroom situations. For most calculators except the HP 48 the distance between printer and calculator should be less than 2 inches.

IR enabled HP Calculators

A quite large number of HP calculator models were able to transmit output through an IR emitter diode. A few even included a receiver to allow for bidirectional communication, using the SIR protocol. At least for the HP 48 some software is available to receive the “Red Eye” protocol.

HP products			
HP 17B[1]	HP 27S	HP 41C[2]	HP 48S[1,3]
HP 17BII[1]	HP 28C	HP 41CV[2]	HP 48SX[3]
HP 17BII+[1]	HP 28S[1]	HP 41CX[2]	HP 48G[1,3]
HP 18C[1]		HP 42S	HP 48 GX[3]
HP 19B	HP 95LX[3.4]		HP 48gII[1,3]
HP 19BII[1]	HP 100LX[1,3,4]		HP 48G+[3]
	HP 200LX[3.4]		HP 49G+[3]
			HP 50g[1,3]
almost HP	**non HP**		HP 38G[1,3]
WP 34S calculator[1]	test equipment		HP 39G[3]
	e.g. from TESTO		HP 39gs[1,3]
			HP 39g+[1]

Table 1: HP calculators and other products able to send out IR signals in “Red Eye” format.

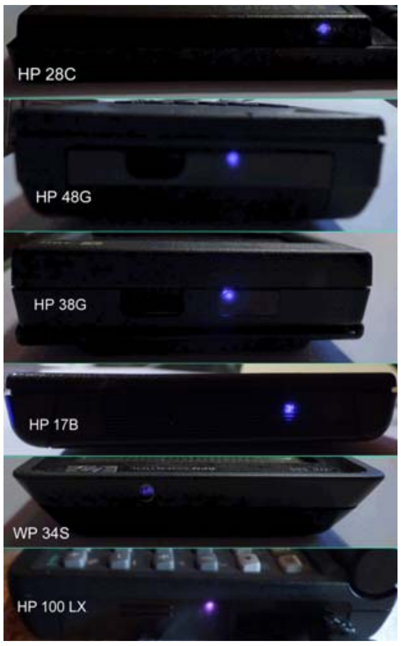


Figure 2: While you cannot see the infrared signal with your naked eye you can detect it with most digital cameras. Even if they are equipped with IR filters they show an active IR LED as a blue light.

[1] These calculators have been used to verify the working of the IR decoder application.

[2] The HP 41 models require the HP 82242 IR module (dubbed „Blinky“) to enable output in „Red Eye“ format.

[3] Besides the output capability these calulators also have infrared input. However this input normally uses the SIR (Serial over Infra Red) protocol which is not „Red Eye“ compatible. For some models (e.g. HP 48G) special software has been written to decode the „Red Eye“ protocol.

[4] The HP 95/100/200 LX models by default support SIR and require special software to print in “Red Eye” format.

Some calculators have no other I/O capabilities than their IR printer interface (except for keyboard and display of course). For these machines the capability to receive the print stream on a PC is useful for documenting and archiving programs and data in the PC or on external media.

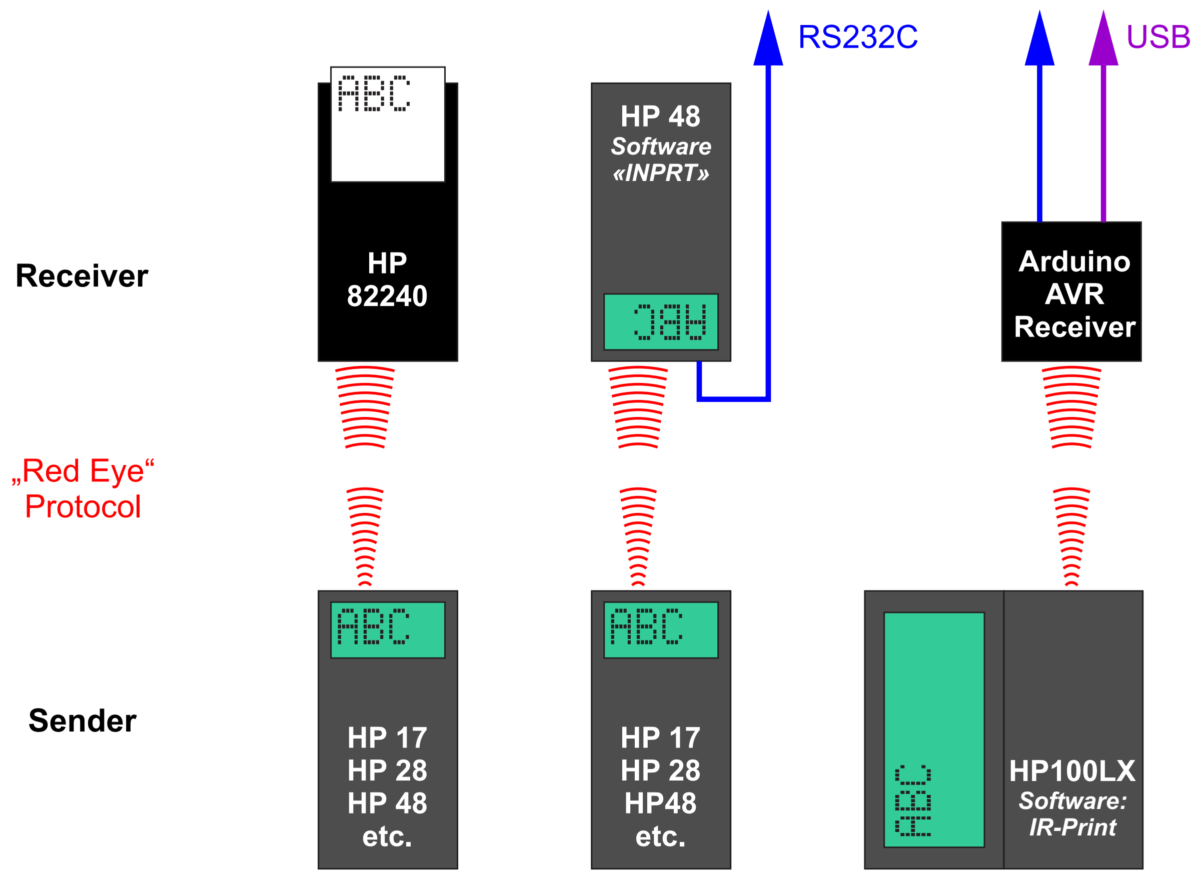


Figure 3: Various possible types of communication using the "Red Eye" protocol. <u>Left:</u> the normal operation as intended by HP drives the 82240 printer. <u>Center:</u> with the "INPRT" software a HP 48 can receive the "Red Eye" format and store or later send the data to a computer via its RS232C interface. <u>Right:</u> The HP palmtops can also send text files using the "Red Eye" protocol using the "IR-Print" software. A microcontroller receiver can output the data via a serial or virtual serial (USB) connection. Other output variants are easy to add.

Note on specific calculators

By default the calculators of the HP 38 and 39 family use the "Red Eye" protocol for their print commands (`PRDISPLAY`, `PRHISTORY`, and `PRVAR`). However for the transfer of applets or data from on calculator to another they are using the IrDA protocol. Their output speed is considerably reduced after sending the first batch of characters to avoid a buffer overflow on the printer side.

The various calculators of the HP 4x series (HP 48, HP 49 and also the HP 50g) need the system flag -34 to be clear to select the "Red Eye" protocol for output.

The IR-Signal

The calculators send a byte stream with one byte per data frame. Each data frame contains error correction bits which allow to correct up to two missed bits. As there is no handshaking involved, timing can be critical and the HP pocket calculators usually allow the user to define a delay between sending the bytes or lines. This is especially important with the relatively slow thermal printers HP 82240A/B. Some calculators automatically slow down their output speed when printing multiple lines to avoid overflowing the printer buffer. For more details about the protocol see the list of references below.

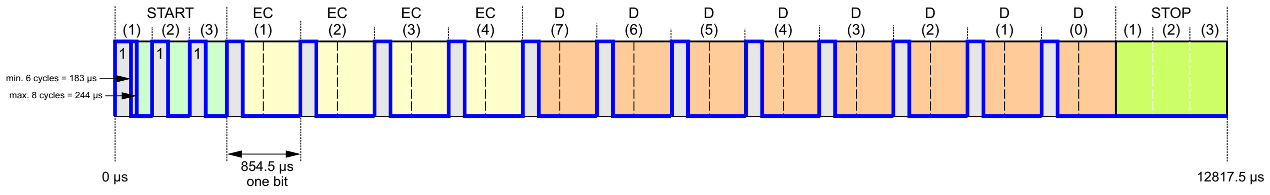


Figure 4: Typical data frame used in the “Red Eye” protocol. Each frame consists of 3 start half-bits, 4 error checking bits, one data byte and 3 stop half-bits. The (nonsense) blue example signal has all bits set to ‘1’.

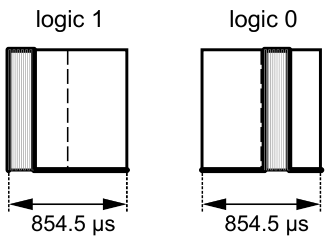


Figure 5: Signal pattern for “1” and “0” bits. Each „high“ signal actually consists of a burst of 6-8 on/off cycles of a 32768 Hz clock (approximately 50% duty cycle).

Using “bursts” of a controlled frequency allows to reduce the power consumption of the sender and to filter out unwanted signals on the receiver side. Each burst consist of 6 to 8 cycles. Depending on calculator model this number may be constant (most crystal controlled devices) or variable. For more details see Appendix A: Variable Timing.

The timing as presented in figure 4 defines the data transfer rate. One character is wrapped in a frame composed of 1.5 start bits, 4 ECC bits, 8 data bits and 1.5 stop bits = 15 bits. Each frame requires 15 × 854.5 µs = 12817.5 µs and the through-put is therefore 1 / 12817.5×10^6 = 78 characters/s.

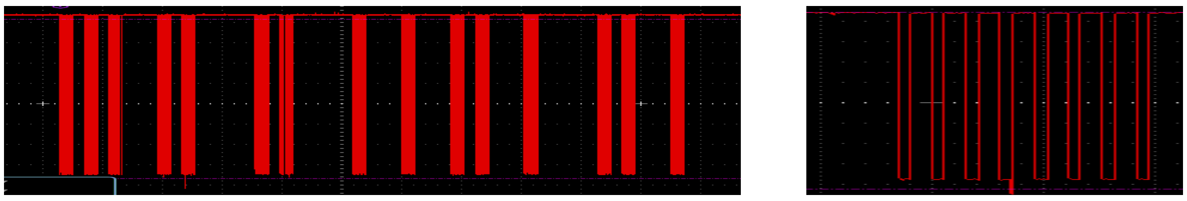


Figure 6: Left: a typical data frame as output by the C4103A receiver. Clearly visible are the bursts representing the 3 start bits, the 4 ECC bits and one data byte (8 bits).
Right: Enlarged view of a typical burst consisting of 8 pulses.

