MULTIMODE MILLIMETER WAVE RFID SYSTEMS AND METHODS THEREOF

FIELD

[0001] This technology generally relates to a radiofrequency identification (RFID) systems and, in particular, to multimode millimeter wave RFID systems and methods thereof.

BACKGROUND

[0002] Existing radio frequency identification (RFID) systems use an integrated circuit or chip (IC) on the RFID tags attached to the items to be tracked. The IC on the RFID tags allows for the use of a device, composed of a wireless transmitter and receiver, which imparts transmitted wireless power to the IC located on the RFID tags. This class of RFID tags is designated as passive, meaning there is no local power source. The IC receives, and turns on a response to, the "read request" from the reader device. As such, the RFID tag is acting as a transponder. The IC also typically contains identification and other data that the reader then records or communicates to other parts of the RFID system.

[0003] Another type of RFID technology uses tags without ICs or chips, and is designated as a "chip-less" RFID system. Chip-less RFID systems make use of millimeter wave synthetic aperture radar (SAR) technology or a radar backscatter approach to allow for communications between the reader and the chip-less RFID tags. However, the use of chip-less RFID tags is limited to readers employing those technologies.

[0004] It is anticipated that RFID technology will be employed in the internet of things (IOT), which includes smart objects with local storage and/or local sensors that are connected through some means to the Internet at large. There are two major challenges for the use of existing RFID technology in connection with the IOT technology: (1) the power required for the devices, and (2) communications between the device and the Internet.

[0005] There is an entire class of IOT devices that do not require continuous power for operation, such as smart sensors that have the ability to detect their state when powered, and to communicate that state during a read. Thus, there is a need to employ readers that can also power such devices for communication.

[0006] RFID tags that would be utilized for IOT and smart sensor applications are small in size. The small size of the RFID tags prohibits using antennas on the tags. As a result, the RFID tags cannot be located in the far-field from the reader during operation. Instead, magnetic or capacitive near-field coupling must be used to power and communicate with the RFID tag. Near-field coupling results in distances of less than a few centimeters from the tag for operation, which limits the ability to employ such devices for the IOT.

SUMMARY

[0007] The present technology advantageously provides a system that has dual mode capability for identification and communication with various types of RFID tags. The system can be implemented using extremely high frequency wireless technology that is advantageously designed to image and locate various types of RFID tags and smart sensors using synthetic aperture radar (SAR) while in a wide antenna beam pattern mode, and then shift to a narrow, beam steered mode for powering and communicating with the RFID tags or smart sensors. The system has the capability to operate in the radar imaging mode to locate various types of chip-less and chipped RFID tags, as well as Internet of Things (IOT) devices, with a high degree of accuracy. Once the tags or devices are located, the system has the additional capability of powering and communicating with the RFID tags in the far-field.

[0008] The system can be advantageously employed and provide the aforementioned advantages in any usage requiring RFID tag or sensor operation, including, but not limited to: inventory identification; asset management tracking and shipping container location; vehicular access control (*e.g.* toll ways); moving vehicle identification; healthcare identification and tracking of patients, drugs, equipment and personnel identification, tracking and monitoring of personnel and equipment for security purposes; identification of luggage and packages at airports; systems for locating lost objects (*e.g.* keys, files, golf balls, clothing articles), although any other uses, including uses for the IOT can be contemplated.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Figure 1 is an environment including an exemplary multimode RFID system of the present technology including a block diagram of an RFID reader device and a schematic view of a plurality of RFID tags to be utilized with the RFID reader device.

[0010] Figure 2 is a block diagram of an exemplary controller for the RFID reader device.

[0011] Figures 3A-3C are schematic views of three exemplary RFID tags that can be employed in the RFID system shown in Figure 1.

