Designing for the next great leap in mobility

by Reina Fan, Ph.D.,
Display Materials & Systems Division
3M

By one generally accepted (but not fully corroborated) account, the first mobile phone call took place on April 3, 1973, when Motorola engineer Martin Cooper invited reporters to join him as he walked around Manhattan and prank-called a rival at Bell Labs.[i] Cooper's device was, by today's standards, a brick: it weighed two pounds, had a battery runtime of 30 minutes, and took *a year* to recharge.

Flash forward to today, four decades later, and the extent of the so-called mobile revolution is apparent. As of January 2014, 90 percent of American adults owned a mobile phone; 58 percent owned a smart phone; 32 percent owned an e-reader; and 42 percent owned a tablet computer.[ii] Perhaps most surprising, the move to mobile is global, with many developing nations approaching the U.S. mobile phone adoption rate and some, such as China and Russia, exceeding it.[iii] As of 2012, around three-quarters of the world's population had access to a mobile phone, and mobile phone subscriptions were expected to exceed the total population in the near future.[iv]

This transition to mobile has been explosive, but it is still in its early stages. The next great leap will be driven by access to data rather than voice; between 2012 and 2017, global mobile broadband connections are forecast to increase from 1.6 billion to 5.1 billion connections (a 26 percent CAGR), with monthly volume ramping up from 0.9 to 11.2 exabytes over that time (a 66 percent CAGR).[v] That shift to mobile Internet access became even more apparent in January 2014 when, for the first time, Americans were more likely to access the Internet using smart phone or tablet apps than a personal computer.[vi]

Clearly, consumers are rapidly migrating to mobile devices for shopping, navigating, making payments, gaming, streaming music, reading the news, social networking and settling arguments around the dinner table. Consumer electronics manufacturers have no choice but to participate in this migration. They must offer their customers devices that are powerful and as mobile as possible: they must be sleek, light, high resolution, bright, powerful and offer a long battery runtime.

How do developers design their products to reach this high bar? Increases in processing capacity, brightness and resolution all require increases in energy, which shortens battery life. To compensate, the battery must be bigger and heavier, which runs afoul of expectations for portability and sleek design.

The only other option is to design mobile devices to be as efficient as possible while still meeting minimal performance requirements. At first glance, this appears to be a complicated and delicate task, one that requires developers to hit an elusive "sweet spot": accept the right amount of weight and size to gain the right amount of performance and battery life.

In fact, the "sweet spot" in mobile devices is not elusive. Simple calculations show that the most efficient display design—one that makes the most of the light generated by the backlight unit (BLU)—results in a display that provides low weight, sleek dimensions, and long battery life. And that display is usually less expensive to build and run than an inefficient design.

Increasing efficiency with virtual batteries

Product designers have a limited arsenal for improving the weight and battery runtimes of their devices.

Certainly, some processors and batteries are more efficient than others and incremental improvements in both can be expected. But for most mobile devices, the greatest opportunities for improved efficiencies (and therefore weight reductions and longer battery runtimes) will be found in device displays. In some instances—for example, a bright tablet in idle mode—the display can constitute up to 75 percent of the energy consumed by the device. In other instances, such as an efficient smart phone being used to play a game, the display can consume less than 15 percent of the power.

Of the dominant mobile display technologies, liquid crystal displays (LCDs) hold the most promise for developers looking to increase device efficiency. OLED (organic light-emitting diode) screens have been popular for smaller screen sizes (smart phones, for example) but have not been used extensively for larger mobile displays (i.e., tablets and notebooks).

LCDs, in contrast, meet consumers' expectations for quality, cost, and durability. Manufacturers have no concerns about capacity. And—most important for developers preparing for the next step in mobility—manufacturers can employ known technologies to improve LCD efficiencies and extend battery runtimes.

Some LCD efficiency gains can be achieved by choices in panel architecture and touch technology but the greatest potential for improvement lies in a more efficiently designed BLU.

