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Powering the Telecosm
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Powering RF Photons

UltraRF has ingenious designs, deep history, critical intellectual capital, as well as a line-up of significant customers

If you're trying to power a Sun server, "clean power" is a perfect 60 Hz sine wave with rock-solid 110 volt peaks. For powering a Pentium-class chip on a motherboard, it's a perfectly steady 1.2 volts DC. And for warming 100 cubic miles of air, clean power is perfect control of voltages that oscillate wildly between 0 and 26 volts at 2.2 GHz — a meticulously scored symphony of frequency and amplitude, with power ranging from pianissimo watts to fortissimo kilowatts.

Hold on, hold on. Who needs clean power to heat the air? Are we talking microwave ovens, here? No, we're talking Qualcomm (QCOM) phones and broadband wireless modems. What matters, of course, isn't the power that ends up warming the air, it's the tiny fraction that gets through the ether to transmit the bits, it's just that most of it doesn't get through. And it takes some remarkable engineering to raise power levels enough at the base station antenna to punch a detectable stream of bits through to the receiver.

Cut to the chase: The technological linchpin to broadband wireless is the multi-channel radio-frequency (RF) amplifier. The single most critical and expensive component inside is the RF powerchip – a chip that can cleanly amplify a gigahertz-frequency signal up to power levels of 10 to 200 watts, and beyond. The best chip architecture is the laterally diffused metal-oxide-semiconductor (LDMOS), first developed in the early 1990s with commercial production emerging less than five years ago. Wherever CDMA (code division multiple access) goes, the LDMOS chip will follow. No, turn that around: the power chip must lead. CDMA isn't going anywhere fast without LDMOS power amplifiers in base stations.

Only a few companies make suitable high-power LDMOS powerchips in the 0.8 to 2.2 GHz frequency range that much of broadband wireless will occupy. Only three make them at the 2 GHz epicenter of the future wireless world, CDMA territory. Two are familiar names from the Telecosm; Motorola (MOT), and Ericsson (ERICY). And then there's UltraRF, the wholly owned semiconductor subsidiary of Spectrian (SPCT), Sunnyvale, CA. It's going to give the big guys a very good run for their money. Lucent (LU), Nokia (NOK), Samsung, LGC, and Alcatel (ALA) are all numbered among UltraRF's customers. And via the UltraRF powerchips inside Spectrian's own amplifers, count also as customers Nortel (NT), Sam Ji Electronics, Pulsar Microwave, Sanmina (SANM), Telaxis (TLXS), Air-Tech, Italtel, Hughes (GMH), Microwave International, and GSS Array Technologies.

Electron Space and Photon Space

It takes power to move bits. Lots of power, in a compact space. Much of it has to be supplied upstream of smartchips, to provide the power that ultimately moves electrons through gates on the surface of silicon. But after the processor, the bits must often move again. A rapidly growing number must travel through the airwaves.

And the ether is rough territory, electrically speaking. The dissipation and decay begin the moment the photons leave the antenna. Each wireless "cell" is a vast volume of atmosphere filled with dust, buildings, and water vapor – which shift phase and create a confusing jumble of reflections and destructive interference. Outside the magnificently pure and isolated confines of fiber optic glass, photon space is an energy-dissipating, entropy-boosting, information-degrading mess.

As readers of our sister publication, the Gilder Technology Report well know, the genius of CDMA is that it uses a very sophisticated coding algorithm to make the best of this inherently bad business. Locked into a very smart feedback loop with its counterpart at the far end of the wireless link, the CDMA coding continuously adjusts both frequencies and power levels, locating and using the clear pathways in the swirling turbidity of the ether, thereby vastly expanding bandwidth, the holy grail of the Telecosm.

But however brilliant this bandwidth-blasting technique, the chip that encodes the signal as CDMA can't generate anywhere near enough power to punch the photons through to their intended destination. The signal emerges from that stage at a power of milliwatts; the base station antenna, by contrast, requires 20 W to 200 W to get signals through to mobile handsets. So the signal needs at least a thousand-fold boost. That takes power amplifiers.

The acoustic amplifier in your den handles a frequency range of about 20 Hz to 20,000 Hz, at a peak power range of (say) 2 x 20 Watts. Notwithstanding what you may have paid for your Harmon Kardon, the truth is, that isn't too hard, not even if you need 10 x 20 kilowatts for a Rolling Stones concert. By electrical standards, audio frequencies are pretty tame. It's quite straightforward to build electronics that are a lot faster than the output required to drive the mechanical cones in loudspeakers.

The amplifier in a wireless base station has to drive an electromagnetic wave in an antenna at ultra-high frequencies, not electrical driving mechanical (audio), but electrical driving electrical (radio). The final output changes almost as fast as it's possible to drive the power electronics that are endeavoring to amplify it. That makes things much more difficult.

