Mobile Displays
Technology and Applications

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Contents

About the Editors xv
List of Contributors xvii
Series Editor’s Foreword xxi
Preface xxiii

1 Introduction to Mobile Displays 1
Zili Li, Achintya K. Bhownik, and Philip J. Bos
1.1 Introduction 1
1.2 Advances in Mobile Applications 2
1.3 Mobile Environment and its Impact on the Display 5
  1.3.1 Illumination Considerations 6
  1.3.2 System Power Considerations 8
  1.3.3 Display Resolution Considerations 11
1.4 Current Mobile Display Technologies 11
  1.4.1 Overview 11
  1.4.2 Operational Modes of LCDs 12
  1.4.3 Viewing Angle and Illumination of AMLCDs 14
  1.4.4 Display Driving Electronics 15
1.5 Emerging Mobile Display Technologies 16
  1.5.1 System-on-Glass Technologies 16
  1.5.2 Organic Light-Emitting Diode (OLED) Displays 17
  1.5.3 Bistable Displays 19
  1.5.4 Electrowetting Displays 19
  1.5.5 Three-Dimensional (3D) Displays 19
  1.5.6 Beyond Direct-View and Rigid Displays 20
1.6 Summary 21
References 22

2 Human Factors Considerations: Seeing Information on a Mobile Display 23
Jim Larimer
2.1 Introduction 23
2.2 The Perfect Image 27
2.3 The JND Map and Metric 27
2.4 Image Bandwidth or Considering a Display or the Eye as an Information Channel 28
2.5 The Control Signal and Scaling for Rendering 29
2.6 Jaggies 30
2.7 Hyperacuity 32
2.8 Bar Gratings and Spatial Frequency 33
2.9 Three Measures of Contrast and Weber’s Law 34
2.10 Contrast Sensitivity Function (csf) 36
2.11 Veiling Ambient Light: Contrast Reduction from Glare 38
2.12 Dither: Trade Offs between Spatial Scale and Intensity 39
2.13 Three Display Screens with Text Imagery 41
2.14 Color 43
2.15 Making Color on Displays 47
2.16 Luminance and Tone Scale 47
2.17 Concluding Remarks 50
References 50

3 Advanced Mobile Display Technology 53
Kee-Han Uh, and Seon-Hong Ahn
3.1 Introduction 53
3.2 Advanced Mobile Display Technology 55
3.2.1 Liquid Crystal Display Mode 56
3.2.2 Operating Principle of VA Mode 57
3.2.3 Super PVA (S-PVA) Technology 59
3.2.4 Mobile PVA (mPVA) Technology 61
3.2.5 Transflective VA LCD for Mobile Application 64
3.2.6 Backlight 65
3.2.7 Substrates 66
3.2.8 Drive Electronics 66
3.2.9 Triple-Gate 68
3.2.10 ALS (Active Level Shifting) 68
3.2.11 hTSP (Hybrid Touch Screen Panel) 69
3.2.12 ABC (Adaptive Brightness Control) 70
3.3 Summary 72
References 72

4 In-Plane Switching (IPS) LCD Technology for Mobile Applications 75
InJae Chung, and Hyungki Hong
4.1 Introduction 75
4.2 LCD Modes 76
4.3 Operational Principle of IPS Mode 80
4.3.1 Voltage Transmittance Relation 80
4.4 LC Equation of Motion under an Electric Field 82
4.5 Schematic Diagram of IPS Pixel Structures 85
4.6 Characteristics of IPS Mode 88
4.6.1 Response Time Characteristics 88
4.7 Light Efficiency 89
4.8 Viewing Angle Characteristics 90
4.9 Color and Gray Level 91
5 Transflective Liquid Crystal Display Technologies

Xinyu Zhu, Zhibing Ge, and Shin-Tson Wu

5.1 Introduction

5.2 Classification of Transflectors
   5.2.1 Openings-on-Metal Transflector
   5.2.2 Half-Mirror Metal Transflector
   5.2.3 Multilayer Dielectric Film Transflector
   5.2.4 Orthogonal Polarization Transflector

