SMPTE

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Covering Emerging Technologies for the Global Media Community

By Laurence J. Thorpe

Introdução:

O presente artigo trata de nada menos que um compilado de 10 anos da evolução das Lentes e Câmeras que tornaram possível o universo do 4K (e, em breve, do 8K, uma realidade) não só nas produções cinematográficas, mas também para as de OTT. Então, se você é como eu, e gosta de saber das histórias por trás das histórias, este artigo é imperdível!!!

Tom Jones Moreira

Abstract

The decade 2010–2020 saw fast-paced developments in professional lenses and cameras—moving on the fronts of both broadcast television production and digital cinematography. The long-established 2/3-in. image format made a surprisingly smooth transition from two decades of high-definition television (HDTV) to 4K ultrahigh definition (UHD)—although, behind the scenes, this posed significant challenges to both lens and image sensor developments. The 2/3-in. B4 lens–camera mount standard remained a foundation for this transition. The decade bore witness to extraordinary international standardization activities that produced the parameter values for 4K UHD and 8K UHD for production and international program exchange—closely following with allied standards on high dynamic range (HDR) and wide color gamut (WCG). The current hesitancy in the U.S. to inaugurate 4K UHD delivery services propelled camera manufacturers to introduce broadcast television cameras that are multiformat—switchable between HD and UHD and between 2K and 4K digital cinema initiative (DCI)—and also multipurpose in being able to switch between HD colorimetry and WCG, and between HDR and standard dynamic range (SDR). Optical manufacturers applied major resources into developing 2/3-in. 4K broadcast television lenses. Meanwhile, amidst this uncertainty, 8K UHD broadcasting became a major agenda in some Asian regions, and the attendant developments in lenses and cameras significantly contributed to technological advances in the parallel 4K systems. The year 2010 saw the transition from the first generation HD/2K Super 35-mm digital cinematography lenses and cameras to 4K acquisition systems. New international manufacturers arrived in both arenas, and vigorous competitive activities escalated the pace of their respective technological developments. Within this decade, the full promise of HDR and WCG became evident for moviemaking and episodic television production. Within this same time span, the extraordinary emergence of the over-the-top (OTT) tech giants into the world of content creation, and international distribution, soon witnessed an upsurge in both the quantity of high-end scripted content and high expectations in quality.

This decade saw finalization of international production standards for UHD-1/4K and UHD-2/8K, which solidified a roadmap for progressive increases in resolution. It also saw a surge of new interest in elevating other dimensions of image quality—notably, extensions to dynamic range, color gamut, and to picture capture rates. All of these affected developments in lenses, cameras, and recording over the last five years. The rapid rise of 4K in the digital cinema world was flanked by an aggressive adoption of the same by some of the OTT media services. The U.S. broadcasters meanwhile showed small enthusiasm to engage in offering 4K delivery services—yet, many are engaged in experimental 4K productions. A new transmission standard ATSC 3.0 was recently finalized, which supports 4K over the air transmissions.

Keywords

Academy Color Encoding System (ACES), Advanced Television Systems Committee (ATSC), advanced video coding (AVC), B4-mount, digital cinema initiative (DCI), 4K and 8K, full frame, high dynamic range (HDR), hybrid log gamma (HLG), International Standards Organization (ISO), over the top (OTT), perceptual quantization (PQ), standard dynamic range (SDR), 2/3-in. format, ultrahigh definition (UHD), wide color gamut (WCG)

Introduction

Imaging Technological Breakthroughs Meet Disruptive Marketplace Dynamics

Astounding technological progress in the last decade has propelled developments in both professional motion imaging lenses and cameras. An additional propellant has been the parallel convulsions the world has seen in the larger content creation universe, with huge consolidations taking place in the traditional media universe and the unforeseen rise of the "tech giants" as contending media goliaths. Movie production in the U.S. has remained fairly steady at approximately 700 movies per year, and box office revenue is fairly constant in the vicinity of $10/$11 billion per year.

But, high-quality television episodic production has increased in the last five years—both in terms of the excellent script writing and the superb production values—driven by the over-the-top (OTT) media delivery services. This unanticipated new drive for excellence in both sound and visual image quality has added impetus to diverse developments in professional lenses and digital camera systems.

