Lawrence Livermore National Laboratory

January 1, 1996

Dear Government Requester:

Thank you for your inquiry regarding the Micropower Impulse Radar (MIR). To effectively address your inquiries, we developed this information packet about our laboratory (U.S. Government-owned, University of California-operated), the MIR technologies, and how you can work with us.

We are not an equipment manufacturer; our goals are (1) to continue to develop variations on the MIR for our Laboratory and government missions, (2) to license the MIR to qualified companies who can develop products, and (3) to seek out new ideas for future directions of this exciting technology.

One common question is if prototypes are available for government applications at no cost. Unfortunately, while the MIR is an inexpensive technology, our in-house prototypes are not yet mass produced, and full cost recovery is mandated by DOE. In the near future, there will be several licensees who can provide low-cost samples, but probably not until 1997. Other ways of partnering with us on MIR are described in "Micropower Impulse Radar (MIR) Government Partnership Information." To help you most efficiently, we ask that you do the following:

> (1) Read the MIR Technology Overview and the Government Partnership Information and the LLNL Disclaimer. The MIR information package is also available on our MIR home page at http://www-lasers.llnl.gov/lasers/idp/mir/files/MIR_govt_info.html.
>
> (2) If you have technical questions regarding the MIR and its use, please mail, fax or e-mail those questions to the address below, and one of our engineers will reply.
>
> (3) If you would like to work with us on an MIR development activity, please state your interest in a letter or FAX (on official letterhead) to the address below. We will respond as rapidly as possible.

Again, thank you for your interest.

Stephen Azevedo
MIR Project Leader

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General Information about Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory (LLNL) is a world-renowned research and development center operated by the University of California for the U. S. Department of Energy. Its mission is to serve as a national resource in applied science and engineering to meet America's needs.

LLNL was established in 1952 by E. O. Lawrence, Nobel laureate and a distinguished pioneer in managing large-scale, innovative research projects that combined the expertise of many disciplines. Historically, the LLNL missions have been in the areas of national security, energy, environmental, geophysical and biomedical research.

Today Livermore is one of the largest research institutions in the world. Its prized staff of some 7,000 employees includes more than 2,500 scientists and engineers and 2,500 crafts people and technicians. With a replacement value in excess of about $5 billion, the Laboratory's research complex includes world-class lasers, super-computers, accelerators, and literally hundreds of laboratories and test facilities.

Laboratory leaders know that the future security of the nation will depend as much on economic strength as on national defense. Livermore is in partnership with American industry to bring the Laboratory's technological breakthroughs to the market place. The goal of these partnerships is to spur domestic economic growth and the nation's economic competitiveness.

Lawrence Livermore National Laboratory's major strengths include:

- Nuclear Science and Technology
- High-Performance Computation
- High-Performance Lasers
- Advanced Sensors and Instrumentation
- Energy Science and Technology
- Space Technology
- Plasma and Accelerator Physics and Technology
- Biology and Biotechnology
- Environmental Science and Technology
- Earth Science
- Atmospheric Science
- Materials, Processing and Fabrication
- Large-Scale Science Systems

Micropower Impulse Radar (MIR)

Technology Overview

The MIR technology was developed at LLNL in 1993 as an evolution of government-sponsored work on radar combined with technology developed for our R&D 100 award-winning 33-gigasample per second transient digitizer. The digitizer was developed to record subnanosecond events generated by LLNL's 100-trillion-watt Nova laser. Shortly after the transient digitizer development, it became clear to Tom McEwan (inventor of MIR) that the same low-cost pulser technology could be used as a radar source and time-gated receiver. What followed was an explosion of ideas to employ the micropower impulse radar technology in a variety of innovative ways.

We intend to facilitate the most rapid transition of the MIR from laboratory use to general use. We've chosen two parallel paths of developing our R&D effort: (1) Working with government sponsors in the DOE or elsewhere to develop programs that utilize the technology. This approach is most appropriate for high-performance or low-volume applications, or where national security information is involved. (2) Licensing of private industrial partners who will establish large-scale manufacture in the U.S. Thus far, only a handful of licenses have been negotiated, but more are expected soon.

The patented inventions related to this technology to-date are shown below. These inventions are available for licensing to qualified private-sector partners. All inventions are available to U.S. government installations on a royalty-free basis, however those installations are obligated to protect the intellectual property from unauthorized use.

1. MIR motion sensor, or "stealth" concealable burglar alarm.

The MIR motion sensor is a revolutionary security sensor that can be fully-concealed behind walls or inside drawers while detecting intruders at ranges of up to 20 ft or more. In addition to being able to "see" through walls, it features a sharply bounded detection range that is easily adjusted for any situation. The sensor can be designed to operate continuously for several years using ordinary alkaline batteries, simplifying installation and eliminating dependence on AC main power.

The operating principle of the MIR sensor is based on a novel form of radar known as ultrawideband (UWB) impulse radar. A very short electromagnetic impulse is propagated from the sensor, and only the echoes that reflect from a defined range are detected. The echo acceptance range or range gate forms a thin, invisible detection shell that is projected about the sensor. When an intruder penetrates the shell, the reflected signal within the range gate is modulated and thereby detected. Only motion modulated signals are detected to eliminate triggering on stationary room "clutter." MIR can also project a set of shells to generate a filled volume of sensitivity. MIR does not respond to objects outside its range gate, and it does not falsely trigger on near objects such as insects.

