History of RF/Microwave Technology Development

An Introductory Work by MovaMicrowave LLC

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Modern RF/Microwave Solutions with Transparency and Speed

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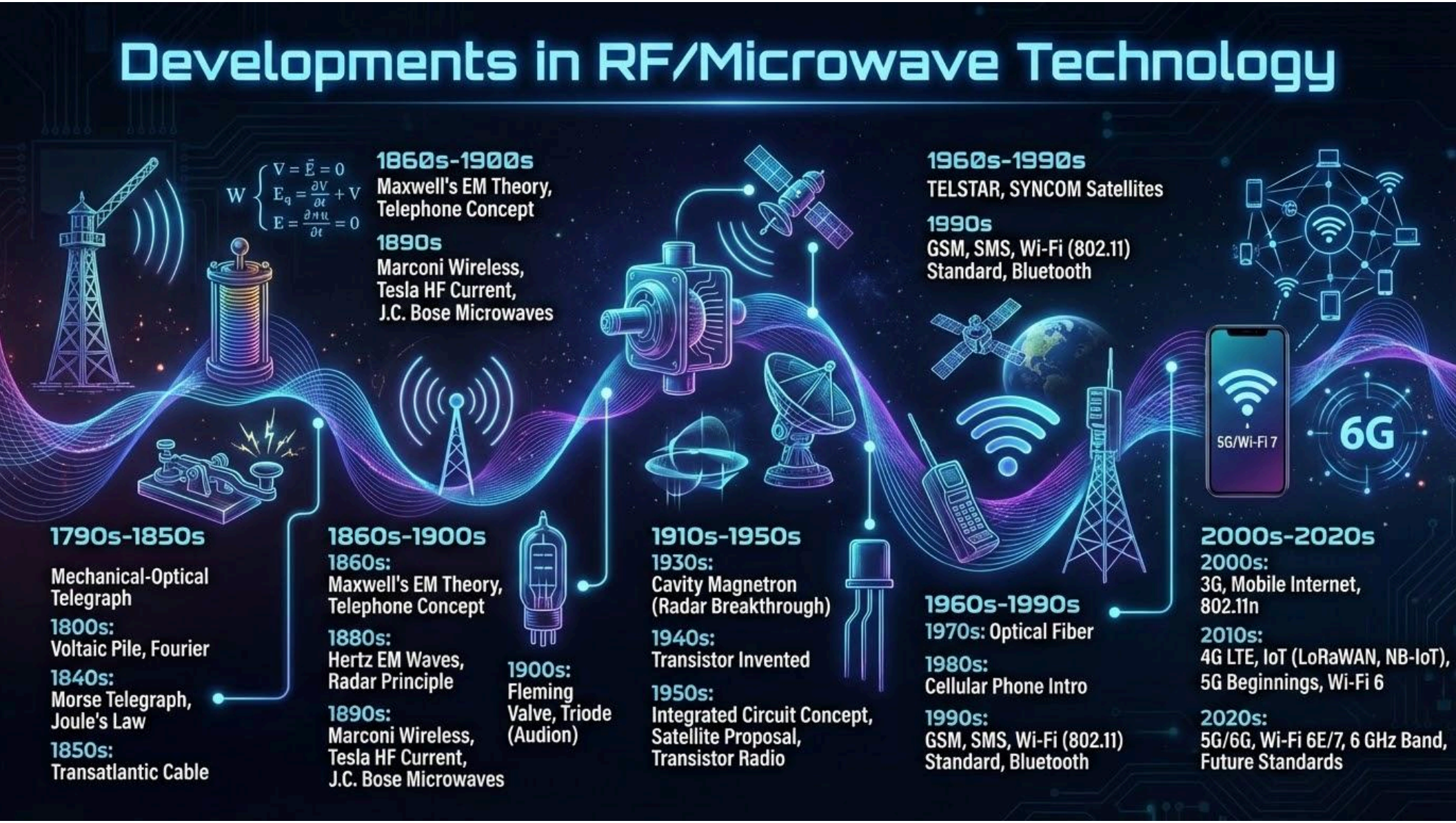

Image generated by ChatGPT using the table below

PURPOSE: introduce the readers and viewers to the rich history of RF/Microwave technology, give credit to the giants that shaped the field, and gain an understanding of the trends and future of the field.

