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Ultrawideband

Regulators, service providers, and even users view today's radio spectrum as leased real estate. If spectrum were visible, you would see leased "plots" of frequency surrounded by barbed wire and "keep out" signs. If you talked to the lessees, they would tell you that *everyone* leasing spectrum *should* pay comparable amounts for the same characteristics (bits per second, error rates, number of channels, etc.), regardless of how these characteristics are achieved technically. These tenets of the radio spectrum: *No Trespassing* and *Price Regulation* are the real barriers that disruptive communication technologies face.

The Federal Communications Commission (FCC) administers the commercial radio spectrum, which comprises electromagnetic frequencies from 3 kHz to 300 GHz. That's a frequency range eight orders of magnitude wide; it starts with much of what you can hear and stops at infrared heat. It includes radio and television broadcasts, satellite transmissions, cell phones, navigation aids, radar altimeters—just about everything that transmits and receives without wires. Methods of transmission and rules for their use have been built up over the last *ninety* years. The methods and rules are based on frequency allocation. Now there's a new kid on the block—ultrawideband (UWB)—that wants to change the methods and the rules.

Narrowband

UWB isn't exactly like your car radio or like your cell phone, but radio is a good place to begin. I borrowed a figure from "MEMS and the Cell Phone" (*Dynamic Silicon*, Vol. 1, No. 7), and I start the explanation there.

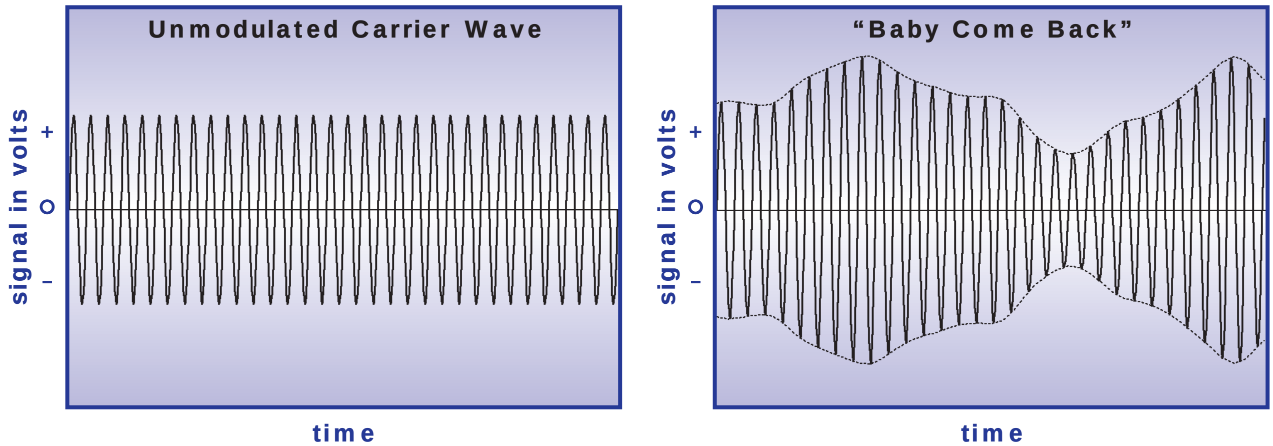

Figure 1. One-millisecond close-ups of the unmodulated (no music signal) carrier wave and of the modulated (music signal mixed in) carrier wave for Bonnie Raitt's song "Baby Come Back."

In This Issue:

More powerful silicon is making new ways of transmitting through the air possible. Called *spread spectrum* and *ultrawideband*, these "wideband" signal processing techniques feature low transmit power, improved security, and high data rates, at consumer price points. They wend the crowded radio spectrum way more efficiently than prevailing techniques because they pack more channels of communication into the same range of radio frequencies. If you are a radio spectrum baron, the chief problem with the previous statement is the the word *same*. Despite the fact that wideband technical magic makes it possible, the owners of radio spectrum just *don't like it*. Because they cannot state their objection this way, they raise their objections under the guise of radio interference.

