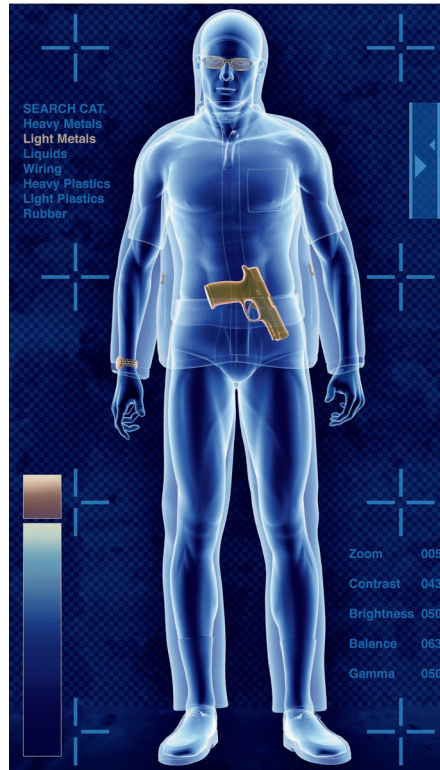


Thintri, Inc. announces the release of **Millimeter Waves: Emerging Markets**, a new market study that explores the current state of millimeter wave technology and market opportunities for systems operating in the millimeter wave range. This in-depth investigation, the second update to Thintri's original 2010 study, discusses millimeter wave technologies already creating significant markets, emerging market opportunities, and overall market development. The report surveys today's technologies and applications, separates hype from reality and assesses the applications where millimeter wave technology will open up significant new markets, with market forecasts going out to 2023.

Thintri Inc.

Thintri Inc. provides business and market intelligence for a wide range of technologies through custom consulting, technology assessments, and published market studies.

- Semiconductors
- Electronics
- Photonics
- Telecommunications
- Materials engineering



Contents

Millimeter Wave Systems Overview

- Technology Background
- Technical Issues (GaAs vs. SiGe/CMOS, packaging, components, etc.)
- Public Policy, Regulation, Licensing
- Standards (WiGig, Wireless HD, etc.)
- Established Markets

Prime Applications

- Imaging
- Telecommunications
- Consumer and Automotive
- Defense and Security

Imaging

- Active vs. Passive Systems
- Markets in Checkpoint Security—Airports, concerts, sports events, etc.
- Markets in Loss

Prevention/Inventory Control

- Markets in Through-Wall Imaging
- Markets in Consumer Retail/Clothing Sales
- Issues of Privacy and Public Perception
- Competing Technologies

Telecommunications

- Established Lower-Frequency Applications
- Applications for Millimeter Waves (Enterprise, Backhaul, P2P, etc.)
- Licensed vs. Lightly Licensed vs. Unlicensed
- Performance and Availability
- 23 to 39 GHz Bands
- 60 GHz Band Markets

Consumer Markets

- 60 GHz: Consumer, Home Media Markets
- Data Compression

- Hardware Considerations
- Market Growth
- Automotive Radar
- 24 GHz vs. 77 GHz
- Market Growth: Trucks, Automobiles

Defense & Security Radar Markets

- Smart Munitions
- Perimeter & Surveillance Radar, Intrusion Detection
- Marine Radar
- Defense & Intelligence Communications

Other Millimeter Wave Markets

- Commercial Ka-Band Satellite (VSAT) Communications
- Medicine and Health
- Chemical Monitoring
- Construction and Infrastructure
- Manufacturing

Background on Millimeter Wave Systems and Their Markets

Millimeter wave (MMW) radiation, that portion of the electromagnetic spectrum generally defined as 20 GHz to 300 GHz, has gained commercial traction in the past decade or so. Now, evolution in technology and changes in the regulatory environment have expanded opportunities in existing millimeter wave applications and opened new, potentially very large markets.