Obviously, designers will employ the most efficient LEDs; here, researchers have made exciting breakthroughs in recent years and additional advances seem likely.[vii] Designers will also want to extract the full potential of the light generated by those LEDS, through the application of a full complement of brightness enhancement films. These films are exceedingly thin but they extend significantly the time that a device can be used—so much so that they are sometimes called "virtual batteries."

There are three such brightness enhancement films.

- Prism films: Prism films were the original brightness enhancement films. By providing much needed battery life to the first laptop computers, they helped make those early devices commercially viable. Their microreplicated surface structures direct light using refraction and reflection. They can be used alone or in pairs (with the prisms placed orthogonally) to control the direction of light and the viewing angle. When a single 90-degree film is used, 37 percent of the light is directed toward the viewer; 58 percent is reflected or refracted toward the back of the BLU; there, it bounces off the rear reflector and is redirected toward the prism film. (In other words, just five percent of the light is wasted through absorption.) The thinnest practical prism films, found in mobile phones, are about 65 microns thick.

- Reflectors: The back of an LCD chassis is lined with a reflector that directs light created by the BLU's LEDs or bulbs—as well as light returned by the prism films or reflective polarizer—back toward the liquid crystal panel. Reflectors can be just a coating of white PET, but the reflectivity of these coatings depends on thickness. A thin layer of PET provides poor reflectivity, which results in absorption and wasted energy; a coating with sufficient reflectivity adds unacceptable thickness to a mobile device. The 3M™ Enhanced Specular Reflector (ESR) uses hundreds of layers of materials with different refractive indexes to create a highly reflective (greater than 98 percent) nonmetallic mirror film that is just 32 microns thick.

- Reflective polarizers: These films transmit light with a polarization state that can be used by the LC panel and reflect light with the unusable or "wrong" polarization state back toward the reflective surface on the inside of the chassis. After it hits the reflector, this light is depolarized—meaning that it again consists of both polarization states in roughly equal proportions—and redirected toward the prism film(s) and reflective polarizer. This cycle is repeated over and over. Virtually all contemporary reflective polarizers are multilayer optical films. 3M Dual Brightness Enhancement Film (DBEF), an industry-leading reflective polarizer, transmits approximately 90 percent of the visible light with the desired polarization; the remaining 10 percent with the desired polarization is reflected and recycled.

Designing for efficiency: two scenarios

The complex interactions among components, costs, energy efficiency, size and battery life can obscure a somewhat surprising reality: in general, the more efficient a device is, the less expensive it is to build and operate, the longer it will run on a battery charge, and the less it will weigh (compared to a device with similar performance characteristics).

There are several ways to demonstrate this. First, consider the differences in brightness and battery life between two devices—one with 3M's brightness enhancement films, one without—that have identical light sources and an identical battery.

Figure 1 shows two 10-inch tablets—one with a highly efficient design that relies on 3M films, the other a less efficient design without the 3M films. Each tablet has 42 LEDs and a 33.75 Whr battery. The efficient design is able to achieve slightly more than 470 nits maximum brightness and a 10.6 hour battery life at 200 nits; the less efficient design—with no reflective polarizer, two generic prism films and a white PET reflector—can achieve only a 257-nit maximum brightness and a battery life of 7.7 hours at 200 nits.

In other words, at 200 nits, the more efficient design runs 37 percent longer. It also uses a thin multilayer reflector film rather than a heavy PET coating; for this and other reasons, the efficient design is about 32 percent thinner than the design without 3M films.

