

## Inductive Coupled Link (Updated October 2004)

### 1. Brief Description

The ICL (Inductive Coupled Link, sometimes referred to as SKCM, Sail Keyed Carrier Module) interface allows non-contact serial communication with an instrument via the pulsed ac magnetic field of a simple coil of wire. It was designed to be used by an ROV or manned submersible to talk or listen to an instrument deployed on the bottom without making a direct electrical contact. It can support half duplex bidirectional communication at any baud rate up to 9600. It uses only about a microwatt while waiting for a signal. It works in air on deck as well as in water.

### 2. Block Diagram

See Figure 1. A complete system uses two or more loops with associated electrical interfaces (the ICL modules). Two types of these modules exist, one for interfacing to a computer via true RS-232 levels (ICL-RS232) and one optimized for building into an instrument using a 5v CMOS interface to save power (SKCM).

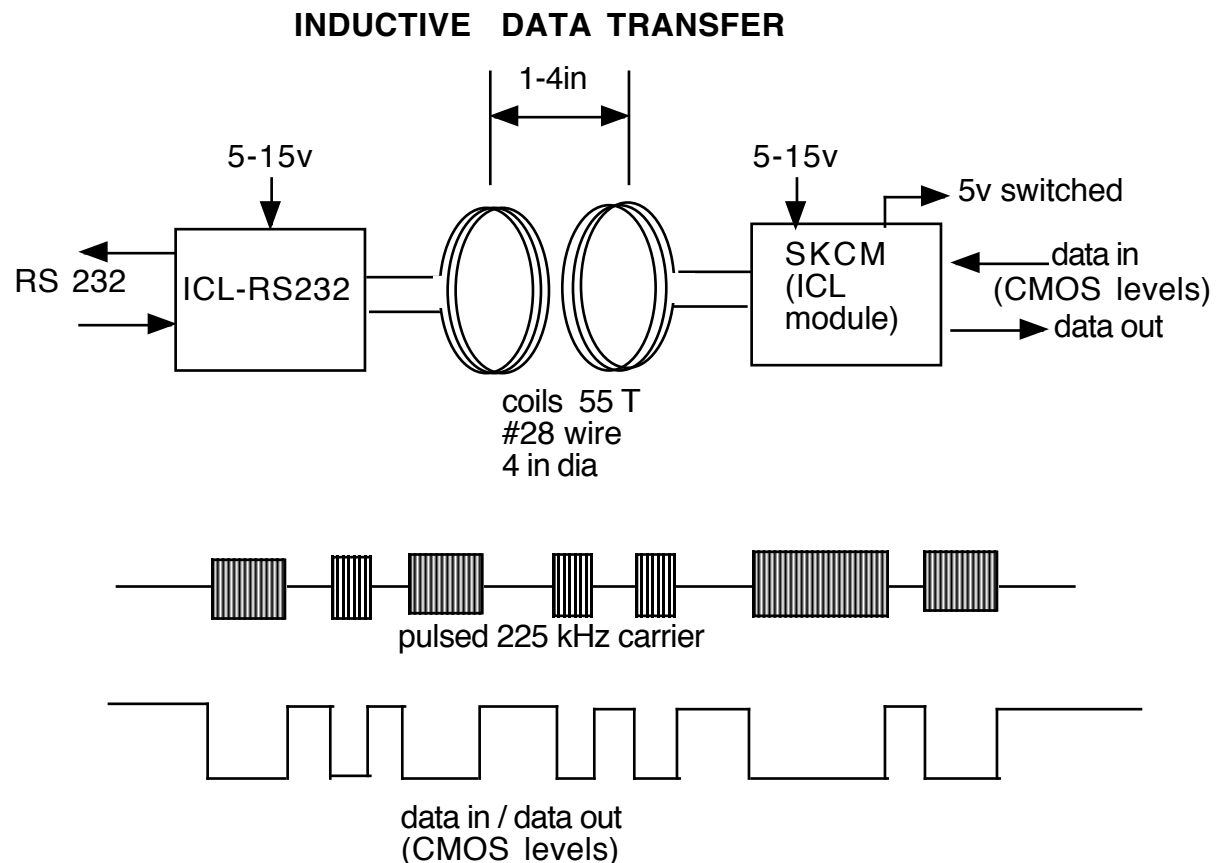


figure 1 - Block Diagram

The ICL modules (SKCM) can operate on any supply between 8 and 15 volts. The allowable separation between the loops will be somewhat over 4 inches at 12 volts but reduces for lower voltages as the transmit power reduces. The modules can function correctly with a 5v regulated supply but will need more careful loop alignment for reliable communication. The

transmit frequency varies a bit as the supply voltage changes. You have to make sure the modules are functioning correctly over the supply voltage range they will see in use.