5.3 Classification of Transflective LCDs
   5.3.1 Absorption Type Transflective LCDs
   5.3.2 Scattering Type Transflective LCDs
   5.3.3 Reflection Type Transflective LCDs
   5.3.4 Phase-Retardation Type Transflective LCDs

5.4 Discussion
   5.4.1 Color Balance
   5.4.2 Image Brightness
   5.4.3 Viewing Angle

5.5 Conclusion

References

6 Wide Viewing Angle and High Brightness Liquid Crystal Displays
Incorporating Birefringent Compensators and Energy-Efficient Backlight

Claire Gu, Pochi Yeh, Xingpeng Yang, and Guofan Jin

6.1 Introduction
   6.1.1 Overview
   6.1.2 LCD Performance Limitations
   6.1.3 Solutions

6.2 WVA (Wide-Viewing-Angle) LCDs with Birefringent Compensators
   6.2.1 Overview
   6.2.2 Extended Jones Matrix Method for Analyzing Large Viewing Angle Characteristics
   6.2.3 Viewing Symmetry in LCDs
   6.2.4 Birefringent Compensators for Liquid Crystal Displays
   6.2.5 Summary of Section 6.2

6.3 High Brightness LCDs with Energy-Efficient Backlights
   6.3.1 Overview
   6.3.2 Backlight without Optical Films
   6.3.3 Polarized Light-Guide Plate Based on the Sub-Wavelength Grating

6.4 Conclusions

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References

7 Backlighting of Mobile Displays

Philip Watson, and Gary T. Boyd

7.1 Introduction

7.2 Edge-lit Backlight Components and Function
## 8 LED Backlighting of LCDs in Mobile Appliances

*Josef Hüttner, Gerhard Kuhn, and Matthias Winter*

<table>
<thead>
<tr>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1 Introduction</td>
</tr>
<tr>
<td>8.2 Basic Physics of LED Technology</td>
</tr>
<tr>
<td>8.2.1 History of LEDs</td>
</tr>
<tr>
<td>8.3 Basic Physics of Semiconductor Light Emission</td>
</tr>
<tr>
<td>8.3.1 Semiconductor Basics</td>
</tr>
<tr>
<td>8.3.2 The p–n Junction and Photons</td>
</tr>
<tr>
<td>8.4 LED Efficiency and Light Extraction</td>
</tr>
<tr>
<td>8.4.1 Chip Technology</td>
</tr>
<tr>
<td>8.4.2 Thinfilm and ThinGaN® Technology</td>
</tr>
<tr>
<td>8.4.3 Design and Manufacturing</td>
</tr>
<tr>
<td>8.4.4 Benefits</td>
</tr>
<tr>
<td>8.5 Packaging Technologies and White LED Light</td>
</tr>
<tr>
<td>8.5.1 Creation of White Light</td>
</tr>
<tr>
<td>8.6 Requirements and Designs for LED-based Backlight Solutions</td>
</tr>
<tr>
<td>8.6.1 Requirements for BLU Systems</td>
</tr>
<tr>
<td>8.6.2 LED Component Design</td>
</tr>
<tr>
<td>8.7 LED-Backlighting Products</td>
</tr>
<tr>
<td>8.7.1 White versus RGB Backlight Units</td>
</tr>
<tr>
<td>8.7.2 Micro SIDELED® (LW Y1SG and LW Y3SG)</td>
</tr>
<tr>
<td>8.7.3 Ambient Light Sensors: Product Introduction</td>
</tr>
<tr>
<td>8.8 LED Backlighting of Notebook LCDs</td>
</tr>
<tr>
<td>8.9 Summary and Outlook</td>
</tr>
</tbody>
</table>