The perfect amplifier is perfectly transparent, it doesn't change the phase or frequency of what it amplifies, its "gain" and "phase shift" are uniform across all frequencies, and for all power outputs. Anything less renders the amplifier part of the fog, part of an entropy-boosting, information-degrading mess. The electron space immediately upstream of the antenna now compounds two of the very problems that it is there to overcome – the phase shifting and interference that degrade performance in the photon space downstream. If the amplifier is boosting more than one "channel," then the added noise may spill from one channel to the next, as "intermodulation distortion" (IMD). The wireless customer at the other end hears cross talk, static, or worse.

High, dynamic range poses especially stiff demands on power amplifiers – and dynamic ranges are rising very fast. In pure frequency modulation (FM) – used, for example, for analog cell phone service – the signal's amplitude doesn't vary at all, so the peak-to-average power ration is 0 dB. The RF power amplifiers used in conventional, analog cell phone service are single-carrier units. To serve multiple users from a single base station, manufacturers use a "combiner" that channels the outputs of multiple single-carrier amplifiers to a single antenna.

But the very genius of CDMA *requires* a wild dynamic power range. In all advanced, higher capacity modulation schemes — TDMA, CDMA, and W-CDMA — one RF carrier supports more than one user. The signal is now modulated in both amplitude and phase. And in one engineering step beyond that, a single amplifier is required to support multiple RF carriers. Even GSM and GSMK have a 1.5 dB peak-to-average ratio. (Even though it is a pure FM modulation, GSM has power control mechanisms that entail some dynamic range in power output.) Power ratios rise sharply from there, as wireless networks move from today's second generation (2G) infrastructure to the rapidly emerging third generation (3G) infrastructure.

All 3G schemes use both phase and amplitude modulation to convey the most information in the least amount of bandwidth. An amplifier that needs to put 20 W (average) to an antenna transmitting CDMA encoded photons must intermittently handle power levels swinging up 9 dB, or 160 W. The 3G world presents veteran designers of RF amplifiers with technology requirements that have never before converged within a single device — much less one that is small, cheap, and reliable enough to deploy in the hundreds of thousands, and then millionsof dispersed based stations — that the 3G network operators will require.

Running Room, Head Room, and Elbow Room

So how have these problems traditionally been solved? Through a give-it-room approach: waste space, waste hardware, waste power, and waste spectrum to save bits. The exact opposite of what is supposed to happen in digital space.

Behold the monstrous TV transmitter, with RF amplifiers running to hundreds of kilowatts containing banks of monster 20 kW vacuum tubes to boost the MHz signals before they are sent to an antenna perched on top of soaring masts 500 to 1,000 feet tall. If that particular transmitter happens to be a 76 MHz antenna 1,689 feet above New York City, then it's WNYW Fox Channel 5 TV, and nobody else within 60 miles will be permitted to broadcast on that channel. Physical spacing is the traditional, dumb, wasteful, answer to the threat of interference in photon space. Collision avoidance is handled in much the same way as it is for jets – just keep them far apart. Call it running room.

Much the same approach has been used to avoid collisions in the electron space of the amplifier. Give each amplifier "head room," fill it with oversized powerchips, back them well off from the peak power they can handle. In other words, build a V-8 Lexus, and drive it at 30 mph. Give it elbow room, too – wide "guard bands" between the frequencies that actually carry data – waste spectrum at the margins, and dedicate separate amplifiers to separate bands.

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At worst, elbow room requirements extend even to separate antennas, feed lines, and (possibly) transmitters and filters. If a single antenna is used, then the outputs of several single-channel amplifiers are first merged in a "combiner," the complexity of which increases with the number of channels combined. Cavity combiners, which cost more, cut final power output by 1.5 dB (from 25 W to as low as 18 W, for example). Hybrid combiners are cheaper, but cut power by about 3 dB (from 25 W to 12 W). And cavity combiners also require at least one carrier spacing between signals, so four carriers require two combiners, and two separate antennas. Cavity combiners waste space – the big metal box, geometrically tuned to precisely the correct frequency, fills the bottom half of a six-foot rack of silicon. Temperature fluctuations change its geometry, which causes frequency drift. Think of it as an expensive, power-wasting, microwave oven that doesn't like heat.

The give-it-room solutions work – but they are at war with the fundamental technology imperatives of the Telecosm. The overarching objective in the wireless Telecosm is to push things in precisely the opposite direction – to use higher frequencies and wider dynamic ranges of power, to stuff more channels into a single amplifier, to shrink the amplifier and its components down, and to run smaller powerchips closer to their maximum rated power. CDMA, the smartest scheme for pumping bits through the fog of the airwaves, is smartest precisely because it modulates both frequency and power levels more aggressively than the alternatives. It pushes dynamic range to the hilt. And it wastes no spectrum on guard bands, not if it doesn't have to.