### **3. What we use the ICL For**

#### **3.1. For small submersible or ROV tools**

We use the ICL for the temperature sensor strapped on a water sample bottle. When the sub or ROV picks up the bottle it brings the loops together as part of the “grip”. The query data command from the ICL on the sub wakes up the circuitry of the temperature sensor and it does its thing. When the bottle is put down, the sensor shuts off after a minute of inattention. Considering the duty cycle, the 9v battery last over a year.

#### **3.2. As a terminal interface to an instrument**

Some instruments don't have to turn off to save power, but need an easily connected and disconnected terminal interface. Of course the ICL works in air and on the bench as well as it does underwater, so we often use it as the main communication interface. The inductive loop provides total electrical isolation which is often valuable, e.g. a pH meter.

#### **3.3. Monitoring an instrument's performance**

Sometimes you don't want to risk messing up an instrument, but you want to eavesdrop on what it is doing. In this case we just leave off the SDO line from the ICL module and just have the instrument broadcast its activity via SDI line into the interface and thus on to the loop. We observe whenever we're there.

### **4. Loop Configuration**

One loop is built into the deployed instrument and an identical one is carried by the ROV or sub. We have used loops from 1 to 4 inches in diameter. The magnetic field generated by one loop must couple into the other. They therefore need to be within about 1/2 of a loop diameter of each other for adequate communication. The bigger the loop, the larger this becomes. Maximum lateral offset is about 1/4 diameter. The number of turns in each loop is adjusted so the loop with the capacitance of its cable resonates at about 225kHz. The appendix has a discussion of loop tuning.

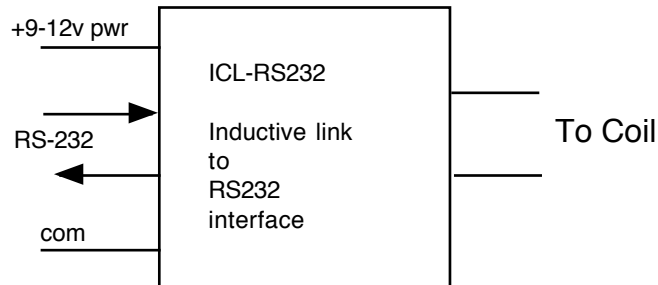
### **5. Communication Method**

Data is passed by keying pulses of a 225 kHz carrier from one loop to the other. Only this single frequency is used for simplicity. To minimize drive power the coils are adjusted to be self resonant in sea water at this frequency. With this single frequency, only half duplex data is possible. (Only one coil can transmit at a time.) When a coil transmits, its receiving circuitry echos back the data being sent. The carrier is keyed on by the start bit of a serial character, then follows the state of the subsequent bits. The stop bit(s) turn the carrier off. Unlike RS485 you don't have to enable drive before you start sending data (and disable to allow receive). The data itself does this.

In general, larger coils are easier to use. The 4 inch diameter coil is made of 55 turns of #28 magnet wire and may be potted or simply wrapped in putty and vinyl tape. (The flexible version is more forgiving of alignment blundering which may be an advantage.) In some applications we have used 1.5" dia coils, but alignment is critical.

### **6. The RS-232 Interfaced ICL**

This is a small circuit card about 1 x 3 inches which may be operated at ambient pressure (6000 db) in oil or inside a pressure housing. It typically has a four wire interface to the sub or ROV. These are ground, +12 volts, RS-232 data in and RS-232 data out. These are true RS-232 levels and connect directly to a serial port on some computer. Two additional wires go to the coil which may be up to about 10 feet from the circuit. (Longer cables are possible, but require readjusting the coil for proper resonance at 225 kHz with the added capacity of the cable by removing turns). The circuit takes several milliamperes (for the Maxim RS-232 interface chip) when listening, and several 10's of ma when transmitting. It will echo back all data sent to it whether or not its coil is near an instrument.