Suppose you are listening to Bonnie Raitt sing "Baby Come Back" at 950 on your car's AM radio. The left-hand side of fig. 1 shows the radio station's unmodulated "carrier wave" at 950 kHz. The right-hand side of fig. 1 shows the carrier wave "modulated" by one millisecond of Bonnie Raitt's music. You can see why it's called a carrier wave: it literally carries the music signal along. You see the sound wave in the peaks and valleys of the carrier's voltage level. When you tune the car radio to 950, the radio filters out other frequencies and it amplifies the signal at 950 kHz. It then "demodulates" the signal. This removes the carrier and it averages the carrier's peaks to extract the music. For an FM station, the music changes the carrier's frequency rather than its strength. Your car's radio reverses the process to extract the music.

"The flaw is a system that treats spectrum as property and auctions frequencies to grant monopolies."

In carrier-wave transmission the transmitter's duty-cycle is 100 percent. A 50,000-watt radio station dissipates 50,000 watts whether or not the music is there.

AM radio and FM radio are examples of *narrowband* signals. For narrowband signals, the information to be broadcast (voice, music, data) changes the carrier wave in some way. Each broadcast station is given a center frequency (such as 950 kHz) plus a "guard band" that separates it from neighboring frequencies, so that you can tune the receiver to a single station without hearing nearby stations. A center frequency and guard band constitute a narrowband communication "channel." This is a dedicated *allocation* scheme. In this scheme, the radio spectrum might as well be a finite number of physical wires, each "insulated" by its guard band, to be handed out to various companies and groups. After they're gone, they're gone.

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Cell phones are radios, too, so their transmitters and receivers need spectrum space. In the original cellular network, each cell phone got its own narrowband channel. Eventually, the number of active cell phone users outgrew the number of channels. There weren't enough dedicated narrowband channels to go around, so engineers invented ways to share the spectrum.

Time-division multiple access. One sharing method, used by cellular networks, is time-division multiple access (TDMA). TDMA recognizes that voice communication doesn't use much of the bandwidth in a typical carrier wave. The analog voice signal is digitized and broken into packets. Six or eight packetized voice streams fit in time-slots on the carrier wave. The receiver extracts digital data from the appropriate time slots and reconstructs one analog voice signal. In the United States, each TDMA narrowband frequency carries eight voice channels; each GSM (the European version of TDMA) frequency carries six voice channels. TDMA supports six to eight times the number of users that the dedicated narrowband channels supported. Like its analog predecessor, TDMA supports only as many users as it has voice channels.

Wideband

Spread spectrum. Another spectrum sharing method, *spread spectrum*, spreads the transmission across many frequencies. How can spreading the signal across more frequencies *increase* the number of channels? Doesn't each user then hog more frequencies? Not exactly. One spread-spectrum method, called frequency-hopping spread spectrum, hops from one carrier-wave frequency to another every few *milliseconds*. The transmitter uses a pseudo-random number sequence to select frequencies. As long as each transmitter uses a different pseudo-random number sequence, the transmitters rarely step on each other by landing on the same frequency at the same time. When two transmitters do interfere, it is only a few milliseconds before they skip off to other frequencies. The receiver uses a pseudo-random number sequence that matches the transmitter it wants to track. The receiver hops around in sync with the transmitter and assembles the message.

With narrowband transmission, there are only as many channels as there are frequencies separated by guard bands. Once the narrowband channels are full, it's not possible to add another user. Wideband transmission, using the same frequencies, creates a "virtual channel" with each unique pseudo-random number sequence. With wideband transmission, there's no fixed limit to the number of virtual channels, and the signal quality degrades slowly as the number of virtual channels increases.

Narrowband is characterized by having a fixed-carrier-wave frequency; frequency hopping employs a variable-carrier-wave frequency.

The U.S. military likes spread-spectrum radios for their inherent security—what the military calls LPD and LPI. LPD is low probability of detection. Since the transmit frequency is hopping around, the radio is difficult to detect. LPI is low probability of interception. Without knowing the unique hop sequence, it's impossible for a receiver to intercept the transmitted message. Spread-spectrum radios are also difficult to jam. It's easy to jam a single frequency, but to jam spread-spectrum transmissions requires jamming a significant fraction of the frequencies in the hop set.