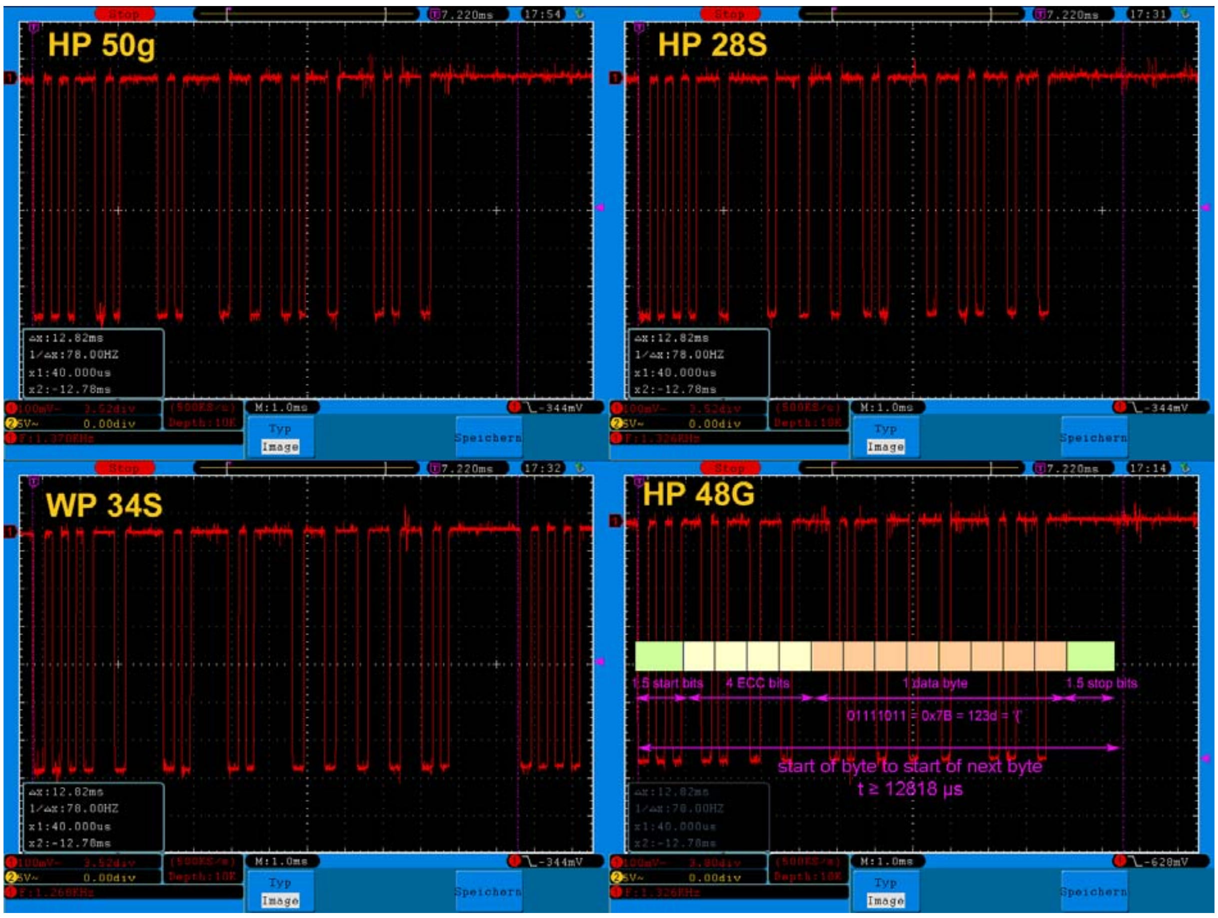


Figure 7: Regular signals as produced by various calculators.

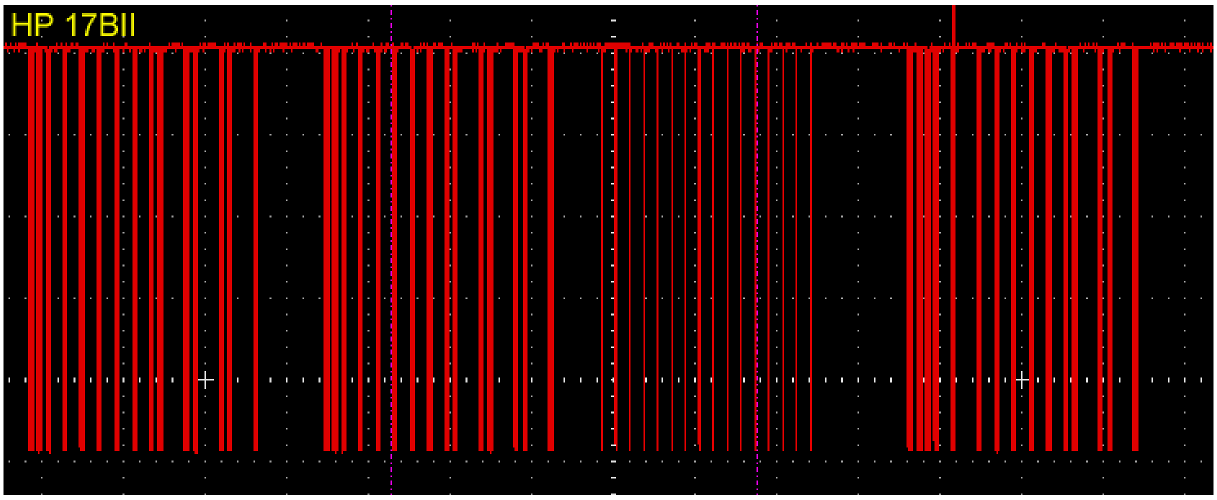


Figure 8: Signal as produced by a HP-17BII calculator. A series of 16 single pulses can be seen between the two leading bytes (left) and the trailing byte (right). This seem to be a bug in this calculator and these pulses have to be suppressed by the receiver.

The IR-Receiver

There are two basic ways to decode the signal: one could use integrating receiver hardware which converts each burst into a continuous pulse stretching over the complete duration of the burst or one could capture the individual pulses of the burst and do the integration by software.

The first approach seems to be straightforward, but requires a receiver chip which can detect the minimum number of six burst pulses and which must also not extend its output pulse too much beyond the end of the burst. Only then it would be able to detect the short gap between subsequent bursts, e.g. between the start half-bits. Most currently available integrating receiver chips are not suited for this purpose because many cannot detect the shortest bursts of 6 cycles (most are designed for 10 and more cycles). Also most of them cannot cope with the rather short gaps between the bursts and they are not able to reliably restart their integration for the next burst. Such receivers then merge the individual bursts. Types like the Telefunken/Vishay TSOP1133, TSOP1333, TSOP1833, or the more recent models TSOP4133 or TSOP2133 will not work properly (see appendix).

Therefore I selected the second method to decode the signal. This means that the required IR-receiver must be fast enough to detect the individual pulses of each burst. One could design such a receiver unit using an IR phototransistor and an amplifier. Instead I found a (for me) simpler way, using a commercial IrDA receiver which also provides a nice case.

For maximum range, the design wavelength of the receiver should be close to 940 nm.

The C4103A IR Transceiver Unit

Some time ago Hewlett Packard produced a small IrDA receiver unit for their laser printers. These units can be found cheap (about 1€ on eBay in 2014) as they were obviously delivered with many printers and in most cases never used. I had originally bought one of these units just for their small case with its infrared window. Then I found that the unit outputs the IR signal "as received" nicely amplified to a full 5V voltage swing with negative logic. Each single pulse of a burst is clearly visible and can be detected. This allows even for accurately counting the pulses in each burst.

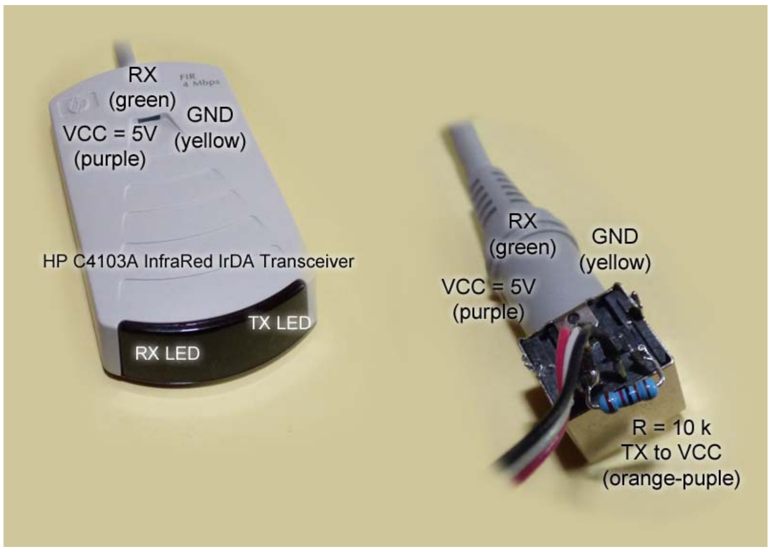


Figure 9: HP C4103A infrared transceiver with experimental connections.

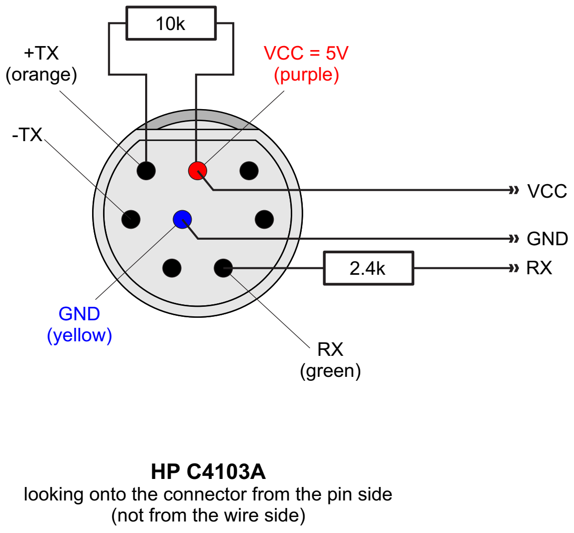


Figure 10: The connector pinout of the HP C4103A infrared transceiver. Following the IrDA specification this connector is a standard Mini DIN plug with 8 pins. Note the asymmetry in the middle row.

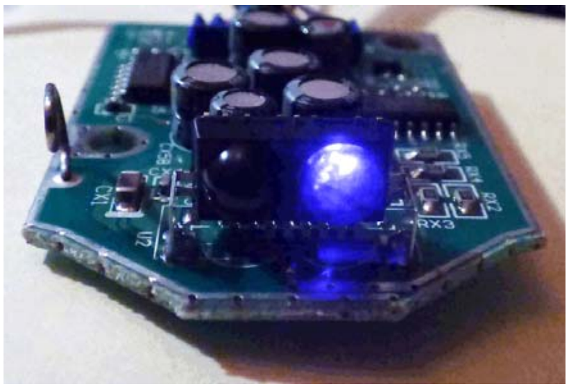


Figure 11: The HP-C4103A transceiver with TX floating free as seen by a digital camera. The LED becomes rather hot – that was how I discovered this problem.

Notes:

- The 10 kΩ resistor pulls +TX (plus TX) to a high level. Its value should not be critical, anything from 1 kΩ to 20 kΩ should do it. This avoids continuous illumination of the TX LED, which would produce a lot of heat and finally could destroy the LED.
- I did not touch –TX (minus TX), one should probably also connect -TX to GND.
- While the pin positions are fixed, the wire colors may be different on your unit.
- I inserted a resistor of 2.4k into the RX line to remove small spikes at the edges of the pulses. These could lead to spurious interrupts.

After developing the code using an Arduino Leonardo I transplanted it to a smaller board. With some effort this allows to integrate the board in the housing (you can also use a plain chip like an AVRtiny).

As there is still free program memory available one could also add another receiver mode for the Infrared output of the HP95/100/200 PDAs.

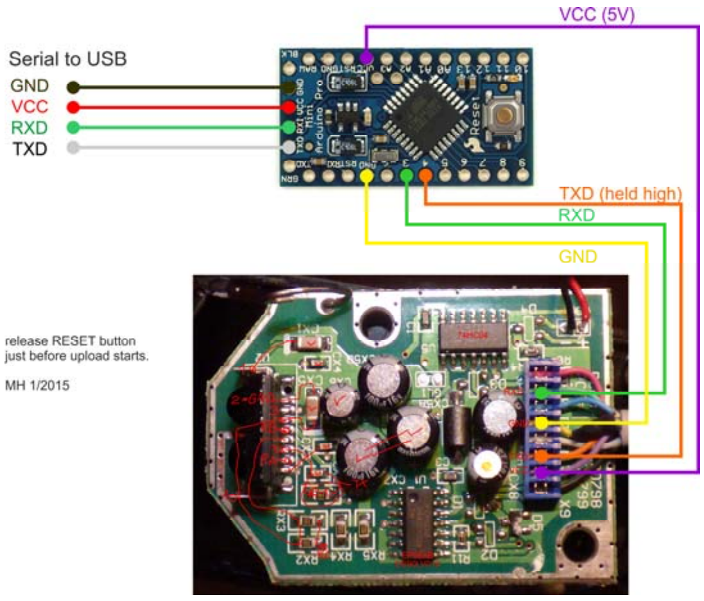


Figure 12: Connection of a 5 V/16 MHz Arduino Pro Mini to the HP-C4103A. The TXD line is only connected to avoid the activation of the sender IR-LED. It could also be used with adapted software to create a full transceiver or for sending "Red Eye" output to a printer. Note that different versions of the HP-C4103A device exist.