References
9.6.5 Row Driver Operation 258
9.6.6 The AM-LCD Driver 261
9.6.7 The System Interfaces 269
9.6.8 Frame Memory and Buffer Architecture 270
9.6.9 Display Lighting and Lighting Control 272
9.7 Requirements for Driving Example Emerging Display Technologies 274
  9.7.1 Sub-pixel Rendering Displays 274
  9.7.2 OLED/OEL 275
  9.7.3 Bistable and Electrophoretic Drive 279
  9.7.4 IMod – the Interferometric Modulator 281
9.8 Summary 281
References 282

10 Mobile Display Digital Interface (MDDI) 285
George A. Wiley, Brian Steele, Salman Saeed, and Glenn Raskin
10.1 Introduction 285
  10.1.1 The Need for Speed 285
  10.1.2 Handset Display and Camera Trends 285
  10.1.3 The Solution is Serial 287
10.2 MDDI Advantages 289
  10.2.1 Space Constraints 289
  10.2.2 EMI Reduction 290
  10.2.3 Power Reduction 290
  10.2.4 Scalability 291
  10.2.5 MDDI System Connections 291
10.3 Future Generations of MDDI 294
  10.3.1 Audio Multiplexed with Video 295
  10.3.2 High Speed IrDA Concurrent on Reverse Link 295
10.4 MDDI Roadmap 296
  10.4.1 MDDI Gen 1.2 296
  10.4.2 Next Generation MDDI 297
10.5 MDDI Technical Overview 297
  10.5.1 Overview and Terminology 297
  10.5.2 Physical Connection 298
  10.5.3 MDDI Physical Layer 299
  10.5.4 Internal and External Modes 301
  10.5.5 Multiple Stream Synchronization 301
  10.5.6 Overview of the Link Layer 301
  10.5.7 Link Hibernation 304
  10.5.8 The Reverse Link 306
  10.5.9 Link Budget 309
  10.5.10 Link Skew Calibration 311
  10.5.11 Display Synchronization 312
10.6 Conclusion 314
References 314

11 MIPI High-Speed Serial Interface Standard for Mobile Displays 315
Richard Lawrence
11.1 Introduction 315
  11.1.1 Motivation for New Standards 316
  11.1.2 Display Architectures and DSI Goals 316
### CONTENTS

11.2 Scope of MIPI DSI Specification 317
11.3 DSI Layers 318
   11.3.1 Physical Layer Specification 319
   11.3.2 Multi-Lane Operation 319
   11.3.3 Bidirectional Operation with DSI 319
11.4 DSI Protocol 320
   11.4.1 Packet Transmission 320
   11.4.2 Packet Formats 321
   11.4.3 Virtual Channels and Data Types 322
   11.4.4 Video-Mode Transmission and Burst Operation 322
   11.4.5 Command-Mode Operation 324
11.5 Dual-Display Operation 324
11.6 Conclusion 328
Notes and Acknowledgements 328
About The MIPI Alliance 328
About MIPI Specifications 328
References 328

12 Image Reconstruction on Color Sub-pixelated Displays 329
   Candice H. Brown Elliott
   12.1 The Opportunity of Biomimetic Imaging Systems 329
      12.1.1 History 331
   12.2 Sub-pixel Image Reconstruction 332
   12.3 Defining the Limits of Performance: Nyquist, MTF and Moiré Limits 333
   12.4 Sub-pixel Rendering Algorithm 342
   12.5 Area Resample Filter Generation 346
   12.6 RGBW Color Theory 348
   12.7 RGBW Sub-pixel Rendering 360
   12.8 RGBW Sub-pixel Rendering Algorithm 361
   12.9 Gamma Correction and Quantization Error Reduction 364
   12.10 Conclusion 366
References 366

13 Recent SOG (System-on-Glass) Development Based on LTPS Technology 369
   Tohru Nishibe, and Hiroki Nakamura
   13.1 Introduction 369
   13.2 Added Value 370
   13.3 Requirements for TFT Characteristics and Design Rule 371
   13.4 Display with Fully-integrated Circuit 372
   13.5 ‘Input Display’ with Scanning Function 374
   13.6 ‘Input Display’ with Touch-panel Function 376
   13.7 Future Application of ‘Input Display’ 380
   13.8 Summary 382
References 382