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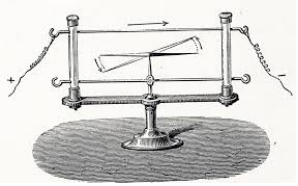
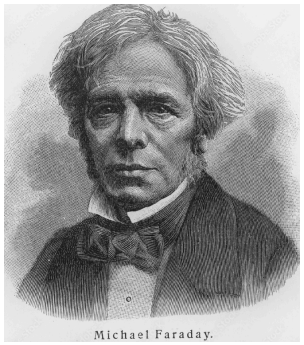
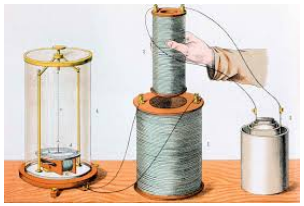
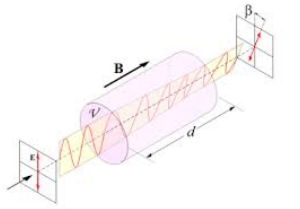
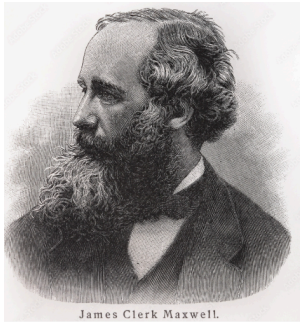
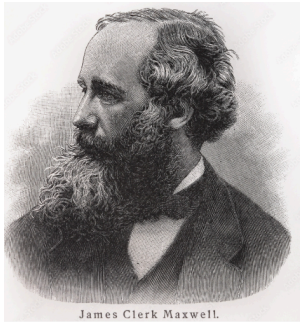
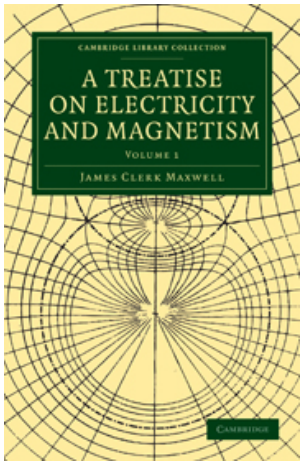
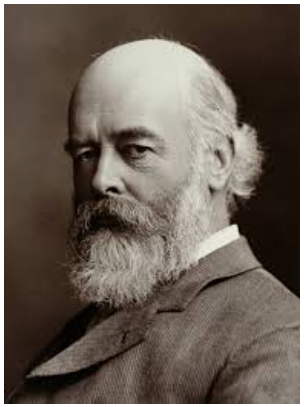
Year	Invention/Milestone	Inventor(s)	Technical Contribution	Branch Created	Impact	Images
Foundational Electromagnetic Physics						
1820	Discovered the relationship between currents and magnetic fields	Hans Christian Orsted	Showed deeper relationship between electricity and magnetism	Electromagnetism	Contributor to the birth of electromagnetics	 Hans Christian Örsted. 

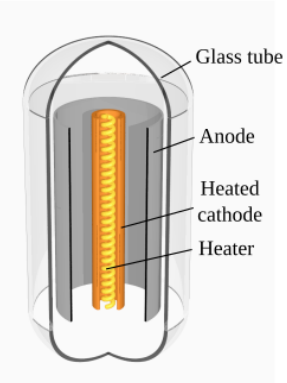
1831	Electromagnetic induction	Michael Faraday	Time-varying magnetic fields induce EMF	Power generation, transformers	Enabled signal and power generation	 
1845	Faraday Effect	Michael Faraday	Magnetic field rotates polarization	Non-reciprocal RF devices	Basis of isolators and circulators	 

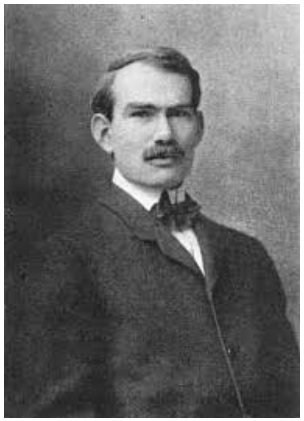
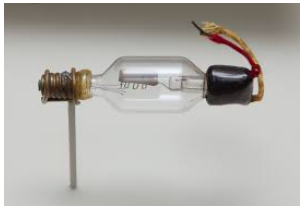
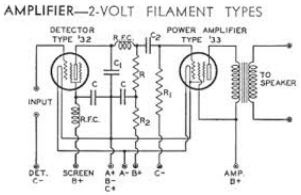
1864	Maxwell's equations	James Clerk Maxwell	Unification of electric and magnetic fields	EM wave propagation theory	Theoretical birth of wireless power transfer	 James Clerk Maxwell. $\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$ $\nabla \cdot \mathbf{B} = 0$ $\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$ $\nabla \times \mathbf{B} = \mu_0\left(\mathbf{J} + \varepsilon_0\frac{\partial \mathbf{E}}{\partial t}\right)$