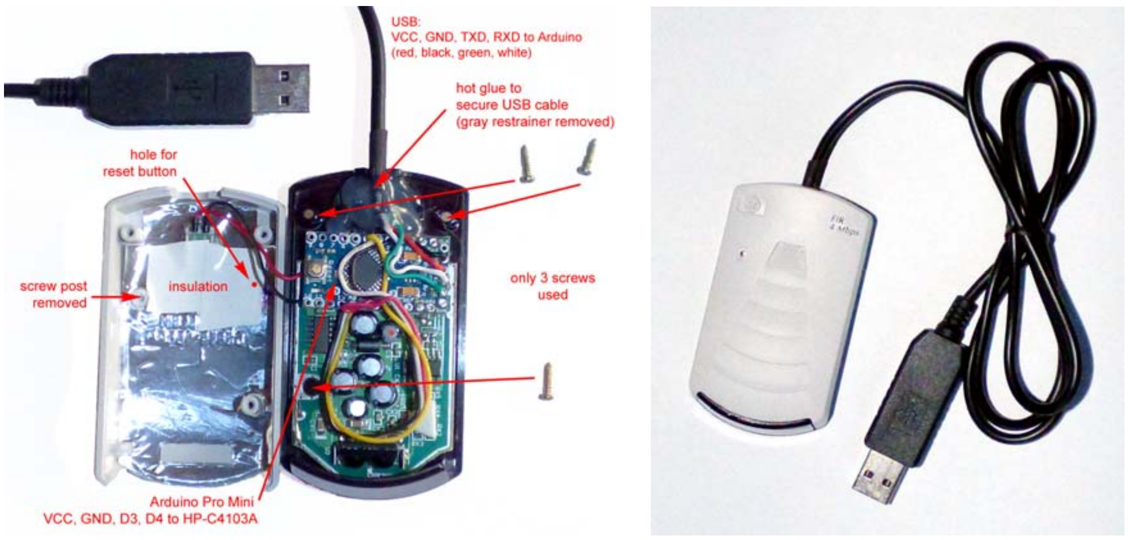


Figure 13: Final result of the integration of an Arduino Pro Mini into the HP-C4103A housing.

The-USB-TTL converter cable provides the serial interface and the 5 V power supply. The blue connector visible in Figure 12, was removed to yield just enough space to fit the Arduino into the available volume. Also one of the screw posts had to be clipped. To drill the reset button hole above the center of the button you can press a bit of modeling clay into the upper shell and close the housing. After opening again you will find a nice imprint of the button to drill through. Access to the reset button allows reprogramming the Arduino *in situ*.

Instead of the TTL-USB converter one could also use a TTL-RS232C converter to link to older computer systems. This option would also have the advantage that no USB-drivers at operating system level are needed.

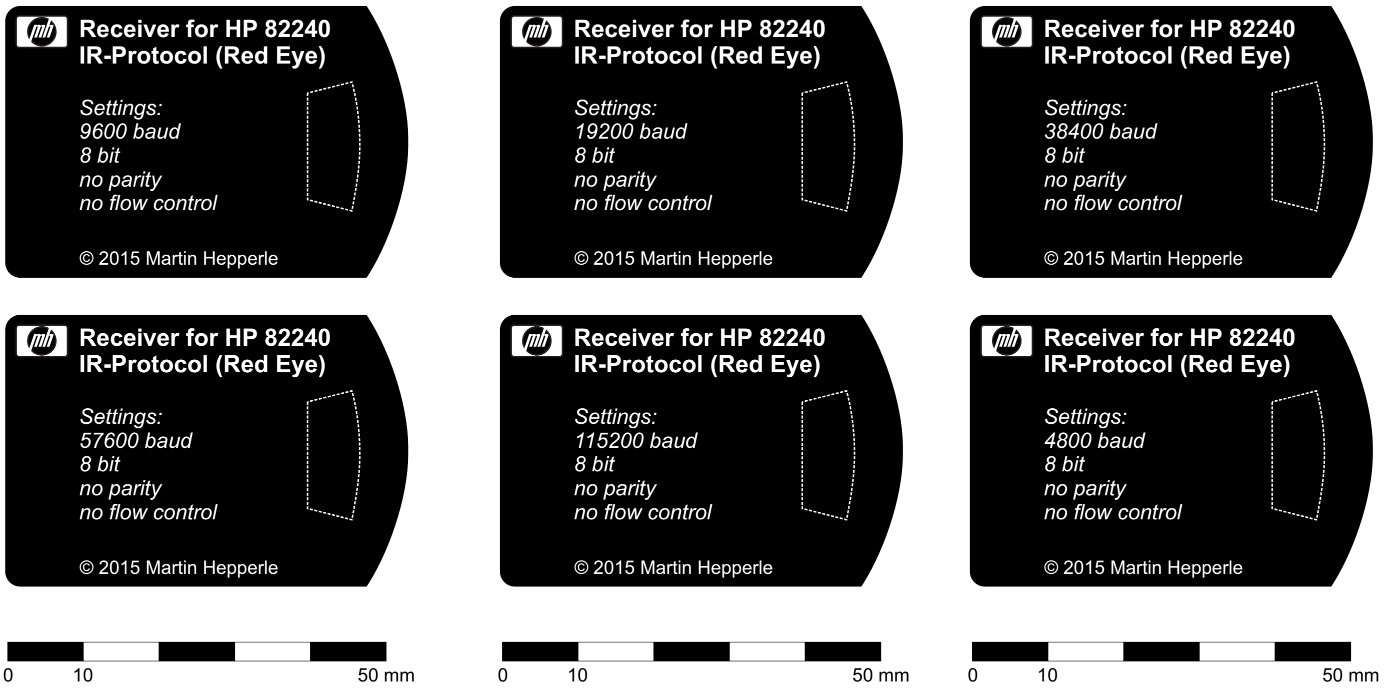
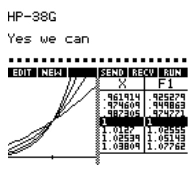
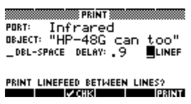
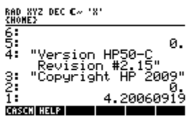
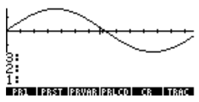
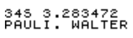

Receiver for HP 82240 IR-Protocol (Red Eye)
Settings: 9600 baud 8 bit no parity no flow control
© 2015 Martin Hepperle
Receiver for HP 82240 IR-Protocol (Red Eye)
Settings: 19200 baud 8 bit no parity no flow control
© 2015 Martin Hepperle
Receiver for HP 82240 IR-Protocol (Red Eye)
Settings: 38400 baud 8 bit no parity no flow control
© 2015 Martin Hepperle
Receiver for HP 82240 IR-Protocol (Red Eye)
Settings: 57600 baud 8 bit no parity no flow control
© 2015 Martin Hepperle
Receiver for HP 82240 IR-Protocol (Red Eye)
Settings: 115200 baud 8 bit no parity no flow control
© 2015 Martin Hepperle
Receiver for HP 82240 IR-Protocol (Red Eye)
Settings: 4800 baud 8 bit no parity no flow control
© 2015 Martin Hepperle
0
10
50 mm
0
10
50 mm
0
10
50 mm

Figure 14: Proposed label for the bottom of the C1403A transceiver. Select your baud rate.

Note on mixing graphics and text

Some calculators allow the user to select whether a print command should automatically send a linefeed character at the end of the output string or not. If this flag is "off", it is possible to mix text and graphics on a single line. However it is up to the user to make sure that the maximum line length of the printer is not exceeded and that a linefeed is sent at the end of the line at all. Therefore printing a text string without linefeed and then sending a screen dump may lead to garbled output. The graphics gets broken in the wrong places or does not show at all. Therefore it is important to activate the linefeed flag or to manually send a linefeed character (which is "4 CHR" in RPL or use the CR command) or by program control to achieve the desired result. Also most calculators use several flags to control printing – consult the manual for details.

				
HP 38G	HP 48G	HP 50g	HP 28S	WP 34S

```
HP-38G
Yes we can
EDIT NEW  SEND RECV RUN
       X        F1
    .961914  .925279
    .974609  .949863
    .987305  .974771
    1        1
    1.0127   1.02555
    1.02539  1.05143
    1.03809  1.07762
```

```
PRINT
PORT:   Infrared
OBJECT: "HP-48G can too"
_DBL-SPACE  DELAY: .9   LINEF
PRINT LINEFEED BETWEEN LINES?
        ✓CHK            PRINT
```

```
RAD XYZ DEC C~ 'X'
{HOME}
6:
5:                 0.
4: "Version HP50-C
    Revision #2.15"
3: "Copyright HP 2009"
2:                 0.
1:         4.20060919
CASCM HELP
```

```
3:
2:
1:
PR1 PRST PRVAR PRLCD CR TRAC
```

```
34S 3.283472
PAULI. WALTER
```

Figure 15: Sample printouts decoded by my receiver unit and converted to bitmap graphics by the HP 82240B printer simulator [6].

References

[1] Harper, Worsley, Stephens, "An Infrared Link for Low-Cost Calculators and Printers", Hewlett-Packard Journal, October 1987.

[2] Anonymous, "HP 82240B Infrared Printer Technical Interfacing Guide", Hewlett Packard.

[3] Steve ?, “IR Printer Information”, The Museum of HP Calculators, HP Articles Forum, 31 July 2000, http://www.hpmuseum.org, [retrieved August 2014].

[4] “Hamming Error Correction Code”, robot room, [web site].

[5] “Error Detection Correction”, supplement to Logic and Computer Design Fundamentals, 3rd Edition, 2004.

[6] Christoph Gießelink, “HP 82240B Simulator”, http://hp.giesselink.com [retrieved August 2014].

[7] Harper, Worsley, “The HP 48SX Calculator Input/Output System”, Hewlett-Packard Journal, June 1991.

[8] Ram Srinivasan, “Low Cost Diagnostic / Configuration Interface”, US Patent 5,237,663, August 17, 1993.

[8] Numerous discussion threads on various internet fora (e.g. www.hpmuseum.org) and news groups (e.g. comp.sys.handhelds, comp.sys.hp48).

The Arduino Software ("Sketch")

This Arduino sketch can be used to decode the infrared signal sent by a Hewlett Packard pocket calculator. It was originally developed using an Arduino Leonardo, later transferred easily to an Arduino Pro Mini. The code decodes the signal and sends the output to a printer simulator or to a terminal program running on a personal computer. Modified versions can easily be produced to send output to other devices (displays, printers or storage devices), to translate special characters or to implement your own control sequences for process control.

Besides the Arduino or a separate AVR chip only a suitable infrared receiver is required. This receiver must be of the "non-integrating" type, i.e. it must output the individual pulses of each burst.

The sketch contains everything needed to decode the signal. If you want to use other interrupt pins instead of INT1 or INT6 as already prepared in the header file, you would have to make small modifications.

The following two figures demonstrate that the postprocessing time spent in the timer interrupt service routine is much shorter than a typical burst and does not affect the timing of the system.