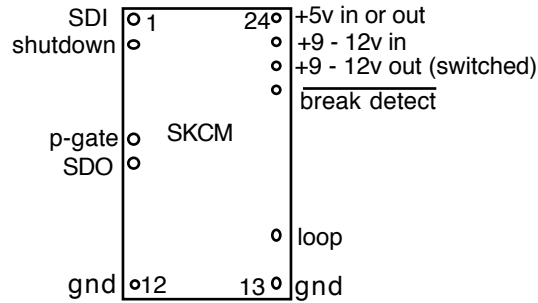


This circuit may be built into an instrument, but usually it is used only on the sub or ROV where standby power isn't a concern. In an instrument, it's usually not necessary to convert to the RS-232 levels and its simpler to use straight 5v cmos levels as described below.

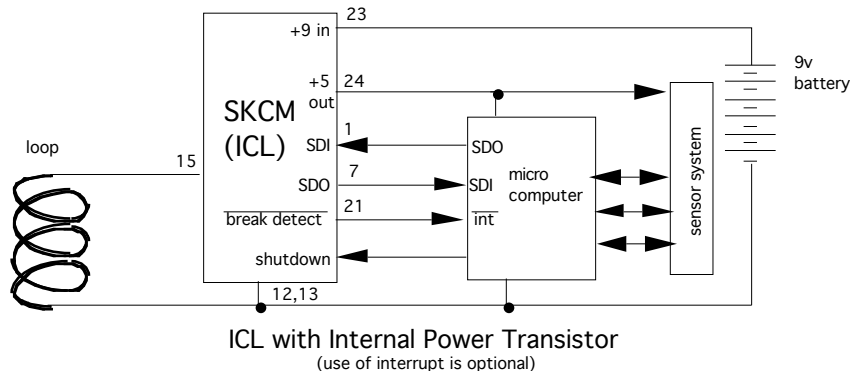
## 7. Instrument Interface ICL (the SKCM)

There are several options for this component. It is built as a 24 pin module about 0.7" x 1.3" x 0.4". It can be built up in two different versions (depending on which components are soldered on the card) and it is important to understand the trade-offs involved.

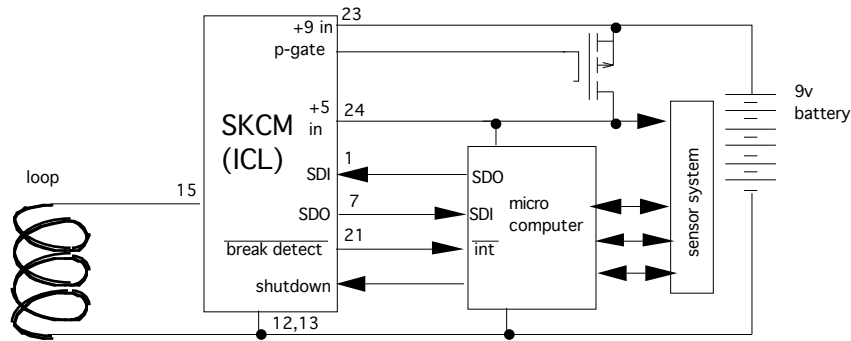
Since the deployed instrument is usually battery powered, every effort has been made to reduce the power drain of the ICL interface. Most applications include long periods when the instrument is not communicating, therefore the interface is designed to be able to listen for a "wake up call" on minimal power. With 12 volts driving the transmitting coil and good alignment, the open circuit voltage on the adjacent receiving coil is over 2vpp. This is enough to turn on a base-emitter junction of a transistor in the receiver which can set a cmos flip flop to "on". Until a signal is received, the circuitry is completely static and uses well below a microwatt. The output of this flip flop goes typically to the gate of a p-channel power FET which turns on power to the rest of the circuitry. Without further data transfers, the power drain is all in a 5v regulator which requires about 50 micro amperes. The user's system should eventually turn off the flip-flop by a pulse to its "reset" input.