14 Advances in AMOLED Technologies 385
   Y.-M. Alan Tsai, James Chang, D.Z. Peng, Vincent Tseng, Alex Lin,
   L.J. Chen, and Poyen Lu
   14.1 Introduction 385
   14.2 OLED Technology 386
      14.2.1 Introduction 386
17 BiNem® Displays: From Principles to Applications
Jacques Angelé, Cécile Joubert, Ivan Dozov, Thierry Emeraud, Stéphane Joly, Philippe Martinot-Lagarde, Jean-Denis Laffitte, François Leblanc, Jesper Osterman, Terry Scheffer, and Daniel Stoenescu

17.1 Introduction 469
17.2 Liquid Crystal Textures of BiNem® Displays 470
  17.2.1 Bulk Textures 470
  17.2.2 Bistability of the U and T textures 472
17.3 Optics of BiNem® Displays 472
  17.3.1 General Equation 472
  17.3.2 Configurations for Bistable Devices 473
  17.3.3 Transmission Spectra of Configurations 475
  17.3.4 Simulated Performance at Off-axis Viewing 476
  17.3.5 Experimental Results in Reflective Mode 476
  17.3.6 Experimental Results in Transmissive Mode 478
17.4 Physical Mechanisms 478
  17.4.1 Switching by Surface Anchoring Breaking 478
  17.4.2 Control of the Switching 481
  17.4.3 Switching by ‘First Order’ Breaking of Slightly Tilted Anchoring 482
  17.4.4 Grayscale 483
17.5 Specific BiNem® Materials 486
  17.5.1 Polymer Alignment Layers 487
  17.5.2 Weak Anchoring Nematic Mixtures 487
17.6 BiNem® Manufacturing Process 490
  17.6.1 Structure of BiNem® Displays 490
  17.6.2 Manufacturing Process 490
17.7 Passive Matrix Addressing 492
  17.7.1 Switching Thresholds 493
  17.7.2 Blanking Signal 494
  17.7.3 Anchoring Breaking Phase 494
  17.7.4 Texture Selection Phase 494
  17.7.5 Final Phase and Multiplexing Scheme 496
  17.7.6 Partial Refreshing 497
  17.7.7 Implementation of the Driving Schemes 498
  17.7.8 Power Consumption 499
17.8 Performance of BiNem® Displays 500
  17.8.1 Optical Performance of Monochrome Reflective BiNem® Displays 500
17.9 Other Developments 503
  17.9.1 Flexible BiNem® Displays 503
  17.9.2 E-documents 504
  17.9.3 Color BiNem® Displays 504
  17.9.4 Active Matrix Driven BiNem® Displays 507
17.10 Applications of BiNem® Displays 508
  17.10.1 BiNem® Displays: Market and Applications 508
17.11 Conclusion 509
References 510

18 Electrowetting Displays for Mobile Multimedia Applications
Johan Feenstra

18.1 Introduction 511
  18.1.1 Market Trends 512
## 21 Operation of a Bi-Magnetic Scanner

21.3 Performance Goals
21.3.1 Scanner Principals of Operation
21.3.2 Scanner Implementation
21.3.3 Scanner Test Results

## 21.4 Operation of an Electrode Comb Scanner

## 21.5 Lasers – New Technology Enabling the Scanned Laser Projector

21.5.1 What Laser Characteristics are Desired?
21.5.2 Laser Speckle
21.5.3 Beam Shaping, Combining and Coupling Optics

## 21.6 Image Quality Considerations

## 21.7 Summary

## References

## 22 Plastic Backplane Technology for Mobile Displays

*Cathy J. Curling, and Seamus E. Burns*

22.1 Introduction
22.2 Flexible Display Applications and Specifications
22.2.1 Electronic Shelf Labels (ESL)
22.2.2 Electronic Signage
22.2.3 Mobile E-readers
22.2.4 E-Paper Technologies
22.2.5 The Importance of a Flexible Active Matrix