MMW imaging is established in airport security and markets are rapidly growing in loss prevention, where systems can quickly scan employees leaving a manufacturing facility to prevent theft. New technology will soon dramatically reduce the cost of such imaging systems, allowing their adoption in a much broader range of venues such as courthouses, concerts, stadiums, schools, dance clubs and many others. Systems are even commercially available for retail clothing shoppers to conduct body measurements to determine clothing sizes and recommend appropriate products and brands.

MMW systems are also transforming telecommunications, offering data rates that approach those of fiber. E-band links are quickly capturing markets in backhaul, where they can be deployed quickly and at a small fraction of the cost of laying optical fiber.

Millimeter waves may be the only viable solution to the bandwidth challenges facing today's telecom industry as it transitions to next-generation 5G networks. Some 4G networks are already approaching the theoretical limit on how much data can be squeezed into a given band. Experts predict that by the year 2020, more than 50 billion devices, including tracking tags, body sensors, vehicles, clothing and a broad range of appliances, sensors and other technologies, will be connected to mobile networks. Wireless data transfer volumes will be 1,000 times greater than they are today, with demand for data transfer rates at 10 to 100 times faster than is practical today.

One of the most exciting frontiers in telecommunications is fixed wireless Internet access, where MMW systems are about to facilitate a game-changing market shift. As small, highly flexible startups move to offer

MMW-based wireless Internet access across broad geographic regions, the walls that once served to separate the various access suppliers will break down. The result will be a Wild West scenario where a large number of players, large and small, compete to offer consumers and businesses up to gigabit data rates at low cost.

Likewise, satellite Internet access, serving rural users and ships at sea, will create billion-dollar markets for millimeter wave equipment.

Automotive radar is another burgeoning market. Eventually, as collision avoidance systems in cars and trucks becomes standard and even mandated in some places, the advantages of millimeter waves in achieving low cost radar systems with high resolution will lead to billion-dollar revenue streams.

The unique properties of millimeter waves lend them to a host of other markets as well, including manufacturing process and quality control, medical diagnosis, munitions guidance, security perimeter radar, and monitoring of chemical processing and pipelines.

The Thintri market study, *Millimeter Waves: Emerging Markets*, makes use of extensive, in-depth interviews with industry executives, market development managers and government and academic researchers. The report provides a survey of the current state of the art in millimeter wave technology, an assessment of potential applications in terms of their commercial viability, discussion of market development and forecasts for individual markets from 2016 to 2023.

Understand the Markets

The outlook for millimeter wave technology is extraordinarily promising. Steady reductions in hardware cost and progress in system development are dovetailing with growing demand in a number of markets and, in some cases, greatly relaxed regulation, all leading to growth in widely diverse markets. Depending on the market, that growth is already well underway, is starting now, or will start soon. Most importantly, some of the most significant markets, including security and telecommunications, are not only potentially quite large but relatively immune

to economic conditions. Other developers are making use of new technologies to bring millimeter wave systems within striking distance of mass markets. Some emerging markets require little more than education of users in the capability of millimeter wave systems while in others, that case has already been made and equipment sales are growing rapidly. In most areas, technologies have matured to the extent that scientific understanding is not an issue; instead, the principal requirement is bringing prices in line with market demand.



Price: \$4,800

Contact:

J. Scott Moore, Ph.D., President
Thintri, Inc.
Mount Kisco, NY
Phone: 914/242-4615
Fax: 914/666-4114
E-mail: smoore@thintri.com
Web: www.thintri.com