DETAILED DESCRIPTION

[0012] An example of a multimode millimeter wave RFID system is illustrated in Figure 1. In this particular example, the system includes a multimode RFID reader device and a plurality of tags and IOT devices with smart sensors, although the system may include other types and/or number of other systems, devices, components, and or other elements in other combinations, including additional multimode RFID reader devices and any number of RFID tags and sensor devices, by way of example only. In this example, the RFID reader includes a millimeter wave radiofrequency device, a beam steered antenna array, a radar modem, a communications modem, a switch, and a RFID control computing device, although the RFID reader may include other types and/or numbers of components and or other elements in other combinations, including additional electronics. The RFID reader can advantageously be programmed to either be in radar imaging mode for locating and decoding chip-less RFID tags, or a transponder/communications mode. The dual mode approach allows the RFID reader to provide a single system solution for use with all categories of RFID tags, as well as IOT devices having a smart sensor.

[0013] The millimeter wave radiofrequency device includes a transmitter and receiver located on a chip for transmitting and receiving millimeter wave radiofrequency through the beam steered antenna array, although the millimeter wave radiofrequency device may include other types and/or numbers of elements, such as a digital signal processor, by way of example only. In one example, the millimeter wave radiofrequency device is configured to operate at 240 GHz with an associated wavelength (λ) of 1.25 millimeters. The millimeter wave radiofrequency device may be formed using silicon germanium semiconductor process, such as disclosed in Bredendiek, C. et al., "A 240 GHz single-chip radar transceiver in a SiGe bipolar technology with on-chip antennas and ultra-wide tuning range," IEEE Radio Frequency Integrated Circuits Symposium (2013) and "High-Resolution 240-GHZ Radar with SiGe Chip", Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR (2018), the disclosures of which are hereby incorporated by reference in their entirety.

[0014] The beam steered antenna array is coupled to the millimeter wave radiofrequency generator to transmit and receive millimeter wave radiofrequency. The beam steered antenna array is programmed to be operable in both a synthetic aperture radar (SAR) mode and a communications mode. In the SAR mode, the beam steered antenna array is programmed to reduce the number of active elements such that the beam pattern emitted from the beam steered antenna array is widened as illustrated in Figure 1. The widened beam pattern can be utilized for high resolution SAR imaging for locating, imaging, and decoding chip-less RFID tags as disclosed in U.S. Patent Nos. 7,460,014 and 7,498,940, the disclosures of which are incorporated herein by reference in their entirety, and described in further detail below. The SAR mode may be utilized for three-dimensional radar imaging to identify and locate RFID tags in the field of the antenna array with a spatial resolution of less than 1 mm.

[0015] In the transponder/communications mode, the beam steered antenna array pattern can be narrowed to selectively power, and communicate with, various individual RFID tags or smart sensor devices located within the array pattern. The beam steered antenna array has a small aperture, on the order of 50 to 100 mm in cross-section, which in the selected frequency range of 240 GHz, by way of example, enables sufficient radiated power to be delivered to a chipped RFID tag having an IC or a smart sensor to provide the required operating power for the device.

[0016] In one example, the millimeter wave radiofrequency device and the beam steered antenna array are formed as an integrated antenna and chip package as disclosed in U.S. Patent Nos. U.S. 7,768,457, U.S. 7,868,841, and U.S. 8,477,070, the disclosures of which are incorporated herein by reference in their entirety, although other packing and manufacturing techniques may be employed.

[0017] Referring now more specifically to FIGS. 1 and 2, the RFID control computing device in this example includes one or more processor(s), a memory, and/or a communication interface, which are coupled together by a bus or other communication link, although the RFID control computing device can include other types and/or numbers of elements in other configurations. In one example, the RFID control computing device is a microcontroller located on the same chip as the millimeter wave radiofrequency device.

[0018] The processor(s) of the RFID control computing device may execute programmed instructions stored in the memory for the any number of the functions described and illustrated herein. In one example, the processor(s) provides instructions to the millimeter wave radiofrequency device and the beam steered antenna array for operation in the different modes described above. In another example, the processor(s) receive radar image data from the millimeter wave radiofrequency device and process the radar image data to identify and locate RFID tags in the field of the beam steered antenna array. In yet another example, the processor(s) provide instructions for communicating with the RFID tags or smart sensors in the field. The processor(s) may include one or more CPUs, GPUs, or general purpose processors with one or more processing cores, for example, although other types of processor(s) can also be used.

