"MOEMS the Word" [Others have copied this title in later years]
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INTRODUCTION

In 1880, Alexander Graham Bell sent his voice over a sunbeam using his newly invented Photophone. Bell believed this concept to be much more significant than his *wire-bound* telephone that had made him rich and famous. Bell was correct, but the world would wait more than a century for photonics to really succeed.

Did you know that you're using *light* to travel the Internet Highway? Our marvelous inter-global network is built mostly of glass – optical fiber. The "copper road" is quickly becoming the "Glass Super Highway" as long-haul land-based communications and transoceanic pathways trade electrons for swift photons. Nothing can be faster than light, but more important, no other medium can offer wider bandwidth when multiplexing strategies are used.

Light-based communications, called photonics, now uses a *rainbow of colors* to get more bandwidth – data/second. This is called WDM for Wave Division Multiplexing. WDM simply means using different wavelengths, or colors, for each stream of data over the same link. The industry is moving to 100's of wavelengths all sent down a single thin fiber. But since multiple fibers span the world, we can multiply the number of fibers by the number of wavelengths for phenomenal bandwidth. Photonics will require new materials, processes and equipment as this multi-billion dollar industry ramps up. The newest photonics systems can carry the equivalent of 12,000 encyclopedias from Boston to Los Angeles on a single fiber in one second.

How will this affect electronics? Will we learn to assemble optical components that are connected with fiber optics instead of copper? Perhaps, but for the present optical controllers and Internet switches have a considerable electronics content. And their electronic zones are still assembled with SMT. The optics modules are hand assembled under a microscope with essentially no automation. But the technology is embryonic and changing at Internet speed, so expect surprises.

MEMS and MOEMS

You've probably already encountered these acronyms but do they have anything to do with circuits and assembly[1]? But first, what do the terms mean? We're familiar with modern solid state electronics where millions of transistors are fabricated into a thumbnail-sized piece of silicon where electrons do all the moving. MEMS, or micro-electro-mechanical systems, adds mechanical movement while retaining the electronics technology. Now add optics to MEMS devices and you have optical MEMS that some prefer to call MOEMS for micro-optical-electro-mechanical systems. Now we have everything on a chip but the kitchen sink. But someone will undoubtedly add that sink since these devices can pump fluids and turn valves. In fact, your ink jet printer cartridge has a MEMS chip with multiple pumps that fire ink micro-drops at the paper.

These newer 21st-century technologies add well-understood sciences to electronics as depicted in Figure 1. But MEMS and MOEMS are not laboratory curiosities. They are commercial today even if their full ramification is not yet fully appreciated. What's been important to success is that materials and process fit the giant semiconductor industry. The infrastructure is already in place. What's more, older fabs that can no longer handle the ultra-high density of advanced CPUs and memory are perfectly good for the dynamic duo that requires less density. The ability to tap into a $200-billion dollar infrastructure gives MOEMS a big advantage and a running start.

Figure 1 – Technology Convergence

The MOEMS Driver

Now we need to step out of the nano-world for a moment and look at the big picture of world-wide communications since that is the new driving force for MOEMS. The Internet is the core of modern communications and it becomes more important each month. Perhaps our ever-increasing boost in productivity is mostly the result of Internet-based transactions, especially B2B (business-to-business). Yes, the Internet is here to stay and we are all caught up in its pervasiveness, as the world becomes totally interconnected. While "dotcoms" can be fun, perhaps enabling the "dotcoms" is even more exciting, especially for us technologists. So let's take a look at the system shown in Figure 2 to understand how this massive network can run at *Internet speed* – using LIGHT!

Figure 2 – Internet Links

Our telephone network adopted photonics, the use of photons for communications, many decades ago. There is nothing faster, more efficient and more economical than light when it comes to terrestrial communications. Fiber was the *right choice* for AT&T and for Sprint who lets you *hear a pin drop*. Intercontinental links, called submarine, since they lie under the oceans, have also gone fiberoptics. And why not since fiberglass does not corrode, few amplifiers are required and they can even be powered by light. So when the Internet went "big time", fiberoptics was the only smart choice, at least for the long haul segments.

The telephone and Internet terrestrial fiberoptics networks have been rather simple in deployment. Electronically modulated lasers fire beams of data down the pipe of fiber at data-rich frequencies. The signals may be boosted a few times by optical amplifiers before getting to their destinations although the newest fiber may handle 2000-meter runs without amplification. Big electronic routers located at strategic geographical points, send the signals to the desired locations by interpreting packet codes that act like zip codes. But today's million-dollar routers must first convert photons to electrons, route the signal and then convert back to photons. This hybrid system is called O-E-O for opto-electro-opto. Yes, it works and many cling to the safety net of using well-understood electronic switching/routing. Some believed that we could stay with this architecture indefinitely, but then came the rainbow.

A few years ago, the Internet hardware makers and providers (often the same) were faced with the dilemma of how to deal with insatiable bandwidth demands. Just add more fibers? No, just add more colors on the same fiber. And the WDM phenomenon was reality. Wave Division Multiplexing simply means adding more wavelengths to carry data. Data 1 could use red and data 2 could use blue giving twice the capacity of the network. NOW – add 100 wavelengths and the system has boosted bandwidth 100 times without adding a single new fiber. While many experts said that WDM could not be implemented, it succeeded rapidly with many technical breakthroughs that surprised the optics industry. In fact, we are already moving to Dense WDM, or DWDM that is defined as 16 or more wavelengths. What's the limit? Hundreds are planned, but thousands may be possible. Figure 3 shows the WDM principles.

Figure 3 – WDM Diagram

How Does WDM Work?