Report Contents

Executive Summary	1
E.1 Introduction.....	1
E.1 Established Millimeter Wave Markets.....	1
E.2 Technology & Hardware	2
E.3 Regulation and Public Policy.....	2
E.4 Imaging	3
E.5 Telecommunications	4
E.6 Consumer Markets	5
E.7 Defense and Security Radar.....	6
E.8 Other Millimeter Wave Markets	7
E.8.1 VSATs.....	7
E.8.2 Medicine and Health	8
E.8.3 Chemical Monitoring.....	8
E.8.4 Construction and Infrastructure	9
E.8.5 Manufacturing.....	9
Part 1: Overview	10
1.1 Introduction.....	10
Figure 1-1 Primary US Microwave and Millimeter Wave Band Allocations	10
1.2 History.....	13
Figure 1-2 Prof. J.C. Bose with his millimeter wave equipment, 1897	14
1.3 Current Markets.....	15
1.3.1 Telecommunications	15
1.3.2 Radar.....	16
1.4 Technology Basics.....	17
Figure 1-3 Propagation of Millimeter Waves.....	18
Figure 1-4 Absorption of Millimeter Waves by Atmospheric Oxygen and Water Vapor	19
Figure 1-5 Overall Atmospheric Absorption Mechanisms of Electromagnetic Radiation	20
1.5 Why Millimeter Waves?.....	21
Part 2:Technology and Hardware	22
2.1 Semiconductors and Packaging	22
2.1.1 Material Systems: GaAs, GaN, SiGe and CMOS	22
2.1.2 Packaging: MCM vs. SMT.....	28
2.1.3 Devices, Circuits & Components	29
2.1.4 RF-MEMS Switches.....	29
2.2 Transmission Lines.....	30
2.3 Antennas.....	31
2.4 Transceivers & Receivers	32
2.5 Systems	32
2.6 Modulation.....	34
2.6.1 Amplitude Shift Keying	34
2.6.2 Frequency Shift Keying.....	34
2.6.3 Orthogonal Frequency Division Multiplexing	35
Part 3: Technical and Safety Issues	36
3.1 Technical Issues	36
3.2 Safety.....	38
Part 4: Public Policy, Regulation, and Standards	40
4.1 Background: Growth of the Current Regulatory Climate	40
4.2 New FCC Rule Changes.....	41
4.3 E-band Regulation	43
4.4 The Effect of Local Government	45
4.5 Standards.....	45
4.5.1 Low Frequency Options	46
4.5.2 Higher Frequency Standards.....	48
4.5.3 Summary	51
Part 5: Imaging	52
5.1 Introduction.....	52
5.2 Imaging Technology.....	53

Figure 5-1 Scissors Imaged Through a Closed Container.....	53
Figure 5-2 Cookies Imaged Through a Closed Container	53
5.3 Imaging Applications.....	56
5.3.1 Checkpoint Security: Airports & Other Public Venues	56
5.3.2 Inventory Control, Theft Prevention	59
5.3.3 Through-Wall Imaging	60
5.3.4 Consumer Retail.....	62
5.4 Active vs. Passive Systems	64
5.4.1 Technical Comparison	64
5.4.2 Application/Market Comparison.....	67
Figure 5-3 Checkpoint Security Imaging Market, Active vs. Passive System Share	69
5.5 Issues of Acceptance: Privacy and Public Perception.....	69
Figure 5-4 Active millimeter wave images.....	70
Figure 5-5 TSA Chart on Millimeter Wave Scanners	72
5.6 The Competition: Backscatter X-Ray.....	73
5.7 Millimeter Wave Imaging Markets.....	75
5.7.1 Market Development	75
5.7.2 Checkpoint Security Imaging Markets	77
Figure 5-6 Millimeter Wave Imaging Systems Sales in Checkpoint Security, Unit Sales	80
Figure 5-7 Millimeter Wave Imaging Systems Sales in Checkpoint Security, Market Volume.....	80
5.7.3 Inventory Control and Loss Prevention Imaging Markets.....	80
Figure 5-8 Imaging Systems Sales, Loss Prevention, Unit Sales.....	81
Figure 5-9 Imaging Systems Sales, Loss Prevention, Market Volume.....	82
5.7.4 Through-Wall Imaging Markets.....	82
Figure 5-10 Millimeter Wave Through-Wall Imaging Systems, Market Volume.....	82
5.7.5 Consumer Retail Imaging Markets.....	83
Figure 5-11 Imaging Systems Sales in Consumer Retail, Market Volume	83
5.7.6 Handheld Systems.....	83
Figure 5-12 Handheld MMW Imaging System Sales, Unit Sales.....	84
Figure 5-13 Handheld MMW Imaging System Sales, Market Volume	85
Part 6: Telecommunications	86
6.1 Introduction.....	86
6.1.1 Conventional Microwave Links	86
Figure 6-1 Conventional Microwave Links, Market Volumes.....	87
Figure 6-2 Conventional Microwave Links, Unit Sales	88
Figure 6-3 Conventional Microwave Links, Hardware Sales by Component.....	88
Figure 6-4 Relative Share of Mobile vs. Enterprise Networks, 6 - 38 GHz, 2016.....	89
6.1.2 The advent of Millimeter Wave Systems in Telecommunications	89
6.2 5G: Backhaul and the Small Cell Model	94
6.3 Licensed vs. Lightly Licensed vs. Unlicensed	97
6.4 The 23, 24, 26 and 39 GHz Bands.....	99
6.4.1 23 and 26 GHz Bands.....	99
6.4.2 24 and 39 GHz Bands.....	99
6.5 60 GHz.....	101
6.5.1 60 GHz Telecommunications Applications	102
6.5.2 Short Range: WiGig and WirelessHD.....	104
6.5.3 Benefits of 60 GHz Technology	106
6.6 The E-band.....	107
6.6.1 Background	107
6.6.2 Propagation Characteristics.....	108
6.6.3 Performance, Reliability and Availability	109