The exact pulse emission and detection times are randomized for three reasons.

1. First, continuous wave (CW) interference, such as from radio and TV station harmonics, may cause beat frequencies with the received echoes that can trigger false alarms. The MIR receiver continuously averages about 10,000 samples of the echoes, and random samples of CW interference are effectively averaged to zero.
2. Second, random operation also means that multiple MIRs can be co-located without interfering with each other. Channel allocations are no longer needed, and a nearly unlimited number of sensors can be co-located even though they occupy the same wideband spectrum.
3. Third, randomizing also spreads the sensor's emission spectrum to the point that it resembles random thermal noise, making it difficult to distinguish from background noise, and thus, quite stealthy.

Application: The MIR motion sensor can be used for home intrusion detection. The MIR sensor can be mounted on a ceiling, perhaps disguised as a smoke alarm; its range gate or detection shell can be set to 6 ft to intercept intruders below while not extending down to the floor where pets may trigger it. Other concealment possibilities are: in a cookie jar, in a hollowed-out book on a shelf, behind a wall-painting near the front door, or in a shoe box in a closet. In a typical installation, the MIR would use a radio transmitter to alert a central alarm system.

With the freedom provided by battery operation and the ability to operate through barriers, MIR can be installed in seconds. Installation typically involves no more than setting the desired operating range and perhaps a radio transmitter code, and then hiding the unit.

The MIR sensor provides an unprecedented combination of features:

- Ability to "see" through walls, allowing concealment

- Sharply defined maximum operating range, reducing false alarms
- Several year battery life, simplifying installation
- Co-location of multiple units without interference, simplifying installation
- Randomized spread-spectrum emissions, making the sensor difficult to detect
- Very low-cost, using entirely off-the-shelf components
- Single silicon chip integration is possible, for low cost and size.

General Specifications

Antenna pattern (H-plane)	360 degrees with a dipole antenna, 160 degrees with a cavity-backed monopole and narrower with horn/reflector/lens
Center frequency	1.95 or 6.5GHz +/-10%
Emission bandwidth	500MHz @ 1.95GHz center
Average emission power	~1 µW (measured)
Duty cycle	<1%
PRF (average)	2 MHz +/- 20%
PRF coding	Gaussian noise, or low coherence swept FM, or pseudo-noise
Receiver noise floor	<1 µV rms
Receiver gate width	250 ps for 1.95 GHz system
Range delay	RC analog, pot/DAC controllable
Range delay jitter	<1 ps rms
Range delay stability	RC component limited over temperature (drift in range delay expands/shrinks shell)
Detection range	adjustable from 2 in. to >20 ft
Motion passband	0.3 to 10 Hz, Doppler-like signature
Analog output	~0.1-2V peak on motion sensing, hand motion at 6' gives ~300 mV peak
Receiver gain	70 dB
Power	5 V @ 8mA, normal power mode, 2.5V @ 20uA, long battery life version
Size	1.5-in. square SMT PCB with 1.5-in. long wire dipole elements
Semiconductors	74AC00 CMOS (1 ea), bipolar or CMOS op amps (2 ea, quads), Si-bipolar RF transistor @ >4 GHz ft (2 ea.), Schottky diodes, Cj (0) <1 pF (2 ea)

A recent phase-coding technique has been incorporated that introduces intermediate frequencies to the MIR receiver to make it unresponsive to radio frequency interference. By employing a statistical detector, the MIR receiver becomes desensitized in the presence of interference without ever triggering a false alarm.

2. Range gated field disturbance sensor

This proximity sensor adds a range gate to the common field disturbance sensor, or CW-Doppler radar motion sensor. Like the MIR sensor, it provides a sharply bounded detection range, is noise encoded, and can have a long battery life. Also like MIR, its sensitivity is relatively range independent. It is an FM chirped homodyne system that may have a cost advantage for proximity sensing systems at high microwave frequencies or at short ranges (<10'). Most specifications are similar to MIR.

3. MIR hidden object locator (studfinder)

The MIR hidden object locator, or impulse radar studfinder, combines the MIR motion sensor with a background subtract circuit that makes it position sensitive rather than motion sensitive--the device provides a steady indication when held over a hidden object or wall stud. It radiates a specially shaped pulse that eliminates the effect of first surface (wall) reflections and makes it responsive only to subsurface objects. Its output is an analog voltage proportional to reflection strength that can be used to drive a thermometer-like LED display. It cannot provide a direct image of an object (see rangefinder, below), and it is intended for short range operation (<12"). Its sensitivity pattern is essentially a constant radius from the housing back--it does not have a highly directional antenna. It relies on very near proximity sensing to limit ambiguities such as objects mounted on a far wall. The cost, complexity and power consumption are all comparable to the MIR motion sensor.