Bluetooth connects consumer gadgets at short range. Bluetooth is a good example of a frequency-hopping spread-spectrum application. It operates in the "junk band" between 2.4000 and 2.4835 GHz. It's called the junk band because it's shared with unlicensed radios, microwave ovens, cordless telephones, baby monitors, and wireless local-area networks. Microwave ovens and other appliances look like jammers, so Bluetooth uses spread spectrum. Bluetooth hops among seventy-nine 1-MHz channels at 1,600 hops per second. Bluetooth works at short range (about 30 feet) and for networks that need 1 Mb/second or less at low power dissipation.

Another spread-spectrum method, called direct-sequence spread spectrum, disperses the signal across a wide frequency range. It does this by creating what are really secondary carrier waves hidden in the main carrier wave. There is one main carrier wave, and its center frequency is fixed. Each of the secondary carrier waves is a separate communication channel. But to the outside, the combined signal looks like one signal, with a single carrier wave that is changing wildly, spanning a wide frequency range.

The direct-sequence-spread-spectrum transmitter uses a pseudo-random number to multiply the main carrier-wave's center-frequency to a new frequency, still within the main carrier wave's allowed range. The information (data or voice signal) is then modulated with the new (secondary) carrier, so that the new carrier's frequency varies around the new center frequency. Now take a new pseudo-random number and take a different voice or data signal, but retain the main carrier's center frequency. Repeat this sequence many times. The resultant signal looks like it has one carrier wave that is being modulated across a wide frequency range. Receivers must have the correct pseudo-random number to reverse this construction, to separate the signal (secondary carrier plus information) they want from the mix. Using unique pseudo-random numbers or mixing unique codes with the information being transmitted creates *virtual channels* over the secondary carrier waves.

Direct-sequence spread spectrum is the basis for CDMA (code-division multiple access) cell phones and for 802.11b.

The IEEE's 802.11b and 802.11a implement wireless local-area networks, commonly called Wi-Fi (wireless fidelity). 802.11b operates in the 2.4-GHz Industrial, Scientific, and Medical (ISM) band—the same band Bluetooth uses. It delivers up to 11 Mb/second at distances to 300 feet with 30 milliwatts of transmitted power. Improving silicon chips enable advances in spread-spectrum communication. 802.11a uses an advanced form of spread spectrum called orthogonal frequency division multiplexing, OFDM. 802.11a operates in the 5.2-GHz Unlicensed National Information Infrastructure (U-NII) band and delivers up to 54 Mb/second with half the range of 802.11b.

Wi-Fi local-area networks based on 802.11a and on 802.11b are invading hotels, libraries, parks, airport terminals, Starbucks and other businesses, and even cities and homes around the world. "Hotspots" provide public wireless network services to mobile visitors. Wi-Fi's access ports and clients have reached critical mass in the market, with more than a million access ports deployed and with sales of client PC cards expected to reach ten million this year. The cost, therefore, to implement Wi-Fi is dropping rapidly. New laptop computers, such as IBM ThinkPads, incorporate Wi-Fi chips. The Wireless Ethernet Compatibility Alliance, which promotes wireless interoperability among Wi-Fi products, has 257 member companies and 495 products (mid-October 2002). That's quick development for a market that didn't exist before the IEEE released its final 802.11b specification in September 1999.

Ultrawideband: technical

Read the headlines and ultrawideband sounds like the ultimate everything. It can locate survivors amidst earthquake rubble. It can enable collision-avoidance systems for passenger cars. It sees through walls. UWB can double the capacity of cable TV coax. It can be radar. It can range objects within a centimeter. UWB can send video and audio signals around the home. Its signals can be difficult to detect and can be hard to intercept, so the U.S. military likes it. It offers low power consumption and high data rates. UWB's transmitters and receivers are simpler to build than conventional transmitters and receivers. UWB doesn't interfere with conventional transmitters and receivers. Sounds unbelievable.

Ultrawideband is a wideband signaling method, as is spread spectrum. But, in ultrawideband, there's no carrier wave. The information is sent as precisely timed *pulses*. The energy in these pulses is spread across a wide frequency range. The information transfer (pulses) is inherently digital. UWB is a descendent of the telegraph; it transmits ones and zeroes the way the telegraph transmitted dots and dashes. In UWB, the information to be transmitted modulates the energy pulses. One way to modulate the energy pulses, called pulse-position modulation, adjusts the time that the pulse is sent. A pulse arriving at the receiver at the expected time might be a zero, while a pulse that's a little late is a one. Another way to modulate the energy pulses, called binary phase-shift keying, transmits a pulse for a one and its inverse for a zero.