The give-it-room solutions are equally at odds with the practical engineering realities of building base stations. Other things being equal, the laws of physics demand more power to pump broadband-sized buckets of photons through the ether than narrowband buckets. That means bigger power supplies, cooling systems, and backup batteries in existing base stations. But few existing base stations have room for such retrofits, least of all the ones in urban areas where the demand is. So the more powerful broadband signals are going to be pushed through smaller amplifiers, not bigger ones, to free up space for the power supplies themselves.

Finally, the defining genius of all cellular wireless schemes is that you can push more bits by packing transmitters more densely. Less power per transmitter – but more transmitters per square mile – lets you move more bits per frequency band, because the same bands can be reused in non-adjacent cells. But there won't be more transmitters per square mile unless they come in smaller packages – microcell (suitcase-sized) and picocell (book-sized) units, small enough to be deployed in many places where larger units wouldn't fit, or would be too unsightly to tolerate. Suitable locations are already in short supply. It's been quite a struggle to find sites for the 140,000-plus base stations already in operation in North America (over a million worldwide). At least 200,000 more will be needed in just the next few years in the U.S. market alone; the coming decade will need a million wireless transmission nodes (macro, micro and picocells), if a broadband wireless infrastructure is to become a reality. The engineers who are building wireless networks recoil at talk of head and elbow room, because more room in the electronics inevitably requires more room in the box, and there is no room to spare.

LDMOS Chips

The solution: a "linear" amplifier that can handle a broad range of frequencies, i.e. a multi-carrier power amplifier (MCPA). Gain and phase shift through amplifier must stay constant as power levels change. One such device can replace four (or more) single-channel power amplifiers (SCPAs). Each carrier frequency is fully used and no spectrum is wasted on guard bands. Dispense with the bulky combiner downstream of the amplifier (along with extra antennas, line feeds, and possibly filters) and combine signals in a passive combiner upstream of the amplifier, at smartchip power levels, rather than at powerchip levels downstream. By shedding clumsy hardware all around it, the amplifier saves power, which means less cooling overhead, and less standby power overhead, which allows for a more compact base station. Deploying smaller base stations in more places means you can push microcell architectures to the limit, which lets you lower the power used by each individual base station further still.

LDMOS has emerged as the architecture of choice for amplifiers in next generation wireless base stations

The key to the highly linear RF amplifier is the LDMOS transistor. The first LDMOS chip was built by Motorola in the early 1990s for low power handset applications; Motorola also came out with the first high-power LDMOS chips (suitable for base station amplifiers) in 1996. It wasn't until 1998, however, that Motorola and others followed up with LDMOS chips specifically designed for broadband wireless telecom and commercial broadcasting. In the two years since, LDMOS has emerged as the architecture of choice for amplifiers in next generation wireless base stations.

Taming electron flows at gigahertz speeds is not easy; the surface physics gets weird, and every stray nook and cranny of charge begins behaving like a disruptive inductor. Physical geometry, symmetry, and the shape and structure of the power leads themselves, all become critical. A key design objective for RF powerchips is that they like to be *very* close to the substrate printed circuit board – RF powerchips tend to look like an IC that's been flattened by a steam roller. Reducing distance lets you boost speed, and improve linearity over a broad dynamic range. But increasing distance, unfortunately, is generally what lets you handle more power – the whole point of a power amplifier.

In an ordinary bipolar junction power-amplifying transistor (BJT), the current flows through the device from top to bottom. As switching frequencies rise, the “thick” BJT hits its speed limit. An LDMOS device, by contrast, is a field-effect transistor (FET) in which the current flows laterally across the silicon surface. That fundamental geometric shift lowers residual capacitance in the gate, and — together with the voltage-driven (rather than current-driven) character of a FET device — greatly improves linearity and dynamic range at RF switching frequencies.

UltraRF has developed a unique geometry to accomodate the power swings of CDMA-style modulation, and to overcome LDMOS's inefficiency when operating off-peak power

BJT-based RF power amplifiers were first developed in the 1960s. In common with all other silicon technologies, BJT transistors have improved a lot over the years in terms of gain, output power, efficiency and reliability. BJTs utterly dominate the current installed base of single channel base station amplifiers, and until very recently were cheaper than LDMOS chips. (The cost advantage largely evaporated this year.) The fundamentals of the BJT architecture sharply limit its linearity as frequencies, power levels, and dynamic ranges rise. Changes that improve linearity (e.g. changing the bias) invariably entail a cost in efficiency and peak power.

LDMOS transistors combine very linear performance with high peak powers in the 1 GHz and 2 GHz range. As voltage-controlled (rather than current-controlled) devices, LDMOS cells are also inherently more scalable. They are also more rugged than bipolar transistors because they exhibit no thermal runaway. When a BJT gets hot it conducts more current, causing it to get hotter yet, and so on, in a cycle of thermal run-away and failure. LDMOS, on the other hand, has a negative coefficient. Which is to say, it becomes less conductive with heat and is thus self-limiting in terms of deadly thermal meltdown. LDMOS can also tolerate, briefly, very high peak “fault” currents. When an antenna is blown off a tower a cable fails, the full RF transmission power is reflected backwards into the amplifier and can, at GHz speed, double the already peak power on the silicon surface. (Protection circuits shunt this fault aside, but often not before the device itself gets a brief hit.) This kind of robustness is important — RF power transistors are the components that fail the most in RF base station amplifiers, and replacing dead amplifiers in the field is expensive for service providers. Amplifiers should fail gracefully (by failing to amplify sufficiently), not catastrophically (by melting down the power transistors), when peak power demands happen to exceed design levels.