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Progress in Broadcast Television Cameras

Enduring 2/3-in. Image Format—High-Definition Television to Ultrahigh-Definition Television (UHDTV)

The 2/3-in. image format size has entered into its fifth decade and endures as the center of the universe in broadcast television lenses and cameras for worldwide studios and outside broadcasts. It was only five years ago that industry speculation seemed unanimous that this small image format could never sustain 4K resolution. But, at NAB 2014, one manufacturer debuted a prototype 4K UHD broadcast studio camera based on that image format. Two years later, four international manufacturers were exhibiting their 4K UHD cameras and lens manufacturers were exhibiting their first 4K 2/3-in. lenses. The BTA-S 1005 document that standardized the 2/3-in. high-definition television (HDTV) lens–camera interface (mechanical, optical, and electronic) back in 1992, continues as the basis for all of the contemporary 2/3-in. 4K UHD lenses and cameras. All of these cameras now utilize CMOS image sensor technologies, adding a finality to the cessation of deployment of charge-coupled device (CCD) image sensors in broadcast television cameras.

High Dynamic Range and Wide Color Gamut Preempt Resolution Advances

In 2015, the international standardization body ITU published the standard International Telecommunication Union – Radiocommunication (ITU-R) BT.2020 for parameter values for 4K and 8K UHD production and followed, a year later, with the publication of the new standard ITU-R BT.2100 for image parameters for high dynamic range (HDR) production. It was significant that this standard defined 1080p/HDR to be a valid member of the UHD family. A year later—at both CES and NAB—the, by now, much-discussed topics of HDR and wide color gamut (WCG) were very visible, with both consumer and professional reference displays vividly demonstrating the progress of these two significant image enhancements. To this day, they are both central to industry debates on how to transition television broadcasting. In 2020, it appears to be a unanimous view among the U.S. broadcasters that 1080p combined with HDR/WCG offers a more stimulating viewing experience on home displays hovering around 60-in. diagonal than 4K UHD on similar-sized screens.

Multiformat and Multipurpose Cameras in an Uncertain Transition Era

To deal with the uncertainties surrounding any transition to 4K, coupled with the near-term interest in 1080p/HDR/WCG, almost all camera manufacturers now offer new multiformat and multipurpose acquisition systems. In terms of multiformat, this latest generation cameras are switchable between HD and 4K UHD—and some can also be switched to 4K DCI and 2K DCI. They are multipurpose in allowing selections between the HDTV color gamut BT.709 and the wider 4K UHD color gamut specified in BT.2020, as well as selections in HDR systems—notably between the hybrid log gamma (HLG) system and the perceptual quantization (PQ) system—in addition to offering standard dynamic range.

Before 4K Reaches Maturity, the 8K Movement Gets Underway

While 4K UHD advances slowly, the last five years have seen a rise in broadcast television interest of 8K UHD services, but largely confined to Japan and China. During those years, some seven camera manufacturers have shown related 8K UHD prototype cameras at the major international broadcast television conventions. A *de facto* new image format size emerged for television outside broadcast 8K cameras, namely the 1.25-in. image format, large enough to support 8K image sensors and small enough to assist in extending depths of field of the lens–camera system. This year would have seen a major international sporting event with broad deployment of 8K UHD production entailing dozens of camera systems, but this has been thwarted by the COVID-19 pandemic.

In the last three years, 8K UHD has played an increasing role in one important niche application in broadcast television, namely replays during sporting events. Wide-angle 8K imagery supports dynamic extraction of 1080p "cutouts" that can verify critical occurrences on the field, while also supporting digital zooming and capture of interesting moments on the benches.

Internet Protocol Expands Broadcast Television

In 2017, SMPTE released the new ST 2110 suite of standards for Professional Media Over Managed IP Networks—a standard for video Internet protocol (IP) offering totally new broadcast television infrastructural

flexibilities that support video carriage over regular IT circuits and allowing passage of a broad range of data rates. Contemporary broadcast studio and field cameras are now providing IP interfaces that support their connectivity within these new infrastructures. Separately, some of these broadcast field/studio cameras incorporate IP interfaces (based on ST 2110) to replace the longstanding SDI-based links between camera heads and their camera control base stations. This reflects the ever-expanding system flexibilities sought in contemporary broadcast studio infrastructures and mobile production systems for outside broadcasts. This empowerment has supported increasing deployment of remote production (REMI) for outside broadcasts.