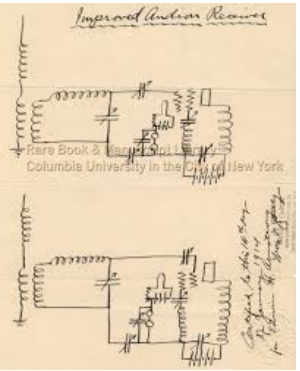
1873	Treatise on Electricity and Magnetism	James Clerk Maxwell	Field equations formalized	Analytical electromagnetics	Physics to engineering transformation	 James Clerk Maxwell. 

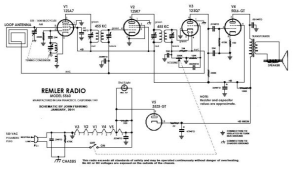
Demonstrations of Early Wireless Technology						
1887 - 1888	EM waves experimentally generated and detected	Heinrich Hertz	Spark-gap transmitter and resonant receiver	Experimental radio	Confirmation of Maxwell's theory; beginning of radio transmissions	 

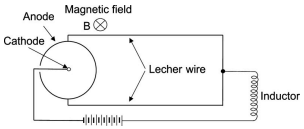
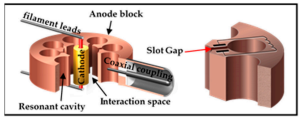
1894	Wireless signaling demonstrations	Oliver Lodge	Coherer-based reception	Wireless detection	Early radio receiver	 
1895 - 1901	Practical wireless telegraphy	Guglielmo Marconi	Antennas, grounding, coherers, systems engineering	Wireless systems	First application of wireless developed	

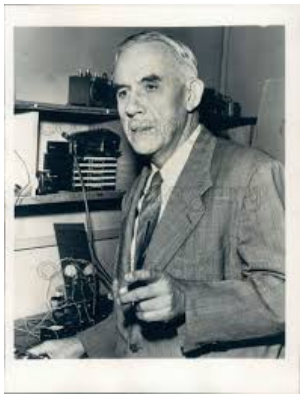
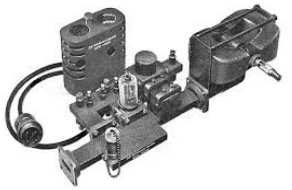
Vacuum Electronics						
1904	Thermionic diode	John Ambrose Fleming	One-way electron flow in vacuum	Vacuum electronics	Reliable RF detection	 

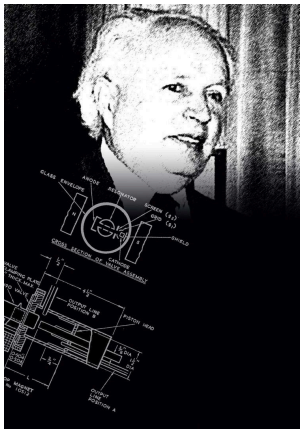
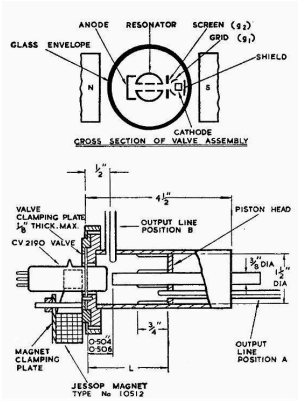
1906	Triode	Lee de Forest	Control grid enables amplification	Active RF	Scalable radio	 
1907 - 1912	Multi-grid tubes	Philips, RCA, …	Gain, stability, bandwidth	RF amplifiers	Enabled broadcasting	 