22.3 Active Matrix Backplane Requirements to Drive Bistable Media in E-Paper Applications
22.3.1 Active Matrix Operation
22.3.2 Active Matrix Backplane Requirements

22.4 Review of Flexible Active Matrix Backplane Processes
22.4.1 Challenges with Fabricating Large Area Electronics on Flexible Substrates
22.4.2 Inorganic TFT Based Processes
22.4.3 Organic TFT Processes

22.5 The Plastic Logic Process for Fabricating Flexible Active Matrix Backplanes
22.5.1 Process Description
22.5.2 How the Process Meets the Active Matrix Backplane Requirements

22.6 The Future of E-Paper Display Technologies for Mobile Applications
22.6.1 The Evolution of E-Paper Display Media
22.6.2 The Evolution of Plastic Backplane Technology for Mobile Displays

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## References

## Index
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A transformation is taking place. Hitherto, mobile displays were regarded as the poor cousins of larger, higher resolution, faster, wider color gamut monitor and TV displays, being smaller, with lower resolution, slower response times, narrower viewing angles and less saturated colors. Now, with the advent of high bandwidth mobile communications, innovative low energy ICs (often developed specifically for mobile applications) and new architecture and display developments, the world is changing. Mobile devices are increasingly becoming the drivers of new product opportunities. One might argue that this transformation is already well underway; mobile phones now combine telephony with still and video photography, touch, email and TV. In our increasingly mobile-centric world, customers in growing numbers now expect that all information — telephony, text, email, audio, radio, TV and video — should not just be accessible on mobile devices, but should be accessible at high audio and visual quality. That is the demand. Satisfying it will be far from easy, but such is the scale of research, development and product introduction that changes are now taking place and will accelerate.

A large measure of enthusiasm is required to push developments into new product opportunities. This can sometimes lead to an overstatement of opportunities and, of course, the manipulation of product specifications is as rife in this highly competitive market as in others, so it is important that a book such as this presents a rational discussion of the visual requirements and the limitations of the often small displays used in mobile devices in terms of pixel density, luminance or reflectance, dynamic range and gray level capabilities; Chapter 2 does this elegantly. There follow chapters which describe how liquid crystal, viewing angle control and backlight technologies, developed primarily for non-mobile applications are being adapted and optimized for the mobile market. Then the extent to which the mobile market is increasingly driving its own developments begins to become apparent, with chapters on low power electronics, mobile-specific serial interface architectures and innovative pixel designs which can reduce pixel count requirements whilst maintaining display legibility. Note that two serial interface architectures are described. There is competition here as well as between different display technologies. Indeed, one might speculate that serial interfaces developed for low power consumption, low connection cost and mechanical flexibility might begin to find application in the increasingly cost and power conscious non-mobile markets. A chapter on the use of polysilicon backplane technology to produce an entire system on glass elaborates on the benefits of being able to add such function as scanner and touch input capability whilst still being able to minimize the mass, volume and the number of interconnections in a mobile device.

Then a number of new or less-established display technologies, OLED, Electrophoretic, Bistable Cholesteric and Nematic LCs and Electrowetting, are described. All but Electrowetting have found application in fixed devices, but it is reasonable to assume that all these technologies will find major, probably their dominant, applications in the mobile sector because of low power requirements
combined with good visual performance. 3-D is discussed, albeit with a rather low expectation of finding wide application soon, but it is interesting to see that 3-D techniques could be developed for lightweight low power devices. Chapters on eyewear displays and scanned beam projectors follow and the book concludes with a chapter on polymer backplane active matrix technology, which is now moving from development into production, bringing the prospect of rugged, thin and flexible displays a step closer.