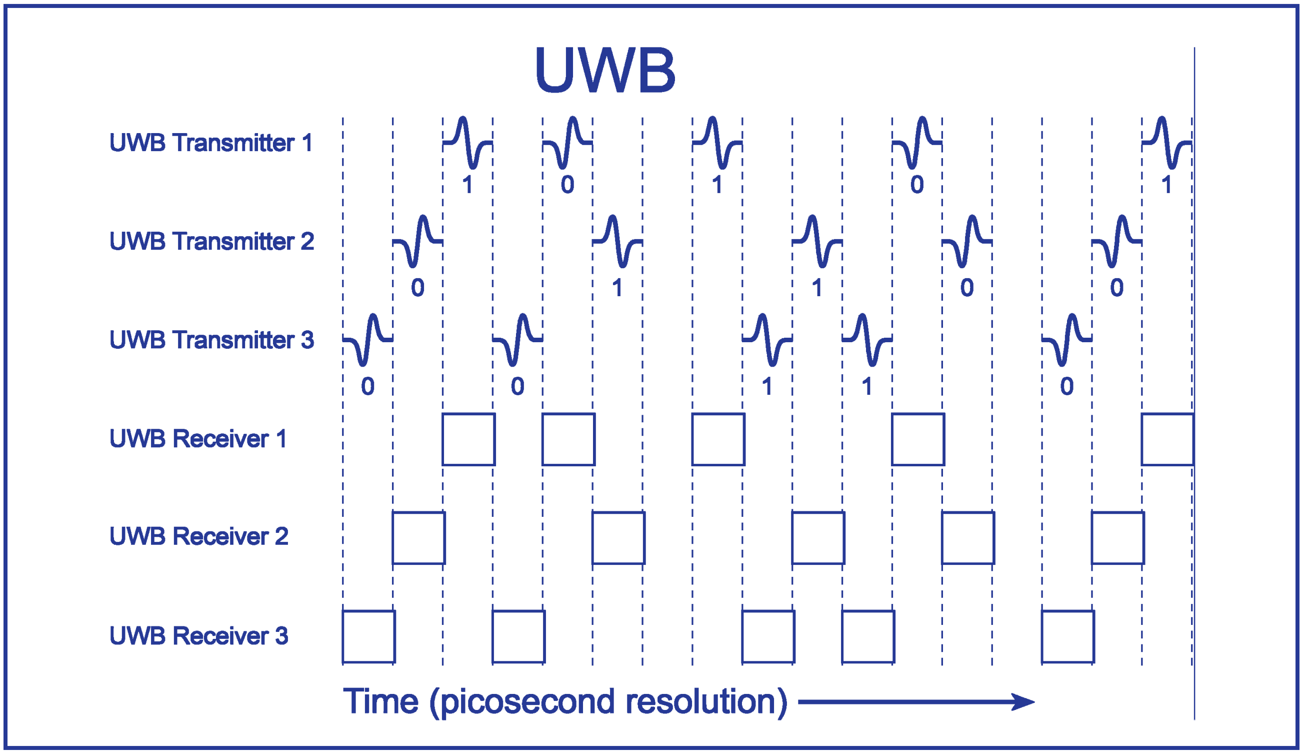
"The debate over UWB is political, not technical."

UWB creates virtual channels for multiple users by determining pulse-transmission times from unique pseudo-random number sequences. The transmitter varies the interval between pulses according to its pseudo-random number sequence; the receiver has to know the transmitter's pseudo-random number sequence to know *when* to listen for each pulse. Fig. 2 shows three transmitters and three receivers. Each receiver is keyed to the corresponding transmitter.

During a packet transmission, the UWB transmitter is on only in bit-long spurts. In contrast, narrowband transmitters and spread-spectrum transmitters are on continuously during packet transmission. Fig. 2 shows an important advantage of UWB transmitters and receivers: *low duty-cycle*. The transmitter is only on during the short pulse-transmit time. In typical applications, UWB's duty-cycle is less than one percent. Similarly, the receiver need listen only during the interval in which it expects a pulse. The low duty-cycle of the transmitter and receiver means low power dissipation and long battery life for portable devices.