The studfinder operates well though wood, gypsum, plastics, oil, and ice. The sensitivity is such that a stud can be detected behind several inches of concrete with the unit held an inch off the surface of the concrete (~40 dB signal-to-noise ratio). It will not operate through metal or aluminum foil.

A current licensee has retained certain exclusive rights to use the studfinder patents in the hand-held tool field-of-use. Rights to the patents are available for other applications, such as for law enforcement and industrial sensing.

4A. Fluid level sensor (electronic dipstick Version 1.0)

The electronic dipstick is a fully solid-state sensor having high-resolution continuous readout of fluid level. As a novel, low-cost implementation of time domain reflectometry, or TDR, it employs a transmission line as the sensor. The transmission line can be a simple non-moving metal strip or dipstick-like wire with a length of several inches to dozens of feet. It is inserted into a fluid and a measurement is taken from the top of the line, or "stick" to the fluid surface.

The dipstick requires a volume of fluid to reflect from, and as such it is impervious to wetting, condensation, corrosion or grime on the sensor element. The electronics are based on low cost components that fit on a 1.5-in.-square SMT circuit board, and can be made substantially smaller when integrated onto a silicon chip. It is possible to implement an extreme micropower version that operates continuously for years on penlight batteries.

Applications include fluid and material level sensing in tanks, vats and silos. In the automotive field, every fluid in a car can be continuously measured and displayed for the driver, including gas, crankcase oil, radiator coolant, transmission fluid, brake fluid, and windshield cleaner. Industrial automation often requires accurate vat fill level measurements, often in severe environments such as with corrosive or explosive materials. Level sensing in acid tanks is easily accommodated by coating the stick with glass or plastic, or the sensor can be a microstrip mounted on an exterior wall. The dipstick can monitor flammable and explosive liquids since the energy contained in its subnanosecond pulses is far below ignition levels.

General Specifications

Range	scalable from several inches to >100'
Accuracy	+/- 0.3" for an 18" dipstick in water (to be improved during 1995)
Resolution	.001" rms incremental (short term stability) ~ 1" differential (layer) resolution
Scale factor	set by an RC analog circuit
Scale factor	stability limited by RC components
Zero offset	~ eliminated by differential measurement on the stick (uses a reference "target" at the top of the stick)
PRF	2MHz
Outputs	1) CMOS range, scale = 1"/ 1 ms pulse width, 2) CMOS sync, 40 Hz square wave, 3) analog equivalent time TDR replica, +/-1V peak
Update rate	40Hz
Sensor element	transmission line = microstrip, coax, or guide wire, may be coated with plastic
Power	5V @ <10mA, normal power mode
Size	1.5" square SMT PCB
Cost	$10 in PCB components/unit qty
Semiconductors	similar to MIR, above

Scale factor linearity is limited to ~1% of full scale. The electronics can be made to automatically compensate for fluid dielectric constant, so accuracy remains unchanged for aqueous or petroleum based liquids (Dipstick Version 1.2).

4B. High accuracy fluid level sensor (Dipstick Version 2.0)

This version of the dipstick incorporates a quartz crystal time base that uses a D-to-A converter to define the resolution and accuracy. Using a 12-bit D-to-A, accuracy is 1 mm at 4 meters, and resolution can be somewhat better through a simple interpolation technique.

Version 2.0 can operate without using the a cable to interconnect the dipstick to the electronics. This simplifies the design of an integrated dipstick and filler cap, with the electronics located in the filler cap. To facilitate this, a directional sampler is employed that can receive reflected pulses even while they are being transmitted down the dipstick, such as when the tank is full. Version 2.0 also incorporates constant fraction discriminators that automatically compensate for reflected pulse amplitude variations that arise from fluid dielectric constant variations, propagation losses, or component variations. The size, cost and power requirements of Version 2.0 are all about double that of Version 1.0.

5. RF fluid level switch

The RF fluid level switch uses low power microwave energy to detect the near proximity of a volume of fluid. Unlike the dipstick, it does not provide a continuous readout of level; it provides a switch closure to indicate a "full" or "empty" level in a tank. By using microwaves, it is able to operate through non-metallic walls so it can be mounted on the outside of a tank.

The RF fluid level switch is comparable to a capacitive sensor. Both types are simple, inexpensive, and have a limited detection range. The major difference is the RF switch is impervious to condensation, wetting, grime, and ionically conductive coatings that may be found on tank walls. It is also impervious to foam, which causes false triggering with ultrasound and capacitive sensors. In addition to sensing fluids, the RF switch can also be used as a proximity sensor for robotics or industrial automation.

The RF switch operates on the principle of detecting the amplitude of oscillation of a microwave RF oscillator that is connected to a sensing antenna. When the antenna is not near a fluid, the oscillation amplitude is high. When the sensing antenna is brought into near proximity of a fluid, the amplitude of oscillation decreases. This decrease is threshold-detected and used to provide a contact closure. A micropower version can run for several years on penlight batteries.

With a 1" wire antenna, it can detect aqueous fluids through plastic walls about 0.25" thick. Using a 5" wire antenna and a low RF frequency, reliable detection extends through 1" thick tank walls. As presently configured, the RF fluid level switch is not suitable for use with low dielectric constant materials such as petroleum products. This capability is covered by other LLNL sensors.