This is a substantial book and it covers its broad subject matter in considerable depth and detail. Inevitably with such a large multi-author volume, there is some overlap between chapters but this has the advantage that each chapter is substantially self-contained, avoiding the need for the reader to keep referring from one chapter to another. Most chapters include a detailed theoretical and technical description of their subject before progressing to descriptions of products and applications, so the reader has considerable choice at which level to read the book. As the editors remark in their Preface, this is the first comprehensive treatment of all aspects of mobile display technology to be published in a single volume. Achintya Bhowmik, Zili Li, and Phil Bos have done an excellent job in bringing this project to a successful conclusion. Written by acknowledged experts in their fields, as new technological developments begin to find their way into mobile products, this book will fill a much-needed gap in the literature.

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Preface

The mobile display industry has been witnessing a rapid growth in recent years, spurred by the tremendous proliferation of mobile communications and computing applications. This has been exemplified by the over 1 billion units of mobile phones and over 100 million units of mobile computers sold in 2007, besides other categories of mobile devices such as MP3 players, digital cameras, PDAs, GPS map readers, portable DVD players, electronic books, etc. This has fuelled a significant investment into the research and development of the display technologies needed to meet the requirements of this burgeoning product category, with key research labs across the display industry and academia producing many exciting technological advancements.

Although at first glance one may think of the mobile display as just a smaller and portable counterpart of the large displays such as the desktop monitors or the flat panel televisions, the widely varying usage and viewing conditions coupled with the stringent power consumption and form factor constraints impose a different set of challenges for the mobile display. Thus, the architects and designers of the mobile devices are increasingly demanding unique attributes for the mobile displays, thereby setting them apart from the domestic tethered terminals and requiring specific developments in the technology. As a result, the display technologies have been advancing rapidly to keep pace with the evolving mobile communications and computing devices. Besides the impressive advancements in the incumbent active matrix liquid crystal display (AMLCD) technologies, the mobile display arena has also been a hotbed for the exploration and development of new technologies, including the emerging active matrix organic light emitting diode (AMOLED) displays, eyewear and mobile projector displays, as well as the flexible displays, among many others.

The objective of this book is to present a comprehensive coverage of the mobile display in a single volume, spanning from an in-depth analysis of the requirements that the displays must meet, through current devices, to emerging technologies. Some of the topics covered are: applications of mobile displays; human-factors considerations; advances in liquid crystal display technologies; backlighting and light manipulation techniques; mobile display driver electronics and interface technologies; as well as detailed analysis of a number of new display technologies that have been emerging in recent years with promises to bring unique capabilities to the landscape of mobile devices and applications. While there are a number of excellent books on display technologies that cover the fundamentals and applications in many other areas, there is, surprisingly, no title dedicated to the important category of mobile displays. Thus, we believe this book will benefit the reader by providing a detailed update on the state-of-the-art developments in this burgeoning field. The chapters have been authored by well-known experts working in the field, selected from both industry and academia in order to present a balanced view of both the fundamentals and applications to benefit both the general and the expert readers.
We are grateful to the authors who worked with us diligently to produce high-quality chapters with in-depth and broad coverage on the various topics related to all aspects of the mobile display, including both technology and applications. We would especially like to thank the series editor, Anthony Lowe, for his encouragement to pursue the idea of this book, and for his conscientious editing of the final manuscript. We thank the colleagues who assisted us in shaping the outline of this book, especially Thomas Holder of Intel Capital who helped enlist authors to cover several of the emerging technologies. We also appreciate the support that the staff at John Wiley have provided us throughout this project. Finally, we would like to thank our wives Shida Tan, Min Jiang, and Barbara Bos for their support and patience during the course of preparation of this manuscript.