In UWB transmitters, there's no fancy signal mixing to overlay the information on a high-frequency carrier. The UWB transmitter transmits ones and zeroes directly as regular or inverted pulses. The receiver gets ones and zeroes directly; there's no fancy signal decoding to recover information from a high-frequency carrier. That simplifies transmitter and receiver design. Further, UWB doesn't need the expensive analog components used in conventional radios. UWB is sometimes called "Moore's law radio" because its implementations—being largely free of analog components that don't scale—should get better, faster, and cheaper with Moore's law progress.

Figure 2. Ultrawideband transmitters vary the time for pulse transmission; the receiver must know when to listen (squares).



COMPANY	DATA TRANSFER	LOCATION	RADAR	WEB	PRODUCTS	COMMENTS
Aether Wire and Location		X		www.aetherwire.com		Prototype demonstrated.
AT&T	X			www.att.com		R&D
Broadcom	X			www.broadcom.com		
Discrete Time Communications	X			www.discretetime.com		
General Atomics	X			www.ga.com		
IBM Research	X			www.ibm.com		R&D
Intel	X			www.intel.com		Prototype demonstrated.
Multispectral Solutions	X	X	X	www.multispectral.com		Military systems in use.
Philips Semiconductor	X			www.philips.com		
Pulse-Link	X	X		www.pulse-link.com		Wireless and coax-based UWB. Chips in 2003.
Pulsicom		X		www.pulsicom.com		Chips in 2003.
STMicroelectronics	X			www.stm.com		
Texas Instruments	X			www.ti.com		
Time Domain	X	X	X	www.timedomain.com	Chipset	Backers include Sony, Kolon Group,WorldCom, Qwest, and Siemens. RadarVision product announced and demonstrated.
XtremeSpectrum	X			www.xtremespectrum.com	Chipset	Backers include Motorola, Cisco, TI.

Table 1. At least a dozen companies are working on UWB applications.

I've said that UWB pulses transmit without a carrier. That's true, but pulses still occupy a range of frequencies. I don't want to get too far into this, but a little is necessary to set the stage for UWB's reported capabilities and for the controversy that it engenders. The frequencies that make up a pulse depend on its rise and fall times and on the pulse duration.

A gunshot illustrates UWB properties. The sound of a gunshot is a pulse that occupies a wide range of frequencies. If you are listening for a gunshot, you don't have to monitor all the frequencies that its sound spreads across. Because it emits so many frequencies, you can detect it even in the presence of other noises or on the other side of a wall that blocks some frequencies. The same is true for UWB. Its receivers can tolerate interference because they know when to listen, and they only need to collect enough information to distinguish between a one and a zero. Some of the pulse's many frequencies will penetrate intervening objects, so the receiver might work through a wall that would block a narrowband signal.

Because it is based on precise timing, UWB can determine the relative distance to objects to within a centimeter. GPS receivers, for example, calculate time to within 20 nanoseconds, to measure position to within tens of meters. By comparison, UWB radios can resolve time differences to within 0.02 nanoseconds (1,000 times the precision). Because its frequencies penetrate objects differentially according to wavelength, UWB systems can image in or through objects. UWB's short pulses and accurate timing make data transmission at rates above 100 Mb/second feasible. A low-power UWB network could deliver multimedia data streams over short distances, such as in a home.

Ultrawideband: marketing

There's a lot of interest in UWB. The military has been its long-term backer and its best user. Civilian backers and interested parties include a who's who of corporate giants: Cisco, DaimlerChrysler, GE, IBM, Intel, Intersil, Motorola, Panasonic, Philips, Sharp, Siemens, Sony, STMicroelectronics, and Texas Instruments. The leaders in UWB are startups. The two key startups are Time Domain and XtremeSpectrum. These startups have funding from the likes of Cisco, Motorola, Qwest, Siemens, Sony, TI, and WorldCom.

