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Wireless Devices: A Survey of Federal Communications Commission Equipment Authorization Database

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EPRI Project Manager

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NOTE

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ABSTRACT

The Federal Communications Commission Equipment Authorization Database was reviewed to identify the radio frequency (RF) emission characteristics of consumer equipment authorized for sale in the United States according to device class, communications technology, and frequency. In addition, the review included wireless-enabled electric utility meters (Smart Meters). The database demonstrates the rapid growth in the number of RF-emitting devices authorized by the Federal Communications Commission for sale in the United States. The database shows a rapid increase in the number of consumer-oriented devices that use digital communications and networking technologies, most of which use Bluetooth, ZigBee, and Wi-Fi technologies or variants thereof. The review also summarizes U.S. limits for the emissions from such devices and considers a simple model for exposure. RF exposures from all the devices considered in this review are highly variable, but under all realistic exposure conditions, they are far below U.S. and international exposure limits. However, close to the devices, RF exposures from such devices can be far above those from sources outside the home, such as broadcast radio or cellular base stations. The wide diversity of RF-emitting devices and the plethora of potential variables related to exposure will make it a challenge to respond to calls for health studies to search for possible health effects from RF exposure from such devices.

Keywords

Exposure
Federal Communications Commission Equipment Authorization Database
Radio frequency energy
Smart meters
Wireless communications

CONTENTS

1 INTRODUCTION 1-1
1.1 Background 1-1
1.2 Methods 1-1
1.3 Abbreviations and Acronyms 1-2

2 RESULTS 2-1
2.1 Time Trends by Device Class 2-1
2.2 Time Trends by Technology 2-4
2.2.1 Wi-Fi (IEEE 802.11) 2-4
2.2.2 Bluetooth and ZigBee 2-5
2.2.3 Digital Cordless Telephones 2-7
2.2.4 Mobile Telephone Handsets 2-8
2.2.5 Other Devices Found in the Home 2-8
2.3 Limits on Power Output of Devices 2-13
2.4 Free Space Model for Comparing Radio Frequency Exposures from Devices 2-16
2.5 Comparison with Other Sources of Radio Frequency Exposure in the Environment 2-18

3 CONCLUSIONS 3-1

4 ADDITIONAL READING 4-1

5 REFERENCES 5-1

LIST OF FIGURES

Figure 2-1 Original grants issued under Part 15C and sum of grants in two digital device classes 2-3
Figure 2-2 Cumulative number of new grants issued for Wi-Fi, Bluetooth, and Zigbee wireless devices 2-4
Figure 2-3 New grants for Wi-Fi-based network equipment by year and by conducted power for each of the two frequency ranges specified in the standard 2-5
Figure 2-4 New grants for Bluetooth devices by year and by conducted power 2-6
Figure 2-5 New grants for ZigBee devices by year and by conducted power....2-7
Figure 2-6 New grants for portable digital telephones and cellular handsets by conducted power 2-8
Figure 2-7 Distribution of leakage fields (W/m^2) measured 5 cm or more from microwave ovens....2-10

LIST OF TABLES

Table 2-1 The 10 Largest Device Classes 2-2
Table 2-2 Vendors of Smart Meters and Networking Solutions Providers 2-12
Table 2-3 Grants Issued for Part 15C Devices 2-14
Table 2-4 Peak and Spatially Averaged Exposure Levels Calculated Using a Free Space Propagation Model 2-17

1 INTRODUCTION

1.1 Background

Over the past 10 years, a flood of digital communications and networking devices that incorporate low-powered radio frequency (RF) transceivers have appeared in ordinary, nonoccupational settings. In several cases (notably, Wi-Fi in schools and Smart Meters on residences) public concern has been aroused related to possible health effects from exposure to RF energy, despite the fact that calculations and measurement show that exposures from such devices are a tiny fraction of U.S. and international exposure limits.

This review attempts to place these technologies in a broader context of the major shift in technology used in consumer-oriented electronic devices toward digital technologies using RF communications and to place RF exposures from Wi-Fi and Smart Meters in the context of those resulting from exposure to the plethora of other RF-emitting devices present in modern environments. This broader picture might help in risk communication; it also makes clear the formidable challenges that will arise when trying to directly measure possible health effects from the new technologies.

The review is based on an analysis of the United States Federal Communications Commission (FCC) Equipment Authorization Database [1]. This searchable database provides an essentially complete record of all wireless devices that are on the U.S. market and provides clear documentation of the explosion in the numbers of digital devices in modern society. As of June 2012, the database contains more than 200,000 records going back to 1981. Each record lists the frequency and power of operation, equipment class, rule under which the device is authorized, and other data. In addition, most records provide RF test results, manuals, photographs of devices, and other information submitted to the FCC as part of a manufacturer's application. Although the database characterizes only devices approved by the FCC (it lacks information about the prevalence of such devices in the market), it nevertheless provides a comprehensive picture of the types of RF-emitting devices that might be encountered in nonoccupational settings.

1.2 Methods

The FCC database was searched to determine operating levels and frequencies of RF-emitting devices with which a consumer might be familiar. The search was limited to original grant applications (excluding modified applications) and grants that had been issued (excluding dismissed applications), which resulted in approximately 200,000 records. In most cases, the searches were grants (FCC device authorizations) approved between January 1, 2010, and April 15, 2012, although in some cases, searches were extended to include all available years. Searches were conducted by device class (the classes roughly correspond to different FCC rules under which the devices were authorized), device type, communications technology, frequency and power level of operation, and year in which the grants were issued. In a few cases, user manuals and equipment test results were also downloaded to examine RF test results. In addition, FCC rules, as contained in Title 47 of the Code of Federal Regulations (47CFR), were examined to determine limits on emissions on the surveyed devices.

1.3 Abbreviations and Acronyms

The following abbreviations and acronyms are used in this report:

AMI	Advanced Metering Infrastructure
DECT	digital enhanced cordless telecommunication
DSSS	direct sequence spread spectrum
EIRP	effective isotropic radiated power
EPRI	Electric Power Research Institute
ERP	effective radiated power
FCC	Federal Communications Commission
FM	frequency modulation
GPS	global positioning system
HAN	home area network
ISM	industrial, scientific, and medical
MPE	maximum permitted exposure
NAN	neighborhood area network
PCS	personal communication services
RF	radio frequency
RFID	radio frequency identification
SAR	specific absorption rate
USB	universal serial bus
VoIP	voice over Internet protocol
WiMax	worldwide interoperability for microwave access

2
RESULTS

2.1 Time Trends by Device Class

The FCC organizes devices into more than 70 device classes that correspond to the different rule parts in 47CFR. Roughly speaking, devices of a particular kind (such as cellular phone handsets) are grouped into particular device classes. However, there are many exceptions. For example, Wi-Fi enabled devices are chiefly found in two classes because of the two frequency ranges in which they operate (2.45 and 5.8 GHz), and some low-powered digital devices can be approved under different rules at the option of the vendor, which places them into different device classes.

The device classes vary greatly in size, and only a few of them contain appreciable numbers of consumer devices. Table 2-1 lists the 10 largest device classes in terms of number of devices. Of these, one class—JBP, Part 15 class B computing device peripheral—regulates spurious emissions from computer equipment, a potential cause of interference, and is not relevant for the purpose of this report. Two other classes—DSC, security/remote control transmitter, and TNB, licensed non-broadcast station transmitter—contain little consumer equipment.

Of the seven remaining classes, five (DTS, PCE, DSS, PCB, NII) consist principally or entirely of digital communications devices. PCE and PCB are for devices using the licensed spectrum, principally personal communication services (PCS) mobile telephones, and NII is used chiefly by 5.8-GHz Wi-Fi devices. These digital device classes represent by far the largest fraction of FCC device authorizations in recent years.