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Introduction to Mobile Displays

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1.1 Introduction

Mobile displays have been undergoing tremendous advances in recent years, in terms of both technology and applications. In the past, the information that needed to be displayed on mobile devices was sufficiently low for the display not to limit the mobile device applications. For example, an early cellular phone only had a 1-line monochrome display consisting of ~10^2 pixels. However, as the mobile applications became richer, the displays also needed to evolve in order to keep pace with increased requirements. Displays with more than 10^5 pixels and up to 12 bits of color depth are common in today’s mobile handsets. On the performance front, the mobile phone display is rapidly approaching the performance of a desktop monitor in terms of brightness, contrast, and color saturation, among other important display parameters. These changes are the results of rapid advances in technology for both wireless network infrastructure and mobile handsets, which are intertwined to provide a far-superior overall communication experience for the consumer. Another mobile application area that has witnessed significant improvements in the display characteristics is the mobile computer. The early notebook computers sported embedded displays of relatively modest attributes, whereas today the majority of laptops include a WXGA resolution (1280 × 800) screen with 18 bits-per-pixel color depth, and the state-of-the-art mobile computer boasts a high-definition screen (WUXGA,
1920 × 1200) with 24 bits-per-pixel color depth. This rapid enhancement of the display is to match the increased richness of visual content offered by the modern mobile computer.

The term ‘Mobile Display’ has only recently appeared in technical literature. A quick scan through the back issues of major display technical publications, such as SID Digest of Technical Papers, International Display Workshop Proceedings, and International Display Research Conference Proceedings, reveals that the earliest session devoted to ‘Mobile Display’ was at the 2002 International Display Workshop held in Hiroshima, Japan [1]. In the past, terms such as mobile display, portable display, or handheld display, were often used interchangeably in the display field with little or no distinction. They were often invoked to refer just to low power display or small size display. Although power and size are important attributes in considering a mobile display, as will be discussed later, these are only a subset of display parameters of importance.

In this chapter, we will first take a look at the burgeoning applications that are driving the increasingly challenging requirements for the mobile display, in particular the ever-growing mobile phone and mobile computer applications, analyze the mobile environment and its impact on the display, and then review the advances in the display technologies in order to meet the stringent requirements imposed by the mobile environment and applications. We will also introduce and place in context subsequent chapters in the book.

1.2 Advances in Mobile Applications

Mobile communication and computing have seen drastic changes over the past decades. As average consumers, we have all witnessed and benefited from these changes. Let’s start with a look at recent trends in mobile communication: smaller and thinner mobile phones with slick design, much longer battery life for prolonged talk time and standby time between charges, higher resolution and color display replacing the monochrome type, much better voice quality, and the wild popularity of text messages. All these advances are happening while the cost per minute is only a small fraction of what it was a decade ago. In 2007 the annual mobile phone production reached a new peak of more than 1 billion units and is projected to maintain double digit annual growth worldwide for the next several years, as shown in Figure 1.1, below, provided by DisplaySearch, a leading display market research firm. This is an astronomical number that few other electronic devices can ever compete with. Besides the mobile phone, which enjoys the largest share of the mobile communications market, other mobile devices have also seen significant growth. Notable among them are mobile personal computers, MP3 players, digital cameras, PDAs, GPS map readers, potable DVD players, electronic books, etc. The

![Figure 1.1 Mobile display growth (courtesy: DisplaySearch).](image-url)
mobile computer segment, in particular, has been witnessing a strong growth in recent years. The shipment of notebook computers exceeded the 100 million units mark in 2007, as shown in Figure 1.2, above, also provided by DisplaySearch. This is approximately five times the volume shipped in 2000. The mobile computer volume is forecast to continue to grow at about five times the rate of the desktop computer counterpart in the coming years. The notebook market share as percentage of the overall personal computer (PC) market is steadily increasing in all regions of the world, already accounting for more than half of the overall PC volume in mature markets. Sustained growth in notebook computers in recent years is fueled by a widespread consumer interest in getting high-bandwidth access to full Internet, anytime and anywhere, besides the computational power to drive PC applications with the levels of processor capabilities that were only common in desktop systems even a few years ago. Another new category of mobile computers is the emerging Ultra-Mobile PC (UMPC), or the consumer-focused variant termed as the Mobile Internet Device (MID), promising to pack the processing and internet capabilities of a full computer into attractive ultra-portable form factors. One of the key technological enablers for the rapid expansion in mobile computing has been the wide availability of color thin-film transistor active matrix liquid crystal displays (TFT AMLCD) [2], besides remarkable innovations in low-power processor, much improved electronic packaging technologies, and the arrival of lithium-Ion battery among many other electronics advancements.