The individual data wavelengths are merged or multiplexed into a single beam that is sent down the fiber. The information travels independently without any significant interference. When it comes time to route, the merged beam is demultiplexed or split back into the original wavelengths, somewhat comparable to shining white light onto a prism to get a rainbow. Now our remarkable photonic system must drop back to electrons, switch, and then return to the photon state. But with all of these additional wavelengths, the O-E-O system and its double conversion is becoming heavily burdened and may eventually crumble under its own weight so to speak.
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But how can we catch a beam of light and send it off in the right direction? The simplest configuration is an on/off switch where an optical valve or shutter can let light pass or block the path. This can be done with an add/drop switch where a particular wavelength is permitted to pass (added) or is blocked (dropped). Add enough of these units and light can be routed. These simple MOEMS devices can be shutters, MARS (Mechanical Anti-Reflective Switch)* and a whole variety of other systems. Today, Internet hardware makers are building A/D modules and assembling them into large switch cards that may be 18" long. The optics components are hand assembled to traditional electronic boards. Alignment is

* Lucent

critical and tedious, taking many minutes under a microscope to align and anchor the hair-thin fiber with solder and adhesives. Figure 4 shows an optical cross-switch configuration. Note that the number of switches is n^2 where n is the number of optical feed lines.

Figure 4 – Optical Cross-Switch

The metal-housed A/D modules, measuring 6 to 8" long are then assembled to router rack cards that are larger and heavier than laptop computers. Right now, a major supplier is assembling 4 A/D modules onto one card, but moving to 8 units soon. After a one-hour manual assembly, the big card is ready to test. Testing can take over an hour using an 8-ft high rack of sophisticated, computer controlled gear costing nearly $1-million. The final switch module destined to direct traffic on the Internet highway sells for a cool $30K to $50K. The units are still really electronic products with a pinch of photonics components. Most of the electronic assembly is traditional SMT. But will it stay that way? Not when the real MEMS gets into the picture.

Right now, photonics is mostly smoke – from solder irons and ovens. But very soon, the mirrors will be added. We are on the verge of the Photonics Revolution where magical micro mirrors will catch a lightbeam and instantly route it into cyberspace. The change from O-E-O to pure optics O-O (opto-opto) will be dramatic, perhaps like moving from vacuum tubes to the transistors. Now enter advanced MOEMS. The Internet giants have bet billions of dollars of acquisition money on O-O switching just in 2000. Imagine a silicon device, no bigger than a computer chip, but with 100's of thousands of moving parts. In fact, the most complex man-made machine, the Boeing 777, took second place when a MOEMS mirror array snatched the crown with higher parts count.

Shedding More Light on MOEMS Mirrors

Advanced MOEMS products have a high level of complexity. The chip is hermetically sealed and a light path is certainly required[2]. The solution is somewhat apparent, but implementation can be a Herculean task. A light-transmissive lid or "port hole" is designed into the package. Several materials can be used. The micro-mirror module from Texas Instruments is one of the best examples of a complex photonic product. Figure 5 shows the Digital Micro-mirror. Switches will most likely use fiber optics connectors instead of windows.

Device™ (DMD) [3]. Figure 5: TI Micro-Mirror Module, ref. 3

The Digital Micro-mirror Device is very likely the most sophisticated MOEMS product that has yet been commercialized and is a preview of what lies ahead. The chip incorporates light beam-directing mirrors that move independently and almost instantaneously during operation. A pixel is turned "on" by pointing a mirror at a projection lens while turning "off" involves pointed away. Mirror arrays are being used for digital projectors right now, but the concept is aimed at optical switches.

The movable mirror principle is a good fit for Internet routing of lightwave signals. The incoming beam can be directed toward the intended outbound fiber. A number of companies have announced products and plans for micro-mirror switches. Some pivot, like TI's while others, like Lucent's, use a bending lever action. Still others rotate and some even have multiple axis movement. MOEMS based optical switches are in beta testing this year on the real Internet.

Lucent has already announced MOEMS switches based on two-axis mirrors that can point to any fiber in an array. The mirror array is designed to point the incoming beam at any of the out-bound fibers instead of just turning off and on. This design reduces the number of mirrors but makes the MOEMS system more complex. Units with 256 mirrors are said to be shipping but the network providers are cautious and there will be considerable testing. We are also seeing a small amount of fiber optics on circuit boards. Some connector vendors are offering optical fiber interconnects for PWBs. Molex has flex circuit-based fiber optics interfaces. Figure 6 shows the Lucent micro-mirror switch.

Figure 6 – Lucent Micro-Mirrors for Lamda Router

ENLIGHTENED FUTURE

So what can we expect as MOEMS moves into the spotlight? First, the big electronic routers will become smaller and require less electronics. Someday, the big stacks of racked equipment could be the size of a laptop. Optics assembly will probably remain a very high precision process but perhaps MEMS will align fibers. Right now, we are not even close to automation. But automation is essential if photonics is to ever move downstream to the Metro Rings and to end users (Fig. 1) where the high assembly cost could be restrictive. We can expect photonics to move forward, not just along the Internet, but to display and other graphical interfaces. Already, the TI DMD™ system is being tested in the cinema where future "films" may be delivered over the Internet. So optical components are in the future of assembly and it's already started. New opto assembly plants have been announced and a few contract manufacturers are beginning to do optical component assembly. So tune into photonics and catch the wave, but it may be light as well as solder.

References

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[3] Mignardi, M., "From ICs to DMDs", TI Technical Journal, pp. 56 – 63, July - Sept. 1998 (http://www.TI.com).