General Specifications

Frequency	2GHz
Outputs	1) CMOS logic, Q = high @ full, 2) NPN switch closure @ full
Response time	< 0.1sec
Sensor element	1" wire or PC strip, may be coated with plastic
Power	3V @ 0.1mA, normal power mode, can also run on 5V
Size	1x3" SMT PCB
Mounting	must be flush mounted to container
Wall thickness	.125" max, plastic or glass
Cost	$2 in PCB components/unit qty
Semiconductors	74HC04 CMOS (1ea), Si-bipolar RF transistor @ >4GHz ft (1ea.), general purpose PNP (1ea.)

6. Micropower RF receiver

The micropower receiver is similar in operation to those used in garage door remote controls and other low-cost short-range RF remote control applications. The difference between conventional technology and LLNL's micropower receiver is typically a factor of 100 or more lower power consumption. The micropower receiver draws only six microamps of supply current, so it can run continuously for a quarter of a century from a single penlight battery (neglecting shelf life).

Low-current operation is vital to battery operated remote control functions where a receive capability is needed. Typically, a remote control transmitter will have long battery life because the transmitter is normally off until a button is pushed. A key fob "clicker" transmitter typically draws only a few milliamperes for a few tenths of a second for each push, so battery life can easily exceed one year. The receiver doesn't know when to expect a transmission and needs to be on continuously. In order to get a year of battery life from a small lithium cell, current draw needs to be well under 100 microamperes.

The micropower receiver enables important new applications such as 1) keyless entry systems, 2) stand-alone, instantly installed MIR and PIR proximity sensors with a 2-way handshake to a central controller, 3) inventory and attractive asset tracking ID cards, 4) medical implant data links, and 5) avalanche rescue transponders. All these applications can be powered by a long life lithium battery--one supplier currently specifies 0.5%/year self discharge rate.

The transmitter normally used with the micropower receiver is comprised of a single low-cost RF transistor that is driven directly from a CMOS encoder. During its pulsed-on state it draws <5mA @ 3-15V. Encoder/decoder pairs and complete key fob transmitters are commercially available with over 100 million address/data combinations. LLNL can supply transmitter schematics and encoder/decoder information to licensees.

General Specifications

Modulation type	AM, 100% modulated pulsed RF
Frequency	315 MHz nominal
Range	50-100' with key fob transmitter
Selectivity	single pole resonator, Q > 100
Frequency stability	set by resonator, +/- 1MHz over temp
Data rate	600 baud
Output	3V CMOS logic levels (with 3V decoder)
Power	1.5 V @ 6uA (receiver section)
Operating temp	-55 to +85deg.C
Antenna	PCB mounted coil
Size	1.5" square SMT PCB, with decoder IC
Cost	$3 in PCB components/unit qty
Semiconductors	74HC04 CMOS (2ea), Si-bipolar RF transistor @ >4GHz ft (1ea.), general purpose NPN (1ea), CMOS decoder

LLNL also developed a 315MHz receiver that has a 10ft range and draws only 0.6uA from 1.5V.

7A. Time-of-flight (TOF) radio location system (tethered version)

The time-of-flight radio location system measures the propagation time of a short RF burst traveling between a transmitter and receiver unit to determine the distance between them. Based on MIR technology, the propagation time of a stream of RF pulses is measured with a short-term uncertainty or jitter of less than of one picosecond, or about .01" of free space distance across a range of 1-10'. The receiver automatically locks on to the first few hundred picoseconds of the RF pulse to eliminate errors resulting from scattered, indirect propagation paths.

The system comprises a transmit unit, a receive unit and a timing cable connecting them. The timing cable can be a simple shielded wire, such as high quality phono cable, or it can be teflon dielectric coax for better range offset stability. The cable also carries DC power to the transmitter. As with MIR, the PRF can be noise coded to allow co-location of multiple systems.

An analog range sweep circuit is used to measure the time-of-flight and to convert the received sub-nanosecond signal to a millisecond-scale equivalent-time replica. The sweep circuit has about 1" linearity error across 10'.

The radio location system is primarily intended to go into high volume computer games and virtual reality systems. In these applications, a transmitter is mounted on the helmet and two or more receivers are used to measure line-of-sight distance and triangulate to determine position. Depending on the configuration, 2-, 3- and 6-axis readout is possible.

The system operates through walls, plastic enclosures, rain, ice, mud splatter, and is generally very robust in harsh environments. Position sensing for industrial robots, active vehicle suspension, and construction sites are potentially good applications.

In some cases the use of a timing cable is unacceptable. During 1995 we plan to eliminate the timing cable (with some increase in circuitry).