Until recently, mobile computing was primarily for use in office, home, or similar environments that were not initially targeted for wireless communication applications. On the other hand, the technical landscape for mobile communication is more complex because both a wireless communication network and wireless communication device need to work together to deliver the rich experience that consumers demand. In fact, the introduction of the Intel Centrino mobile platforms in 2003 that integrated broad wireless network connectivity and interoperability into the notebook PCs spurred the subsequent rapid growth in the mobile computer market.

In the next section we will explain how the interplay at both the network and device levels laid the technology foundation for the rapid expansion in mobile communication applications and how these new applications drive the technological advancement in displays used in mobile devices.

Taking the evolution of the cellular network as an example, Figure 1.3, below, depicts the application expansion as the wireless network bandwidth increases. The initial wireless network was based on analog technology and only capable of providing voice calls due to its limited bandwidth. As we moved to the 2nd generation (2G) network, not only were large numbers of channel capability added to enable more users, but service quality in voice communication also significantly improved. However, non-voice services such as text messaging were not enabled until the cellular network was further upgraded to use packet data service network or 2.5 generation (2.5G) network, primarily due to the low bandwidth capability from the earlier networks. Nowadays the landscape of wireless communication is
much more complex than just a few years ago when cellular network had the monopoly for the most part, though cellular network is still dominant and hundreds of billions of dollars have been spent to move from 2G to 3rd generation (3G) network. In some parts of the world 3G network has already entered into service. The 3G network enables a bandwidth of 10–100 times of a 2G network, ranging from a few megabits per second (Mbps) to ~50 Mbps. In research labs around the world, next generation cellular networks beyond 3G have started to move away from the drawing board into limited field testing. On the other hand, among the developments that are occurring using non-cellular network with unlicensed spectrum band, WiMAX has a large coverage distance up to multiple miles and could provide more bandwidth than a 3G network. For a short range, the now ubiquitous Wi-Fi systems also provide high bandwidth in the range 10s of Mbps. These increased bandwidths are able to support data and image transmission in addition to voice transmission. In parallel, improvements in signal processing techniques, such as data compression and decompression, have allowed further optimization of the utility of the available bandwidth to enhance transmission quality.

In parallel with the network bandwidth explosion, in the past decade we have also witnessed vast enhancements in mobile terminal devices. In this regard, there has been a tremendous similarity between mobile communication and mobile computing at the device level. Much of the technological advancements discussed here are also applicable to the mobile computing devices. The early analog mobile phone had very limited process and memory that were only capable of handling voice communication. As we move to 2G and 3G handsets, there are several important technological developments at components and subsystem level. First of all, rapid progress has been made in miniaturization. This makes the much needed compact package readily available for designers. In addition to smaller components, interconnections among components are also much more condensed through varieties of high density interconnection technologies. The optimized usage of miniaturized active and passive components through design innovation has further driven the overall package volume down. Reduction of the power consumption of these devices has been another major advancement. These reflect the combined results from drastic improvements from base-band and other processors, power amplifier, and more efficient power-management chipsets. Memory devices have also seen major power reduction over the years in addition to its own size reduction. All these made it possible to integrate a much more powerful processor, high capacity memory chip, and other active and passive components into a compact package of a handheld device. Figure 1.4, below, depicts this general trend versus different generations of mobile devices. At the time of writing, a 3G handset can deploy as much as 256 MB memory with an equivalent processing power of an early mobile computer processor. Some handsets even have a hard drive in addition to flash memory. With all these advances, it may not be exaggerating to say that a modern mobile communication handset may be regarded as a PC in your palm.