Table 2-1
The 10 Largest Device Classes

Category	Description	Number of Original Grants January 1, 2010, to April 15, 2012	Percent of Total New Grants	Rule Parts That Govern Emissions	Examples
DTS	Digital transmission system	7307	20.5	15C	Wi-Fi access points, Wi-Fi clients (module in computer), several Smart Meter communications modules
PCE	PCS licensed transmitter held to ear	5531	15.6	24 (22, 22H, 24D, 24E, 24H)	Mobile phones (850, 1900 MHz bands)
DSS	Part 15 spread spectrum transmitter	4789	13.5	15C	Bluetooth modules for many devices, several Smart Meter communications modules
JBP	Part 15 class B computing device peripheral	3388	9.5	15B	Unintentional radiators (spurious emissions)
DXX	Part 15 low power communication device transmitter	3495	9.8	15C	Telemetry devices, wireless headphones, remote control devices, radio frequency identification (RFID) readers
PCB	PCS licensed transmitter	2982	8.4	24	Smart Meters (Echelon), 1900-MHz cellular communications devices, universal serial bus (USB) dongles for Internet access
NII	Unlicensed national information infrastructure transmitter	1999	5.6	15E	5.8-GHz Wi-Fi access points
TNB	Licensed non-broadcast station transmitter	1476	4.2	22	Base stations for communications systems (few consumer devices exist in this class)
DSC	Part 15 security/remote control transmitter	980	2.8	15C	Security transmitters, Keyless entry systems, Remote pendants for healthcare monitors
8CC	Part 18 consumer device	189	0.5	18	Microwave ovens

Total new grants (January 1, 2010, to April 15, 2012) — 35,564

Figure 2-1 shows the number of grants under Part 15C (which covers most low-powered RF-emitting devices found on the consumer market) and the rapidly growing fraction of authorizations under two digital classes (DTS and DSS) in Part 15C. Before 2000, most RF-emitting devices in the home—garage door openers, wireless oven thermometers, and remote controls—used analog technologies. Beginning in the early 2000s, a flood of devices appeared that incorporated digital communications, in part due to consumers rapidly adopting the Internet and in part due to device vendors beginning to incorporate digital wireless interfaces. Presently, the greatest fraction of Part 15C devices that are approved by the FCC incorporate digital communications. Figure 2-1 shows the original FCC authorizations issued under Part 15C (any section) and the sum of grants in two digital device classes in Part 15C (DSS and DTS), illustrating the shift in devices toward digital communications technologies during the 2000s. Other device classes in Part 15C also use digital communications but are not shown in this figure.

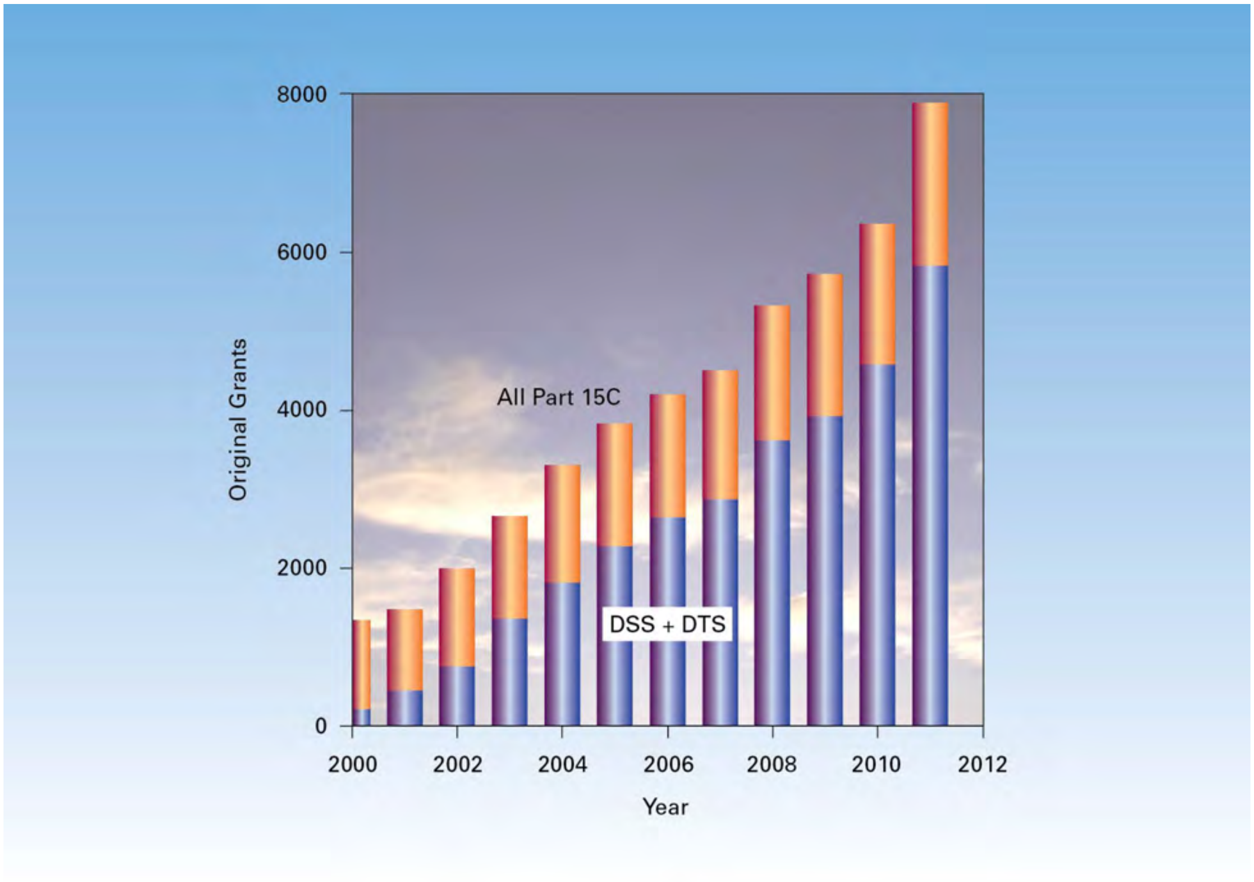

Figure 2-1
Original grants issued under Part 15C and sum of grants in two digital device classes

Figure 2-2 shows the cumulative number of FCC grants since 2000 for three wireless technologies—Wi-Fi (used in wireless routers and access points and for wireless interfaces for devices), and Bluetooth and ZigBee (for low-powered wireless interfaces to devices and networking applications). Although other networking technologies are available, these three account for by far the largest fraction of device authorizations. Each grant applies to a single device type by a single manufacturer.

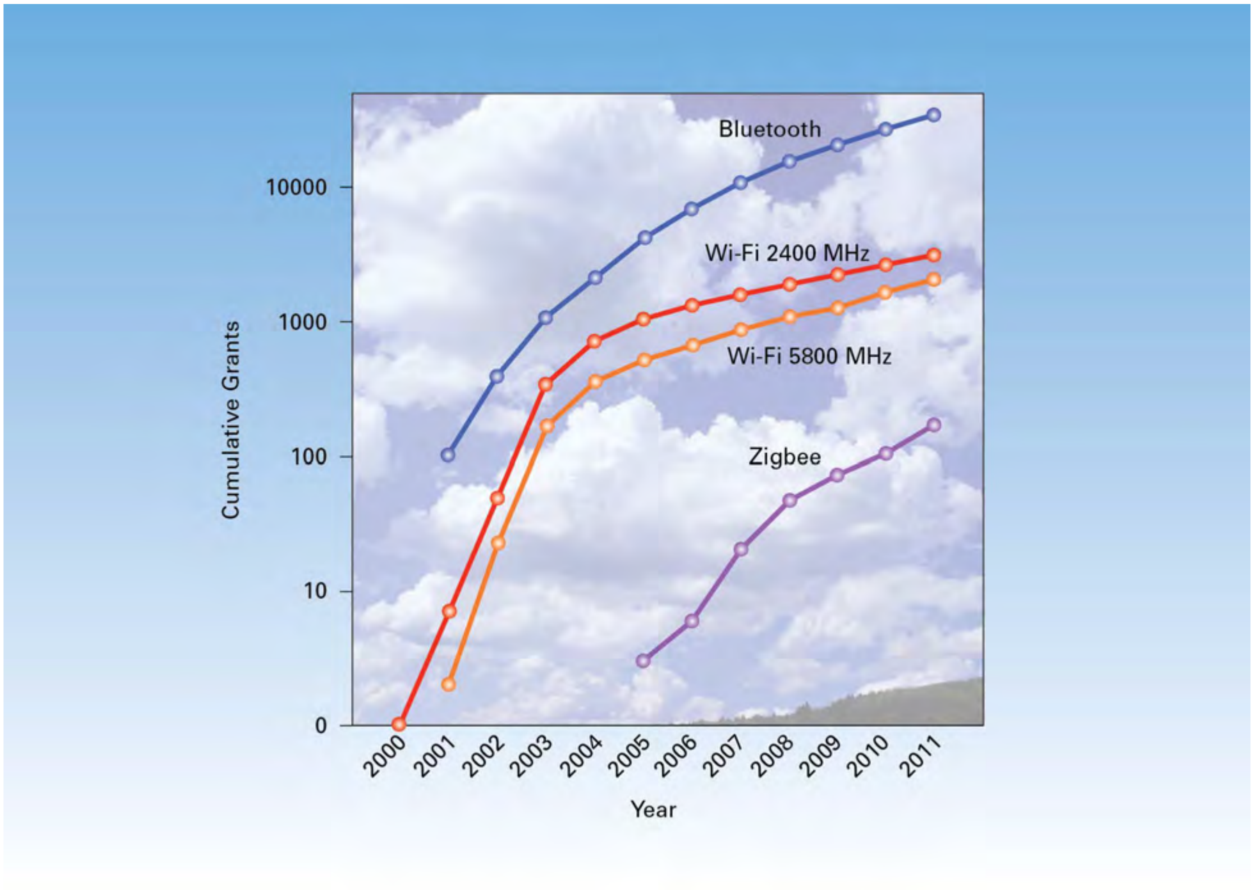

Figure 2-2
Cumulative number of new grants issued for Wi-Fi, Bluetooth, and Zigbee wireless devices

2.2 Time Trends by Technology

2.2.1 Wi-Fi (IEEE 802.11)

Wi-Fi is a commercial name for local area wireless networking technology based on the IEEE 802.11 family of communication standards [2]. Initially developed as a wireless replacement for Ethernet cable to connect computers to networks, Wi-Fi access points and wireless local area networks started to become commonplace in American homes, coffee shops, and businesses in the late 1990s to provide wireless Internet access to laptop computers. Initially using the unlicensed 2450-MHz band, many Wi-Fi interfaces are being designed to use the 5.8-GHz band, as well. Most Wi-Fi devices operate at or below 0.1 W (measured in terms of power applied to their antennas) but a significant fraction of these devices operate at power levels up to 1 W (see Figure 2-3).