Broadcast Television Lenses

2/3-in. Optics Comes of Age

Global considerations of 4K UHD over the last five years have had a profound effect on developments in broadcast television lenses. Many technical challenges underlie the development of 2/3-in. 4K lenses. That four-fold increase in spatial sampling, coupled with ever-increasing home display sizes, demanded close attention to improving image sharpness across the image plane. Important experiences were gained from the early 4K broadcast television experimental shoots around the world—that redoubled optical research & development (R&D) and led to close scrutiny of all phases of lens manufacturing and assembly. Second-generation lenses appeared two years ago and were reflective of the multiple new design and manufacturing strategies that had been implemented. The last decade also saw the separate agenda of 8K optical developments that were to have an important trickle-down influence on the optical performance of 4K UHD broadcast television lenses.

Development of super-fine processing technology became a crucial underpinning of the necessary nanometer tolerances on 4K lens element surfaces, making it possible to produce large-aperture aspherical and spherical lenses. The recognition that retainer rings for individual glass elements could produce micro-deformations of the element that affected critical ray transmission led to computer optimization, producing a significant new design that recognized both the glass material and its shape.

HDR considerations led to new optical and opto-mechanical technologies to minimize contamination of blacks from flare, veiling glare, and ghosting. WCG capability saw new strategies in shaping the spectral transmission of the lenses. At the same time, HDR/WCG together combined to elevate the subjective visibility of even small degrees of chromatic aberration. The 4K image sensor exacerbated this sensitivity. Radical new optical designs were required to further suppress these aberrations that included new glass materials, new lens element groupings, increased deployment of aspheric surfaces, and stringent control of surface precision. The increased sensitivity to motion blur of the exceedingly sharp 4K image caused by physical perturbations of the lens–camera system (platform vibrations, wind, etc.) spurred new developments in the built-in image stabilization systems in long-zoom field lenses.

Emerging recognition of the new challenge in ensuring sharp focus in 4K UHD outside broadcast lenses spurred the recent collaborative development between lens manufacturers and Sony camera developers of remote back focus (RBF) control from the video operational panel in the mobile production truck, where 4K reference displays guide the achievement of precision focus.

New Optical Developments Drive Broadcast Field Lens Zoom Ranges Beyond 100:1

The ever-expanding coverage of global sporting events—many entailing venues far larger than ballfields—continued to drive progressive extensions in broadcast field lenses. The last two years have seen 4K UHD outside broadcast field lenses emerge with zoom ranges extending to 111:1, 122:1, and 125:1, while also extending their respective wide-angle settings. The improvements to their built-in image stabilization systems were accompanied by advanced new control algorithms that finally resolved the longstanding problem of image "drift" associated with the sudden cessation of a pan/tilt operational move in a lens when the built-in IS is engaged.

Overcoming the Longstanding Nemesis of Zoom Lens F-Drop and Peripheral Illumination

A technical collaboration between Sony and Canon two years ago led to a definitive solution to an operational dilemma that has haunted worldwide broadcast camera operators for many decades. Digital reporting from the Canon lens to the Sony camera of lens zoom/focus/iris realtime dynamic operational settings, coupled with lens files reporting on relative light distribution alterations, empowered implementation of realtime digital correction of two vexing optical shortcomings—the lens ramping that occurs at long focal lengths and the dynamics of peripheral illumination. The camera actuates a gain control in synchronization with the lens zoom control to compensate for lens ramping (fall-off of light transmission beyond a critical focal length), while additionally modulating the gain across the image plane (effective realtime dynamic shading) to counteract the variations in relative light distribution, as the focal length and aperture of the lens are operationally adjusted during shooting. The system is formally known as automatic restoration of illumination attenuation (ARIA)—and the collaboration has been extended to another broadcast lens manufacturer.