Table 1 lists companies working on ultrawideband applications. UWB applications fall into three categories: data transfer, location and ranging, and radar and imaging. If that range of disparate applications makes UWB sound too good to be true, you may be thinking about it in the wrong way. Carrier-wave-based systems do all of those things, so we should expect to be able to implement the same applications with time-based systems. Carrier-wave-based systems

> **"Our static, fixed, dedicated frequency-allocation scheme makes spectrum space *seem* scarce."**

and time-based systems all use the same electromagnetic spectrum. The differences are in how they use the spectrum and in how efficiently they use it, not in what they can do with it.

A UWB radio might complement a GPS receiver in a cell phone. The GPS receiver gives absolute position if the cell phone is visible to enough satellites. Inside buildings or in places where GPS doesn't work well, the UWB radio complements the GPS receiver with precise relative location. A 100,000-transistor UWB radio occupies about 0.1 square millimeters, about the size of a bonding pad.

Time Domain's second-generation PulseON P200 chipset includes two silicon-germanium timer chips, two silicon-germanium correlator chips, and a CMOS logic chip. The timer chip is able to resolve pulse delays to 3 picoseconds. It takes light (or radio waves) about 3,000 picoseconds to travel one meter, so Time Domain's chip can resolve distances to about a millimeter. Time Domain expects to have a single-chip UWB radio, in a silicon-germanium and CMOS process, by 2004.

Ultrawideband: politics

In the last section, I said there was a lot of interest in UWB. There is, but it also has a lot of enemies and that's a big part of the story. The debate over UWB isn't technical; it's political. UWB's main opponents have been the airlines, the cellular carriers, the GPS industry, and the military.

This year, the FCC (Federal Communications Commission), which manages commercial radio spectrum, sent the UWB industry a valentine in the form of a new "report and order." After a long delay and despite enormous opposition, the FCC showed real backbone in issuing UWB's report and order. The FCC has promised to revisit the ruling. That's what happened with CDMA. Once CDMA got a foot in the door, subsequent rulings over a ten-year period improved its position. Now, UWB has a foot in the door.

"The right solution is an open spectrum policy."

The FCC's recent report and order established authorized frequencies and power limits for UWB operation. Generally, UWB is allowed to operate from 3.1 to 10.6 GHz. This frequency range avoids the issue of interference with GPS, which is at 2.4 GHz. The FCC's report and order also set power limits on UWB transmissions. UWB's transmit limit was set *2,000 times lower than the allowed RF leakage from a personal computer*. Some see this as a crippling limitation; UWB's advocates see this as better than nothing. They will at last be able to field systems.

Regulatory-process observers believe that Europe and Asia are likely to follow the FCC's report and order in approving UWB for their countries. Doing so would make it easier for UWB to succeed. Mirroring the FCC's allocations makes sense, as chipset and system development costs would be amortized over larger markets.

I said the FCC, which was established by the Communications Act of 1934, manages commercial spectrum, but that's only part of the story. The real spectrum management organization is more complex. The FCC is like the Wizard of OZ; the little man behind the curtain is IRAC. IRAC, the Interdepartmental Radio Advisory Committee, established in 1922, consists of representatives from twenty federal agencies (all branches of the military, DoC, DoJ, HHS, FAA, FCC, FEMA, GSA, DoI, NASA, NSF, USPS, et al.). Nominally, the IRAC is an advisory committee under the NTIA. The National Telecommunications and Information Administration, formed in 1977, is the FCC's counterpart for management of government spectrum. So, Congress controls the FCC, which controls the commercial radio spectrum. The executive branch controls the NTIA, which controls the government radio spectrum. And the IRAC is an NTIA committee. The kicker is that the IRAC, the granddaddy organization, has to vet FCC spectrum allocations, so the government's executive branch, not Congress, has the last word in control of spectrum.

I said the U.S. military was UWB's best backer and its biggest user. I also said the U.S. military is fighting UWB. Like spread-spectrum radios, UWB transmitters can be difficult to detect and their signals can be difficult to intercept. Since they are wideband radios, they are difficult to jam. UWB systems can give centimeter-accurate relative location, they can see through walls, penetrate foliage, and image inside of objects. What works for the military in a tactical situation can also work for its opponents. What puts the U.S. military on both sides of the issue is that the military would like to keep UWB for itself. That's not going to happen.

Even if UWB's development is stifled by political forces in the United States, UWB is not likely to be squashed everywhere. Singapore seems particularly receptive, but there's also China, Korea, Japan, and the United Kingdom.