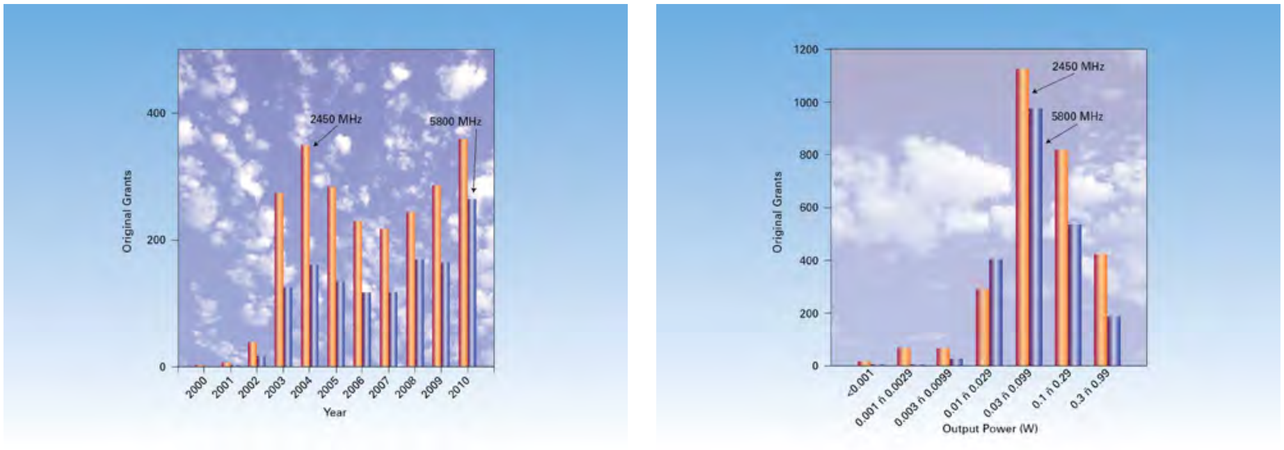

Figure 2-3
New grants for Wi-Fi-based network equipment by year and by conducted power for each of the two frequency ranges specified in the standard

Wi-Fi technology has become omnipresent in modern society. Industry sources report that more than 1 billion Wi-Fi units of various description (consumer electronics, cellular phones, computers, and networking equipment) have been shipped as of 2011 [3], and virtually every laptop, smart phone, and tablet computer comes equipped with a Wi-Fi interface. One recent study estimated that 61% of American households presently have Wi-Fi for Internet access [4], each having a wireless access point with an IEEE 802.15 transceiver.

Moreover, IEEE 802.11 technology is finding its way into a variety of household appliances—such as home entertainment electronics, thermostats, and electric outlets—to enable remote control and programming via the Internet. Individuals can upload their weights to a website using a Wi-Fi enabled bathroom scale (Fitbit; San Francisco, CA) or download books into their e-book readers through their built-in Wi-Fi access cards. Many more Wi-Fi-enabled appliances are coming; one firm (Electric Imp) has just announced the availability of inexpensive devices to control appliances via a wireless IEEE 802.11 interface. IEEE 802.11 is one of three wireless protocols being evaluated for home area networks as part of the Smart Grid initiative for use with smart appliances [5].

2.2.2 Bluetooth and ZigBee

Bluetooth operates in the same 2.45-GHz, unlicensed frequency range as most Wi-Fi devices, but it uses different channels and modulation characteristics. The technology was originally developed in the early 1990s as a replacement for wire cables between devices. The technology is coming into widespread use for personal area networks, which link devices used in close proximity to an individual, such as wireless headsets, computer mice, and speakers for household audio systems. Chiefly intended for short-range, low-powered applications, most Bluetooth interfaces operate at levels below 1 mW but higher-power devices are also available, such as a Bluetooth dongle (broadband wireless adaptor) for computers (Azio; City of Industry, CA). Figure 2-4 shows new grants for Bluetooth devices by year and by conducted power. The database search for these data used keywords “DSS” and “Bluetooth.”

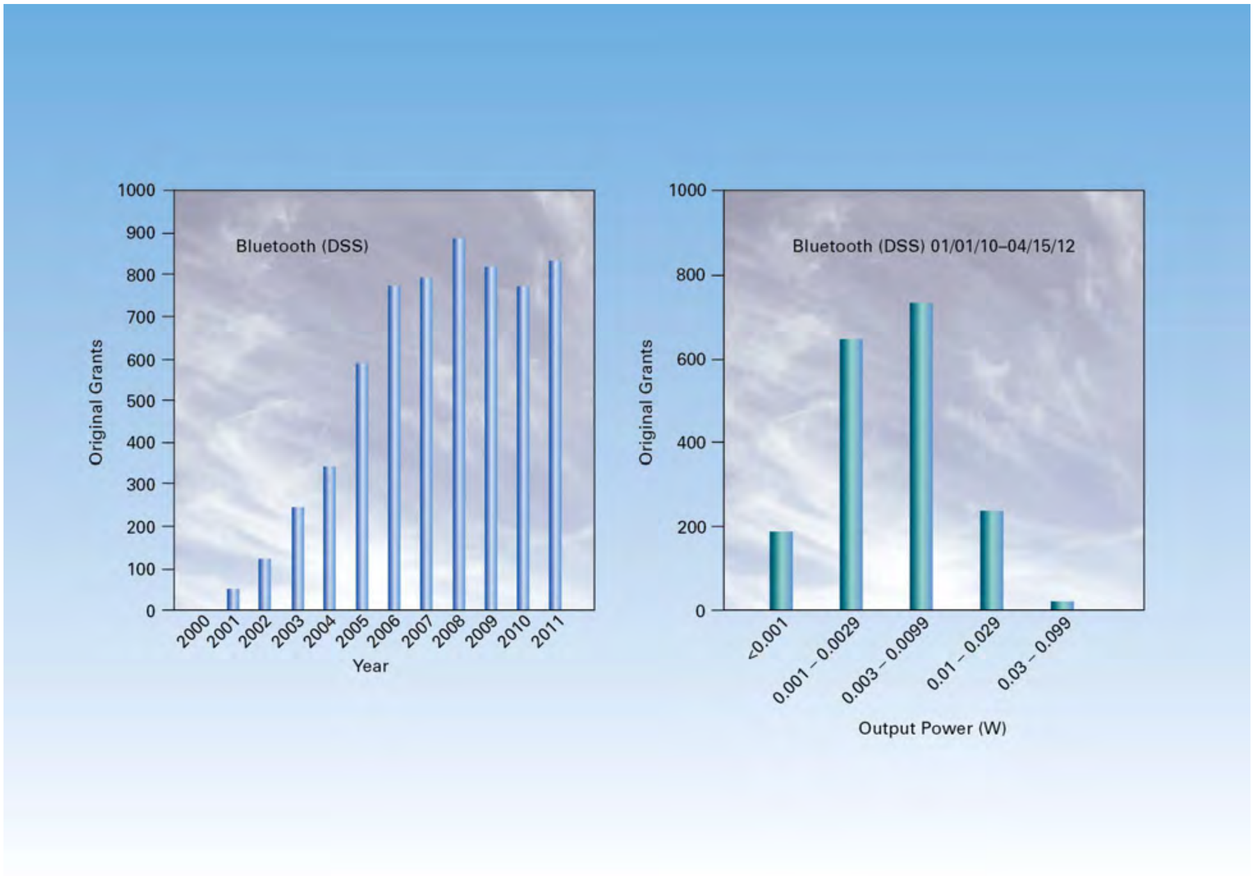

Figure 2-4
New grants for Bluetooth devices by year and by conducted power

According to industry sources, approximately 14,000 companies are presently building Bluetooth interfaces into their products, 30 million Bluetooth units are shipping per week, and more than 3 billion Bluetooth devices are currently in use [6]. Virtually every new laptop computer, smart phone, and tablet computer has a Bluetooth interface, as do many new automobiles. Some widely sold toys incorporate Bluetooth interfaces; for example, the Nintendo Wii video game console, with reported worldwide sales of 50 million units, incorporates a Bluetooth module, and the Sony PlayStation Pro PSP-N1000, with total sales of about 100 million units, contains both Wi-Fi and Bluetooth modules.