Table 6-1 Five Nines Link Range and Availability for Several Cities.....	110
6.6.4 Applications & Users	112
Table 6-2 Frequency vs. Beamwidth at 1 km using a 1 foot diameter antenna	113
Figure 6-5 Beamwidth comparisons for wireless backhaul solutions	115
6.6.5 E-band Licensing.....	118
6.7 The Competitive Technology Landscape.....	119
Figure 6-6 Telecommunications Backhaul: Shares by Technology	120
6.8 The Millimeter Wave Telecom Market	121
6.8.1 Past Market Growth.....	121
6.8.2 The Shift to backhaul.....	122
6.8.3 WISPs: Fixed Wireless Internet Access	123
6.8.4 Present and Future Market Growth.....	130
Figure 6-7 Markets, Millimeter Wave Telecommunications Links, 20 to 38 GHz.....	131
Figure 6-8 Markets, 20 to 38 GHz, by Component	131
Figure 6-9 Millimeter Wave Systems Markets, Telecom, 60 GHz.....	132
Figure 6-10 Telecom Systems Markets by Component, 60 GHz.....	133
Figure 6-11 Millimeter Wave Systems Markets, Telecom, 60 GHz, Unit Sales	133
Figure 6-12 Millimeter Wave Systems Markets, Telecom, E-band.....	134
Figure 6-13 Telecom Systems Markets by Component, E-band.....	134
Figure 6-14 Millimeter Wave Systems Markets, Telecom, E-band, Unit Sales.....	135
Figure 6-15 Millimeter Wave Systems Markets, 60 GHz, by Application	135
Figure 6-16 Millimeter Wave Systems Markets, E-band, by Application	136
Figure 6-17 E-band Enterprise Markets, Government/ Municipalities, General Business	136
Figure 6-18 E-band Enterprise Markets, Healthcare, Education, Misc.....	137
Part 7: Consumer & Automotive.....	138
7.1 Introduction.....	138
7.2 60 GHz Systems: Consumer & Home Media.....	139
7.2.1 Background: 60 GHz in Multimedia	139
7.2.2 Data Compression	141
7.2.3 Hardware Considerations	142
7.2.4 60 GHz Consumer Media Markets	143
Figure 7-1 Markets for 60 GHz Consumer Multimedia Products.....	144
Figure 7-2 Markets for 60 GHz Consumer Multimedia Products, Unit Sales	144
7.3 Automotive Radar.....	145
7.3.1 Background: Millimeter Wave Radar	145
7.3.2 MMW Radar Applied to Transportation	146
7.3.3 History	148
Figure 7-3 The 1959 Cadillac Cyclone with Radar.....	148
7.3.4 MMW Radar Technology	150
7.3.5 24 GHz vs. 60 GHz vs. 77 GHz vs. 79 GHz.....	153
Table 7.1 Assigned Tasks by Band.....	155
Figure 7-4 Market Share, Auto Radar, 24 GHz vs. 77 GHz, Automobiles.....	156
Figure 7-5 Market Share, Auto Radar, 24 GHz vs. 77 GHz, Trucks	157
7.3.6 Infrastructure and Vehicle-to-Vehicle Communications.....	158
7.3.7 Automotive Radar Markets.....	158
Figure 7-6 Worldwide Unit Sales, Cars and Trucks	160
Figure 7-7 Unit Sales, Radar Systems, Trucks and Automobiles.....	161
Figure 7-8 Markets for Automotive Radar, 24 GHz and 77 GHz.....	161