[0019] The memory stores these programmed instructions for one or more aspects of the present technology as described and illustrated herein, although some or all of the programmed instructions could be stored elsewhere. A variety of different types of memory storage devices, such as random access memory (RAM), read only memory (ROM), hard disk, solid state drives, flash memory, or other computer readable medium which is read from and written to by a magnetic, optical, or other reading and writing system that is coupled to the processor(s), can be used for the memory.

[0020] Accordingly, the memory of the RFID control computing device can store one or more applications or programs that can include computer executable instructions that, when executed by the RFID control computing device, cause the RFID control computing device to perform actions described below. The application(s) can be implemented as modules, threads, pipes, streams, or components of other applications. Further, the application(s) can be implemented as operating system extensions, module, plugins, or the like.

[0021] Even further, the application(s) may be operative in a cloud-based computing environment. The application(s) can be executed within or as virtual machine(s) or virtual server(s) that may be managed in a cloud-based computing environment. Also, the application(s) may be running in one or more virtual machines (VMs) executing on the image acquisition computing device. The communication interface operatively couples and communicates between the RFID control computing device and the millimeter wave radiofrequency device, the communications modem, and the radar modem.

[0022] In another example, the RFID control computing device is a highly integrated microcontroller device with a variety of on-board hardware functions, such as analog to digital converters, digital to analog converters, serial buses, general purpose I/O pins, RAM, and ROM. The microcontroller may be located on the same chip as the millimeter wave radiofrequency device, by way of example.

[0023] Although the exemplary RFID control computing device is described and illustrated herein, other types and/or numbers of systems, devices, components, and/or elements in other topologies can be used. It is to be understood that the systems of the examples described herein are for exemplary purposes, as many variations of the specific hardware and software used to implement the examples are possible, as will be appreciated by those skilled in the relevant art(s).

[0024] In addition, two or more computing systems or devices can be substituted for the RFID control computing device. Accordingly, principles and advantages of distributed processing, such as redundancy and replication also can be implemented, as desired, to increase the robustness and performance of the devices and systems of the examples. The examples may also be implemented on computer system(s) that extend across any suitable network using any suitable interface mechanisms and traffic technologies, including by way of example only teletraffic in any suitable form (*e.g.*, voice and modem), wireless traffic networks, cellular traffic networks, Packet Data Networks (PDNs), the Internet, intranets, and combinations thereof.

[0025] The examples may also be embodied as one or more non-transitory computer readable media having instructions stored thereon for one or more aspects of the present technology as described and illustrated by way of the examples herein. The instructions in some examples include executable code that, when executed by one or more processors, cause the processors to carry out steps necessary to implement the methods of the examples of this technology that are described and illustrated herein.

[0026] The millimeter wave radiofrequency device is coupled to the radar modem and the communications modem through the switch, which allows the RFID reader device to alternate between the SAR mode and the communication mode, as described in further detail below. In one example, the radar modem is a frequency modulated continuous wave (FMCW) radar modem, although other suitable radar modems may be employed. In one example, the communications modem is a quadrature amplitude modulated communications modem, although other suitable communications modems may be employed.

[0027] Referring now more specifically to Figures 1 and 3, the RFID system includes a plurality of RFID tags that may be utilized with the RFID reader device described above. Each of the tags may use parametric reflective technology that may be utilized for SAR as disclosed by way of example in U.S. Patent Nos. 7,460,014 and 7,498,940, the disclosures of which are incorporated herein by reference in their entirety. Specifically, in this example the RFID tags include a plurality of antenna elements that are formed on a substrate or directly on an object, such as an object in the IOT. The antenna elements are oriented and have dimensions to provide polarization and phase information representative of the information encoded on the RFID tag, which can be read-out by the RFID reader device. The antenna elements re-radiate radiofrequency signals received from the RFID reader device back to the RFID reader device to form a radar image. The radar image may be utilized to spatially locate each of the RFID tags in the scanned area, such that the RFID reader device can ascertain the location of the RFID tags at a spatial resolution of less than one millimeter and target the direction of the narrow millimeter wave beam or other beam.