Lessons

I thought to write a simple article about the state of ultrawideband. It was not to be. The issues are political ones. The real issues aren't the pros and cons of carrier-wave communication versus time-based pulse-driven communication. These are just two forms of communication. The magic things UWB's proponents say it can do are also possible with spread-spectrum systems. Real spread spectrum suffers from the same political problems that UWB is having and will continue to have. UWB and spread-spectrum systems are being forced to operate in an edict-based, narrowband, carrier-wave model that restricts their capabilities.

The flaw is a system that treats spectrum as property and auctions frequencies to grant monopolies. There's plenty of room for all the transmitters that want to operate: it's our static, fixed, dedicated frequency-allocation scheme that makes spectrum space *seem* scarce. Frequency allocation was instituted to separate the primitive radios of the 1920s. We no longer need a scheme that accommodates primitive radios. In fact, having a scheme that protects unsophisticated radios encourages manufacturers to build unsophisticated radios. Radios can now be a *lot* smarter than they were when frequency allocation was instituted. It's now cost-effective to use millions of transistors to make radios smart enough to avoid stepping on each other. Radios can improve at Moore's law rates; bureaucracy evolves at Darwinian rates.

The right solution is an *open spectrum* policy. Open spectrum would operate like our highway system, with free access to anyone and with a set of traffic laws. In today's allocation system, the company that wins a spectrum auction pays a huge premium for a monopoly on a wedge of frequencies. It must then build out the network to sell services. The company incurs two huge costs, buying the spectrum and building the service infrastructure, in exchange for a monopoly through which it hopes for a handsome return on its investment. Once the monopoly is established, there's little incentive to improve services. Moving to open spectrum avoids the cost of buying spectrum, which lowers the cost of entry for delivering services. Lowering the cost of entry encourages market-based competition. Companies can respond faster to market demand in delivering new capabilities.

Open spectrum isn't an impossible dream. It isn't as if we have to throw out the incumbents and start over. With spread-spectrum and with UWB, it's possible to "underlay" the current structure, which means that new services operate *below the noise floor* of legacy narrowband services. Legacy narrowband services continue to operate while spread-spectrum and UWB systems are implemented and deployed. Wi-Fi is a microcosm of the entrepreneurial market-based growth that an open-spectrum environment engenders.

It won't be easy. Carriers, who paid for radio spectrum, want to own it exclusively. Federal agencies don't want to share or to give up their part of the spectrum. The executive branch wants to control the spectrum, which it continues to view as real property. And the U.S. military doesn't want the capabilities of its proprietary equipment going to potential enemies.

> Normally, good questions and points for assessing technology are:
>
> What does it do that can't be done better, cheaper, or with less power, by conventional techniques?
>
> What applications value these improvements to the extent that one can reasonably expect it to be adopted?
>
> Replacing existing systems is hard.
>
> How much of the energy is vendor push vs. customer pull?
>
> Get answers to these questions outside an environment of hype.

What's arresting about this for wideband is that even with answers that strongly favor wideband adoption, the biases of the frequency-allocation bureaucracy make this assessment moot.

I'd like to choose a couple of UWB companies and to say that their future is assured, but I can't do that. While UWB has technical advantages in implementation simplicity and in power efficiency, it lags Bluetooth and Wi-Fi in the market. Bluetooth and Wi-Fi may have too great a lead in deployed systems and in moving down the learning curve toward cheap integrated implementations. To complicate the situation, both UWB and spread spectrum are hamstrung by powerful political interests and by real-estate-mentality frequency management.

Dynamic Silicon Companies

The world will split into the tethered fibersphere (computing, access ports, data transport, and storage) and the mobile devices that collect and consume data. Dynamic logic and MEMS will emerge as important application enablers to mobile devices and to devices plugged into the power grid. We add to this list those companies whose products best position them for growth in the environment of our projections. We do not consider the financial position of the company in the market. Since dynamic logic and MEMS are just emerging, some companies on this list are startups.