General Specifications

Frequency	2 GHz
Bandwidth	500MHz
PRF (average)	2MHz +/-20%
PRF coding	Gaussian noise, or low coherence swept FM, or pseudo-noise
Transmit power	1 uW average
Receiver	Equivalent time sampler with 60 dB AGC range
Antennas	1.5" long wire monopoles
Antenna pattern	360deg. in the H-plane
Range	1 to 10 feet, nominal. 100ft possible
Range linearity	~ 1" across 10ft (to be improved during 1995)
Resolution	.003 to .01" rms (range dependent)
Scale factor stability	limited by RC components
Outputs	1) CMOS range, scale = 1ft/ 1ms pulse width 2) CMOS sync, 40Hz square wave 3) analog equivalent time RF replica, +/-1V peak
Update rate	40Hz
Power	5V @ <10mA, normal power mode
Size	RX = 1.5" square SMT PCB TX = 0.5x1" SMT PCB
Cost	$10/pair in PCB components/unit qty
Semiconductors	similar to dipstick, above

Scale factor linearity is presently limited to 1% of full scale. Versions with a scale factor accuracy of 12 bits or better can be realized using the time base described for dipstick Version 2.0. An untethered TOF system will be available in late 1995.

7B. Wireless time-of-arrival (TOA) location system

The wireless TOA system features an untethered transmitter that can freely roam within a volume. The transmitter emits microwave pulses and a set of receivers sample the pulses to produce outputs representative of the relative arrival times of the pulses. The relative arrival times are used to triangulate the location of the transmitter in N dimensions relative to the *known* positions of the N+1 receivers[[arrowhorizex]]a 2-dimensional fix requires 3 receivers.

The transmitter is comprised of a pulse rate oscillator, a short-pulse microwave oscillator, and a battery. Battery life is several months for a AA lithium cell.

All the receivers operate from a common quartz crystal that provides high accuracy and resolution of the time-of-arrival pulses. The arrival-time pulse outputs from the receivers occur in equivalent time on a millisecond-scale for simplified digitizing, as described in the time-of-flight system. Determination of location from relative arrival times is more complex than from direct time-of-flight measurements, since location solutions lie along hyperbolas. Most hardware specifications are similar to the time-of-flight system.

8. Organ motion sensor

The microradar organ motion sensor, or heart monitor, is a breakthrough in non-invasive diagnostics. It is a motion sensor that detects cardiac contractions and produces a signature that compliments the ECG waveform as a stimulus-response pair. It also detects arterial wall motion, respiration (from a distance), and vocal cord activity. Motion signatures can be detected almost everywhere in the body, such as from the carotid, brachial and femoral arteries, and from the cranium.

We envision the microradar heart monitor to be a vital compliment to the ECG monitor. For the first time, physicians will be able to routinely evaluate both the cardiac stimulus and its response. One possible configuration would have the microradar co-located with standard ECG electrodes so the combined radar/ECG data can be obtained without modifying existing procedures. Given the low cost of the microradar and its high informational value, it is possible that it will become an integral part of all ECG equipment.

Home health care is another potential application area. The microradar can be designed to automatically lock onto the cardiac signature and display the average heart rate or interval between any two beats. When combined with a large numeric LCD display, a through-clothing heart rate monitor will be especially useful for the hearing impaired, for elderly patients, and for athletes.

Non-contact respiration monitoring with the microradar sensor will help get wires off patients in the OR, ICU and long-term ward. It can sense respiration through a mattress or through a chair back. Its range-gated "bubble" of sensitivity can be limited to a several foot radius to eliminate interference from passersby.

Similarly, the microradar respiration monitor may be used for sudden infant death syndrome (SIDS) monitoring. Although the microradar is sensitive to any motion, not just respiration, the SIDS monitor can sound an alarm or beep a pager when there is a cessation of motion. A related application is remote detection of breathing for law enforcement use and earthquake rescue. The microradar can detect respiration at 12 feet, and can do so through walls.

The non-acoustic microradar microphone detects breathing sounds in the chest that cannot be heard with a conventional stethoscope. It also robustly detects vocal cord motion when held over the Adam's apple. Since the microradar "stethoscope" is immune to external noises, it is particularly useful in an ambulance or helicopter, or on the battlefield.

The microradar can be time multiplexed between two or more range cells so one radar can provide multiple simultaneous outputs, each output corresponding to a different motion sensitive region. When the radiated waveform is sinusoidal, pairs of motion sensitive regions can be offset by 1/4 wavelength so quadrature range-gated Doppler signatures can be obtained for vector processing into magnitude, speed and direction. The multiplexed mode provides motion sensitive slices in depth, so for example, heart motion can be simultaneously recorded at multiple depths into the chest.

The RF emission level from the microradar was measured with a broadband bolometer and found to be about 1 microwatt. Most international safety standards set one milliwatt/cm^2 as the safe limit for continuous whole body exposure. The microradar is 1000 times or more below most limits and is thus inherently safe. Interaction with implanted electronics is not known (one might expect zero interaction due to the low emission levels, but this remains to be tested).

General specifications: similar to the MIR motion sensor, above.

9. Microradar Rangefinder

The radar rangefinder is a compact, low-cost ultra-wideband radar with a swept range gate. The device generates an equivalent-time A-scan (echo amplitude vs. range, similar to a WW-II radar) with a typical range sweep of 4" to 10' and an incremental range resolution, as limited by noise, of .01".