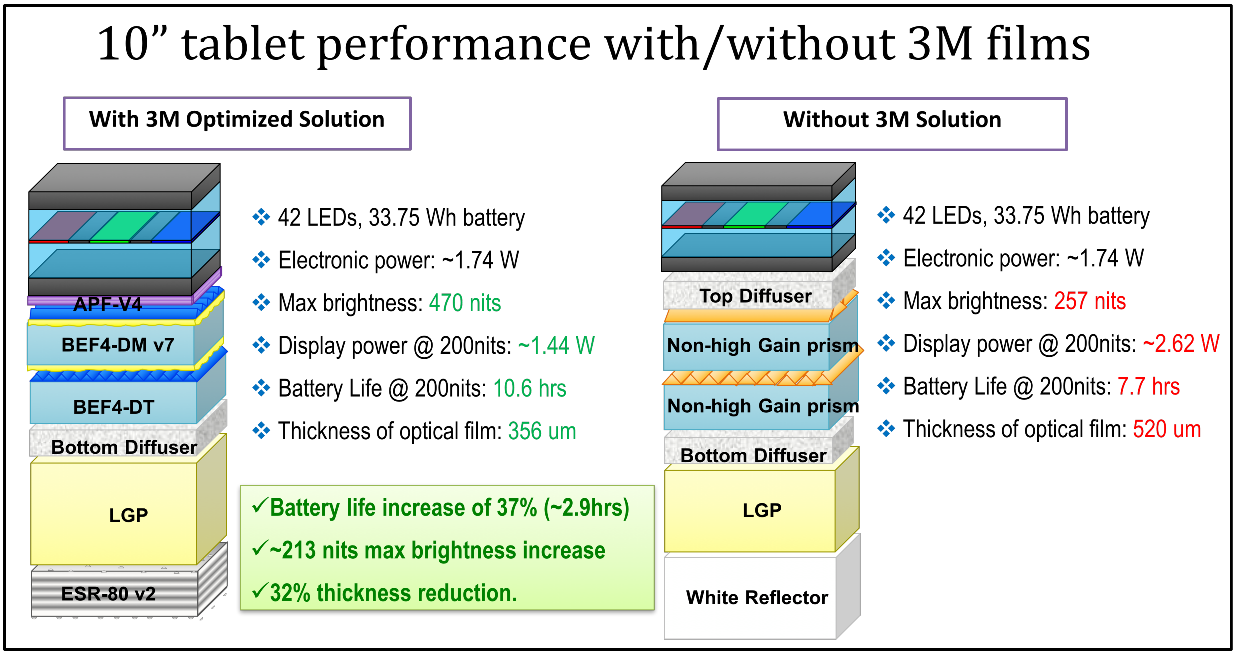

Figure 1. When the LEDs and battery are held constant, the more efficient design with 3M films has a much greater maximum brightness and a much longer battery life. The film stack is also almost a third thinner.

In the marketplace, a maximum brightness of 257 nits is probably not enough to satisfy consumers. Because tablets and other mobile devices are sometimes used outdoors or in brightly lit rooms, a 400-nit maximum is a common specification. Also, the market often expects a 10-hour battery runtime.

Figure 2 also shows efficient and less efficient 10-inch tablet designs, only these are equipped to achieve that 400-nit maximum brightness and a 10-hour runtime at 200 nits. The more efficient design can reach those benchmarks with fewer LEDs and a much smaller battery, which generates less heat. Even with the smaller battery, its battery life at maximum brightness is longer than the less efficient design.