Company (Symbol)	Technology Leadership	Reference Date	Reference Price	9/30/02 Price	52-Week Range	Market Cap.
Altera (ALTR)	General Programmable Logic Devices (PLDs)	12/29/00	26.31	8.67	8.88 - 27.59	3.32B
Analog Devices (ADI)	RF Analog Devices, MEMS, DSPs	12/29/00	51.19	19.70	19.07 - 48.84	7.2B
ARC Cores (ARK**)	Configurable Microprocessors	12/29/00	£0.34	£0.27	£0.20 - £0.64	£0.77M
ARM Limited (ARMHY***)	Microprocessor and Systems-On-Chip Cores	11/26/01	16.59	5.9	5.26 - 19.20	1.98B
Calient (none*)	Photonic Switches	3/31/01				
Celoxica (none*)	DKI Development Suite	5/31/01				
Cepheid, Inc. (CPHD)	MEMS and Microfluidic Technology	12/17/01	4.73	3.85	2.23 - 11.48	118.1M
Chartered Semiconductor (CHRT)	CMOS Semiconductor Foundry	7/31/01	26.55	5.43	5.43 - 30.36	752.6M
Coventor (none*)	MEMS IP and Development Systems	7/31/01				
Cypress (CY)	MEMS Foundry, Dynamic Logic	12/29/00	19.69	6.56	6.77 - 26.20	807.9M
Cyrano Sciences, Inc. (none*)	MEMS Sensors	12/17/01				
Energy Conversion Devices (ENER)	Ovonic Unified Memory	6/18/02	27.69	10.85	9.47 - 25.73	237.6M
Flextronics International (FLEX)	Contract Manufacturing	8/6/02	7.68	6.97	5.85 - 29.99	3.62B
Foveon (none*)	CMOS Imaging Chips	6/18/02				
Legend Group Limited (LGHLY.PK)	PCs and Consumer Electronics	8/6/02	6.63	6.90	N/A	N/A
Microvision (MVIS)	MEMS-based Micro Displays, Nomad Head-Worn Display, Scanners	6/18/02	6.80	3.78	2.64 - 16.32	54.7M
National Semiconductor (NSM)	Geode x86 Microcontrollers, Consumer Orientation, 51% Ownership of Foveon	6/18/02	32.30	11.94	11.25 - 37.30	2.16B
QuickSilver Technology, Inc. (none*)	Dynamic Logic for Mobile Devices	12/29/00				
SiRF (none*)	Silicon for Wireless RF, GPS	12/29/00				
Taiwan Semiconductor (TSM†)	CMOS Semiconductor Foundry	5/31/01	14.18 ††	6.35	6.33 - 19.08	23.5B
Tensilica (none*)	Design Environment Licensing for Configurable Soft Core Processors	5/31/01				
Transmeta (TMTA)	Microprocessor Instruction Sets	12/29/00	23.50	0.97	0.85 - 4.47	123.0M
Triscend (none*)	Configurable Microcontrollers (Peripherals)	2/28/01				
United Microelectronics (UMC†)	CMOS Semiconductor Foundry	5/31/01	10.16	3.53	3.59 - 10.02	9.42B
VIA Technologies (2388.TW)	x86 Microprocessors for "Value" PCs	6/15/02	78.00	47.60	45.00 - 127.87	N/A
Wind River Systems (WIND)	Embedded Operating Systems	7/31/01	14.32	3.22	3.30 - 20.14	253.3M
Xilinx (XLNX)	General Programmable Logic Devices (PLDs)	2/28/01	38.88	15.84	13.71 - 47.16	5.36B

† Also listed on the Taiwan Stock Exchange

†† TSM reported a stock split on 6/29/01. The Reference Price has been adjusted for the split.

* Pre-IPO startup companies.

** ARK is currently traded on the London Stock Exchange

*** ARM is traded on the London Stock Exchange (ARM) and on NASDAQ (ARMHY)

NOTE: This list of Dynamic Silicon companies is not a model portfolio. It is a list of technologies in the Dynamic Silicon paradigm and of companies that lead in their application. Companies appear on this list only for their technology leadership, without consideration of their current share price or the appropriate timing of an investment decision. The presence of a company on the list is not a recommendation to buy shares at the current price. Reference Price is the company's closing share price on the Reference Date, the day the company was added to the table, typically the last trading day of the month prior to publication. The authors and other Gilder Publishing, LLC staff may hold positions in some or all of the companies listed or discussed in the issue.