Finally, because of its planar current flow, and LDMOS chip's input-output connections are all on one side, the chip can be bonded directly to a circuit board, using a bond optimized for thermal efficiency alone. BJT chips require one connection on each side; electrical isolation and thermal conductivity have to be supplied in the same place. Manufacturers use highly toxic beryllium-oxide.

The principal alternative to the LDMOS chip is Gallium Arsenide (GaAs) FET. GaAs is a remarkable (albeit expensive) semiconductor material, allowing very high frequency response and admirable linearity. GaAs transistors already are used extensively in wireless handsets.

The main limitation with GaAs centers on voltage, and thus power. An LMDOS chip operates at 26 V (with “drain source” outer limit about 65 V); a GaAs chip can't run reliably above about 12 V (with a drain-source limit of roughly 18 V). To push as much power through a GaAs chip, therefore, requires higher current. No problem for the GaAs chip itself – but the current has to come from outside the chip, across metal-to-semiconductor junctions. That interface is itself messy and gives rise to all sorts of new distortions and non-linearities when current flows get high. You can get around that problem, too, by making bigger chips or using more of them. Either way, you increase the total surface area of chip-to-metal contacts, and therefore reduce the current. But currents will still remain high on the “rail” that powers the chip. GaAs devices also require more elaborate and expensive protection against faults where their low peak voltage tolerance is a major liability.

GaAs is clearly the best option for the fractional-watt amplifiers found in handsets. But LDMOS is now rapidly emerging as dominant above 10 W, in base stations. GaAs may eventually rule base stations too, when they give way to millions of 5 W to 10 W picocells. But that will take a while, and by then LDMOS on silicon carbide may well have emerged as an even better option. (UltraRF, among others, is quietly researching the awesome thermal performance of SiC RF powerchips.) For now the base station action is centered on 200 W amplifiers for macrocells, and even larger, higher-power units for wide-area footprints. At that kind of power, LDMOS is better.

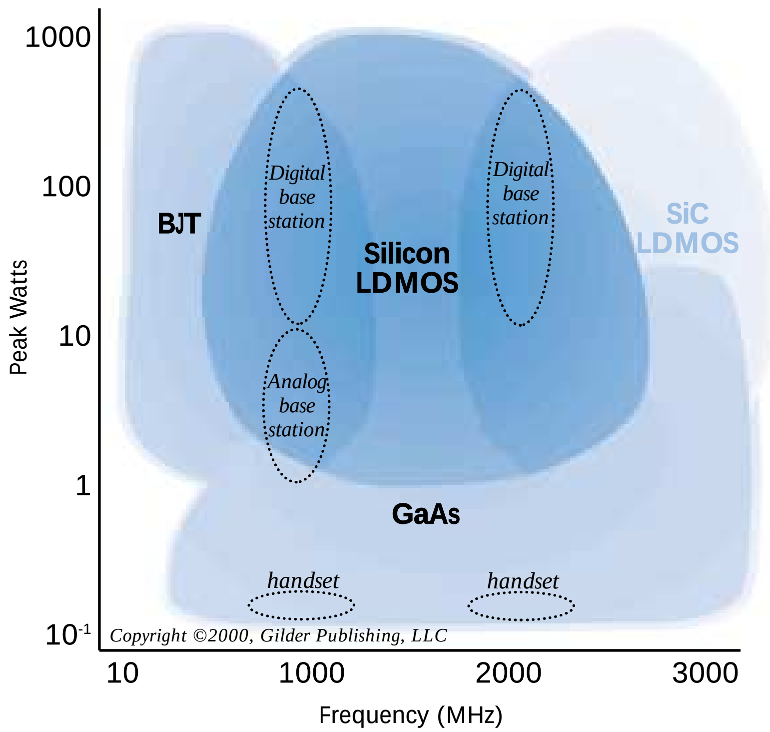
Spectrian / UltraRF

The high-power LDMOS market hardly existed four years ago. Today it accounts for roughly 50 percent of total sales of high-end RF powerchips. Virtually all next generation power amplifier design work is now anchored in the LDMOS chip.

But whose chip? Motorola remains the giant in the RF semiconductor field with roughly half the market overall, and a comparable share of the LDMOS market. Ericsson has roughly 20 percent. At the critical emerging 2 GHz frequency, UltraRF stands essentially alone today as a third player, and (we hope) a soon-to-be independent source. The market is still very young – still wide open for superior designs to emerge and dominate.