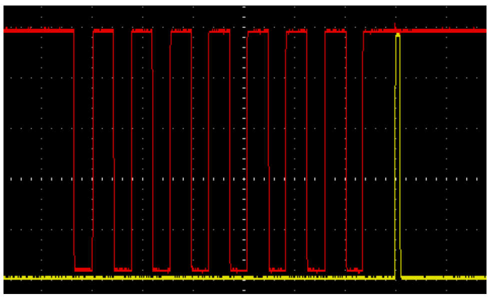


Figure 16: Typical burst of a start half-bit (red) followed by postprocessing in the timer ISR (yellow).

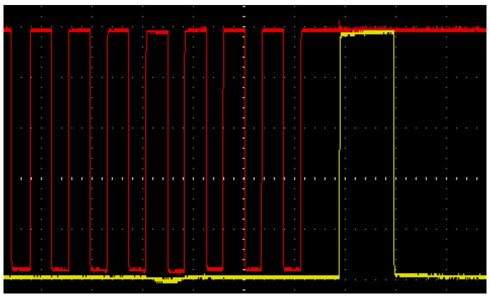


Figure 17: Typical last bit of a data frame (red) followed by the "lengthy" postprocessing of the completed byte including error detection in the timer ISR (processing time shown in yellow).

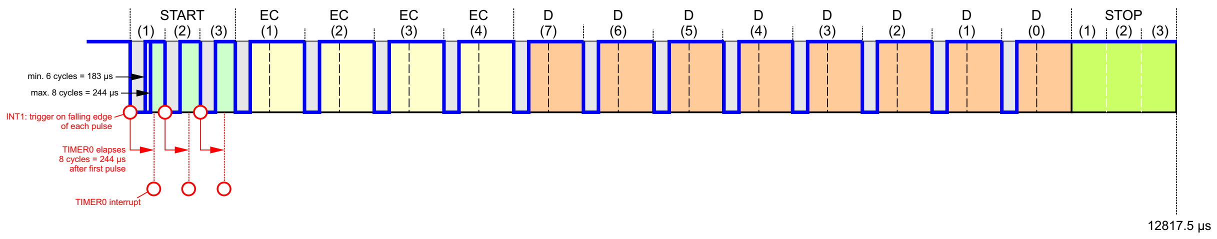


Figure 18: Inverted signal as delivered by the IR-receiver and triggering/sampling scheme controlled by interrupt 1 and timer 0.

```
/*
 ***********************************************************************
 * A decoder for the HP82240 infrared printer protocol.
 ***********************************************************************
 *
 * Copyright (C) 2014-2015 Martin Hepperle.  All rights reserved.
 *
 * This library is free software; you can redistribute it and/or
 * modify it under the terms of the GNU Lesser General Public
 * License as published by the Free Software Foundation; either
 * version 2.1 of the License, or (at your option) any later version.
 *
 ***********************************************************************
 *
 * Purpose of this code
 * ====================
 * This software implements a decoder for the HP 82240A/B infrared
 * printer protocol as used by Hewlett Packard pocket calculators of
 * the 1980/90s (e.g. the HP 28C and S as well as the HP 48 family).
 * The protocol, also known as the "Red Eye" protocol was used before
 * the development of the IrDA standard.
 * Some more recent HP pocket calculators still support this protocol but
 * favor the IrDA standard before finally dropping IR links for wired RS232
 * and USB connections.
 * The "Red Eye" protocol is also implemented in the WP34S, a repurposed
 * HP 20b/30b pocket calculator.
 *
 * Suitable Hardware
 * =================
 * This software requires a receiver hardware which captures infrared
 * signals sent from a suitable calculator.
 * The decoding is done by this software using facilities of an Amtel
 * AVR chip, with at least one interrupt and one timer.
 * The output of the decoder is a serial byte stream which is sent via
 * a serial connection to a PC or any other device having a serial interface.
 * It is possible to use a serial-to-USB converter cable to simulate a COM
 * port via USB.
 * One could also easily adapt the code to support a parallel printer.
 *
 * The processing hardware can be a small Arduino (I used a Leonardo, but
 * a smaller variant of AVR chip would be sufficient) plus an IR receiver
 * connected to an input pin of the microcontroller.
 *
 * The IR receiver must be able to detect individual pulses sent with a
 * frequency of 32.768 kHz.
 * Therefore integrating receivers like the TSOP/VS family and similar are
 * NOT suited for this purpose. The problem with these modern (2014)
 * integrating receivers is that they require a pause between bursts which
 * is longer than the pause provided by the "Red Eye" protocol.
 * Therefore I used a HP C4103A receiver unit, which was originally provided
 * for HP laser printers.
 *
 * The range with a HP-48G is more than 1 meter and vary robust.
 * With more recent HP calculators and the WP-34S the maximum distance is
 * much shorter, more something like 100 mm or even less.
 *
 * Receiving Software
 * ==================
 * The byte stream contains escape sequences which control the printer,
 * for example to switch to graphics mode and back.
 * One means to interpret this stream is Christoph Gießelinks excellent
 * HP 82240B printer simulator program on Windows, which can read its
 * input from a COM port.
 *
 * For other platforms the command line printer simulator from Khanh-Dang
 * Nguyen Thu-Lam works well. I tried it on Windows and only a tiny
 * modification was required to capture incoming text and graphics.
 * As pure C-code this tool will also work on all other platforms which
 * have a C compiler (I used gcc).
 *
 * This Software
 * =============
 * Besides the simple pass-through mode the code also implements a simple
 * interpreter with a state machine for control codes of the printer.
 * This could be modified to drive any printer or perform other tasks,
 * like controlling devices or whatever you like.
 *
 * All printer control sequences are decoded but in the current
 * implementation no special action is taken.
 * Bitmap graphics are also recognized and stored for further processing.
 *
 * Sending the command characters A(nalyzer), I(nterpreter), T(ranslate) via
 * the serial (USB) link allows to activale some special modes:
 *
 * The Interpreter mode is the normal operating mode. It passes all data
 * straight through.
 *
 * The Analyzer mode creates output formatted like this:
 * (8)27(8)26(8)54(8)27(8)53(8)80(8)53(8)54(8)53(8)54(8)53(8)27(8)80(8)53(8)
 *      D = 4, 1/2-bit = 26
 * The numbers in parentheses indicate the number of pulses per burst
 * and the numbers between the bursts specify the gap time.
 * D = is the data byte recognized and at the end the half bit time
 * derived from the start half-bits is given.
 *
 * The Translate option switches between passing through and replacing the
 * character code 0x04 by a linefeed character. This allows to view the
 * print stream of some calculators in a terminal (emulator).
 *
 * Some comments on the basic architecture:
 * ========================================
 * In order to achieve a smooth operation, one interrupt and one timer is used:
 * - The interrupt is used to capture the start of each pulse (when the
 *   input pin goes low, as my IR sensor has an inverted logic).
 *   Thus this interrupt counts all pulses within each burst.
 *   It flags the first pulse of each burst and determines the time between
 *   subsequent bursts. Invalid (too short) bursts are skipped.
 *
 * - Timer 0 is started to trigger just after the end of each burst
 *   assuming the maximum nominal length of 8 pulses per burst.
 *   When the timer is due, the time to the previous bit is evaluated
 *   and the appropriate bit value is set. There is enough time after each
 *   burst to do this processing.
 *   The timer also resets the pulse count to be ready for the next burst.
 *
 * - The error checking nibble and the data byte are thus composed bit by bit.
 *
 * - After the last bit has been decoded, the resulting byte is put into a
 *   ring buffer.
 *
 * Any post-processing of the data in the ring buffer (if desired) can be
 * performed in the main loop. This may be interrupted at any time when
 * new data arrives.
 * This setup yields a very reliable system, even if larger amounts of data
 * are sent. Such larger amounts of data occur when graphics, e.g. a screen
 * copy, is sent.
 *
 ************************************************************************
 *
 * "Red Eye" infra red signal (for more details see references [1,2])
 *
 * The following sketch shows the usage of interrupt and timer:
 * The interrupt INT is triggered on falling edge of each pulse
 *
 *   INT on first pulse starts TIMER0
 *      |-------------TIMER0-------------------->
 *                                              |
 *                                              | TIMER0 elapses
 *                                              | after 8+ bursts
 *     INT  INT  INT  INT  INT  INT  INT  INT   |
 *      |    |    |    |    |    |    |    |    |
 *      v    v    v    v    v    v    v    v    v
 * -----+ +--+ +--+ +--+ +--+ +--+ +--+ +--+ +----------------
 *      | |  | |  | |  | |  | |  | |  | |  | |
 *      +-+  +-+  +-+  +-+  +-+  +-+  +-+  +-+
 *      1    2    3    4    5    6    7    8 pulses
 *                                           @ 32.768 kHz
 *      <------------- one burst ------------->
 *
 *
 * The following sketch shows the encoding of the 0 and 1 bits:
 * (bursts are indicated by the three vertical lines)
 *
 *    burst       burst             burst       burst burst
 *      |           |                 |           |     |
 *      v           v                 v           v     v
 *      |  logic 1  |  logic 1  |  logic 0  |  logic 0  |  logic 1  |
 *      |           |           |           |           |           |
 *      |  .  |  .  |  .  |  .  |     |     |     |     |     |     |
 * -----|||---------|||---------------|||---------|||---|||---------
 *      |||         |||               |||         |||   |||
 *      .     .     .
 *      <====>      .
 *    one half-bit = 427.25 microseconds
 *      .           .
 *      <===========>
 *         one bit = 854.5 microseconds
 *
 * Each bit takes 854.5 microseconds (28 cycles of a 32768 Hz clock of the
 * IR driver).
 * The shortest spacing occurs within the three start bits which are are
 * spaced 854.5/2 = 427.25 microseconds apart.
 * A burst at the start of the FIRST  half-bit represents a logic '1'
 * A burst at the start of the SECOND half-bit represents a logic '0'
 * IMPORTANT:
 * Per specification the burst time is 6-8 cycles of the 32786 Hz clock,
 * which amounts to 183-244 microseconds (183 = 1/4.67 of the bit time).
 * The number of pulses in each burst can vary between 6 and 8.
 * Some calculators (e.g. the HP 28S) adapt the number of pulses to
 * achieve a "good" average timing, which, despite these efforts is less
 * accurate than e.g. the signals produced by machines which use a crystal
 * for the inter-bit timing.
 *
 ***********************************************************************
 *
 * References
 * [1] Harper, Worsley, Stephens, "An Infrared Link for Low-Cost
 *        Calculators and Printers", Hewlett-Packard Journal, October 1987.
 * [2] Anonymous, "HP 82240V Infrared Printer Technical Interfacing Guide".
 * [3] Steve ?. "IR Printer Information"", The Museum of HP Calculators,
 *        HP Articles Forum, 31 July 2000, [web site]
 * [4] "Hamming Error Correction Code", robot room, [web site].
 * [5] "Error Detection Correction", supplement to Logic and Computer
 *        Design Fundamentals, 3rd Edition, 2004.
 * [6] Christoph Gießelink, "redeye.c" source code from EMU28 project, 2011 .
 *
 *
 ************************************************************************
 */
// see redeye.cpp
#include "RedEye.h"

/*
 * I have implemented an interpreter with limited postprocessing.
 * This can be expanded to interface to any printer or other device.
 * This implementation covers only the basic skeleton - a more complete
 * implementation is left as an exercise to the user.
 */

// state codes for interpreter
#define TEXT        0
#define GRAPHICS    1
// character codes
#define ALT_CR      4  // char 4 ==  carriage return/linefeed for 82440 printer
#define LF         10  // char 10
#define ESC        27  // char 27 0x1B

// state of the machine
int state = TEXT;
// for collecting a line of textual respectively graphics bytes
// (must be at least 166 bytes long)
#define BUFFER_SIZE 200
byte lineBuffer[BUFFER_SIZE];
// counter for textual bytes
int idxLineBuffer;
// special counter for graphics bytes
int numGraphicsBytes = 0;
// is true: translate alternate CR 0x04 to linefeed 0x10
boolean translateAltCR = false;

/*****************************************************************************/
/*
 * This is the usual Arduino style setup() function which is executed
 * only once.
 */
void setup()
{
  // Prepare the serial output port.
  // You can connect Christoph Gießelinks printer simulator to the
  // appropriate COM port to receive and save the printout on a Windows PC.
  // note that this only supports baud rates up tp 9600 baud
  Serial.begin(9600);
  // we should make sure that Serial is ready. Possibly unnecessary,
  // but cannot hurt.
  delay(2500);

  // here comes the heavy stuff...
