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Former Chairman of the FCC, and Senior Research Fellow at Harvard Kennedy School

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Communications Practice Leader, Hogan Lovells LLP
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SUMMIT RIDGE GROUP

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The Spectrum Handbook 2018

This updated Handbook explains the fundamental business, legal, and technical issues around electromagnetic spectrum use today

J. Armand Musey, CFA JD/MBA
E. Barlow Keener, JD, MA, CIPP

Summit Ridge Group, LLC
535 Fifth Avenue, 4th Floor, New York, NY 10017

The Spectrum Handbook 2018

- **Spectrum valuation framework**
- **Sources and timing of new mobile spectrum**
- **Break-out of mobile wireless spectrum allocations, demand and fundamental business dynamics**
- **International comparative analysis of spectrum regulation and allocation**
- **Explanation of spectrum and wireless technology issues**
- **Overview of fundamental regulatory and licensing issues**
- **Explanation of spectrum usage in all major frequency bands**

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Any remaining errors or omissions remain those of the authors.

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"*The Spectrum Handbook 2018* offers comprehensive and accessible answers to just about every question one could have about spectrum management and the wireless business. Authors Armand Musey and Barlow Keener have made a truly worthwhile contribution to the literature by compiling this indispensable resource. You will use this primer frequently."

Rob Frieden
Pioneers Chair and Professor of Telecommunications and Law
Penn State University

Praise for The Spectrum Handbook 2018 (Con't)

"As pervasive as wireless services are today, the wireless revolution is just getting started. Whether you invest in startups or public companies in technology, media or communications understanding how radio spectrum is allocated, licensed, used, shared, bought and sold - and which bands support different services - will give you an edge. With the 2018 update the Summit Ridge handbook is an even more comprehensive desk reference for investors - just the right amount of information on a huge range of topics in a manageable size with extensive references for further research. I don't know of anything like it."

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President, Spectrum LLC
Former partner, Pillsbury Winthrop Shaw Pittman LLP

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John Heitman
Chair of Communications Practice
Kelley Drye & Warren LLP

"Spectrum and wireless data are the fundamental building blocks of cloud computing and hence our economy, and this fabulous book describes these assets and technologies better than anything else we have ever read."

Timothy K. Horan
Managing Director
Head of Communication and Cloud Services Research
Oppenheimer & Co., Inc

"*The Spectrum Handbook 2018* is an invaluable resource for operators and investors in the fixed and mobile broadband ecosystems The Summit Ridge Group has distilled the technical, regulatory and practical elements of understanding spectrum into an easily digestible and referenceable format.

There really is no other publication out there like it."

Jeff Kohler
Co-Founder
Rise Broadband

"There is a wind of change in spectrum use; learn where the wind is blowing. The breadth of the handbook overwhelms by covering technology, economics, law, and regulations affecting the use of spectrum bands in the U.S. and globally. I compliment the authors for collecting and presenting deep spectrum knowledge with juristic accuracy but without losing readability."

Dr. Heikki Kokkinen
CEO and Co-Founder
Fairspectrum Oy, Finland

Praise for The Spectrum Handbook 2018 (Con't)

"Summit Ridge's handbook is a boon for academics and practitioners seeking to engage the difficult issues of valuing, transacting, and planning wireless investments. It provides a comprehensive and holistic overview of the technical, legal, and economic challenges of spectrum management in a single and easily accessible volume that still manages to go deep in addressing the challenges confronting the experts today. In light of the fast pace of innovation, we are lucky to have a recently updated and expanded Spectrum Handbook 2018!"

William Lehr, PhD
Research Scientist
Massachusetts Institute of Technology

"An extraordinary comprehensive and well-organized overview of the multi-faceted complexities of spectrum issues, including technical, economic and regulatory considerations. *The Spectrum Handbook 2018* is an invaluable primer for both those new to the field and a handy reference for experienced practitioners."

Andrew D. Lipman
Partner and Legal Practice Group Leader
Morgan Lewis

"*The Spectrum Handbook 2018* is a rare – and extremely valuable – guide to the business and regulatory issues affecting the use of spectrum in the 21st Century. The Handbook goes beyond the typical review of US regulatory issues by supplying the technical overview that is so often lacking from other handbooks. Additionally, the Handbook provides an excellent review of global markets, plus an insider's discussion of the valuation process. The Handbook is a great reference guide for both experienced telecoms professionals and those new to the industry."