ZigBee is the commercial name for devices that comply with a different communications protocol, IEEE 802.15, operating in both the unlicensed 915 MHz and 2450 MHz bands. This standard was developed to allow secure short-range communications at low data rates, using simpler and less expensive hardware than Bluetooth. Although initially intended for industrial applications, such as acquiring data from transducers, ZigBee interfaces are increasingly being used in household devices ranging from remote light switches to in-home patient monitors. Devices based on IEEE 802.15, or nonstandard versions of this protocol, operate at a range of power levels up to 1 W. Figure 2-5 shows new grants for ZigBee devices by year and by conducted power.

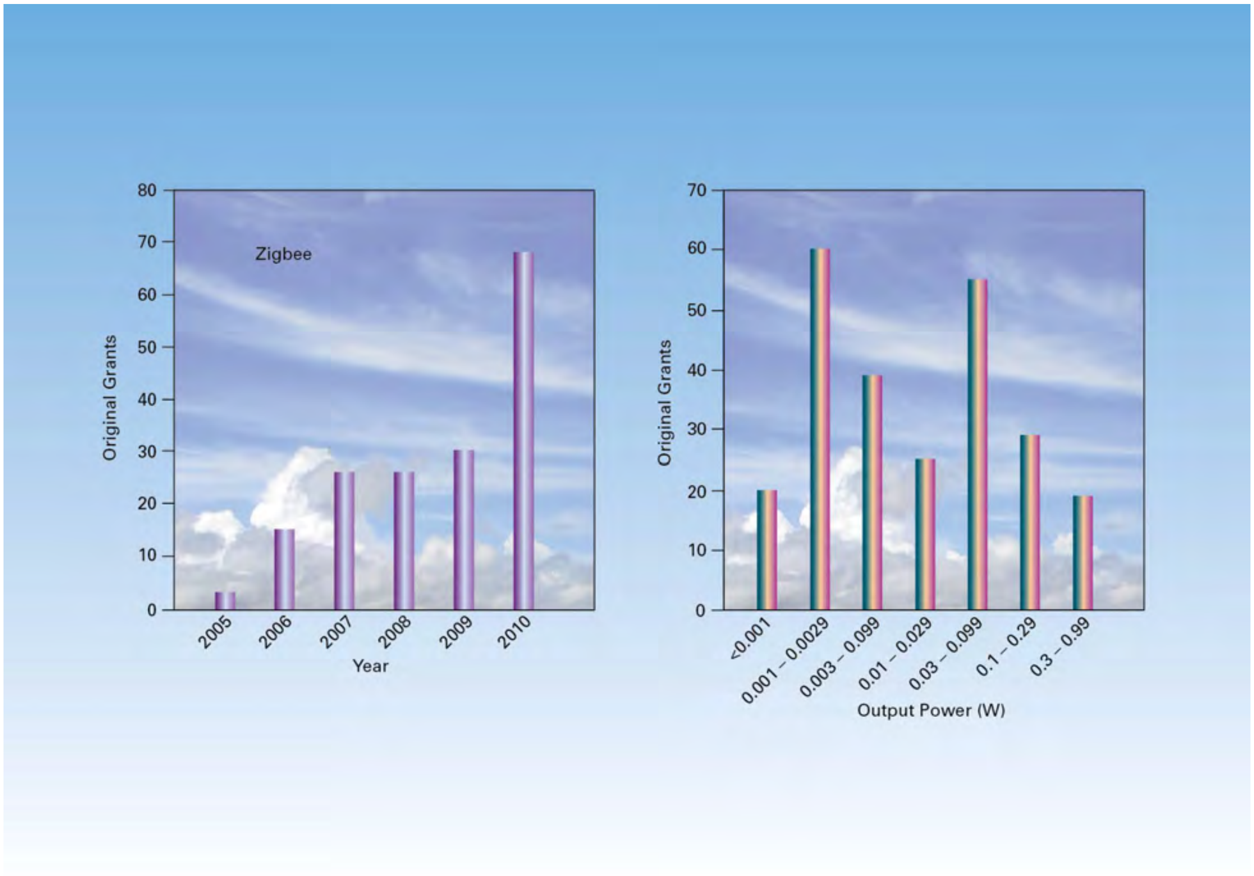

Figure 2-5
New grants for ZigBee devices by year and by conducted power

2.2.3 Digital Cordless Telephones

The first generation of cordless phones operated at 46–49 MHz and used analog RF technologies. Although some analog phones are still on the market (typically low-end devices), most new cordless phones use digital communications technologies and operate in the unlicensed industrial, scientific, and medical (ISM) bands at 915, 2450, and 5800 MHz, as well as in the PCS band at 1920–1930 MHz (digital enhanced cordless telecommunication [DECT] phones). A search of the FCC equipment authorization database identified 132 original grants issued between January 1, 2010, and April 15, 2012, for cordless phones operating at frequencies between 900 and 6000 MHz. Of these, 3 grants were for phones operating near 900 MHz, 114 were for DECT phones operating in the 1920 MHz band, and 13 were for digital phones operating in the 2400 MHz band. The power levels of operation (in this case, measured in terms of effective radiated power or effective isotropic radiated power) range up to about 1 W. Figure 2-6 (left) shows grants for DECT telephones by conducted power.

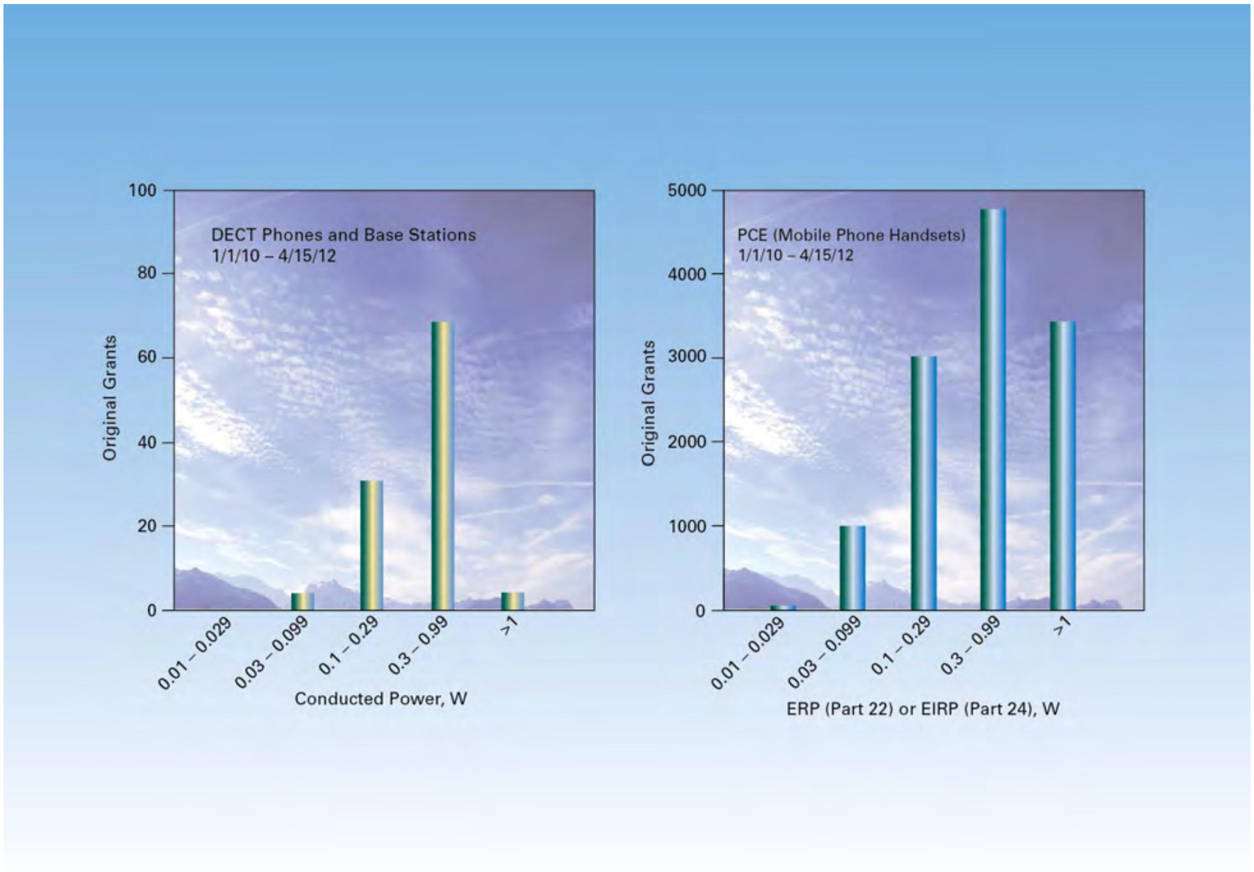

Figure 2-6
New grants for portable digital telephones and cellular handsets by conducted power

2.2.4 Mobile Telephone Handsets

Most of the extensive literature on RF exposures from mobile phones pertains to exposure to the user of the handset. However, mobile handsets operate at similar peak power levels as the other devices described in this review, with peak power levels (measured in terms of effective radiated power or effective isotropic radiated power, depending on frequency range) up to a few watts. However, because the devices transmit pulsed energy and use adaptive power control (reducing power output in areas of strong signals from the base station), the actual time-averaged output is far below these levels. In the United States, most mobile handsets operate at frequencies close to 850 or 1900 MHz, with a smaller number operating at frequencies close to 1700 MHz. Figure 2-6 (right) shows the distribution of power levels of recently authorized mobile handsets.