At first blush, the RF powerchip market might not seem very different from the field of AC/DC powerchips

The Sweet Spot for RF Powerchips



Bipolar junction transistors (BJT) power today's analog cellular base stations, LDMOS chips will dominate next generation digital base station RF amplifiers; Gallium Arsenide (GaAs) chips dominate in handsets and will compete with silicon carbide (SiC) LDMOS as wireless frequencies keep rising.

addressed in the April and May DPRs, with the technology edge centered in a straightforward core of intellectual property and engineering skills. But RF frequencies are thousands to millions of times higher than those encountered in the conventional power field. At the same time, RF amplifiers must deal with power levels that are millions of times higher, per gate, than those encountered in (say) a GHz Pentium of comparable speed. At these combinations of speed and power level, everything in and around the powerchip begins to look like an antenna, or inductor – a problem, in other words, that can all too easily distort the signal and contribute to the fog. Much of the art in manufacturing these chips and assembling them into clean amplifiers lies in the myriad details of the engineering. It is still at least half art, in the tradition of Stradivarius or the Swiss watchmakers of yesteryear.

The best design is the one that addresses this new chip architecture's gravest deficiency – its low electrical efficiency – when operating anywhere much below its peak power. Because broadband wireless algorithms yield average power levels well below peaks, LDMOS amplifiers threaten to create more waste heat, and run at higher temperatures that can degrade device reliability and life. Moreover, the main opportunity for LDMOS-based MCPAs in the short term is for replacing SCPAs in existing networks. For that to happen the MCPAs have to be not only physically compatible but *thermally* compatible, too, with existing base station set-ups. The big opportunity, however, is in the build-out of the 3G network, which will get seriously underway next year. (Ericsson, Nokia and Nortel are seen as the top network builders, and the latter two are expected to outsource most of their MCPA and LDMOS requirements.)

An LDMOS incorporates a set of individual RF cells linked in a long row. UltraRF's newest 60 W UltraGold II, for example, contains two 30 W LDMOSs each with 26 such cells. And UltraRF has come up with a unique geometry to accommodate the wild power swings of CDMA-style modulation, and to overcome the LDMOS's inherent inefficiency when operating off-peak power.

UltraRF has a solid history in RF amplifiers. Its parent was founded in 1984, as Microwave Modules & Devices, a military contractor. It acquired American Microwave Technology in 1988, a company selling RF power amplifiers to radio and TV equipment manufacturers. It entered the original bipolar cellular power amplifier market in 1990. Spectrian exited the military business in 1993, went public the next year and entered the new wireless telephone arena in 1995 with a Nortel Networks contract to support the build out of Canada's PCS base stations. Chris Tubis, UltraRF's current president, joined the company eighteen months ago, after doing time with National Semiconductor (NSM) wireless, and previously Siliconix's (SILI) power semiconductor group and Philips' (PHG) cellular chipset group. The UltraRF executive team brings experience from Fujitsu Wireless (FJTSY), NEC (NIPNY), Atari, Stellar, AMD (AMD), Boeing (BA) and ITT Industries (ITT).

UltraRF's UltraGold II high-power CDMA-focused LMDOS cell architecture looks like a bowtie when viewed from the top. Smaller, low-power cells are in the middle, where the knot in the tie resides, and bigger, high-power cells are on the wings. Power swings are handled by letting the smaller cells handle the signal during low power phases, and the big cells during the high power phrases. This nearly doubles efficiency under typical CDMA operating conditions, and achieves the industry's highest power density. (Under the less demanding intermediate move to 3G, EDGE – "enhanced data for GSM and TDMA evolution" — with 3 dB power swings, the architecture still yields 30 percent to 40 percent efficiency gains.)

UltraRF has implemented an additional (patented) efficiency-enhancing scheme as well. The concept itself dates back to 1936 – it was developed by Bell Labs' W.H. Doherty for use with big vacuum tube amplifiers – but UltraRF has adapted it to the LDMOS environment. Doherty's trick, adapted by UltraRF, is to divide the RF signal into two parts, one that contains a signal of fairly steady, average power, the other contains the high-power excursions. The steady component has a very limited, predictable dynamic range, and can be amplified through a different class of lower cost and highly efficient LDMOS amplifier. The unsteady component, which now contains less power than the original, is handled by a separate state-of-the-art LDMOS amplifier. Overall efficiency rises another 20 percent.

The second large challenge with LDMOS chips arises where the semiconductor connects to the rest of the world. RF engineering is an endless war against the stray sources of distortion that bedevil all RF power engineers. Ninety percent of the genius, in short, resides in sweating the engineering details. UltraRF has sweated them.