Advances in Digital Cinematography Cameras

Rise of Super 35-mm Digital Cinematography Cameras

The decade opened with increasing development in Super 35-mm single-sensor digital cinematography cameras and camcorders. They had already replaced the earlier three-chip 2/3-in. HD cameras which had pioneered digital cinematography in the previous decade. New international players steadily entered the digital cinema marketplace, as worldwide motion picture film production continued to decrease.

Dramatic advances in the single Bayer-based complementary metal-oxide-semiconductor (CMOS) image sensors are testament to vigorous global competition and creative aspirations. In the last four years, large-format cameras (larger than Super 35 mm) have emerged—based on variants of the traditional full frame format of still photography—accompanied by resolutions of 5K, 6K, and 8K.

Advances in Digital Cinematography Image Sensors

The relentless digital pursuit of the many beloved attributes of 35-mm motion picture films saw progressive advances in Super 35-mm image sensor technologies. Dynamic range caught up with and, then surpassed that of the negative film, while noise floors progressively lowered. Fifteen to sixteen stops of dynamic range typify the current state-of-the-art of S35 image sensors. Dual native ISO capability was introduced into a number of Super 35-mm cameras that has been very favorably received. While it varies among manufacturers, it is centered around a switch between ISO 800 and ISO 3-5000 operation that incurs only a minor increase in the noise level. It exploits the advantage of analog column amplifier gain switching indigenous to the CMOS image sensor readout. One digital cinema camera has extended this to five levels of native ISO, covering ISO 800 to ISO 12800.

Auto focus has long been shunned by directors of photography, but again new technologies drove impressive advances in the precision and reliability of these systems. One camera manufacturer uses two photodiodes within each sensor photosite to provide precision phase measurement for their system which is followed by high-speed algorithmic data processing.

Academy Color Encoding System and Camera Input Device Transforms

The remarkable work of the Academy of Motion Picture Arts and Sciences on the Academy Color Encoding System (ACES) continued and saw the publication of ACES version 1 and, most recently, of ACES version 2. In addition to the fast-growing adoption of this imaging and color management system by the moviemaking and television production communities, it is now recognized as a powerful enabling technology for harnessing the potentials of HDR and WCG. A number of digital cinema camera manufacturers have integrated ACES features into their products, so they can reliably be used in ACES color-managed workflows. This especially includes publication of the all-important input device transform (IDT) for their respective cameras.

Recording Codecs and Recording Media

RAW recording—well understood in the still photography world—migrated to motion imaging and today is central to moviemaking and high-end television production. Many flavors of RAW are now in the marketplace and spirited debate ensues on the relative merits and demerits of each. The large file sizes entailed saw broad use of SSD media having TB-size capacities. More recently, different bitrate reduction strategies have emerged that reduce those storage demands and now the more compact high-capacity storage media like CFast 2.0 and CFexpress are emerging. More importantly, these advances now see RAW recording beginning to be incorporated within the cine cameras.

The majority of productions, especially in television, avoid the complexities of processing RAW material; instead they use high-performance YCbCr 4:2:2 at 10-bit internal recording using established codecs. Variants on the Motion Picture Experts Group (MPEG)-4 AVC/H.264 are common to most—each identified by terms such as XAVC, XF-AVC, and AVC-Intra. Various tiers of the Apple ProRes codec are sprinkled among some prominent cinematography cameras.

In recent years, digital cinematography cameras have made strides in terms of the elevation of their recording of increasingly higher picture-capture rates of both 4K and 2K, and more recently of 6K and 8K.

Progress in Digital Cinematography Lenses

Super 35-mm Format Cameras

The initial large-format digital cinematography cameras adopted the 3-Perf Super 35-mm image format because of the extensive available worldwide inventory of Super 35-mm motion picture film lenses. The associated *de facto* lens–camera mount was the positive lock (PL) mount—initially developed by ARRI back in the 1970s. Other mounts followed.

As 4K quickly moved to the forefront in digital cinematography, some shortcomings of motion picture film lenses emerged. Many did not meet 4K resolution. Resolution at image extremities was compromised in some and chromatic aberrations became visible in many. The world's major optical manufacturers soon initiated developments of new-generation Super 35-mm zoom and prime lenses specifically to deal with such issues. A quite astonishing proliferation of these new-generation lenses have emerged in recent years—now from more than 20 international optical manufacturers.