  setupRedEye();
}

/*****************************************************************************/
/*
 * This is the usual Arduino style main() loop.
 */
/*****************************************************************************/
void loop()
```

```
{
  // we twiddle our thumbs here - but at full speed
  // to conserve energy and to save the planet, one
  // could also reduce processor speed and speed it
  // up again whenever data is received.

  while ( true )
  {
    if ( isDataAvailable() )
    {
      // there is something in the receiving buffer
      // avoid that reading and updating idxRead is interrupted
      // pull the byte from the buffer ...
      byte data = getByte();

      if ( ! isInterpreter() )
      {
        // not in interpreter mode
        // just pass the raw data
        Serial.write(data);
      }
      else
      {
        // this is our interpreter state machine

        switch ( state )
        {
          //----------------
          case ESC:
          //----------------
            // we are in ESCape state (previous character was ESC / 27d / 0x1B)

            // switch to TEXT state (may be overwritten below)
            state = TEXT;

            switch ( data )
            {
              // ESC control codes
              // we just swallow the following codes
              case 255:  reset();
              case 254:  /* "SELF TEST"          */
              case 253:  /* "DOUBLE WIDE"        */
              case 252:  /* "SINGLE WIDE"        */
              case 251:  /* "UNDERLINE"          */
              case 250:  /* "NO UNDERLINE"       */
              case 249:  /* "ISO 8859 Latin 1"   */
              case 248:  /* "Roman8"             */
                // pass through
                addToBuffer(ESC);
                addToBuffer(data);
                flush();
                break;

              /*
               * we can define our own escape sequences like
               * ESC 0 or ESC (167 to 247).
               * ESC 1 ... 166 is blocked by graphics.
               * One could also enter another mode e.g. by ESC 0, read some
               * commands and then switch back with another ESC 0
               */
              case   0:
                // ESC 0
                // swallow ESC and zero
                break;
              default:
                if ( data > 0 && data < 166+1 )
                {
                  // within allowable range for graphics width (1...166)
                  // empty current buffer and prepare for new graphics bytes
                  flush();
                  // # of graphics bytes to follow
                  numGraphicsBytes = data;
                  // switch to GRAPHICS state
                  state = GRAPHICS;
                }
                else
                {
                  Serial.print("UNKNOWN ESC ");
                  Serial.println(data,DEC);
                  addToBuffer(ESC);
                  addToBuffer(data);
                }
                break;
            }

            break;

          //----------------
          case GRAPHICS:
          //----------------
            // store the next graphics byte
            lineBuffer[idxLineBuffer++] = data;
            if ( idxLineBuffer == numGraphicsBytes )
            {
              // graphics sequence is complete
              // flush buffer to insert proper graphics ESCape prefix
              flush();
              // revert to normal text mode
              state = TEXT;
            }
            break;


          //----------------
          default:
          //----------------
            // not in ESCape state, not in GRAPHICS state, therefore TEXT state
            switch ( data )
            {
              case ESC: // 27: escape
                // do not output the escape character now
                state = ESC;
                break;

              case ALT_CR: // 0x04: alternate line feed,
                       // is generally used  by HP 48, HP 28C
                if ( translateAltCR )
                {
                  data = LF;  // replace
                }
                // fall trhough
              case LF: // 0x0A: linefeed
                addToBuffer(data);
                // ship out content of printer buffer and prepare for new data
                flush();
                break;
```

```
              default:
                // store data in printer buffer
                addToBuffer(data);
                break;
            }
            break;
        }
      }
    }

    // check for input
    while ( Serial.available() > 0 )
    {
      int b = Serial.read();
      switch ( b )
      {
        case 'A':
          // change mode
          setMode ( MODE_ANALYZER );
          Serial.print("=>MODE_ANALYZER\n");
          break;

        case 'I':
          // change mode
          setMode ( MODE_INTERPRETER );
          Serial.print("=>MODE_INTERPRETER\n");
          break;

        case 'T':
          translateAltCR = !translateAltCR;
          Serial.print("=>CR-translation: ");
          Serial.print(translateAltCR ? "ON" : "OFF");
          Serial.print("\n");
          break;
      }
    }

  } // while ( true )
}
/*****************************************************************************/
void addToBuffer( byte data )
{
  // perform possible modification here
  lineBuffer[idxLineBuffer++] = data;

  // check for line overflow (should never occur)
  if ( idxLineBuffer == BUFFER_SIZE )
  {
    flush();
  }
}
/*****************************************************************************/
/*
 * Reset the printer.
 *
 */
void reset()
{
  idxLineBuffer = 0;
  numGraphicsBytes = 0;
  Serial.write(0x04);
}
/*****************************************************************************/
/*
```

```
 * Flush the printer buffer.
 *
 */
void flush()
{
  if ( idxLineBuffer > 0 )
  {
    if ( numGraphicsBytes > 0 && numGraphicsBytes == idxLineBuffer )
    {
      // there is some GRAPHICS in the buffer

      // send the graphics buffer with proper ESC+COUNT prefix
      Serial.write(ESC);
      Serial.write(numGraphicsBytes);
#ifdef FUN
      // just for fun: invert image
      for ( int i=0 ; i<numGraphicsBytes ; i++ )
      {
        lineBuffer[i] = ~lineBuffer[i];
      }
#endif
      Serial.write(lineBuffer,numGraphicsBytes);
      // reset count
      numGraphicsBytes = 0;
    }
    else
    {
      // there is some TEXT in buffer

      // send the graphics buffer with proper ESC+COUNT prefix
      Serial.write(lineBuffer,idxLineBuffer);
    }
    idxLineBuffer = 0;
  }
}
/****************************************************************************/
```
Figure 19: Source file IR_RedEye.c

```
/*
 *********************************************************************
 * A decoder for the HP82240 infrared printer protocol.
 *********************************************************************
 *
 * Copyright (C) 2014 Martin Hepperle.  All rights reserved.
 *
 * This library is free software; you can redistribute it and/or
 * modify it under the terms of the GNU Lesser General Public
 * License as published by the Free Software Foundation; either
 * version 2.1 of the License, or (at your option) any later version.
 *
 *********************************************************************
 *
 * This sketch was written for an Arduino Leonardo with the IR sensor
 * attached to digital pin #2 or digital pin #6.
 *
 * I wanted to avoid the indirection via a jump table by the Arduino interrupt
 * functions attachInterrupt() and detach Interrupt(). Therefore the low level
 * interrupt service routines ISR() used.
 * If you want to use a different board, you have to adapt several things.
 *
 * Leonardo
 *                       +----------+
 *                       |          |
 *                       |          |
 *                       |     A    |
 *                       |     r    | D7 <---- IR RX (if INT6 is used)
 *  IR receiver <--- 5.0V |     d    | D6
 *                       |     u    | D5
 *                       |     i    | D4 <---- mode switch --[ 1k ]---| GND
 *                       |     n    | D3 <---- optional debug output -> OSCI
 *  IR receiver <---- GND |     o    | D2 <---- IR RX (if INT1 is used)
 *                       |          | D1
 *                       |          | D0
 *                       +----------+
 *
 * Pro Mini
 *                       +----------+
 *                       |          | VCC, GND, TX, RX from USB-TTL cable
 *                       |          |
 *                       |     A    |
 *                       |     r    | D7
 *  IR receiver <--- 5.0V |     d    | D6
 *                       |     u    | D5
 *                       |     i    | D4 ----> TX IR-LED (not used)
 *                       |     n    | D3 <---- IR RX (if INT1 is used)
 *  IR receiver <---- GND |     o    | D2
 *                       |          | D1
 *                       |          | D0
 *                       +----------+
 */

/*****************************************************************************/

#include "RedEye.h"


// we can use either INT1 or INT6 (see redeye.h)
#if INT_NO == INT1
  // INT1 on PD1 is part of the input pins port D (PIND)
  #define sensor_PORT   PIND
  // the output of the IR receiver goes to PD1 (physical pin D2 on Leonardo)
  #define sensorPin     1
  #ifdef PRO_MINI
     // the output of the IR receiver goes to PD3 (physical pin D3 on Pro Mini
     #define sensorPin     3
  #endif
#endif
// note #elif did not work as desired, therefore multiple #if
#if INT_NO == INT6
  // INT6 on PE6 is part of the input pins port E (PINE)
  #define sensor_PORT   PINE
  // the output of the IR receiver goes to PE6 (physical pin D7 on Leonardo)
  #define sensorPin     6
#endif

/*****************************************************************************/
/* We use a ring buffer filled by the interrupt service routine of timer 0
 * and emptied by the main loop, which ships out the bytes through the
 * serial interface.
 * A value of 1024 defines a large buffer, for simple printing applications
 * from a HP pocket calculator with DELAY of 1.x seconds a value of 8 bytes
 * is sufficient
*/
#define RING  1024
volatile int idxWrite = 0;  // write pointer, accessed from interrupt
volatile int idxRead = 0;   // read pointer, accessed from main loop
static byte databuffer[RING];
/*****************************************************************************/
// some local functions
static void appendToOutput ( const char * pErrorMsg );

/*****************************************************************************
 * if PIN_OUTPUT is defined, the Arduino pin 3 can be used to indicate events
 * so that they can be monitored on an oscilloscope.
 */
//#define PIN_OUTPUT
#ifdef PRO_MINI
   #undef PIN_OUTPUT
#endif
#ifdef PIN_OUTPUT
  // Leonardo: D3 == PD0
  #define signalArdiunoPin  3  // Arduino "pin 3" ...
  #define signalPin         0  // ... is "PD0" on PORTD of the AVR chip
                               // pin used for debug output, e.g. timing
crosscheck
  #define signalPORT   PORTD
#endif


/*****************************************************************************
 * input port D is used for mode selection switch (interpreter/analyzer)
 * If the mode switch is open, the pullup pulls the modePin high.
 * Then the interpreter mode is ON.
 */
#define MODE_SWITCH
// Leonardo: D4 == PD4
#define modePORT   PIND
// the switch may connect PD4 (physical "pin 4" on Leonardo) to ground
#define modePin     4

#ifdef PRO_MINI
  #undef MODE_SWITCH
#endif

/*****************************************************************************
```