Even small (5 percent) changes in frequency call for microscopic but significant adjustments in locations of current carrying leads; at these RF frequencies, the entire device has to be perfectly tuned if it is to behave cleanly. UltraRF has developed ways to change the height of the wires that bond the already flat chip depending on whether it is destined for 1800 MHz, 1900 MHz, or 2100 MHz applications. The company has patents on such seemingly mundane things as how the transistor element is clamped down, how the gold is actually deposited, where and how the surface is patterned, how the ceramic packaging is assembled, and on the inclusion of special silicon nitride capacitors (fabricated on site by UltraRF) on the side of the packaging. All affect the final "tuning" of the device. UltraRF has optimized its fab line to accommodate the unique precision and repeatability from the pick-and-place equipment to the test equipment. UltraRF has designed and built its own off-the-shelf testers to qualify and sort its powerchips; such equipment can't be bought off the shelf, the testing of GHz chips at hundreds of watts is a new realm that demands precision and specialized cooling not required elsewhere.

The transition from narrowband to broadband wireless will spur a massive new investment for RF amplifiers

Aluminum is the standard for almost all ICs, but at RF frequencies aluminum behaves poorly and over time grows brittle. And at the high current densities typical in high-power LDMOS applications, aluminum atoms get pushed around too easily, the connections open up and the device fails. Many RF chips do employ aluminum nonetheless – but not the highest performance units from Ericsson or Motorola, nor any of UltraRF's chips. Gold leads are the answer, but gold is far more difficult to manage and etch into fine lines. And worse yet, gold atoms are a deadly poison to any CMOS line, any LDMOS line included.

Alone in the industry, UltraRF has mastered the operation of a fully integrated LDMOS Gold/MOS fab. Motorola relies on fully separate lines to fabricate its LDMOS chips and to bond the gold leads — indeed, the LDMOS chips now come from ON Semiconductor, which Motorola spun off last year. The gold metalization occurs at a separate (old) bipolar fab line that Motorola still owns. Ericsson uses a similar approach (although it owns both lines).

Together, these advances make for more thermally efficient chips, which can be packaged more compactly, which lets them move closer to the antenna, allowing the cell site to be built smaller still. Some 50 percent of the amplifier's power is typically lost in the cable that links the base station to the antenna. Build a small enough amplifier and it can be located at the top of the tower (or church steeple or fake tree) rather than the bottom. UltraRF's new PFM 1950 module pumps out 50 W in a package the size of a couple of KitKat bars.

Supplying LMDOS Chips to MCPA Manufacturers

A number of companies now build pretty fair approximations of a multi-carrier linear amplifier. Motorola, Ericsson, Lucent and Nokia collectively currently own about two-thirds of this $1.5 billion market. (The market is growing at about 25 percent a year.) The balance of the market is dominated by three smaller, fleet-of-foot pure-play companies; Powerwave (PWAV), Irving, CA, Microwave Power Devices (MPDI), Hauppauge, NY, and Spectrian. A few other niche players occupy the market too, such as RF Microdevices (RFMD), Greensboro, NC, and GHz Technologies, Sunnyvale, CA. MPDI left the "merchant" supplier market last month when Ericsson acquired it (a reversal of the network industry's trend towards outsourcing specialty hardware).

Spectrian, with $180 million in sales, ranks as one of the larger pure-play manufacturers of multicarrier RF amplifiers and the first to ship one able to handle CDMA and TDMA outside of the Ericsson-like integrated majors. Spectrian clearly benefits from the fact that network companies want more than one supplier of the hardware they need to ramp up in wireless broadband. And Spectrian is nimble – it has pushed its design-to-fabrication cycle from two years down to six months. But we consider the manufacture of LDMOS chips by Spectrian's subsidiary, UltraRF, more significant. And at least half the functionality, not to mention at least one third the cost of a PA, resides just in the RF powerchips.

Motorola and Ericsson (and Philips eventually, with their lower frequency LDMOS) remain formidable competitors to UltraRF, and together still dominate the LDMOS market. Motorola has the longest history in LDMOS, extensive patents, and appears to remain the leader in product variety and production volume. Philips's LDMOS chips are (at least for now) primarily in the 1 GHz range, too low for the critical 3G space. Ericsson recently made the mistake (in our view) of acquiring its own MCPA amplifier manufacturer (MPDI), which will surely make other MCPA competitors less eager to depend on it too strongly for their LDMOS supplies.

Spectrian now appears to be moving in the opposite direction. The company established UltraRF as an autonomous business unit in November 1999, then in June this year moved it one step closer to freedom, creating a wholly owned subsidiary, UltraRF Inc. Now it is exploring options to "enhance shareholder value" through various divestiture alternatives. With 30-plus patents (nearly a dozen more pending) and a team of 40 dedicated engineers in the LDMOS space, UltraRF's fab in Sunnyvale, CA, produces 12,000 wafers per year and is expandable to double that rate. Perhaps a spin-off IPO will provide the financing to do just that.