Uses include replacement of ultrasound range finders for fluid level sensing (a dipstick without the stick), vehicle height sensing, and robotics control. When positioned over a highway lane, it can collect vehicle count, vehicle profile, and approximate speed data for traffic control. Some versions transmit RF packets rather than a short impulse, and can provide swept-range quadrature Doppler information.

A major application for this microradar is imaging (see below). It operates in spectral regions that readily penetrate walls, control panels, and to an acceptable extent, concrete and human tissue.

The basic antennas have a very broad beam width and corresponding low gain. They are suitable for synthetic beam imaging where broad illumination is desirable. Narrower beam widths and higher gain can be obtained on a broadband basis with horns, reflectors or dielectric lenses.

General Specifications

Antennas	1.5" aperture ea., T and R, 160deg. beam width, a horn/reflector/lens can be added
Center frequency	3 GHz, typical
Emission bandwidth	3GHz, typical
Average emission power	~ 1uW
Duty cycle	< .001
PRF (average)	2MHz +/- 20%

PRF coding	Gaussian noise, or low coherence swept FM, or pseudo-noise
Receiver noise floor	3 uV rms (without preamp)
Receiver gate width	100 ps
Receiver STC	~60dB
Range sweep	RC analog, pot/DAC controllable
Range timing jitter	< 1ps rms
Range sweep stability	RC component limited over temperature
Sweep range	4" to 10ft, 100ft possible
Sweep rate	40Hz, typical
Sensitivity	20dB S/N on 4x6" metal plate at 10 ft
Signal to clutter	30 dB from 4" to >10ft, without digital subtract
Analog output	+/-2Vmax equivalent time replica spanning 25 ms
Digital output	CMOS sync, 40Hz square wave CMOS range, scale = 1ft/ 2ms pulse width
Receiver gain	100dB (STC = max)
Power	5V @ <20mA, normal power mode, long battery life version possible
Size	1.5x3" SMT PCB
Cost	$10 in PCB components/unit qty
Semiconductors	74HCxx, 74ACxx, CMOS op amps, Si-bipolar RF transistors @ >4GHz ft (2ea.), Schottky diodes, Cj (0) < 0.5pF (2ea), General purpose NPN (1 ea.)

The STC (sensitivity-time control) increases voltage gain with R^2. In addition, a peak-sensing AGC (automatic gain control) can be provided to maintain a constant receive pulse amplitude independent of range or target characteristics. For fluid level sensing, return pulse amplitude is held precisely constant and independent of fluid dielectric constant, so accuracy remains unchanged for aqueous and petroleum based liquids. Scale factor linearity is 1% of full scale using an analog time base. Versions with scale factor accuracies of 12-bits or more use the dipstick V2.0 time base.

10. Laser Rangefinder

The laser rangefinder uses the direct pulse-echo flight time of a collimated visible or IR laser beam to measure the range to the spot of light projected by the laser. Thus, non-contact range measurements can be made from a single location and the precise measurement location is pinpointed by the laser spot. Its advantage over the radar rangefinder is 1) it has a very narrow beam to facilitate operation in tight locations, and 2) the projected spot of light tells the user where the measurement is being taken.

The laser rangefinder is similar in operation to the radar rangefinder, except a laser diode replaces the transmit antenna, and an avalanche photodiode replaces the receive antenna. Equivalent time processing is used for low cost, and high accuracy is obtainable using the time base described for Dipstick V2.0. The cost of eyesafe visible beam laser diodes is under $10 in volume. The cost of avalanche photodiodes may currently range up to $100 due to low volume usage. The low volume SMT component cost for the rest of the system is under $20.

The laser rangefinder has countless industrial safety, measurement and object profiling applications. A truly low cost laser rangefinder will revolutionize the way people measure things[[arrowhorizex]]it will replace the yardstick and tape measures that are in everyday use.

11. Electronic Trip Wire

The electronic trip wire performs the equivalent function of a physical trip wire that is commonly used for game trapping, land mine detonation, conveyor belt counting, people counting, and safety sensing for automatic doors. It is based on the emission of a very short RF burst at a first location and the range-gated detection of the RF burst at a second location. Range gating is employed to selectively detect only the shortest-path arrival of the RF burst while excluding the longer-path scattered-RF components that would adversely expand the detection zone. In a preferred mode, a total eclipse of the transmit-to-receive path by the intruder is required, thereby limiting the sensitive zone to a small cylindrical region between the transmitter and the receiver. The RF circuitry comprises a noise-coded ultra-wideband spread spectrum system that allows co-location of multiple trip wires without the need for frequency assignments. The trip wire can be designed to run continuously on batteries for several years and is inexpensive to manufacture.

A unique property of ultra-wideband systems is the ability to exploit time-of-flight techniques to precisely determine range, or in this case, to exclude all but the direct path propagation components of an RF burst traveling between two points. Thus, simple omni-directional antennas can be used while effectively achieving narrow beam operation. By adjusting the range gate, the invisible wire can be "tensioned" to vary the width of the detection region. Unlike the MIR motion sensor, the electronic trip wire does not require motion to trigger it--the alarm remains on continuously when an eclipse continuously occurs.