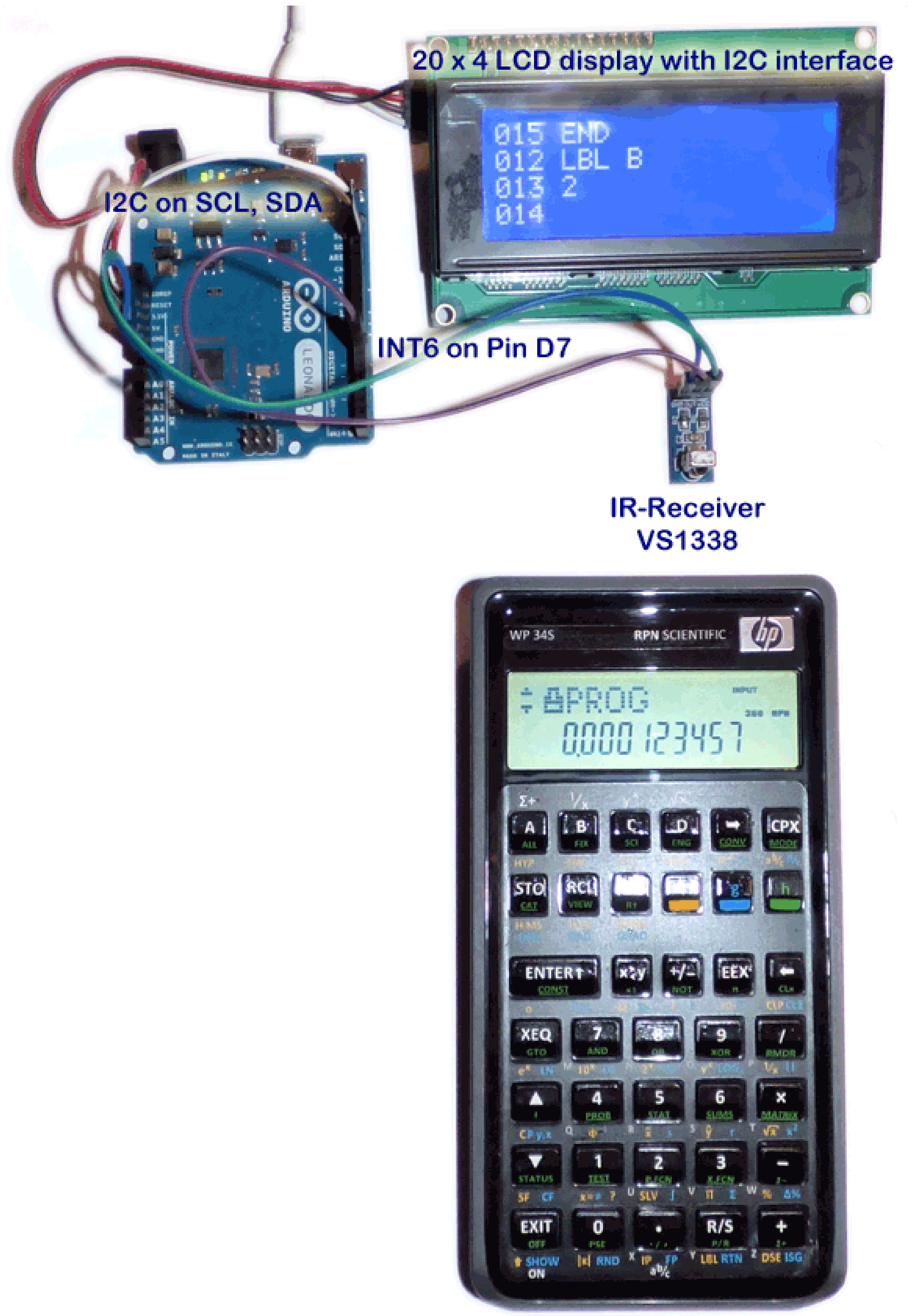
```
 * Per HP documentation we need 6 to 8 pulses for a valid burst.
 * Note that the HP 48G may send out les than 6 pulses when the
 * batteries are low. Therefore the lower pulse count is relaxed
 * to 5 here, but the solution is to use fresh batteries.
 * The problem manifests itself in losing characters.
 */
#define MIN_PULSES 5


/******************************************************************************
 * MODE_INTERPRETER  all bytes are filtered and passed to the serial interface
 * MODE_ANALYZER     pulse count and gap duration will be output
 *                   (IR signal analyzer for debugging purposes)
 *
 * Example output in analyzer mode:
 * Sending the string ABC from a HP 48 starts with the escape sequence to
 * select the character set followed the string enclosed in single quotes.
 * (8)27(8)27(8)53(8)27(8)80(8)27(8)80(8)53(8)54(8)26(8)54(8)80(8)27(8)53(8)
 *      D = . = '27', 1/2-bit = 27
 * (8)27(8)27(8)53(8)27(8)80(8)27(8)53(8)54(8)53(8)53(8)54(8)80(8)53(8)27(8)
 *      D = . = '249', 1/2-bit = 27
 * (8)26(8)27(8)27(8)53(8)80(8)54(8)53(8)53(8)27(8)80(8)54(8)26(8)54(8)53(8)
 *      D = ' = '39', 1/2-bit = 26
 * (8)27(8)27(8)26(8)54(8)80(8)27(8)80(8)26(8)80(8)53(8)53(8)54(8)53(8)27(8)
 *      D = A = '65', 1/2-bit = 27
 * (8)27(8)27(8)26(8)80(8)27(8)53(8)81(8)26(8)80(8)54(8)53(8)54(8)26(8)80(8)
 *      D = B = '66', 1/2-bit = 27
 * (8)26(8)27(8)27(8)80(8)53(8)54(8)53(8)27(8)80(8)53(8)54(8)53(8)27(8)53(8)
 *      D = C = '67', 1/2-bit = 26
 * (8)27(8)27(8)27(8)53(8)80(8)53(8)54(8)53(8)27(8)80(8)53(8)27(8)54(8)53(8)
 *      D = ' = '39', 1/2-bit = 27
 * (8)27(8)27(8)53(8)27(8)53(8)80(8)54(8)53(8)54(8)53(8)53(8)27(8)80(8)54(8)
 *      D = . = '4', 1/2-bit = 27
 *
 * The numbers in parentheses are the pulse count of a burst.
 * The numbers between the pulses are the times between the start of
 * subsequent bursts.
 * The D = part shows the character (if printable) and its decimal code.
 * The line ends with the half bit time derived from the start bits.
 */

// Select one mode. I used a variable so that it could also be switched
// at run time
byte mode = MODE_INTERPRETER;

// pulse count is restarted for each burst
volatile byte pulse = 0;
// bit count, is restarted for each data frame
volatile int idx = 0;
// the number of timer ticks measured between the three start half-bits
byte halfBitTicks = 25;  // default, will be determined at run time
// the time interval betwen the starting edge of subsequent bursts
byte dt;
/******************************************************************************/
/*
 * Return true if interpreter mode is ON.
 * This is the case when the mode switch is open and the pullup pulls
 * the pin HIGH.
 */
boolean isInterpreter()
{
  return mode == MODE_INTERPRETER;
}
/******************************************************************************/
```

```
void setMode ( int newMode )
{
  mode = newMode;
}
/*****************************************************************************/
/*
 * Return true if there is at least one new byte in the receiving buffer.
 *
 * You can call getByte() afterwards to extract the next byte.
 */
boolean isDataAvailable()
{
  return idxWrite != idxRead;
}
/*****************************************************************************/
/*
 * Return the next byte from the receiving buffer.
 *
 * You should call dataAvailable() first to make sire that there is something
 * in the buffer.
 */
byte getByte()
{
  // there is something in the mailbox
  // avoid that reading and updating idxRead is interrupted
  // pull the byte from the buffer ...
  byte data = databuffer[idxRead];
  // ... and advance read pointer
  idxRead = (idxRead+1) % RING;

  return data;
}

/*****************************************************************************/
/*
 * This function is called from the usual Arduino setup() function.
 */
void setupRedEye()
{
  //
#ifdef PIN_OUTPUT
  pinMode(signalArdiunoPin, OUTPUT);
  bitClear(PORTD, signalPin);
#endif

  // prepare for mode switch
  pinMode(modePin, INPUT);
  digitalWrite(modePin,HIGH); // turn on internal pull-up on the modePin

  /***********************************************************
   *  we use timer/counter 0 for measuring the time between bursts
   */

  // there is no need for action on any pin by timer
  TCCR0A = 0;

  // we tick timer 0 at F_CPU/256 = 16/256 MHz = 62.5 kHz
  TCCR0B = (1<<CS02);

  // disable the compare output A interrupt
  TIMSK0 = 0;

  // set timer output compare A register so that the timer
  // fires after a maximum burst time of 8 cycles
  OCR0A = (byte)(F_CPU*8L/32768L/256L);

  /************************************************************
   *  We use a interrupt INT_NO to capture the first (FALLING)
   *  edge of each pulse. INT_NO is associated with a certain
   *  Arduino pin.
   */
  // diable interrupts first to avoid interrupt on change
  EIMSK = 0;

  // interrupt INT_NO shall occur on the falling edge of the signal
#if INT_NO == INT1
  EICRA = (EICRA & ~((1<<ISC11) | (1<<ISC10))) | (FALLING<<ISC10);
#endif
#if INT_NO == INT6
  EICRB = (EICRB & ~((1<<ISC61) | (1<<ISC60))) | (FALLING<<ISC60);
#endif
  // finally enable the interrupt
  EIMSK |= (1 << INT_NO);
}
/******************************************************************************/
/*
 * Calculate the error correction nibble for the given data byte.
 * (as per HP 82240B Infrared Printer Technical Interfacing guide))
 */
static byte calcECBits ( byte data )
{
  byte ret = 0x00;
  if ( (data &   1) != 0 ) ret ^= 0x03;
  if ( (data &   2) != 0 ) ret ^= 0x05;
  if ( (data &   4) != 0 ) ret ^= 0x06;
  if ( (data &   8) != 0 ) ret ^= 0x09;
  if ( (data &  16) != 0 ) ret ^= 0x0A;
  if ( (data &  32) != 0 ) ret ^= 0x0C;
  if ( (data &  64) != 0 ) ret ^= 0x0E;
  if ( (data & 128) != 0 ) ret ^= 0x07;

  return ret;
}
/******************************************************************************/
/*
 * Calculate the even parity bit for the given data byte.
 */
static byte parity ( byte data )
{
  byte ret = 0x00;

  if ( (data &   1) != 0 ) ret++;
  if ( (data &   2) != 0 ) ret++;
  if ( (data &   4) != 0 ) ret++;
  if ( (data &   8) != 0 ) ret++;
  if ( (data &  16) != 0 ) ret++;
  if ( (data &  32) != 0 ) ret++;
  if ( (data &  64) != 0 ) ret++;
  if ( (data & 128) != 0 ) ret++;

  return ret % 2;
}
/******************************************************************************/
/*
 * Append a null terminated string to the output buffer.
 */
static void appendToOutput ( const char * pErrorMsg )
{
  while ( *pErrorMsg )
  {
    databuffer[idxWrite] = *pErrorMsg;
    idxWrite = (idxWrite+1) % RING;
    pErrorMsg++;
  }
}
/*****************************************************************************/
/*
 * Output the number of pulses during this burst.
 * used when ANALYZER mode is active.
 */
static void outputPulseCount()
{
  char s[8];
  appendToOutput ("(");
  itoa(pulse, s, 10 );
  appendToOutput ( s );
  appendToOutput (")");
}
/*****************************************************************************/
/*
 * Output the time between this and the previous burst.
 * used when ANALYZER mode is active.
 */
static void outputGapTime()
{
  char s[8];
  itoa(dt, s, 10 );
  appendToOutput ( s );
}
/*****************************************************************************/
/*
 * This handler routine is called when the comparison A interrupt of
 * timer/counter 0 occurs.
 * Counter 0 is reset at the first edge of a burst and the comparison
 * register is set to a value which covers 8 cycles of the 32768 Hz
 * burst signal. Thus this interrupt is called when a burst is just
 * over and the time elapsed since the previous burst has been stored
 * in the variable dt by the edge detection interrupt.
 * The processing time for the idx == 14 case is the longest and takes
 * about 45 us. This still fits nicely in the gap before the next data
 * frame can be expected.
 */
ISR(TIMER0_COMPA_vect)
{
#ifdef PIN_OUTPUT
    // signal start of activity
    bitSet(signalPORT, signalPin);
#endif

  if ( pulse < MIN_PULSES )
  {
    // If the timer elapsed and we got less than MIN_PULSES pulses,
    // no burst is in progress.
    // This actsthen as a watchdog event to make sure we are ready
    // for the next data byte, even if something went wrong
    pulse = 0;
    idx = 0;

#ifdef MODE_SWITCH
      // check mode switch
      if ( (modePORT & _BV(modePin)) == _BV(modePin) )
      {
        setMode ( MODE_INTERPRETER );
      }
      else
      {
        setMode ( MODE_ANALYZER );
      }
#endif
  }
  else
  {
    // we arrive here after a burst of up to 8 pulses has finished

    /* The index counter idx works as follows:
     *
     *       S  S  S  E  E  E  E  7  6  5  4  3  2  1  0
     *       |__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
     *  idx  0  1  2  3  4  5  6  7  8  9 10 12 13 14 15
     *
     */
    if ( idx == 0 )
    {
      // this is the start of first burst
      if ( mode == MODE_ANALYZER )
      {
        // output the number of pulses during this burst
        outputPulseCount();
      }
    }
    else
    {
      // this is the start of the second or later burst

      //-------------------
      if ( mode == MODE_ANALYZER )
      {
        // output the time interval between bursts
        outputGapTime();

        // output the number of pulses during this burst
        outputPulseCount();
      }
      //-------------------


      if ( idx == 1 )
      {
        // second start half-bit
        // gap 1 after second burst
        halfBitTicks = dt;
      }
      else if ( idx == 2 )
      {
        // third start half-bit
        // gap 2 after third burst
        // take the average of the two gaps between the three start half-bits
        halfBitTicks = (halfBitTicks + dt) >> 1;
      }
      else
      {
        // other gaps
        // use static variables as we return here 12 times to compose the
        // 4 ECC bits and the 8 data bits step by step
        static byte lastbit = 0;
        static byte token   = 0;
        static byte missed  = 0;
        static byte ECC     = 0;
        static byte data    = 0;

        // ECC:  idx=3,4,5,6
        // data: idx=7,8,9,10,11,12,13,14

        if ( idx == 3 )
        {
          // start of the error correction nibble
          // set lastbit from last start half-bit which equals a zero
          lastbit = 0;
          // reset bit collector
          token = 0;
          // start with no missed bits in ECC nibble
          missed = 0;
        }
        else if ( idx == 7 )
        {
          // start of the data byte
          // we carry lastbit over from ECC
          // reset bit collector
          token = 0;
          // start with no missed bits in data byte
          missed = 0;
        }

        // determine number of 1/2-bit intervals since last burst (rounded up)
        int t = (dt + halfBitTicks/4) / halfBitTicks;

        if ( lastbit == 1 )
        {
          // we have to adjust by one interval to match the correct
          // interval in the following switch (t)
          t--;
        }

        // here we detect the bit sequence for this interval
        // in case of missed bits we remember this in the
        // missed bit mask and also increment the index idx.
        // this could be written more compact, but I preferred a readable form
        switch ( t )
        {
          case 0:
            // second burst in same bit: this is an error which we ignore
            break;

          case 1:          // one bit '1'
            lastbit = 1;
            token <<= 1;   // slot for new bit
            token |= lastbit;    // set '1'
            missed <<= 1;  // no missed bit, just move mast to the left
            break;

          case 2:          // one bit '0'
            lastbit = 0;
            token <<= 1;   // slot for new bit
            // nothing to set for '0'
            missed <<= 1;  // no missed bit, just move mast to the left
            break;

          case 3:             // one missed bit, one bit '1'
            lastbit = 1;
            token <<= 1;      // skip missed bit
```

```
          token <<= 1;      // slot for new bit
          token |= lastbit;       // set '1'
          missed <<= 1;     // move mask to the left
          missed |= 1;      // insert one missed bit
          idx++;            // account for missed bit in bit count
          break;

        case 4:           // one missed bit, one bit '0'
          lastbit = 0;
          token <<= 1;   // skip missed bit
          token <<= 1;   // slot for new (null) bit
          // nothing to set for '0'
          missed <<= 1;
          missed |= 1;      // insert one missed bit
          idx++;            // account for missed bit in bit count
          break;

        case 5:         // two missed bits, one bit '1'
          lastbit = 1;
          token <<= 1; // missed bit
          token <<= 1; // missed bit
          token <<= 1; // slot for new bit
          token |= lastbit;  // set '1'
          missed <<= 1;
          missed |= 1;
          idx++;            // account for missed bit in bit count
          missed <<= 1;
          missed |= 1;
          idx++;            // account for missed bit in bit count
          break;

        case 6:         // two missed bits, one bit '0'
          lastbit = 0;
          token <<= 1; // missed bit
          token <<= 1; // missed bit
          token <<= 1; // slot for new (null) bit
          // nothing to set for '0'
          missed <<= 1;
          missed |= 1;
          idx++;            // account for missed bit in bit count
          missed <<= 1;
          missed |= 1;
          idx++;            // account for missed bit in bit count
          break;

          // anything else would be an error which we ignore
      }


      if ( idx == 6 )
      {
        // we have captured all 4 error correction bits
        // note: ECC:  idx=3,4,5,6
        if ( missed )
        {
          // missed bit(s) in ECC nibble
          // it does not make sense to try a correction of the data byte
          ECC = 0;
        }
        else
        {
          // save for possible later correction of the data byte
          ECC = token;
        }
      }
      else if ( idx == 14 )
      {
        // we have captured all 8 data bits
        // note: data: idx=7,8,9,10,11,12,13,14

        if ( missed > 0 )
        {
          // there are more than three missed bit(s) in data byte
          // error message shows missed bits as a binary mask
          char s[8];
          appendToOutput ( "{M=" );
          itoa( missed, s, 2 );
          appendToOutput ( s );
          appendToOutput ( "}" );
        }

        //byte checkECC = calcECBits ( token );

        // correction of missed bits
        if ( ECC != 0 && missed > 0 && missed < 3 )
        {
          // ECC nibble is o.k. and we have one or two missed bits

          //static const byte H[] = { 0x78, 0xE6, 0xD5, 0x8B };
          static const byte H[] = { 0b01111000,
                                    0b11100110,
                                    0b11010101,
                                    0b10001011 };

          while ( missed != 0x00 )
          {
            for ( byte i=0 ; i<4 ; i++ )
            {
              // handle the four ECC bits from left to right
              byte mask = H[i];
              byte x = missed & mask;

              if ( parity( x ) == 1 )
              {
                // this mask has exactly one bit in common with the
                // missed bit mask
                if ( parity ( token & mask ) != ((ECC>>(3-i)) & 0x01) )
                {
                  // set bit
                  token |= x;
                }
                // else
                // { bit stays empty }

                // nullify missed bit
                missed &= ~x;
                // continue with next missed bit (if any)
                break;
              }
            }
          }
        } // correction of missed bits


        //-------------------
        if ( mode == MODE_ANALYZER )
        {
          // output the half bit time for information
          char s[8];
          appendToOutput ( " = '" );
          s[0] = token > 31 ? (token < 128 ? token : '.') : '.';
          s[1] = '\0';
          appendToOutput ( s );
          appendToOutput ( "' = 0x" );
          if ( token < 16 ) appendToOutput ( "0" );
          itoa(token, s, 16 );
          appendToOutput ( s );
          appendToOutput ( ", 1/2-bit = " );
          itoa(halfBitTicks, s, 10 );
          appendToOutput ( s );
          appendToOutput ( "\n" );
        }
        //-------------------

        if ( mode == MODE_INTERPRETER )
        {
          databuffer[idxWrite] = token;
          idxWrite = (idxWrite+1) % RING;
        }

        // the last burst is over
        // reset index for storing timing of next byte
        // will be incremented to 0 below
        idx = -1;
      } // idx == 14
    } // idx > 2
  } // idx > 0

  // burst is over, prepare for next bit
  idx++;

  // prepare for next burst
  pulse = 0;
}

#ifdef PIN_OUTPUT
// set output pin to low to signal end of activity
bitClear(signalPORT, signalPin);
#endif
}
/*****************************************************************************/
/*
* This interrupt function is called when the input pin with the IR sensor
* drops (negative logic).
* This indicates the start of a cycle of an IR-burst.
*/
#if INT_NO==INT1
ISR(INT1_vect)
#endif
#if INT_NO==INT6
ISR(INT6_vect)
#endif
{
// check for the first pulse and increment the pulse count
if ( pulse++ == 0 )
{
  // this is the first pulse of a burst

  // save time since start of last burst
  dt = TCNT0;

  // restart the timer to measure the time to the next burst
  TCNT0 = 0;

  // enable output compare A interrupt
  TIMSK0 = (1<<OCIE0A);

  // Now a burst is in progress. The index idx will be increased after
  // the burst is over in the TIMER0_COMPA_vect service routine.
}
}
/******************************************************************************/
```