The all-important LDMOS market must inevitably come to be served by independent manufacturers, in much the same way as companies like International Rectifier (IRF) and IXYS (SYXI) are independent suppliers to the major brick and silicon-power-plant vendors like Power-One (PWER) and Artesyn (ATSN). RF power amplifier manufacturers won't want to rely on a single source for their critical LDMOS chips in any event, and will surely prefer to do business with chip suppliers that are not also direct competitors in the MCPA market itself. UltraRF has designed a number of 'plug replaceable' LDMOS modules to compete directly against Motorola and Ericsson units.

We do not expect many other competitors to emerge any time soon. Many smart chips – microprocessors, DSPs, and so forth – can be assembled through a lego-like process of assembling a substrate from one vendor, a chip from another, a heat sink from another, and packaging from yet another, and so forth. Hence, the proliferation of silicon foundries, and a growing class of merchant assemblers of OEM silicon devices. But you can't make a Stradivarius that way, nor an RF power amplifier. At RF frequencies, it's the entire assembly that has to be painstakingly tuned. Reverse-engineering your competition's violin is virtually impossible; the know-how about processes that yield the final result aren't discernable in the final package itself.

UltraRF has the opportunity, and by all accounts the skills, intellectual property, and management focus to challenge the big guys. As we noted at the outset, Lucent, Nokia, Samsung, LGC, and Alcatel are all already numbered among UltraRF's LDMOS-chip customers. UltraRF established earlier this year foundry support to supply LDMOS devices to amplifer-maker Stanford Microdevices (SMDI) as well as GHz Technologies. (Lucent has subsequently taken a minority stake in GHz to gain access to their linear amplifiers.) UltraRF also says it recently secured an OEM supply arrangement (following the industry-standard long 12 to 18 month design/validation cycle) with an unnamed major European wireless vendor.

A final validation of UltraRF's chips comes from the company that still remains (for now) its parent. Spectrian sells amplifiers built around UltraRF chips to Motorola, Sam Ji Electronics, Pulsar Microwave, Sanmina, Telaxis, Air-Tech, Italtel, Hughes, Microwave International, GSS Array Technologies.

Powering Photons

It takes power to move bits, and still more power to push bits through chaos-inducing media like the airwaves. Power amplifiers are the solution, if they work well enough. Defeating the fog in electron space is the essential precursor to penetrating the fog in photon space.

Broadband wireless is by far the most important application for LDMOS-based power amplifiers , but there are others. Television broadcasting still relies almost entirely on massive water-cooled vacuum-tube amplifiers – massive glowing beasts redolent of grade B Sci Fi movies of the 1950s. High-definition digital television creates a new class of power requirements. Tube-type amplifiers will give way, in the coming decade, to solid-state devices, built around massively parallel arrays of air-cooled LDMOS chips. The solid-state replacements will be more linear and reliable, easier to maintain, and much more efficient. Tube amplifiers have to be painstakingly tuned to the correct frequency; solid-state amps are field programmable. Power-supply voltages used in solid state transmitters are 500 to 1000 times lower than those required for tube transmitters. Other applications are emerging, such as pulsed radar systems, used in Traffic Collision Avoidance Systems in aircraft. Compact RF amplifiers can excite a small gas ampule producing controllable light of blazing intensity, suitable for radically new types of lighting and (perhaps) computer monitors.

But it is the transition from narrowband to broadband wireless that will spur truly massive new investment in RF amplifiers. At least half of all wireless customers are expected to have data-capable handsets by 2005. There are credible forecasts of a billion users worldwide accessing the Web over wireless links by 2004. Where the photons meet the network is in the hardware build-out, which will have to be massive and soon if demand grows anywhere near as fast as the projections suggest. Hundreds of thousands of new base stations will have to be deployed within a few years, in the United States alone, and millions more worldwide. Each unit will be required to have a much higher bandwidth — which will increase the average amount of silicon per station five- to ten-fold over today's configurations.

A substantial fraction of that silicon will be in RF powerchips. And the lion's share of those chips will be LDMOS chips. UltraRF is a relatively small company, and faces much larger, established competitors. But it has ingenious designs, deep history, and critical intellectual capital, as well as a line-up of very significant customers. If it does emerge as a fully independent vendor of high-frequency high-power RF powerchips — as we hope it will very shortly — it will be perfectly positioned to become a major supplier to the numerous manufacturers of RF power amplifiers that will be building for the vast new market of third generation broadband wireless.