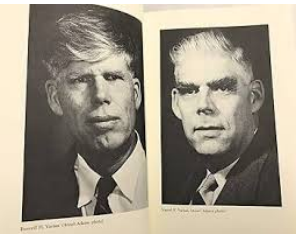
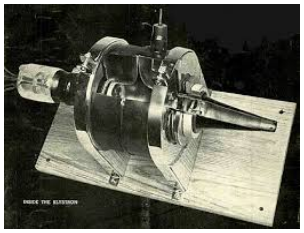
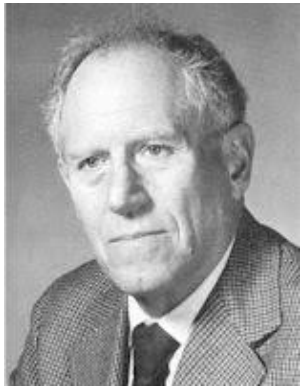
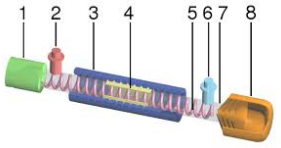
Receiver Revolution						
1913 - 1914	Regenerative receiver	Edwin Howard Armstrong	Positive feedback RF gain	High-sensitivity receivers	Amplification of weak signals	 

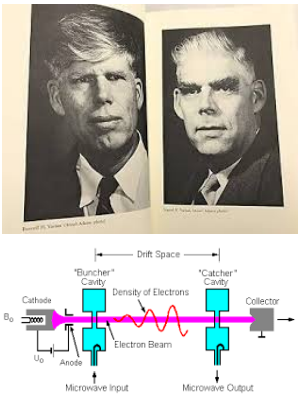
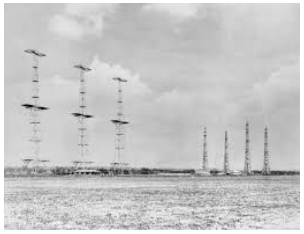
1917 - 1919	Superheterodyne receiver	Armstrong (priority dispute with Levy)	RF to IF frequency conversion, relaxing filter requirements	Modern receiver architecture (for a long time)	Used in radios, radar, cellular, SDR, spectrum analyzers, …	 
1933	Wideband FM	Armstrong	Noise immunity via frequency modulation	Low-noise communications	VHF/UHF radio, mobile philosophy	

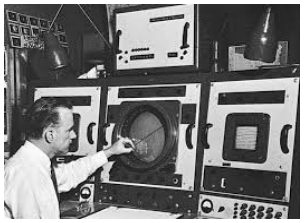
Microwave Power Generation: Magnetrons						
1921	Magnetron principle	Albert W. Hull (GE)	Electron control via axial B-field	Microwave oscillators	Birth of magnetrons (microwave sources)	
1924	Split-anode magnetron	Erich Habann	Sustained HF oscillation	Higher-frequency tubes	GHz feasible	
1929	Slotted-anode magnetron (5.35 GHz)	K. Okabe (Tohoku Univ.)	Centimeter-wave generation	Microwave radar	Cm-wave threshold crossed	

1935 - 1938	Multi-cavity magnetron	Hans Erich Hollmann	Resonant cavities increase power	High-power microwaves	Architecture breakthrough	 
1940 - 1941	Cavity magnetron (radar-grade)	Randall and Boot (UK)	10cm, 100 kW pulsed	Radar transmitters	WWII radar dominance	 

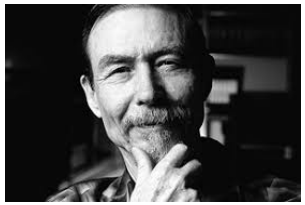
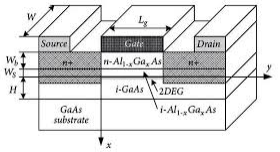
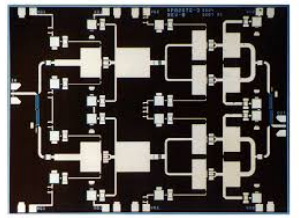
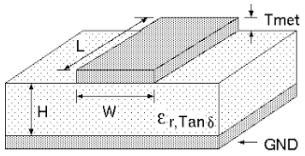
Microwave Power Generation: Klystrons and Linear Beams						
1935	Velocity modulation theory	Agnesa Arsenjewa-Heil, Oskar Heil	Electron bunching physics	Linear beam tubes	Amplification	 