For 8K studio production, the Super 35-mm format has been adopted by some seven camera manufacturers and three of them have also developed full frame (and larger) cameras. The major optical manufacturers have also been heavily preoccupied in developing 8K lenses for both of these formats.

Full Frame and Large-Format Lenses

Three years ago, the first full frame camera appeared—based on the established 36 mm × 24 mm full frame of still photography. It was soon followed by competitive products that manifested themselves with a range of variants of this 1.5:1 aspect ratio format. In addition, the drive for resolutions beyond 4K progressively elevated photosite numbers on image sensors and they, in turn, grew larger than full frame—and all of which posed moving targets for lens design. Full frame, or large-format, cameras are presently available from six manufacturers. The last two years have seen a surge of activity among the lens manufacturers to produce lenses that are at least 4K capable and have optical image circles capable of encompassing most, if not all, of these large-format image sizes.

Digital Cinematography Lens–Camera Mount Dilemma

The last five years have witnessed a surge in global manufacturers—many of whom had never been heard of in the digital cinema world—where more than eight camera manufacturers and some 20 different companies are offering new-generation lenses with ever-broadening price ranges. And, with this proliferation of lenses and cameras, there is an expanding range of lens mounts—among which are PL/EF/E/FZ/L/LPL/PV mounts. This does pose quandaries for many in the motion imaging community.

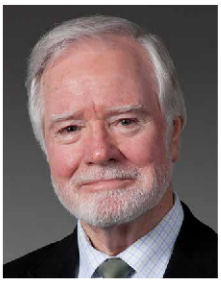
HDR Lens Designs Vie With Anamorphic and Vintage Lenses?

HDR and WCG considerations have also played an increasing role in new cinematography lens design. This has stirred interesting debates in the content creation communities of moviemaking and high-end episodic television production. In the moviemaking world, the anamorphic lenses are widely used today, and apart from the widescreen aspects there is a creative affection for artifacts such as oval bokeh effects and flares created by speculars that are associated with these lenses. There is also an increased preoccupation with vintage lenses and their associated aberrations, which offer unique creative effects.

The HDR lens, on the other hand, seeks a pristine management of light transmission, in terms of very tight control over any contamination of blacks and accurate reproduction of speculars. A variety of optical design and manufacturing strategies were, and are, being mobilized to reach the HDR performance goals. They include new glass materials and new optical coating materials flanked by improved deposition techniques, to minimize all of the internal reflections inherent at each air–glass surface. Advanced optomechanical strategies are included to preempt the light reflections that can take place within the lens barrel and lens element mountings. Curtailing optical ghosting artifacts that can be stimulated by strong light intrusions such as the sun entering at an angle into the lens is also central to the high-performance HDR lens.

It would appear that the vigorous developments in the last decade—in lenses and cameras—offer something to meet all creative aspirations.

About the Author



Laurence J. Thorpe joined Canon U.S.A., Inc., Melville, NY, in 2004, as a national marketing executive for the Broadcast & Communications Division. He was promoted to senior fellow in 2012 and currently holds that title in the Company's Imaging Technologies & Communications Group. A renowned industry expert in the field of video acquisition, he spent more than 20 years at Sony Electronics, pioneering the development of high-definition television (HDTV) and digital production technologies in the U.S. broadcast and motion picture industries. Prior to that, he worked for RCA's Broadcast Division, Camden, NJ, from 1966 to 1982, where he developed a range of color television cameras and telecine products. From that work, he holds ten patents in the field of broadcast development. He has published more than 60 papers on camera technology and the topic of HDTV imaging. He is a Life Fellow of SMPTE. He is a graduate of the College of Technology, Dublin, Ireland, and began his career as a design engineer with BBC, London, U.K. In 1981, he won the David Sarnoff Award for his innovations in automatic studio color cameras. He received the Montreux 2000 Gold Medal Award for Digital Cinematography, the NAB 2001 Television Engineering Achievement Award, the Society of Television Engineers (STE) 2001 Award, and the Broadcasting & Cable Technical Leadership Award in 2004. In 2014, he received the Charles F. Jenkins Lifetime Achievement Award, honoring an individual whose ongoing contributions have significantly affected the state of television technology and engineering. The award was presented during the 66th Primetime Emmy Engineering Awards ceremony in Las Vegas. In 2015, SMPTE conferred Honorary Membership on Thorpe, which recognizes individuals who have performed eminent service in the advancement of engineering in motion pictures, television, or in the allied arts and sciences.