2.2.5 Other Devices Found in the Home

2.2.5.1 Baby Monitors

These devices monitor sounds from a baby and transmit them to caregivers via RF links. The FCC database identified 91 grants for baby monitors during the period of interest, all operating in the 915 or 2450 MHz ISM bands or the 1920 PCS band. Their power levels range up to approximately 0.1 W conducted power.

2.2.5.2 Microwave Ovens

Virtually all microwave ovens in homes and offices operate in the unlicensed ISM band at 2400 to 2500 MHz and are regulated under 47CFR18, which applies to industrial, scientific, and medical equipment but specifically excludes communications equipment. Typically, domestic microwave ovens generate 500–1000 watts, nearly all of which is contained within the oven. However, even in well-functioning ovens, a small amount of microwave energy escapes through the seals around the doors.

Although the FCC has strict limits on the out-of-band emissions of such devices, it does not directly limit the power that such devices can radiate within the ISM band. However, microwave ovens (as all RF-emitting devices) must comply with FCC exposure limits, which are 10 W/m^2 power density at 2450 MHz averaged over 30 minutes (general population limits). In addition, the U.S. Food and Drug Administration limits the power density from leakage from a microwave oven to 50 W/m^2 at a distance of 5 cm from the oven, to protect against burns to a user in close proximity to the oven. Assuming that an oven leaks at the maximum permissible level and that this leakage radiation falls off as the square of distance from the oven, the corresponding power density at a distance of 3 m from the oven would be approximately 14 mW/m^2. A similar exposure level would be produced by a half-wave dipole radiating 1 W.

A search of the FCC database disclosed 63 grants for microwave ovens between January 1, 2010, and April 15, 2012. The RF test reports for all these ovens were retrieved from the database; nearly all included measurements of the maximum RF power density at distances 5 cm or more from the ovens. A summary of the RF test data shows that the leakage radiation from all of these ovens was less than the FCC limit of 10 W/m^2 (see Figure 2-7). However, these tests were all conducted on new ovens of recent manufacture; undoubtedly, older ovens that have been in use for a long time and that might have dirty or damaged door seals will exhibit somewhat higher leakage radiation.

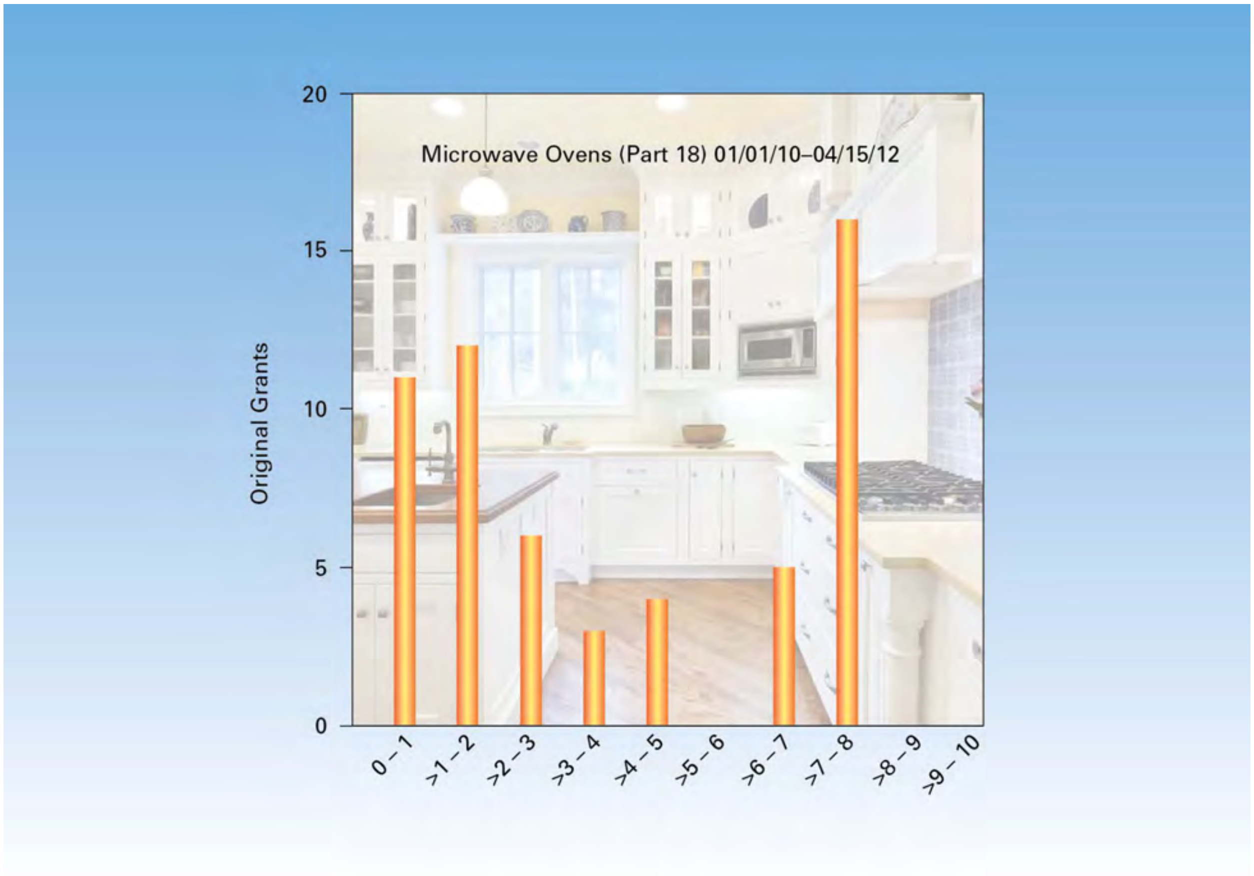

Figure 2-7
Distribution of leakage fields (W/m^2) measured 5 cm or more from microwave ovens

2.2.5.3 Smart Meters

Wireless-enabled electric utility meters, called Smart Meters, are presently being installed in many areas throughout the world. In part, the motivation for the present large-scale rollout of these devices is to comply with legislation that requires time-of-use pricing and, consequently, frequent (hourly or more frequent) reading of utility meters. In the future, the meters might be linked to appliances in the home to allow utilities and consumers to monitor and control power consumption. Smart Meters have aroused public concern and local political opposition, partly on the grounds of health concerns.

At present, Smart Meters and the Advanced Metering Infrastructure (AMI), of which the meters are a part, are not standardized but vary greatly with different vendors and even within different product lines of a particular vendor. Depending on the utility, Smart Meters can have one or more RF transceivers incorporated into them. These include the following:

- Neighborhood area network (NAN). Most AMI systems link meters in a neighborhood into a mesh network based on variants of standard communications technologies, typically based on IEEE 801.11 or 802.15 and perhaps combined with proprietary network architecture.

- Home area network (HAN). Smart Meters and AMI are designed to eventually allow utilities or homeowners to control the consumption of electricity by household appliances. To accomplish this, Smart Meter systems might include additional transceivers for a HAN that links appliances to the meter (although these transceivers might be absent or not activated in currently installed meters). Most AMI systems use standard technologies such as ZigBee for their HAN.
- Collector. AMI systems typically use a third wireless system for a *backhaul* function to transmit meter data to utility backoffices. Different approaches to backhaul include the use of the commercial cellular telephone system, through cellular telephone modems; proprietary wide area networks; or in some cases, broadband Internet through wired or fiber-optic connections. Collectors, when present, can be mounted on meters or, more commonly, on nearby utility or traffic light poles.

To characterize the RF emission characteristics of Smart Meters, the database was searched for six major vendors of AMI systems in the U.S. and Canada (see Table 2-2), separating information for transceivers used for NAN, HAN, and collection functions, when possible. Supplementary information was obtained from vendors' websites. Given the diversity of systems being sold by the vendors, the characteristics of the AMI in any particular region would have to be determined separately.