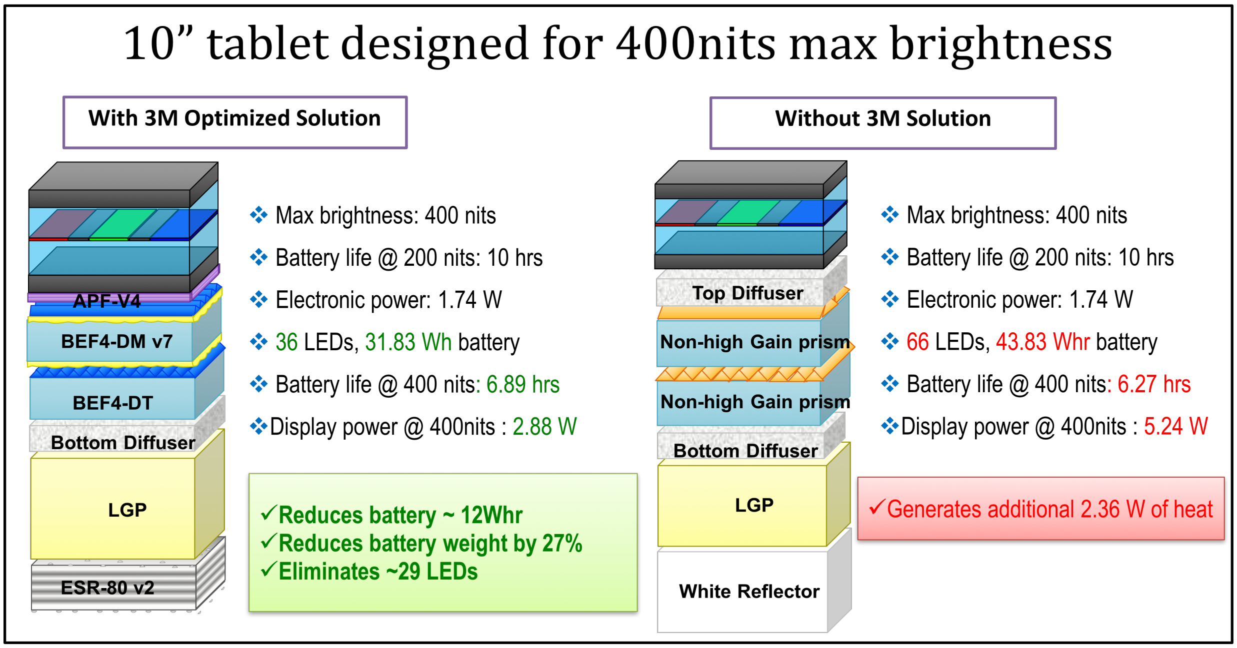

Figure 2. For a tablet designed to achieve 400 nits maximum brightness and a 10-hour battery runtime at 200 nits, the more efficient design with 3M films allows fewer LEDs and a smaller battery; it also has a longer battery life at 400 nits.

The less efficient design is burdened with about 83 percent more LEDs. It also requires a battery that is approximately 38 percent more powerful and 27 percent heavier. The larger battery and thicker PET reflector also affect the device's thickness.

The less efficient design also generates significantly more heat than the more efficient design with 3M films. The comparison in Figure 2 shows that 2.36 watts of additional heat is generated by the less efficient design.

Figure 3 gives thermal profiles of an efficient and an inefficient design. The difference in display power—1.48 watts—makes the average display temperature of the more efficient design about 2.8°C cooler that the inefficient design; its maximum temperature is 3.8°C cooler.