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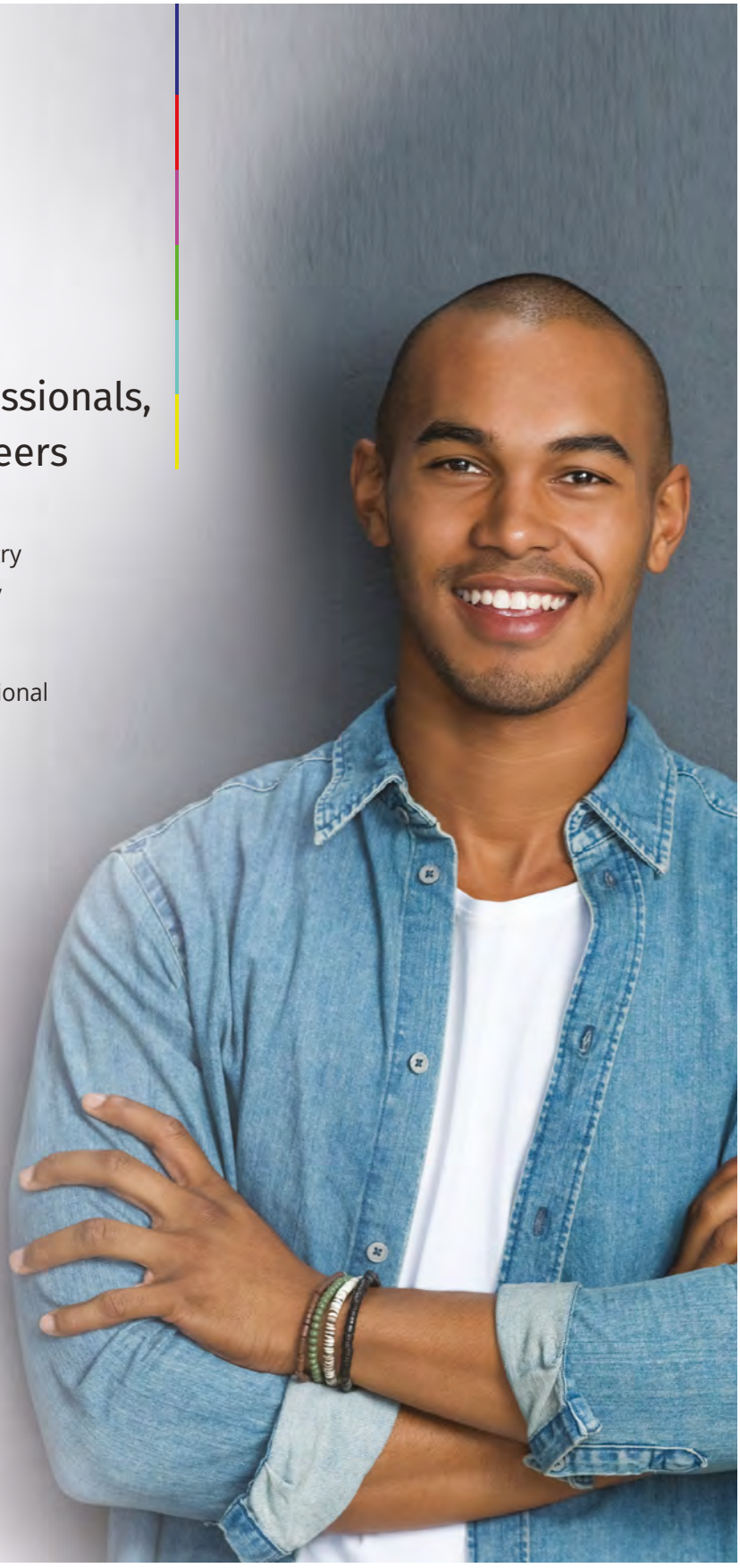

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