Table 2-2
Vendors of Smart Meters and Networking Solutions Providers

Vendor (Grant Number)/ FCC Identification of Model Examined	Communications Technologies Used	Parts Under Which the Devices Are Authorized
Itron (West Union, SC) (EWQ)	NAN: 902–928 MHz frequency-hopping spread-spectrum (FHSS); 0.15 W conducted power to antenna	15.247
OpenWay CENTRON	HAN: 2.45 GHz, IEEE 802.15.4, 0.07 W	15.249
SK9AMI-2A	Collection: Global System for Mobile Comunications (GSM), 850/1950 MHz modem, 1.5 W	22H (cellular), 24E (broadband PCS)
Landis+Gyr (Lafayette, IN) (ROV)	NAN: 902–928 MHz FHSS; 0.1-0.2 W	15.247
Landis+Gyr FOCUS AX meter with the Cellnet direct sequence spread spectrum (DSSS) retrofit.	HAN: 2.45GHz, IEEE 802.15.4, <0.1 W	15.247
ZigBee Transceiver Module (FCC ROV-CLTR900M)	Collection: Various networking, including WiMAX 802.16e, not mounted in meter	
Sensus Metering Systems Inc. (Morrisville, NC) (SDB), iCON, Gen 3 Electric Meter	NAN: Wireless mesh network using licensed spectrum, 901–960 MHz, up to 1 W	24D, 90I, 101C
ZIGELS01 ZigBee module, for use with Elster A3 meter	HAN: 2.45 GHz, IEEE 802.15.4 , 0.01 W	15.247
Endpoint	PCS licensed transmission, 901–960 MHz, up to 1.4 W equivalent isotropically radiated power (regional collectors not on meters)	24, 101
Elster Solutions LLC (Raleigh, NC) (QZC)	NAN: FHSS 902–928 MHz FHSS, 0.2 W	15.247
A3 Alpha Meter	HAN: 2.45 GHz, IEEE 802.15.4, 0.01 W	
EA Gatekeeper with wireless WIC	Collection: cellular telephone (850, 1950 MHz) 0.25 W (usually incorporated in the meter)	22H, 24E
Trilliant (Redwood City CA) (IZP)	NAN: 2.45 GHz, IEEE 802.15, 0.1–1 W nominal input power to antenna	15.247
TMB-EM000019 (module for NAN)	HAN: 2.45GHz, IEEE 802.15.4	
TMB-TNIQ2426B GSM module for collection point	Collection: GSM PCS 1850–1900 MHz, 1 W (usually mounted on utility poles, not on meter)	24E
Echelon (San Jose CA)	NAN: Sends data over power lines; alternatively, 800 MHz, using variant of IEEE 802.11n.	
IEEE 802.15.4 HAN CARD Model Number 79010-01	HAN: 2.45 GHz, IEEE 802.15.4, 0.08 W	15.247
	Collection: Various; collector connects with any Internet protocol–based work	22H, 24E

This search showed the following results:

- NAN. The transceivers used by different vendors used variants of standard communications technologies, operating in unlicensed (915 or 2450 MHz) or licensed (901 MHz) bands. The devices identified in the database used protocols based on IEEE 802.11 or 802.15, operating at peak conducted power levels of 0.1–1 W, essentially similar to Wi-Fi or ZigBee transceivers. However, in at least one case (Echelon) the NAN uses a nonstandard version of IEEE 802.11 to operate at 915 MHz (the IEEE standard does not include that frequency band) to take advantage of the longer propagation distances for a given power output from an antenna.
- HAN. Most of the devices identified in the database with the HAN transceiver in the meters operated in the unlicensed 2450-MHz band and were based on the IEEE 802.15.4 protocol used by ZigBee. The operating power was in the range 0.01–0.1 W, lower than that for the NAN (a consequence of the shorter communication range).
- Collectors. Most of the systems identified used transceivers that were authorized under Parts 22H and 24E (825 MHz and 1850 MHz GSM mobile phone bands, respectively) with power outputs similar to those of cellular telephones.

The transceivers identified with Smart Meters vary, but all use variants of standard communications technologies, operate at similar power levels, and are regulated by the same set of FCC rules.

2.3 Limits on Power Output of Devices

In part for historical reasons, the limits on intentional radiators such as the devices summarized in the previous section are stated in different ways in different rule parts of 47CFR. These limits might be in terms of conducted power to the antenna, effective radiated power (ERP), effective isotropic radiated power (EIRP), or maximum allowable electric field strength at a distance of 3 m from the device. By contrast, the FCC and international limits for human exposure to RF energy are expressed either in terms of the incident power density, S, that impinges on a person's body or, for devices to be used against the body, in terms of the specific absorption rate, which is a measure of power dissipated in the body of the user.

For an antenna radiating into free space (neglecting reflections from other surfaces) these quantities are related by Equation 2-1:

$$S = \frac{PG}{4\pi r^2}$$
$$E = \sqrt{377S}$$

Eq. 2-1

where P is the input power to the antenna (all of which is assumed to be radiated), G is the power gain of the antenna in the direction of interest relative to an isotropic radiator, and S and E are the power density and electric field strength, E, at distance r from the antenna. The effective isotropic radiated power EIRP is given by PG.

Equivalently, the ERP with respect to a half-wave dipole is defined as shown in Equation 2-2:

$$ERP = PG / 1.64 \quad \textbf{Eq. 2-2}$$

where 1.64 (2.15 dB) is the gain of a half-wave dipole antenna. The gain can be expressed as decibels with respect to an isotropic radiator (dBi) or with respect to a half-wave dipole (dBd), which is 2.15 dB lower.

Title 47, Part 15, of the Code of Federal Regulations, which applies to unlicensed transmissions, subsumes most low-powered consumer equipment. Part 15C applies to *intentional radiators*, (devices designed to transmit energy); other subparts govern *spurious* (unintended) emissions. Unless a device qualifies under some particular rule in Part 15C, the limits are highly restrictive. A device is limited to producing 200 μV/m (216–960 MHz) or 500 μV/m (above 960 MHz) electric field strength, measured 3 m from the device's antenna. Table 2-3 shows grants issued from January 1, 2010, to April 12, 2012, for Part 15C devices.

Table 2-3
Grants Issued for Part 15C Devices

Peak Conducted Power (W)	Number of Original Grants	Sample Consumer Devices
>1	7	Outdoor wireless access points (not consumer equipment)
0.3–0.99	1973	Many Wi-Fi access points, wireless routers, e-book readers with Wi-Fi, many Wi-Fi client cards for laptop computers, Wi-Fi USB adapters, utility meter reading systems (Diablo, Itron, Nexus, Silver Spring Networks, Trilliant)
0.1–0.29	2833	Wi-Fi access points (many), Wi-Fi modules in cell phones (many), Blu-ray disc players, extended Range ZigBee modules, digital jukeboxes (networked media players for home audio), RF baby monitors, e-book readers
0.03–0.09	2462	Wi-Fi enabled baby monitors, Wi-Fi clients in laptops and cell phones (many), wireless light switches, wireless speakers for home audio, digital photo frame with Wi-Fi, wireless USB drives, wireless dog trainer (receiver collar), wireless stereo headphones, Bluetooth headsets, smart power receptacles, Wi-Fi equipped baby monitors, home monitoring gateways
0.01–0.029	1863	Bluetooth modules (many), digital stereo wireless indoor/outdoor speaker systems, e-readers, iWallet (expense trackers), Wi-Fi modules (many), wireless baby monitors, Wi-Fi modules for mobile phones, computers (many), wireless portable entertainment centers, Bluetooth headsets for bicycle helmets, Wi-Fi enabled programmable thermostats, Wi-Fi enabled home theaters

Table 2-3 (continued)
Grants Issued for Part 15C Devices

Peak Conducted Power (W)	Number of Original Grants	Sample Consumer Devices
0.003–0.009	1876	Bluetooth interfaces for audio and other consumer devices (many), Bluetooth interfaces for mobile phones (many), digital wireless headphones, mobile television receivers, remote controls for cameras, remote controls for keyboards, voice over Internet protocol (VoIP) cordless telephones, Wi-Fi interfaces for laptops (many), Wi-Fi interfaces for mobile phones (many), wireless headphone systems, wireless water meters, wireless interface for brain-computer interface (such as Mindwave by Neurosky)
0.001–0.0029	2164	Bluetooth modules (many), Bluetooth headsets for mobile phones (many), Bluetooth-enabled entertainment devices (many), digital photo frames, golf course global positioning systems (GPS), wireless remote keypads, wireless headphones, wireless remote control for cameras, wireless-enabled home thermostats, wireless-enabled car audio systems, wireless-enabled car navigation systems, wireless controllers for household electronics and lighting, wireless controlled thermostats (several)
<0.001	758	Bluetooth-connected computer devices (computer mouse, keyboard), Bluetooth interface for speakers, Bluetooth module in cellphones (many), cameras with wireless interfaces, VoIP telephone handsets and base stations, wireless-connected fitness monitors, wireless-connected GPS, wireless-equipped Braille displays
Power not stated	3185	Mostly low-powered devices authorized under §15.209, §15.231, §15.249

Total number of original Part 15C grants issued between January 1, 2010, and April 15, 2012: 17,121

The general limits under Part 15C correspond to an ERP somewhat below 0.1 μW from a half-wave dipole antenna, which is too low to allow communication over any appreciable distances. A typical device authorized under the general rules of Part 15C would be a frequency modulation (FM) transmitter that sends music from an MP3 recorder to a car radio via low-level signals in an otherwise licensed FM broadcast band.