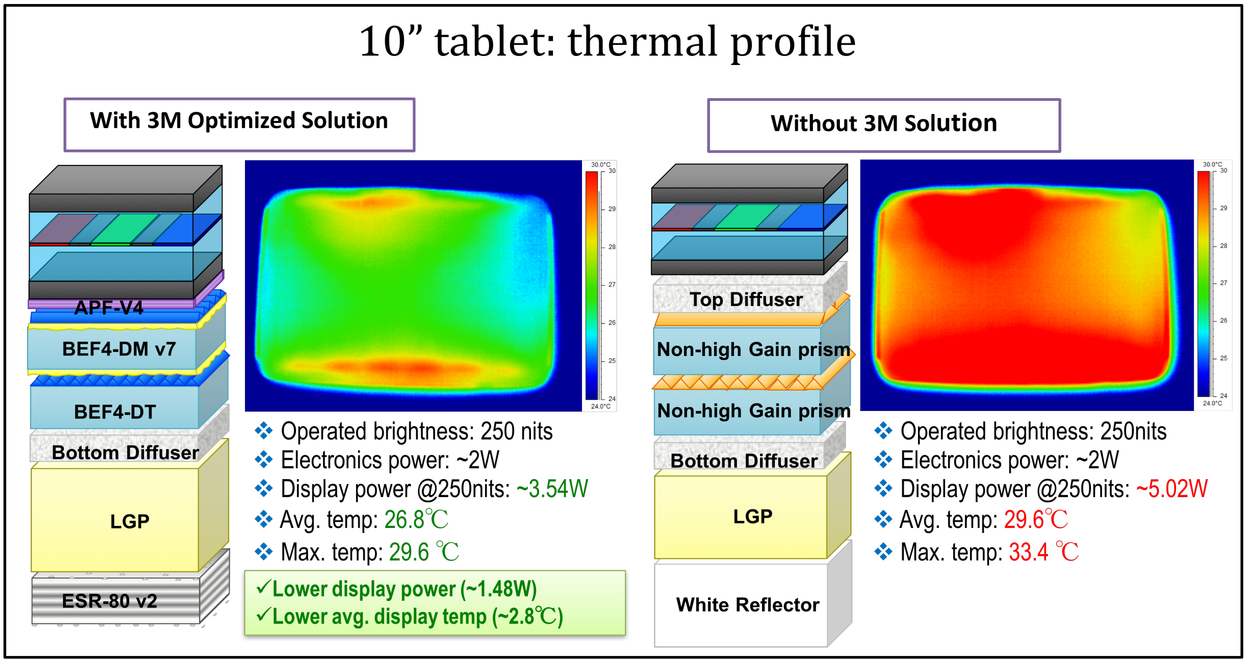

Figure 3. The more efficient design generates less average heat and a lower maximum temperature.

Certainly, in the fiercely competitive consumer electronics industry, every configuration of product attributes must be weighed against its cost. Product developers who feel they have little or no price flexibility will be tempted to compromise on some features, sacrificing a little in battery life, size or performance to hit their cost targets.

In fact, the system cost of equipping a mobile device with highly efficient films can be less than the cost of the additional LEDs and a much more powerful battery. (The precise figures vary depending on the specific films and the size of the order.) The films also provide additional value in less heat output and reduced thickness and weight.

Calculating the benefit

The interplay between efficient BLU design and device performance is shown in Figure 3. A recent model smart phone was equipped with three different film stacks; the power draw and the battery life are calculated for four different functions.

Varying the film configurations can have a pronounced impact on luminance and battery life: Phone 1a (with a very efficient film stack) has a maximum brightness that is 91 percent higher than Phone 1c (which has a much less efficient stack). At 200 nits, Phone 1a’s battery life in display mode is 34 percent (3 hours) longer than Phone 1c’s; for movie-watching, Phone 1a’s battery lasts 30 percent (2.3 hours) longer.

				Power at 200 Nits (W):				Battery Life @ 200nits (h)			
Device	Battery Size (Wh)	Film Stack	Max Lum	Display	Movie	Game	Web	Display	Movie	Game	Web
Phone 1a†	11.9	APF / TBEF2-DML / TBEF2-DT / ESR	464	1.01	1.19	2.58	1.6	11.8	10	4.6	7.1
Phone 1b†	11.9	BEFRP4-DM / TBEF2-DT / ESR	417	1.04	1.23	2.62	1.64	11.4	9.7	4.5	7.3
Phone 1c†	11.9	TBEF2-M n / TBEF2-T n / WBR	243	1.36	1.55	2.94	1.95	8.8	7.7	2.83	6.1
† Display diag. = 5.5"/ Resolution 1920x1080											

Key: APF = 3M Advanced Polarizer Film
TBEF2-DML, TBEF2-DT, TBEF2-Mn and TBEF2-Tn are versions of 3M BEF
ESR = 3M Enhanced Specular Reflector
BEFRP4-DM is a version of 3M's BEFRP, multifunctional reflective polarizer/b rightness enhancement film
WBR = White back reflector

Figure 3. More efficient film stacks can have a significant impact on smart phone brightness and battery life

Similar relationships between efficient BLU design and longer battery life can be established for other mobile devices.

That greater efficiency implies opportunities for lower weight and sleeker dimensions. And, while not obvious from the table above, an efficient display is usually less expensive to build and run than an inefficient design. For additional information on the cost advantages of a more efficient design, please contact your 3M Display Materials and Systems Division representative.

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