Peter Huber & Mark Mills
November 2, 2000

The Power Panel

Ascendant Technology	Company (Symbol)	Reference Date	Reference Price	10/31/00 Price	52wk Range	Market Cap	Customers
Ghz Power RF Powerchips: LDMOS	UltraRF (SPCT)†	10/31/00	11 3/4	11 3/4	11 3/8 - 36 5/8	128m	Nokia, Samsung, Lucent LGC, Alcatel, Nortel
Network Transmission and UPS: High-temperature superconductor	ABB***	9/29/00	96 61/64	88 5/16	N/A	N/A	National Grid (UK), Microsoft, Commonwealth Edison, American Electric Power
	American Superconductor (AMSC)	9/30/99	15 3/8	48 15/16	15 9/16 - 75 1/8	983m	ABB, Edison (Italy), ST Microelectronics, Pirelli Cables, Detroit Edison, Electricite de France
Power: Heavy-Iron-Lite	General Electric (GE)	9/29/00	57 13/16	54 9/16	41 5/8 - 60 3/4	541b	Reliant Energy, Enron, Calpine, Trans Alta, Abener Energia, S.A.
	Catalytica (CTAL ➪ CATX)*	9/29/00	12 3/8	13 1/4	7 1/2 - 16 1/4	770m	GE, Kawasaki Turbines, Enron, Rolls Royce, Solar Turbines
Electron Storage & Ride-Through Flywheels	Active Power (ACPW)	8/8/00	17**	37 1/8	17 - 79 3/4	1.4b	Enron, Broadwing, Micron Technologies, PSI Net, Corncast Cable, ABC
	Beacon Power (BCON)	IPO date pending	11-13**	N/A	N/A	N/A	Century Communications, Verizon, SDG&E, TLER Associates, Cox Cable
Hydrogen Generation	Proton Energy Systems (PRTN)	9/29/00	17**	26 7/8	15 3/16 - 36	858m	Matheson Gas, NASA
Distributed Power Generation Microturbines	Capstone Turbine Corp. (CPST)	6/29/00	16**	55 1/16	16 - 98 1/2	4.1b	Chevron, Williams ECU, Tokyo Gas, Reliant Energy
Fuel Cells	FuelCell Energy (FCEL)	8/25/00	49 7/8	76 3/4	8 3/4 - 108 3/4	1.2b	Santa Clara, RWE and Ruhrgas (Germany), General Dynamics, LADWP
Micropower Nano-fuel cells	Manhattan Scientifics (MHTX)	8/25/00	2 3/4	3 1/16	15/16 - 8 5/8	N/A	Incubator (no customers)
Silicon Power Plants In-the-room DC and AC Power Plants	Emerson (EMR)	5/31/00	59	71 15/16	40 1/2 - 72 3/8	30.7b	Citicorp, Verizon, Nokia, Motorola, Cisco, Exodus, Qwest, Level 3, Lucent
	Power-One	*(see below)*					
Motherboard Power Bricks, High-end DC/DC converters	Power-One (PWER)	4/28/00	34 1/8	71	6 1/32 - 89 3/16	5.2b	Cisco, Nortel, Teradyne, Lucent, Ericsson
Powerchips: Insulated gate bipolar transistors (IGBTs)	IXYS (SYXI)	3/31/00	6 25/32	26 3/8	1 17/32 - 45 3/8	697m	Rockwell, ABB, Emerson, Still GmbH Eurotherm Ltd. (UK), Alpha Technology
IGBTs	International Rectifier (IRF)	3/31/00	38 1/8	45 3/16	19 7/8 - 67 7/16	2.8b	Nokia, Lucent, Ericcson, APC, Emerson, Intel, AMD, Ford, Siemens
	Advanced Power (APTI)	8/7/00	15	31 1/2	15 - 49 5/8	247m	Alcatel, Ericsson, ITI, Power-One, Advanced Energy Industries, Emerson

Note: This table lists technologies in the Powercosm Paradigm, and representative companies that possess the ascendant technologies. But by no means are the technologies exclusive to these companies. In keeping with our objective of providing a technology strategy report, companies appear on this list only for the core competencies, without any judgment of market price or timing. Reference Price is a company's closing stock price on the Reference Date, the date on which the Power Panel was generated for the Digital Power Report in which the company was added to the Table. All "current" stock prices and new Reference Prices/Dates are based on the closing price for the last trading day of the month prior to Digital Power Report publication. IPO reference dates, however, are the day of the IPO. Though the Reference Price/Date is of necessity prior to final editorial, printing and distribution of the Digital Power Report, no notice of company changes is given prior to publication. Huber and Mills may hold positions in companies discussed in this newsletter or listed on the panel, and may provide technology assessment services for firms that have interests in the companies.

** On August 2, Catalytica (CTAL to become CATX) announced plans to merge with DSM, (Heerlan, Netherlands). The Combustion Systems unit and Catalytica Advanced Technologies, will be spun off together, to shareholders, as "Catalytica Combustion Systems" (CATX) in December 2000. This will leave Catalytica's third subsidiary, Catalytica Pharmaceuticals (largest current source of corporate revenue) with DSM.*

*** Offering price at the time of IPO.*

**** ABB presently trades on the Zurich Exchange but plans on a U.S. listing on the NYSE later this year.*

† UltraRF Inc. is a wholly owned, separate subsidiary of Spectrian with an announced plan to explore options to "enhance shareholder value" including the possibility of spin-off or IPO.