Figure 20: Source file RedEye.cpp

```
************************************************************************
 * A decoder for the HP82240 infrared printer protocol.
 ***********************************************************************
 *
 * Copyright (C) 2014 Martin Hepperle.  All rights reserved.
 *
 * This library is free software; you can redistribute it and/or
 * modify it under the terms of the GNU Lesser General Public
 * License as published by the Free Software Foundation; either
 * version 2.1 of the License, or (at your option) any later version.
 *
 ***********************************************************************
 */
#include <Arduino.h>

/* Adapt pin and port as needed
 *
 * Here we use interrupt 1 or interrupt 6
 *
 * Example: interrupt 1:
 * In the ATmega32U4 chip this is connected to pin PD1 (pin 1 of port D).
 * On the Arduino Leonardo board this is connected to digital Pin D2.
 * So we connect the wire to Pin 2, but in the code we have to use
 * the ATmega parameters for "input pins, port D" (PIND) and pin 1 (PD1).
 *
 * If we want to use SDA and SCL on pins D2, D3 so that we cannot use INT1.
 * Then we can use INT6 on pin D7
 */
#define INT_NO    INT1
//#define INT_NO    INT6

/****************************************************/
// global functions
extern void setupRedEye();
extern boolean isDataAvailable();
extern byte getByte();
extern boolean isInterpreter();
/****************************************************/
```
Figure 21: Source file RedEye.h



```
015 END
012 LBL B
013 2
014
```

Figure 22: Experimental setup with redirection of printer output to a nonscrolling LCD display (first tests still using a remote control receiver TSOP1338).

Appendix A: Variable Timing

The HP Calculators with accurate timing (normally using a crystal clock) usually compose each burst of a constant number of cycles. Other HP calculators with less accurate or variable clocks vary the cycle count during the transmission of a byte to obtain a valid average timing. The HP specification requests valid cycle counts to be within 6 and 8.

The following strings show the number pulses per burst in parentheses as measured by my receiver unit. The numbers between these bursts represent the gap time in pseudo time units. The example data frame is for a space character (CHR(32)t

All HP calculators with accurate timing like the HP 38G, the HP 48G and the HP 50g all send 8 cycles per burst:

```
(8)26(8)25(8)26(8)51(8)77(8)51(8)51(8)51(8)26(8)76(8)51(8)52(8)51(8)51(8)
```

Another example is the WP 34s equipped with a with crystal, It sends exactly 7 cycles per burst:

```
(7)27(7)27(7)26(7)54(7)80(7)53(7)54(7)53(7)27(7)80(7)53(7)54(7)53(7)54(7)
```

On the other hand the HP 17B varies the pulses for each burst between 6 and 8 cycles:

```
(8)26(8)27(8)27(7)53(7)80(7)54(6)53(6)54(6)26(6)78(7)54(6)53(6)54(6)53(6)
```

Similarly, the HP 28S sends 6 to 8 pulses per burst:

```
(8)27(7)26(7)27(6)51(7)81(6)53(6)51(7)53(7)27(6)80(6)51(7)54(6)53(6)53(6)
```

Appendix B: Why a Remote Control Receiver Chip won't work

- One complete bit takes 854.5 µs
- The modulation frequency of the signal is f = 32768 Hz so that each pulse (at 50% duty cycle) has a duration of t_{pulse} = 1/32768 / 2 *1E6 = 15.26 µs.
- For each burst the HP docs specify 6 to 8 pulses = 183 to 244 µs as a valid range. The calculators indeed exploit this range.
- A logic one starts immediately with a burst of e.g. 8 pulses = 8 / 32768 *1E6 = 244 µs followed by a pause of 854.5 - 244 = 610.5 µs which corresponds to 610.5 / 1E6 * 32768 = 20 cycles.
- A logic zero starts with a half bit pause of 854.5/2 * 1E6 = 427.25 µs followed by e.g. 8 pulses = 8 / 32768 * 1E6 = 244 µs, followed by a pause of 427.25 – 244 µs = 183.25 µs. If the following bit is a logic one, the pause between end of zero and start of one corresponds to 183.25 / 1E6 * 32768 = 6 cycles.
- The gap between the bursts of the start half-bits is also 427.25 – 244 = 183.25 µs = 6 cycles.