There are currently two configurations. In both, the interface requires 9-15v and only draws power when active. (The cmos flip-flop is powered by this voltage.) In the simpler version, both the p-channel power switching FET and the 5v regulator are included with the interface. The serial data signals (SDI and SDO) are 5v cmos levels and idle at 5v. (This allows direct connection to a UART.) The interface can supply 5v to the instrument limited by the heat sinking on the LT1121-5 regulator. The circuit draws a few ma when receiving data, a few 10's of ma when transmitting and about 50 microamps when on, but waiting for data. A positive pulse of one volt or more on the "kill" input shuts down the regulator until the signal from the coil turns it on again. When the flip-flop is in the off state, the 5v supply drops and brings down the SDO (data out) line. (This may confuse some UARTS which may report continuous framing errors.) The SDI (data in) line is not clamped to the 5v and may remain either high or low.



In the more invasive version (which is simpler in many systems but requires more effort at integration) the p-channel power switch and 5v regulator are removed. The flip-flop output is still available to tell the instrument that the interface has been turned on and may be used to turn on the gate of an external p-channel FET with heat sinking for high power needs. The 5v for the level shifters must be supplied by the instrument. The SDI and SDO signals remain the same. All the circuitry is now static and draws essentially no power unless data is being sent or received. The state of the flip-flop has no effect on the rest of the circuit. This would be the preferred configuration for an instrument that blurts out occasional data frames whether someone is there or not.



ICL with External Power Transistor  
(use of interrupt is optional)

## 8. Why Did We Do It This Way?

We looked at many options and picked the simplest that would do the job. But others would undoubtedly do it differently. For all you who are curious here's some of our thinking...

### 8.1 Why Is It Not Acoustic?

Echos from nearby rocks and ROV parts make decoding of acoustic signals difficult. One can either have very low data rates (waiting out the echos) or use a lot of high powered hardware (big DSP modules) to cancel the echos. Twenty thousand dollars buys you about 1200 baud and several km range. Several hundred dollars buys you about 10 baud and 10 meters.

### 8.2 How About Optical?

Mud is the problem here. Pulsed LEDs would be great for many applications and relax the alignment requirements, but are stopped by stirred up sediment. Maybe you will always work in clear water, but we aimed for a more universal solution. For very high data rates, fiber optic links are excellent, but require precise alignment.

### 8.3 Bottom Line

The ICL is a compromise between conflicting requirements. If you can live with 9600 baud, can get one inch alignment, and need zero standby power, use the ICL. If you need higher baud rates, can get good alignment tools, and can afford a bit of power, use a fiber optic link. If mud is not a problem, but alignment is awkward, use a blue LED. If you have lots of money, love C programming, and have a surplus of DSP post docs, use an acoustic link. If you need only very low data rates, a company in Nova Scotia once advertized a really cute pulse spacing system for a good price.

## 9. Where Do I Get an ICL?

At this point the market for ICL modules is just too small for us to be able to sucker any company into making them. But they are relatively easy to make and we're set up to do it. Get in contact with our group and we'll figure how to get some to you.

The bad news is that your group will have to understand what the ICL is and design it into your own equipment. We've tried to make it as easy as possible and can give you advice.