Several rules under Part 15C provide considerably higher limits. In particular, section 247 (47CFR15.247) applies to devices that use *frequency hopping* (shifting frequently in frequency) or certain forms of digital modulation, which covers most of the wireless networking devices on the U.S. market. Under 47CFR15.247, devices that operate in the unlicensed ISM bands near 915, 2450, and 5800 MHz can operate up to a maximum conducted power of 1 W, provided that they use low gain (broad beamwidth) antennas with gain less than 6 dBi (that is, a gain of 4). For such a device (which is typical of most communications equipment), that would correspond to an EIRP of up to 4 W. This represents the maximum input power; digital devices invariably operate using pulsed energy, and the time-averaged power output is far less than the maximum allowable peak level.

Cellular telephones and associated communications equipment operate in licensed frequency bands and are authorized under different sections of 47CFR. For example, CFR47 Parts 22 and 24 apply to cellular (850 MHz) and PCS (1950 MHz) mobile phones. The limits in 47CFR22.913 and 47CFR24.232 are 7 W (ERP) and 2 W (EIRP), respectively, for portable transmitters including mobile phone handsets. Such devices must also comply with FCC limits on absorbed power in the body (specific absorption rate). Canadian limits are generally similar to those in the United States, whereas European limits, in some cases, are considerably lower. For example, the peak conducted power of Wi-Fi devices operating in the 2.45-GHz band is limited to 0.1 W in the European Union compared to 1 W in the United States and Canada.

Although the FCC rules are complex, they generally limit the power of Part 15 devices to low levels, typically 1 W of conducted power for digital devices that qualify under 47CFR15.247 and to much lower levels for other Part 15 transmitters. Most equipment, in fact, operates at levels well below FCC limits.

2.4 Free Space Model for Comparing Radio Frequency Exposures from Devices

The RF exposures from Wi-Fi, DECT phones, Smart Meters, and other devices in ordinary, nonoccupational environments have been extensively surveyed. The propagation of RF energy through structures is complicated due to reflections and attenuation by building materials and furniture in the room as well as variations in the beam pattern.

However, a free space propagation model (Equation 2-2) provides a simple comparison of exposures at distances within a few meters of the antenna, even inside a building [7]. Table 2-4 compares the peak exposure levels from typical devices at distances of 20 cm (assumed to be a distance of closest approach) and exposure averaged over an area extending from 0.2 to 5 m from the antenna (as a crude estimate of the spatially averaged exposure over an area the size of a typical room). The table also shows the distance from the antenna at which the exposure has fallen to 1 mW/m^2 (a typical order-of-magnitude field level in residential settings from diverse sources). These comparisons assume that the antenna is a half-wave dipole oriented vertically, producing an azimuthally uniform beam.

Table 2-4
Peak and Spatially Averaged Exposure Levels Calculated Using a Free Space Propagation Model

Typical Technology/Frequency	Peak Conducted Power, W	Peak Power Density At 20 cm, mW/m^2 (Percent of FCC Exposure Limit at 2.45 GHz)**	Distance to Incident Power Level of 1 mW/m^2, m	Power Density, Spatially Averaged from 0.2 to 5 m from the Antenna, Assuming Dipole Radiation Pattern, mW/m^2, (Percent of FCC Exposure Limit at 2.45 GHz)**
Smart Meter (0.9 or 2.45 GHz); cellular telephone handset	1	3262 (32%)	11.4	8 (0.08%)
Typical Wi-Fi access point or client card in laptop; Bluetooth Class 1 device (some Bluetooth interfaces), 2.45 GHz	0.1	326 (3.2%)	3.6	0.8 (0.008%)
Bluetooth Class 2 device (some wireless-enabled appliances, toys), 2.45 GHz	0.025	81 (0.8%)	1.8	0.2 (0.002%)
Microwave oven, leaking 50 W/m^2, at a distance 5 cm from oven, 2.45 GHz	~1	3000 (30%)	11	~8 (~0.08%)
Bluetooth Class 3 device (many cordless mice, computer peripherals), 2.45 GHz	0.001	3.2 (0.03%)	0.36	0.008 (0.00008%)

* Calculated from Equation 2-2, assuming a simple dipole antenna oriented vertically so that its beam is uniform in a plane parallel to the floor.
** Not including time-averaging of exposure.

As Table 2-4 makes clear, the RF power density from these devices is well within FCC exposure limits, even close to the antennas. In fact, under any realistic exposure scenarios, the exposures will be considerably smaller than indicated in this table. Digital devices characteristically operate using pulsed energy at low duty factors (<1%), whereas the exposure levels in the table represent temporally peak values. U.S. and international exposure limits are in terms of time-averaged exposures—in the case of the U.S. limits, 30 minute averages. Moreover, the FCC limits apply to the exposure averaged over the whole body [8], whereas the exposure that is sustained at a distance of 20 cm from a device would be to only a small part of the body. Thus, the exposure to a resident of a house from RF fields from the devices considered in this review will, under all realistic exposure conditions, be far below FCC and other guidelines.

2.5 Comparison with Other Sources of Radio Frequency Exposure in the Environment

Tell and Mantiply extensively surveyed the background levels of RF fields in the environment in the United States [9]. More recently, European groups have conducted far more extensive surveys to provide a baseline for epidemiological studies on possible health effects of environmental exposures to RF energy [10–13].

The results of these surveys show low but highly variable exposures. For example, Joseph and colleagues reported that the mean exposure to RF fields in homes in five European countries was approximately 0.1 mW/m^2, with the largest contribution (0.05 mW/m^2) coming from the uplink signal from mobile phones; that is, from phones being used or carried in the house [14]. Other significant contributions to the background levels of RF signal in the homes were from the downlink signal from mobile phones (that is, from the base stations outside the house [0.016 mW/m^2]), from FM transmitters outside the house (0.01 mW/m^2), from DECT portable telephones inside the house (0.014 mW/m^2), and from Wi-Fi routers inside the house (0.005 mW/m^2).

A different perspective is from measurements of peak exposures close to appliances. For example, in an extensive survey of RF fields near appliances in 20 Australian homes, Croft and colleagues reported average power densities of up to 440 mW/m^2 at distances of 20 cm from microwave ovens, and noted that in homes with a microwave oven, "it was the source of highest exposure 79% of the time." [15]. Tell and colleagues measured maximum fields of approximately 100 mW/m^2 (900 MHz) at a distance of 30 cm in front of an Itron Smart Meter, from the transceiver for the NAN [16]. The measurements on the microwave ovens reflected peak values while the oven was turned on; the measurements on the Smart Meter were done on meters that had been modified to transmit at 100 % duty factor, even though the meters normally transmit with a low duty factor (<1%). Any plausible 30-minute average exposure from these sources would be far smaller, possibly in the range reported by Joseph and colleagues [14].

3
CONCLUSIONS

As the previous sections make clear, the world is awash with low-powered RF-emitting devices, most of which are digital communications devices that operate at similar peak power levels and in similar frequency ranges. The RF exposures from such devices are inevitably far below United States and major international exposure limits, and health agencies such as the World Health Organization have not expressed concern about potential health impacts of such devices because of their low potential exposure levels [17].

With the exception of mobile phones and, to a very limited extent, Wi-Fi, there has been virtually no technology-specific research on possible health effects of the digital communications technologies described here, despite the explosive growth in the use of such devices. At least one health authority has called for health monitoring of children exposed to Wi-Fi radiation in schools [18]. Separating the exposures from devices with a particular technology (such as Wi-Fi routers, client cards in laptops, or Smart Meters) from the many other exposures to RF energy encountered during daily life would be a difficult problem in planning such studies. Moreover, the potential variables to characterize such exposures are several—including peak and temporally averaged exposure, modulation characteristics, and frequency. If technology-specific studies are needed to examine possible health consequences of Wi-Fi, how extensive should they be? Should such studies be extended to separately consider ZigBee, Bluetooth, and other communications technologies that use the same general part of the spectrum and produce RF exposures that are variable but generally similar in magnitude? At present, there is no scientific rationale or established mechanism of interaction that would inform such choices.

4
ADDITIONAL READING

The following EPRI reports provide additional information:

- *An Investigation of Radio Frequency Fields Associated with the Itron Smart Meter*. EPRI, Palo Alto, CA: 2010. 1021126.