Lee G. Petro
Special Counsel, Pillsbury Winthrop Shaw Pittman LLP
President, Federal Communications Bar Association (2018-2019)

"A very comprehensive book covering, every aspect and issues related to spectrum, a necessary resource for all wireless services. Excellent read and reference source for anyone involved in spectrum from new to the field to experienced practitioners, they are guaranteed to learn something."

Veena Rawat, O.C., Ph.D
Senior Spectrum Advisor and CEO, Expert Strategies International
Former President of Industry Canada's Communications Research Center

"*The Spectrum Handbook 2018* is a comprehensive survey of spectrum regulation, key technologies, and the state of the wireless business. It focuses on the United States, but includes surveys of key countries world-wide. It would serve well as either a primer for someone entering the field or as a handy reference for those well-versed in the field."

Pierre de Vries
Co-director, Spectrum Policy Initiative at Silicon Flatirons Center
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About Summit Ridge Group, LLC

Summit Ridge Group is the premier provider of valuation and financial advisory services specializing in the satellite, media and telecom sectors. We provide business appraisal, intangible asset valuation, strategic consulting, custom research and litigation support service. The client needs we service include transactional support, financial reporting, financial analysis, market analysis, strategic analysis, regulatory support and litigation support/expert witness testimony. Visit us at:

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The Spectrum Handbook 2018

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Executive Summary

This updated Handbook has three objectives: 1) to serve as a primer for explaining the complex issues around the use of electromagnetic spectrum; 2) to analyze, from both an economic and a legal perspective, the regulatory processes being considered or underway to reallocate or change the use of spectrum bands; and 3) to be a reference source for industry professionals. Part I of the Handbook provides an overview of the spectrum and the regulatory process. Part II provides an in-depth overview of various spectrum bands, discussing their range, location, and physical properties and how these impact their ability to be used. Part III explains the various Regulatory Dynamics. Part IV provides a comparative international overview. Part V is an overview of valuation methods and trends. An analysis of the current allocation of these spectrum bands in the United States follows. Throughout the Handbook, we provide links in the footnotes to sources for additional information.

From a macro-perspective, regulators worldwide are in the middle of a spectrum reallocation, primarily for 5G, that is unprecedented in its size and speed. This is occurring at a range of spectrum bands. The most noticeable change since our 2013 Handbook is the clear trend towards increase demand for higher frequencies, most notably, millimeter wave spectrum in the U.S. In addition, the unlicensed spectrum and spectrum sharing movements have graduated from a niche into the mainstream. Various forms of spectrum sharing are now supported by major companies such as Google and Microsoft. In a sense, they may be a portend a long-term upheaval of the sector by Silicon Valley players; however, mobile operators are ahead in deployed infrastructure.

In addition, regulatory bodies, including the FCC, repurposed and reallocated spectrum from 2012 to 2018 for both licensed and unlicensed use. This has dramatically increased the availability of spectrum, AWS-3, AWS-4, H-Block, 600 MHz incentive auction and others. And the process is continuing. The 3.5 GHz Citizens Broadband Radio Service, or CBRS, spectrum sharing proceeding, which will begin operating by the end of 2018 will add 150 MHz of new mid-band service for mobile and fixed use. The 2018 FCC proceeding to study proposals for satellite vendors to repurpose spectrum from 3.7-4.2 MHz will in the near future add up to another 500 MHz to the 150 MHz at 3.5 GHz. The 24 GHz and 28 GHz auctions are expected at yearend 2018.

Software defined networking technology has also increased the flexibility of communication networks in all areas from satellite to terrestrial wireless to submarine cables. Moreover, new technologies to increase spectrum efficiency, such as MIMO, spectrum sharing, small cell densification, beamforming antennas and spectrum aggregation (licensed and unlicensed) have evolved at unexpectedly rapid rates. As a result, not only has spectrum availability increased, but the historical near linear relationship between bandwidth demand and needed capacity has been broken. This makes evaluating carriers' need for spectrum an increasingly difficult exercise.