Part 8: Defense & Security Markets.....	163
8.1 Background	163
8.2 Millimeter Wave Radar for Security and Intrusion Detection	164
8.2.1 Perimeter and Surveillance Radar.....	165
8.2.2 Range Considerations.....	167
8.2.3 Technical Considerations.....	168
8.3 Munitions Applications.....	168
8.4 Marine Radar.....	169
8.5 Defense and Intelligence Communications.....	170
8.6 Active Denial Systems and Non-Lethal Weapons.....	171
8.7 Defense & Security System Markets	172
Figure 8-1 Surveillance/Perimeter Radar, Defense vs. Non-Defense, 2016.....	173
Figure 8-2 Millimeter Wave Surveillance/Perimeter Radar Markets	173
Figure 8-3 Millimeter Wave Munitions Radar Markets.....	174
Figure 8-4 Marine Radar Millimeter Wave Markets	175
Figure 8-5 Defense & Intelligence Millimeter Wave Communications Markets	175
Figure 8-6 Overall Defense & Security Markets.....	176
Part 9: Other Millimeter Wave Markets.....	177
9.1 Commercial Ka-band Satellite Communications.....	177
Figure 9-1 Unit Sales, VSAT Terminals.....	181
9.2 Medicine and Health.....	182
Figure 9-2 Millimeter Wave Markets in Medicine, Health and Safety	185
9.3 Chemical Monitoring	185
Figure 9-3 Markets for Millimeter Wave Systems in Chemical Monitoring	186
9.4 Construction & Infrastructure	186
Figure 9-4 Millimeter Wave Systems Markets in Construction and Infrastructure.....	187
9.5 Manufacturing.....	187
Figure 9-5 Millimeter Wave Markets in Manufacturing	188
Part 10: Millimeter Wave Semiconductor Markets	189
10.1 Introduction.....	189
10.2 The Evolving Semiconductor Landscape.....	189
Figure 10-1 Overall MMICs by Application, All Frequencies, 2016	191
Figure 10-2 MMIC Sales by Application, Millimeter Wave Only, 2023	192
10.3 Consumer Applications.....	192
Figure 10-3 Semiconductor Markets in Car Radar, Multimedia	192
10.4 Imaging	193
Figure 10-4 Millimeter Wave Semiconductor Markets, Active Imaging Systems.....	193
Figure 10-5 Millimeter Wave Semiconductor Markets, Passive Imaging Systems.....	194
10.5 Defense and Security.....	194
Figure 10-6 Defense & Security Millimeter Wave Semiconductor Markets	195
10.6 Telecommunications	195
Figure 10-7 Telecommunications Millimeter Wave Semiconductor Markets	195
10.7 Other Millimeter Wave Applications	196
Figure 10-8 Semiconductor Markets in Other Millimeter Wave Applications.....	196