  The Smart Meters studied in this report are deployed by two electric utilities in California. The meters are part of wireless mesh networks in which one meter is configured as a collector point, referred to as a *cell relay* by Itron, for each of approximately 500 to 750 *end point meters*. The cell relay collects data from the various end point meters and conveys these data onto the cellular wireless wide area network for communication back to the electric utility company's data management system. Mesh network communication among the many meters is provided by the 900-MHz band transceiver RF LAN. A HAN feature is supported by a 2.4-GHz transceiver. Data collection was carried out in a laboratory setting and at residences and in neighborhoods in southern California and Colville, Washington, supplemented with theoretical modeling studies. The results indicate that RF fields from the investigated Smart Meter are well below the maximum permitted exposure (MPE) established by the FCC. For occupants of a home equipped with a Smart Meter, interior RF fields would be expected to be at most 1/10 as intense, simply due to the directional properties of the meter. When the attenuation afforded by a stucco home's construction is included, a realistic value of the interior RF field would be about 0.023% of the MPE for an end point meter and about 0.065% for a cell relay. Regardless of duty cycle values for end point and cell relay meters, typical exposures that result from the operation of Smart Meters are quite low and comply with scientifically based human exposure limits by a wide margin.

- *An Overview of Common Sources of Environmental Levels of Radio Frequency Fields*. EPRI, Palo Alto, CA: 2002. 1005496.

  A general overview of common RF sources across the frequency spectrum is provided. A discussion of operational characteristics and environmental field levels is provided for each RF source. Also included is a comprehensive list of references, RF source photographs, and a glossary. The variety of RF sources includes radio and television broadcast stations, various forms of wireless communications equipment, and equipment used to heat materials in certain factory processes such as dielectric and induction heating. This report provides electric power employees with a perspective of the variety of radio frequency sources in our modern environment. The range of RF fields that can exist are important, but proximity to the source and operational characteristics strongly affect exposure. The results provided in this report facilitate an understanding of RF exposure sources and a context for understanding common RF sources.

- *Characterization of Radio Frequency Emissions from Two Models of Wireless Smart Meters.* EPRI, Palo Alto, CA: 2011. 1021829.

  This report addresses the interest to characterize RF emissions from wireless Smart Meters. The EPRI report *An Investigation of Radio Frequency Fields Associated with the Itron Smart Meter* (1021126) provided a detailed characterization of RF emissions from one type of wireless Smart Meter deployed across several service territories in the United States. This report describes emissions from wireless Smart Meters produced by two manufacturers that are currently in operation within a large service territory in the United States. The RF field levels from the Smart Meters studied are below the exposure limits stipulated by the FCC. Furthermore, data from the meter provider permit one to estimate that, as the system currently operates, nearly 99.9% of the meters transmit 1% or less of the time, and 99% of the meters transmit less than 0.4% of the time. These duty cycles are taken into account when estimating potential exposures of people in relation to FCC exposure limits for the general public, which are based on a 30-minute average of power density across the body.

- *Development of Radio Frequency Exposure Standards*. EPRI, Palo Alto, CA: 2004. 1009803.

  Many organizations and agencies have been involved in the development of RF safety standards. These groups include the United States Federal Communications Commission, National Council on Radiation Protection and Measurement, Institute of Electrical and Electronics Engineers, American National Standards Institute, and International Commission on Non-Ionizing Radiation Protection. These groups have followed different procedures for selecting relevant literature and assessing the relative validity of different studies, but all have come up with similar, although not identical, results. All standards start with specific absorption rate (SAR; the amount of absorbed power in watts/kilogram) equal to 4 w/kg. Two kinds of safety factors are applied: 1) explicit safety factors, such as those applied to the basic SAR value to obtain lower values for setting limits, and 2) implicit safety factors, such as those involved in setting assumptions and procedures designed to be on the safe side. Implicit safety factors mean that limits defined in the standards are conservative in nature; that is, the factor of safety is greater than that specifically stated. Different explicit safety factors are applied for controlled and uncontrolled environments, generally relating to the workplace and general public. Larger factors of safety are used for uncontrolled environments, giving lower allowable MPE limits, the quantity used in the standards for assessing compliance. MPE values in the standards are legal limits and, as such, are not to be exceeded. However, MPE values are not the kind of hard physical limits such that exceeding the specified values by a small amount would be considered to immediately pose a hazardous situation. Likewise, exceeding specified SAR values by a small amount would not necessarily be dangerous. This situation arises because of the explicit and implicit safety factors incorporated into SAR and MPE values. These safety factors result from the conservative approach used in the development of the standards.

- *Overview of Personal RF Communication Technologies*. EPRI, Palo Alto, CA: 2008. 1016819.

  The report provides an overview of wireless communication fundamentals, starting with why modulation of the basic radio carrier wave is necessary. Topics addressed include choice of frequency, FCC rules and allocations, relevant IEEE standards, analog and digital modulation types, modulation in the frequency and time domain, multiplexing, bandwidth, and data rate. Multiple access approaches discussed include frequency division multiple access, time division multiple access, and spread spectrum and code division multiple access. Overviews of personal communication devices include cordless telephones, analog cell phones, digital cell phones, Wi-Fi and wireless local-area network, ZigBee, Bluetooth, ultrawideband, (RFID tags, wireless medical telemetry, worldwide interoperability for microwave access (WiMax), automatic meter reading, and wireless Internet service providers.

- *Overview of Wireless Facilities for the Electric Power Industry*. EPRI, Palo Alto, CA: 2005. 1011722.

  Wireless transmitting devices are ubiquitous in our environment. Communications systems are found throughout the electric power industry today and include both the RF systems used for internal company communications, commonly installed on dedicated communications antenna towers, and cellular telephone base stations now being installed ever more frequently on electric power transmission towers and distribution poles. In some cases, even domestic broadcasting systems have found their way to electric transmission structures. These systems produce RF fields that occasionally can be strong enough to approach or exceed applicable RF exposure standards or regulations established for safe human exposure. With the advent of wireless communications base stations occupying space on electric power company property, the issue of appropriate work practices in close proximity to the antennas has become a more common topic of discussion among electric power industry health and safety and telecommunications professionals. This report is intended to provide a basic overview of these systems to assist the electric power industry in properly identifying RF systems that might be installed on their property and structures. The report provides a general background on the relative likelihood of finding strong RF fields in the vicinity and the relative probability of power industry personnel encountering exposure to these fields. The report is intended to give the reader both an insight to identifying the systems and a sense of the relative importance of different systems from the perspective of RF safety.

- *Radio Frequency Exposure Fundamentals*. EPRI, Palo Alto, CA: 2002. 1005495.

  The purpose of this report is to introduce power system employees to the physical concepts used to describe electromagnetic fields and their interactions with the human body at radio frequencies. Such information will provide the background for understanding government and other standards on human exposure to RF electromagnetic fields. This, in turn, can lead to an informed development of work practices appropriate near communications transmitters located on or near structures owned by electric power companies. The material is presented as a set of questions and answers. This method facilitates identification of relevant portions by readers who have interests in specific issues covered in the document.

- *Radio Frequency Safety for the Electric Power Industry*. EPRI, Palo Alto, CA: 2002. 1005419.

  The relatively new business of leasing space on electric power transmission and distribution line structures has introduced a new and, in some cases, unfamiliar element in the work environment for workers not normally acquainted with radio frequency antennas. These antennas are most often used as cellular and PCS telephone base stations. Although power levels associated with these new antennas are relatively modest, RF fields next to them can, in some cases, exceed the FCC limits for occupational exposure. Hence, precautions must be taken to ensure compliance with the exposure limits. The combination of unfamiliar antennas and a general lack of RF safety awareness training among workers has led to a need for RF safety programs within the electric power industry. The results provided in this report facilitate an understanding of RF safety issues and identify key elements of an RF safety program. This report provides information and general guidance on issues useful in understanding RF safety and in developing an RF safety program. The project team developed a general introduction to RF safety issues. Topics include an overview of RF safety basics, RF exposure limits and their rationale, personal protective equipment, use of warning signs, and general guidelines on the components of an RF safety program. Also included is a comprehensive glossary of terms related to RF safety.

- *Use of SAR Modeling for RF Exposure Limit Compliance*. EPRI, Palo Alto, CA: 2007. 1014950.

  The report provides an overview of an in-depth theoretical, RF dosimetry study performed under contract from EPRI with the Health Protection Agency in the United Kingdom. This work provided new insight to the issue of assessing compliance with RF exposure standards, with an emphasis on relating field measurements to underlying limits inherent to RF exposure standards and guidelines. This study examines in great detail how RF fields are absorbed within the body through the use of a three-dimensional model of a man exposed to both plane waves and dipole near-field conditions. Electromagnetic energy absorption in the model was calculated using a finite difference time domain formulation. A fundamental aspect of modern day RF standards in which exposure limits are based on measures of the spatially averaged RF fields has been examined at a level of rigor never accomplished before. The study illustrates how spatial averaging is a sound approach to relating RF field exposure to the basic restrictions of various standards and is found to be generally a conservative approach, even for highly nonuniform fields.

5
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