Table of Figures

Critical Dates in Spectrum History

The history of wireless communications mirrors that of many fields of science. After many centuries of little progress, significant new technological developments occurred during the Enlightenment. Progress has generally accelerated ever since, responding to the increased communications needs of modern society.

- 5th Century B.C.
  - Greek Pre-Socratic philosopher Empedocles opines (correctly) that light travels at a finite speed
- 1600s
  - Isaac Newton opines that light is made-up of particles (1672)
  - Christiaan Huygens postulates the wave theory of light (1678), a dualistic understanding (waves and particles) that continues today
- 1700s
  - Leonard Euler (1740s) and Benjamin Franklin (late 1700s) support Huygens' controversial theory which supports Newton's view
- Early 1800s
  - Thomas Young confirms Huygen's wave theory of light (1803)
- Mid 1800s
  - James C. Maxwell formulates the mathematical equations for classical electromagnetic fields using Michael Faraday's discovery of electromagnetic fields (1861)
  - International Telegraph Union (later to become the International Telecommunication Union) founded in Paris (1865)
- Late 1800s
  - Heinrich Rudolph Hertz proves electromagnetic waves exist (1886)
  - Guglielmo Marconi transmits and receives the first wireless signal
- Early 1900s
  - Reginald Fesseden makes first voice radio transmission (1900)
  - Guglielmo Marconi transmits first transatlantic wireless signal (1901)
- 1910s
  - Titanic tragedy emphasizes importance of radio communication (1912)
  - During WW I, the U.S. Navy takes control of all radio technology
  - After WW I, the Radio Corporation of America (RCA) established to take over patent control from the government
  - First AM licensed radio station, 740 kHz KCBS AM, San Jose, CA (1909)

- 1920s
  - First radio program transmitted on a daily basis (1920)
  - Marconi discovers short wave radio can reflect from ionosphere (1920)
  - Working television is demonstrated in London by John Logie Baird at Selfridge's Department Store (1925)
  - First color television transmission is delivered in Scotland (1928)
- 1930s
  - Frequency-modulated (FM) radio invented by Edwin Armstrong (1933)
  - The Federal Communications Commission (FCC) established (1934)
  - First FM station, WAAF 107.3 MHz Westborough, MA (1937)
- 1940s
  - Wartime military needs encourage deployment of radio services
  - Radiotelephony commercialized
- 1950s
  - First Soviet satellite, Sputnik 1, launched, followed by the first U.S. satellite, Explorer 1
  - First color television introduced in the U.S. (1953)
- 1960s
  - Telstar I satellite relays transatlantic television signal (1962)
- 1970s
  - LORAN becomes leading navigation system
  - The FCC allocates 40 MHz for cellular service
- 1980s
  - Cellular spectrum given to local Bell operating companies and ATT (1983)
  - The first commercial handheld mobile phone was approved by the FCC (1983)
  - Bell Breakup (1984)
  - First cell phone services begin (1984)
  - FCC allocated ISM bands for unlicensed use (1985)
  - First generation of GPS satellites completed (1985)
  - First Internet services provided through dial-up connections
- 1990s
  - Second generation (2G) cellular technology (digital) launched
  - First text messages sent from cell phone to cell phone
  - FCC conducts its first spectrum auction (1994)
  - Internet commercialized and opened up to the public in 1995
  - FCC finally publishes unlicensed Wi-Fi standards allocated in 1985 (1997)
  - Digital television broadcasting begins (late 1990s)
  - Wi-Fi is trademarked by the Wi-Fi Alliance (1999)
  - Apple adds Lucent Wireless LAN into the new iBook and Airport (1999)

- 2001
  - Third generation (3G) cellular technology launched
- 2006
  - Fourth generation (4G) cellular technology released in South Korea
    - 4G not launched in the U.S. until 2008 by Sprint Nextel
- 2008
  - First reallocations of U.S. spectrum bands in the 700 MHz range
  - Analog services phase-out to digital service begins
  - Licensing TV white spaces accelerates share spectrum movement
- 2015
  - 4G LTE penetration reaches 100% of the U.S. population
- 2018
  - 3GPP or Third Generation Partnership Project, defines 5G standards