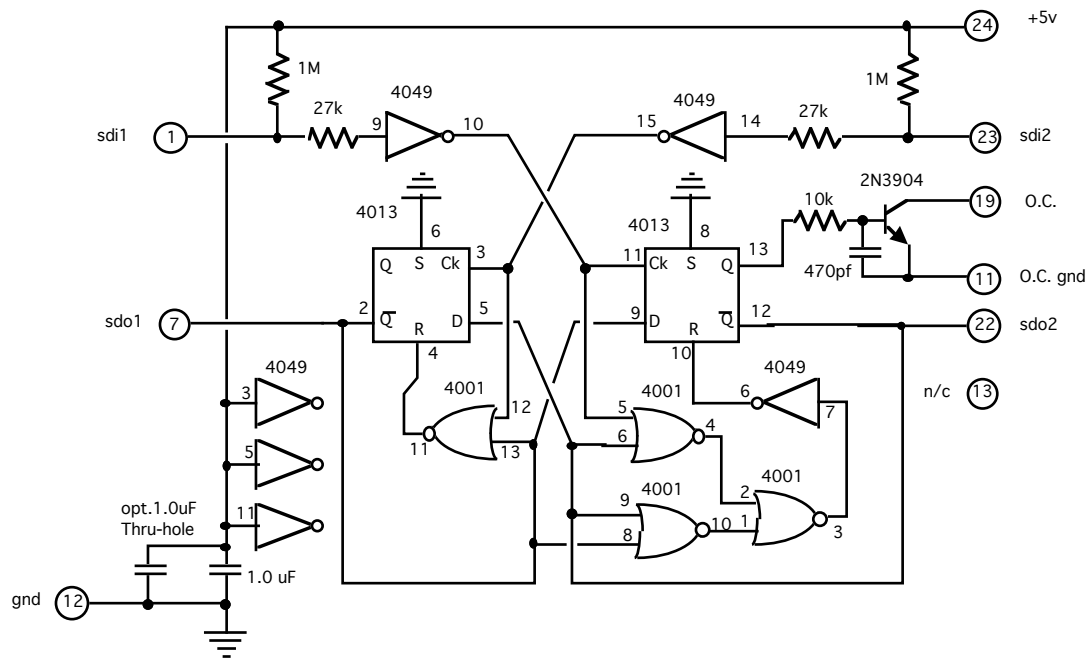
## 10. Historical Note

The ICL is actually a LF radio link using near field coupling between the antennas. The signaling method is CW. This permits using a wideband passive detector which keeps it small

and simple. Of course much larger ranges are possible, but would require either excessive drive levels or amplification at the receiver. The latter would require continuous power drain of perhaps a few milliwatts.

### 11. But My Computer Really Needs Full Duplex!

Some really nice low powered computers are designed by the clueless who don't think enough about the applications. (Check our "Persistors" by Peripheral Devices). They're designed to talk to a terminal over a full duplex link and if their own output is fed back to them, they lose their minds. You can still use an ICL (or any other half duplex link) if you "plug its ears whenever it talks". Here is a simple circuit to do this.



This is available as a 24 pin dip module with the pinout shown. It is wired between the computer and the ICL. It doesn't really give your computer full duplex, but it suppresses echos from either direction.

### Appendix - Coil Construction and Tuning

#### The Coil

We use two kinds of coils, flexible and potted. Both start the same way with about 55 turns of #28 enamel magnet wire wound in a compact bundle on a 4" form. Slip it off the form and wrap it with an open serving (spiral wrap) of dental floss to keep it together. About one turn to the half inch around the circumference is about right. Don't cover the wire too much. Strip and solder the ends to the cable you will use. At this point the combination should be tuned.

#### Tuning

Connect the coil with attached cable to a sine wave oscillator with a 600 ohm output impedance. (If it has a 50 ohm output just add some resistance.) With an oscilloscope measure the amplitude of the signal on the coil. Now tune the oscillator frequency to find the peak amplitude which should be above 225 kHz. Finally add a small capacitor at the junction of the

coil and cable to bring the peak down to 225 kHz. With the 600 ohm source the Q will be rather low, but the resonance should show up clearly. This tuning isn't too critical and +/-15kHz is allowable, but the better it is tuned the greater the separation you'll get. The capacitor is typically several hundred pico farads. Make sure it is a type which will withstand hydrostatic pressure.

### Potting

The coil is now ready for potting. We have done this by turning a shallow cup out of one inch thick PVC plate to accommodate the coil. The inside cavity is around 1/2 inch deep and we leave a boss in the center with a 1/4 inch through hole for eventual mounting to your gear. A Woodhead fitting for the cable is screwed into a pipe tapped hole in the base. Tune the coil in place since the cable needs to be put through the woodhead fitting first. Before you pot the coil make sure the cable is "water blocked" so the potting compound won't wick in the end and make the cable stiff. A bit of 5 minute epoxy works well for this part. Use a potting compound that is very low viscosity and vacuum backfill to get it between the turns of the magnet wire. The surface can be turned smooth if you wish after the potting has cured.

### Flexible Waterproofing

After tuning the coil-cable combination, wrap it with a thin layer of electricians putty (known in the trade as "monkey dung"). This will eventually flow in between all the turns of the magnet wire when the coil sees pressure. Obviously you don't need much but it will eventually have to get to all the voids. Finally wrap the coil with electrical tape (Scotch #33). Make the first layer complete and not too tight as it will try to push the putty out ahead of the wrap. Try hard to avoid all wrinkles in the tape. For the tight spot around the capacitor it may help to cut the tape to half width to make it easier. Additional putty around the capacitor is usually necessary. Finish with several additional layers of vinyl tape with a close spiral wrap. The coil will remain somewhat flexible and is very forgiving in the hands of ROV manipulators.