As a security device, the electronic trip wire detects people passing between the transmit and receive units. These units can be concealed behind wood door frames or walls--the electronic trip wire is stealthy in terms of zero (installed) visibility and nearly undetectable RF emissions.

As a safety or industrial sensor, it can detect the presence of a person or a car in an automatic doorway, or it can detect objects on a conveyor belt. Due to low component cost and the fact that its transducer is simply a short piece of wire for the antenna, it will be lower in cost than virtually any sensor that uses a transducer, including optical, ultrasound and magnetic sensors. It can be hermetically sealed against harsh environments, and it is impervious to blockage by dirt, snow, wood, and rain, all of which can completely disable ultrasound and optical sensors.

The system comprises a transmit unit, a receive unit and a timing cable connecting them. The timing cable can be a simple shielded wire, such as high quality phono cable, or it can be teflon dielectric coax for better trip wire "tension" stability. The cable also carries DC power to the transmitter.

General Specifications

Frequency	2GHz
Bandwidth	500 MHz
PRF (average)	2 MHz +/-20%
PRF coding	Gaussian noise, or low coherence swept FM, or pseudo-noise
Transmit power	1 uW average
Receiver	Equivalent time sampler
Antennas	1.5" wire monopoles
Antenna pattern	360deg. in the H-plane
Range	1 to 20 feet, >100ft possible
Sensitivity	Adjustable for total or partial eclipse
Response time	< 0.1sec
Outputs	1) NPN switch closure, 2) Analog RX signal indication
Power	5V @ <10mA, normal power mode
Size	RX = 1.5" square SMT PCB TX = 0.5x1" SMT PCB
Cost	$10/pair in PCB components/unit qty
Semiconductors	similar to dipstick, above

12. Strip proximity sensor ("Smart Wire")

The strip proximity sensor uses a wire to detect the near proximity of objects. The wire can range from several inches to tens of feet in length and has two modes of operation: 1) radiating and 2) non-radiating or near field. Both modes generate a cylinder of sensitivity around the wire, with the radiating mode extending to several feet of more, while the non-radiating mode is confined to about 1cm in radius. Generally, the radiating mode is motion sensitive only, while the non-radiating mode can be either presence or motion sensing.

Smart wire can be routed around a vehicle or a building to provide a zone of protection, or it can be a fine wire embedded in a power window for safety purposes: it easily detects a finger while ignoring foam rubber gasketing.

In operation, a sub-nanosecond pulse or short microwave burst is launched along the wire, which operates as an electromagnetic guide line. A pulse detector at the far end of the wire detects amplitude changes resulting from disturbance of the near field pattern about the wire, or from pulse-echo reflections from more distant objects. The sensor system requires units at each end of the wire; however, power for the far-end unit can be carried by the sensor wire itself to simplify installation. Component cost is below $10 in unit quantity.

13. Micropower Impulse Radar Imager

The MIR imager consists of small, low power, broadband radars (such as the microradar rangefinder above), that are being developed for a wide range of imaging applications. These radars are coupled to antenna arrays and a portable computer to form a complete radar imaging system. Software is used to reconstruct 2D and 3D views of the scene.

Due to their low-cost and small size, numerous MIR sensors can be assembled into arrays for synthetic- and real-aperture image formation in 2D and 3D. Radar return signals are digitized and stored in a portable lap-top computer. Reconstruction of cross-sectional images from B-scan or waterfall type data is performed by diffraction tomography software on the lap-top. Images of the scene are displayed directly on the screen within 10 seconds (in 2-D).

We have developed one array of 32 sensors for test and evaluation, and others are being designed. The imaging system detect differences in the dielectric constant of the materials under inspection--larger differences cause larger radar return signals. Resulting images, then, have high intensities at interfaces between materials of differing electrical properties. Effective resolution of the current system is about 1-2 cm, depending on the medium and depth. The current array uses monostatic imaging, but future versions will be capable of multistatic operation.

General Specifications: Same as the microradar rangefinder above; variable depth (range) resolution, wideband pulser for fine cross-range resolution, briefcase-sized for portability, various antennas from 100 MHz up to 5 GHz, 2D imaging in less than 10 seconds, long battery life, exceedingly low emissions, and low cost.

Applications:

- Ground-penetrating imaging for mines and buried ordnance
- Through-wall detection of people
- Nondestructive evaluation of civil structures
- Inspection of road beds and bridges
- Location of rebar and conduit in concrete
- Moisture content locator in wood, soil or concrete

Micropower Impulse Radar (MIR) Government Partnership Information

In general, government partnership with LLNL on the MIR technologies is handled through the Imaging and Detection Program offices at the following address:

Michelle Lynch, Imaging and Detection Program

Lawrence Livermore National Laboratory

P. O. Box 808, L-495

Livermore, CA 94551

Tel: (510) 423-1077; FAX: (510) 422-1796; email: mir@llnl.gov

A number of general application areas have been identified in which we are now actively involved. When contacting us please identify your area of interest so that we may route your request to the appropriate person. In some cases we have technical papers in the field that can be mailed to you, but in others we are in the initial phases of development. The general application areas are the following:

* Underground mine detection and imaging
* Proximity fusing
* Personnel motion behind walls and over short ranges
* Short-range altimeters; ice and snow-thickness
* Security (motion sensors)
* Radar ocean imaging
* Robotics control and imaging
* Road-bed and bridge-deck imaging arrays
* Underground detection and imaging of utility pipes and conduits
* Power pole inspection
* Nondestructive evaluation of concrete, ceramic, and composite structures
* Remote heart monitoring
* Respiration detection through walls and floors
* Transportation

We are seeking the best methods to both develop new radars and to get them distributed as rapidly as possible. While we continue to refine our operations, we ask your patience: our obligations to provide royalty-free support to legitimate government sponsors must be balanced with the need to perform adequate R&D that ensures quality of the final prototype. Many of the conceptual solutions attributed to the MIR still require significant engineering effort to bring about success.

While publicity about MIR often refers to it as a "$10 radar" and the combined cost of the electrical components themselves is in that range, the current cost to build, test, and package our custom prototype units is significantly more. As we and our partners begin building them in quantity, the prices will go down, but for now they remain high. For that reason, we cannot provide trial units at this time without full cost recovery.

Still, there are several ways to explore if MIR technology is the right tool for government applications. We are willing to share some of the costs by leveraging other internal funds if there is laboratory interest in the problem. Our preferred mode, then, is to team with government agencies to address their problems in a collaborative effort. All of this points to the following ways of obtaining MIR technology:

1. Collaborate with us on joint research and development in your field of interest: We can write joint proposals for collaborative research on problems that require specialized MIR expertise.
2. Contract with us to perform the R&D necessary to develop the application: LLNL has extensive expertise in all aspects of modeling, simulation, design, fab, and test to develop prototype MIR units.
3. "Purchase" a prototype from us: In special cases where we have developed prototypes, and where vendors are not yet supplying production models, we would be willing to fabricate limited numbers of existing MIR modules.
4. Wait until market pressures are such that a licensee steps forward to supply the technology: Several licensees are working with us on products that may match a new government request. We can forward any government request to the vendor.

Finally, we must remind you that the MIR technology is owned and managed by the University of California and the DOE. We ask your cooperation in protecting this intellectual property, and the rights of the licensees, from unauthorized use. Accordingly, if you should choose to work with us as described above, we will ask you and your organization to sign a confidentiality agreement regarding the MIR technology (see next page).

Frequently Asked Government Partnership Questions

Question: On what type of government sponsorship is LLNL able to collaborate?

> **Answer:** As a DOE national laboratory, our major missions involve research in energy, national security, environmental, and industrial competitiveness. While the majority of our funding is from DOE, we can work and have worked with other federal agencies on a variety of topics. We cannot, however, work with a single company to provide a competitive advantage over another when bidding for federal funds; we must provide equal opportunity to all.

Question: What type of licenses do you grant to industrial partners?

> **Answer:** All licenses on the MIR technology are non-exclusive and allow commercialization in only one field of use. One company may sign multiple licenses for different fields-of-use, and other companies in the same field may also receive the same license (i.e., it is non-exclusive).

Question: What are our rights and obligations as government collaborators on MIR development?

> **Answer:** The U.S. Government has a non-exclusive royalty-free license to use the MIR technology for their applications. However, please be aware that the MIR technology is owned and managed by the University of California and the DOE. We ask your cooperation in protecting this intellectual property from unauthorized use and to sign and abide by our confidentiality agreement for this technology.

Question: Can we get copies of all applicable patents?

> **Answer:** Some patents have not yet been granted from the Patent Office, so they are not yet published. Those that have are available from the Patent Office. We will be happy to supply the patent numbers for those if interested. We do not supply copies of the patents themselves.

Question: Are MIR samples available?

> **Answer:** We can supply some samples for a minimum $5000 MPR transfer of funds, depending on the MIR module required and the current availability. If collaborative research is being done, we will supply samples as needed.

SAMPLE CONFIDENTIALITY AGREEMENT

(To be signed when we enter into a collaboration)

Reference:

Dear

The purpose of this letter is to notify you of conditions applicable to the delivery of the Micropower Impulse Radar (MIR) Technology to you.

The MIR Technology will contain patented, copyrighted, and proprietary materials. The MIR Technology must be used solely for Government purposes. You must not transfer the MIR Technology to any commercial third parties without prior written approval from LLNL. Commercial use or application of the MIR Technology is prohibited.

As required by the University of California (UC), which operates LLNL for the Department of Energy (DOE), you are also advised that the MIR Technology is experimental in nature and is provided without warranty of merchantability or fitness for a particular purpose or any other warranty, expressed or implied. The UC, LLNL, DOE, and the US Government make no representation or warranty that the use of the MIR Technology will not infringe any patent or other proprietary right. Please immediately return a copy of this letter, countersigned by your organization, evidencing your compliance with these conditions to the undersigned.

Read and Accepted:

____
Cognizant Addressee
Representative<>

Return to:

Chung T. Bothwell
Operations Manager
LLNL
P. O. Box 808; L-465
Livermore, CA 94551