To summarize: the duration of a burst is 6-8 cycles and the shortest gap between bursts is 6 cycles.

The datasheet of available integrating receivers of the TSOP or VS family show that this is too short for these receivers.

Example: TSOP 18XX

The burst length should be 6+ pulses, which fits into the HP specs.

TSOP 18XX needs a gap of at least 9 cycles to recover after each burst

$t_{gap} > 9 / 32768 * 1E6 = 274.7$ µs

This is longer than the time between the start-halfbits, so that a TSOP 18XX may smear these bits together and that's exactly what one can see on an oscilloscope. Therefore this receiver will not work reliably.

Example: TSOP 11XX, 21XX, 23XX, 41XX, 43XX, 25XX, 45XX

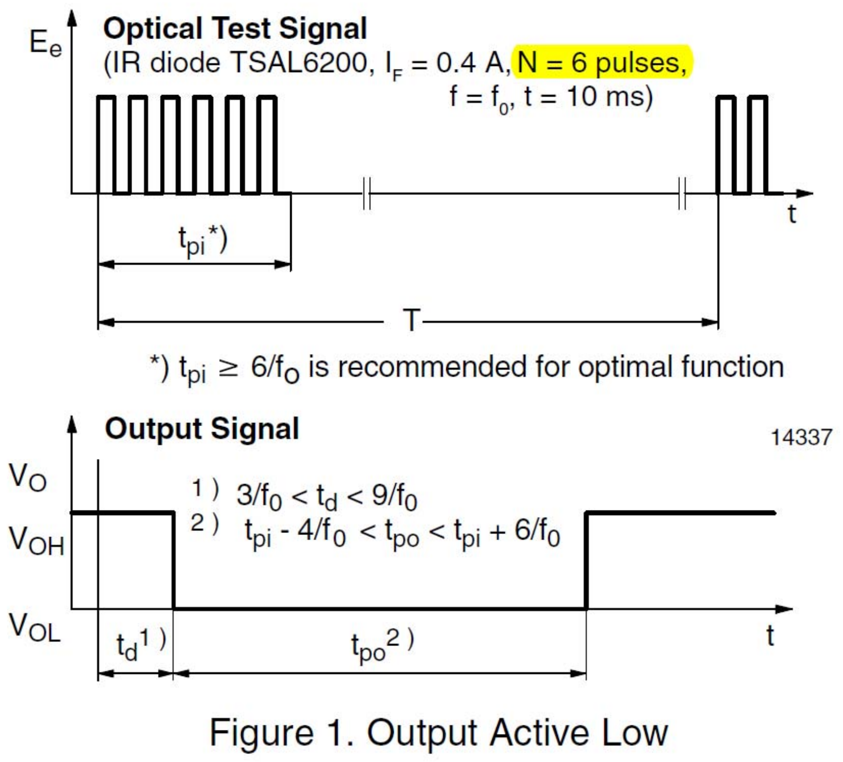
The burst length should be 6+ pulses, which fits into the HP specs.

A burst time of at least 6/f = 6/32768 * 1E6 = 183 µs is recommended. This is at the lower limit but within the HP specs.

However, the integrated output pulse of the TSOP 11XX has a length t_{out} within the range

$t_{burst} - 4/f < t_{out} < t_{burst} + 6/f0$

which means that it may be 4 cycles shorter or 6 cycles longer than the actual burst. If the output is at the upper limit of this range, it will close the gap between two bursts. Thus these receivers are also not useable.



Optical Test Signal
(IR diode TSAL6200, I_F = 0.4 A, N = 6 pulses, $f = f_0$, t = 10 ms)
E_e
t_{pi}*)
T
t
*) $t_{pi} \geq 6/f_O$ is recommended for optimal function
Output Signal
14337
V_O
V_{OH}
V_{OL}
1) $3/f_O < t_d < 9/f_O$
2) $t_{pi} - 4/f_O < t_{po} < t_{pi} + 6/f_O$
t_d1)
t_{po}2)
t
Figure 1. Output Active Low

Figure 23: Timing diagram taken from a TSOP data sheet.

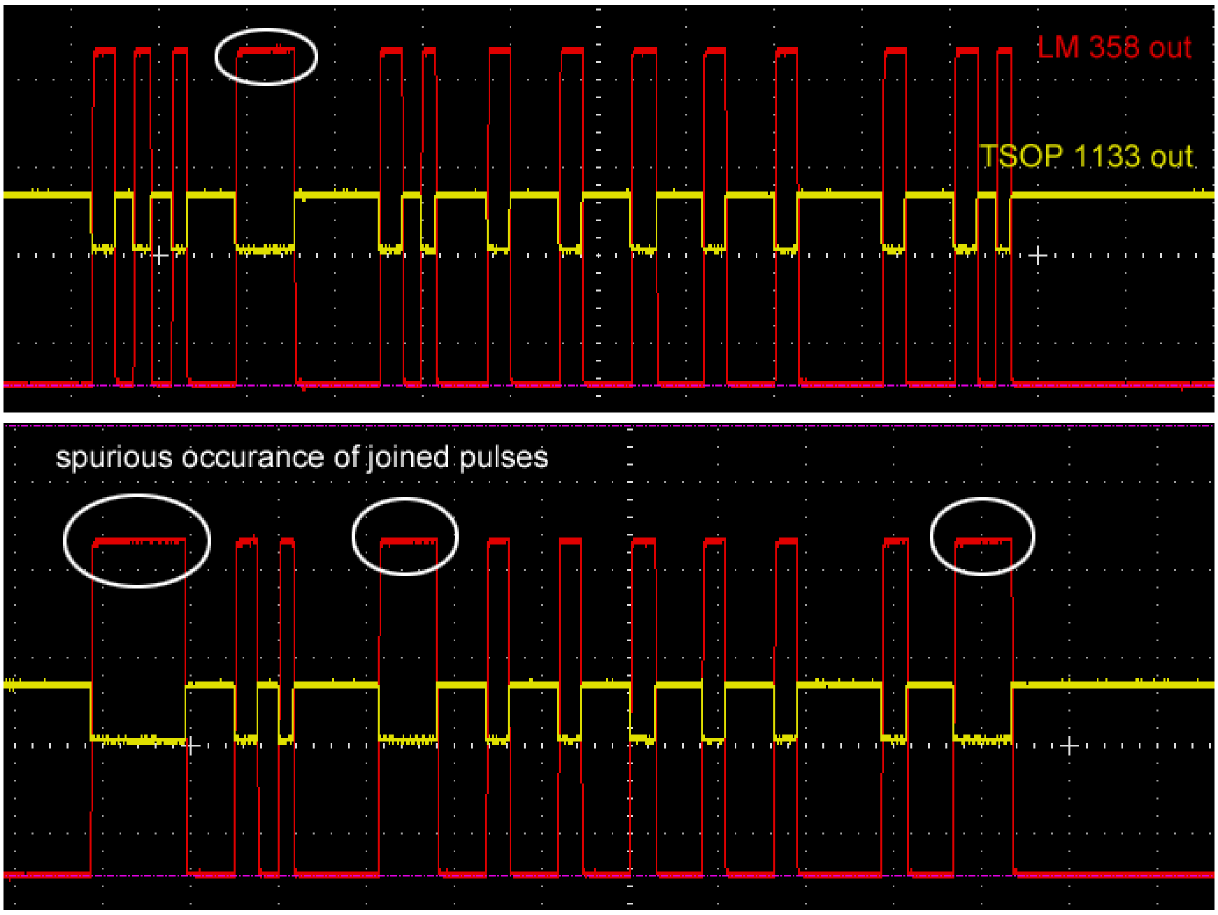


Figure 24: Output of a TSOP 1133 (also amplified by a LM 358 op amp) showing insufficient time resolution leading to occasional joining of pulses. The two output traces have been produced by sending the same data byte twice. They should be identical but are not.

The SIR Protocol

Later HP calculators and palmtop computers introduced a second infra-red protocol. The “serial over infra-red” (SIR) protocol is a serial communications protocol. It maps the wire based serial protocol used for RS232 links to the infra-red connection. Later this protocol was further developed into the IrDA standard and widely used in palmtops, handhelds, printers and mobile phones

Using the same hardware of Arduino and the HP-4103A transceiver it is possible to implement this protocol.

Due to the risk of the receiving reflections of its own transmission SIR as well as IrDA are “half duplex”, i.e. a device can either transmit or receive, but can't do both at the same time. The initial SIR protocol as introduced with the HP 48 used a transmission speed of 2400 baud with a tolerance of ±2.5%. IrDA requires tighter tolerances, typically in the order of less than ±1%.

The SIR signal for one data byte consists of one start bit, the 8 data bits and one or two stop bits. Thus at least 1+8+1=10 signal bits are needed to transmit one data byte. As in the wire bound serial protocol the 8 data bits may be replaced by 7 data bits and a parity bit, reducing the number of characters to the classical 7-bit ASCII range from 0 to 127.

A logical zero is represented by a constant (non-modulated) pulse of IR light having a duration of 3/16 of the bit time and at least 1.6 us (which corresponds to a maximum speed of 115200 baud).

The start bit is a logical zero '0', the stop bits are logical ones '1'. Therefore stop bits are not visible at the end of a byte but act as a pause.

The SIR Timing

The transmission speed is determined by the “baud” rate. The baud rate defines the number of bits transmitted per time. One baud means one bit per second. The duration of one bit is therefore given by

$$\Delta t_{bit} = \frac{1}{baud} \;.$$

Implementation

To allow for the transfer of international characters we use 8 data bits and terminate the sequence by two stop bits. The baud rate may be adjusted and is stored in the EEPROM of the AVR controller. For the internal calculations and in order to minimize storage space in the EEPROM the baud rate is specified as a reduced value of

$$baud_{300} = \frac{baud}{300}$$

The rounded bit time in µs can then be calculated by the integer expression

$$\Delta t_{bit,\,\mu s} = \frac{10000 + \frac{3 \cdot baud_{300}}{2}}{3 \cdot baud_{300}}$$

The specification calls for a pulse duration of 3/16 of the bit time (or at least 1.6 µs). The rounded duration of the pulse in µs is therefore determined by the integer expression

$$\Delta t_{pulse,\ \mu s} = \frac{3 \cdot \Delta t_{bit,\ \mu s} + 8}{16}$$

Finally the remaining pause time after a pulse to fill the bit time is given by the difference

$$\Delta t_{pause,\ \mu s} = \Delta t_{bit,\ \mu s} - \Delta t_{pulse,\ \mu s}$$

As we use the available delay function with uses units of microseconds some rounding errors are present. These are listed in table 2 below. Tests showed that these are acceptable by the existing receiver hardware, otherwise a variable bit timing scheme would have to be implemented.

		accurate	rounded	rounding	rounded	rounded
$baud$	$\frac{baud}{300}$	$\Delta t_{bit,\ \mu s}$	$\Delta t_{bit,\ \mu s}$	error [%]	$\Delta t_{pulse,\ \mu s}$	$\Delta t_{pause,\ \mu s}$
300	1	3333.33	3333	-0.01%	625	2708
1200	4	833.33	833	-0.04%	156	677
2400	8	416.67	417	0.08%	78	339
4800	16	208.33	208	-0.16%	39	169
9600	32	104.17	104	-0.16%	20	84
19200	64	52.08	52	-0.16%	10	42
38400	128	26.04	26	-0.16%	5	21
57600	192	17.36	17	-2.08%	3	14
115200	384	8.68	9	3.68%	2	7

Table 2: Timing parameters for various baud rates. Note that the lowest and highest baud rates have not been implemented.

Notes on specific devices

HP 100/200LX

The MSDOS command SERCTL can be used to control the serial and infra-red ports.

To power up the infrared port with the default setting of 2400 baud:

```
SERCTL /I
```

To power off the current (infrared) port to save power:

```
SERCTL /O
```