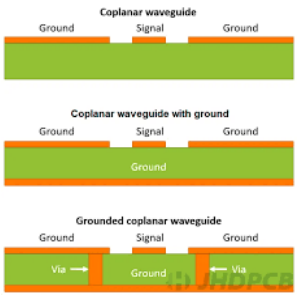
1937 - 1939	Klystron	Russel and Sigurd Varian, W.W. Hansen	Resonant cavities amplify microwaves	Microwave amplifiers	Radar, relays, accelerators	 
1943	Traveling Wave Tube (TWT)	Rudolf Kompfner	Broadband slow-wave amplification	Broadband microwave power	Satellites, electronic warfare	 

1950s	Multi-cavity and reflex klystrons	Varian/Industry	Power and stability scaling	Microwave sources	Lab and industrial RF	
Radar Systems						
1938	Chain home radar	UK Air Ministry	Early HF/VHF radar network	Air defense	First operational radar	

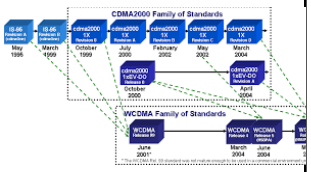
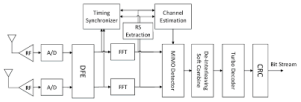
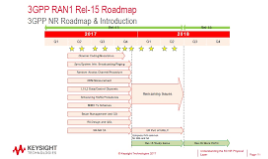
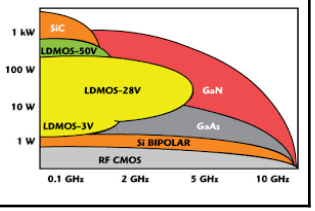
1940s	Pulse radar, duplexers	MIT Rad Lab, UK teams	Tx/Rx isolation, timing	Radar architecture	Modern radar forms	 
1950s	Doppler radar	Multiple labs	Velocity extraction	Signal processing radar	Weather, tracking	 

Solid-State Revolution						
1947	Transistor	Bardeen, Brattain, Shockley (Bell Labs)	Solid-state amplification	Semiconductor electronics	Miniaturization	 
1954	Silicon transistor radio	Texas Instruments	Portable electronics	Consumer RF	Mass adoption	

1966	GaAs MESFET (late 70's utilizes HEMT)	Carver Mead	High-speed Microwave FET	Solid-state microwave	MMIC foundation	 
1970s	GaAs MMICs	DARPA/industry	Integrated microwave circuits	RF integration	Size and reliability	
Printed Microwave and Integration						
1953	Microstrip	MIT/industry	Planar transmission lines	Printed RF	Manufacturable microwave circuits	

1960s	Stripline, CPW	Various	Controlled impedance media	RF layout science	Predictable RF	
1980s	RF CAD and EM solvers	Touchstone, SuperCompact, Libra, ANACAT, MiCAD, E-Syn, mwSPICE	Field-based design	Modern RF workflows	Reduced design time	
Cellular Phones and GPS						
1973	Hand-held cellular phone	Martin Cooper (Motorola)	Portable cellular RF	Personal wireless	Mobility explodes	
1978	GPS satellites	US DoD NAVSTAR	RF timing and navigation	PNT systems	Global infrastructure	

1989	Pocket cellular phones	Motorola	Consumer mobility	Mass adoption	Wireless everywhere	
Modern Digital Wireless Systems						
1991	GSM	ETSI/Nokia	Digital cellular	2G	Scalable mobile	
1997	IEEE 802.11	IEEE	WLAN	Wi-Fi	Short-range broadband	

2001	W-CDMA	NTT DoCoMo/3GPP	Packet data	3G	Mobile internet	
2009	LTE	3GPP	OFDM, MIMO	4G	Video mobile	
2015	LPWAN	LoRa Alliance/3GPP	Low-power IoT	IoT networks	Massive sensors	
2019	5G NR	3GPP	Massive MIMO, mmWave	Advanced wireless	Industry automation	
2024	5G-advanced/Wi-Fi 7	3GPP/IEEE	Extreme throughput	Converged RF	Next decade base	
Solid-State High-Power Microwave						
1990s - 2000s	GaAs PHEMT	TriQuint, NEC	High-frequency solid-state devices	High power RF/microwave	Replaces tubes (low power)	

2000s - present	GaN HEMT	Cree/Wolfspeed, Qorvo, MACOM, ...	High-power, high-voltage microwave	High power RF/microwave	Solid-state radar, base station, industrial heating, ...