[0028] The RFID reader device can be utilized with entirely chip-less SAR tags as illustrated in Figure 3A, or the RFID reader device can also be used to identify SAR elements located on chips also having an IC or a sensor tag associated therewith, as illustrated in Figures 3B and 3C, respectively. The RFID reader device can also be utilized in its communications mode, as described in further detail below, to selectively power and communicate with the chips illustrated in Figures 3B and 3C.

[0029] By utilizing RFID tags that have SAR chip-less type patterns in conjunction with smart chips (Figure 3B) and smart sensors (Figure 3C), various RFID tag combinations can be designed for use with various RFID and smart sensor IOT applications. A tag can be designed for chip-less, SAR use only (Figure 3A), SAR use with a transponder chip (Figure 3B), or SAR use with transponder and IOT smart sensor technology (Figure 3C). The technology can be utilized with any smart sensors known in the art for sensing any physical parameter. By including the SAR chip-less technology on each of the RFID tags, the SAR radar function allows any type of RFID tag to be spatially located with high resolution, in addition to other transponder and smart sensor features.

[0030] An exemplary operation of the multimode RFID reader device of the present technology will now be described with reference to FIGS. 1-3.

[0031] First, the RFID reader device operates in SAR mode to output a wide beam that transmits electromagnetic radiation to a large area at a desired frequency using the radar modem. In this example, the RFID reader device transmits the radiation at a frequency of 240 GHz with an associated wavelength (λ) of 1.25 millimeters, although other frequencies may be employed.

[0032] The electromagnetic radiation is received at the RFID tags in the scanned area, causing the SAR antenna structures of the RFID tags to resonate at the desired frequency and re-radiate the electromagnetic signals back toward the RFID reader device. The RFID reader device samples and stores the received signals from the RFID tag(s), as well as reflected electromagnetic radiation from all objects in the scanned area, and builds a signal phase history in a memory of the RFID control computing device.

[0033] Through mathematical coherent phase analysis, the RFID reader device processes the phase history and polarization samples using general SAR signal processing algorithms, although other processing algorithms are contemplated. The RFID reader device is then able to generate images of the scanned area from the phase history samples and associated polarization data to identify the RFID tags in the area. In other words, the RFID reader device is able to "view" the scanned area using radar technology and "see" the RFID tags and distinguish the tags from other objects and RFID tags by the orientations and dimensions of the antenna structures thereon. The use of radiofrequency waves at 240 GHz, by way of example, allows for three-dimensional radar imaging to identify and locate RFID tags or smart sensors having the SAR technology located thereon in the field of the antenna array with a spatial resolution of less than 1 mm. The SAR interrogation can also be utilized to decode chip-less RFID tags, such as the tag illustrated in Figure 3A, which does not include an IC thereon.

[0034] Next, the RFID reader device can operate in the transponder/communications mode to selectively power and communicate with RFID tags whose location has been identified in the scanned area using the communications modem. The beam steered antenna array has a small aperture, on the order of 50 to 100 mm in cross-section, which in the selected frequency range of 240 GHz, by way of example, enables sufficient radiated power to be delivered to a chipped RFID tag having an IC or a smart sensor to provide the required operating power for the device, such as the chips illustrated in Figures 3B and 3C. The technology can be used to power and communicate with these types of chips in any manner known in the art. The antenna beam pattern can be made sufficiently narrow such that each tag or device within the pattern can be selectively powered and provide communications independently of other tags and devices.

[0035] Accordingly, the RFID system of the present technology advantageously provides an RFID system that can be used with SAR-enabled tags. The RFID reader device is to either be in the SAR mode for locating and decoding chip-less tags using the radar modem and the wide antenna pattern, or in a transponder/communications mode, using the communication modem and a narrow beam steered pattern. This dual mode approach provides a single system solution for all categories of RFID tags and allows RFID technology to be utilized in various applications, including the IOT.

[0036] Having thus described the basic concept of the invention, it will be rather apparent to those skilled in the art that the foregoing detailed disclosure is intended to be presented by way of example only, and is not limiting. Various alterations, improvements, and modifications will occur and are intended to those skilled in the art, though not expressly stated herein. These alterations, improvements, and modifications are intended to be suggested hereby, and are within the spirit and scope of the invention. Additionally, the recited order of processing elements or sequences, or the use of numbers, letters, or other designations therefore, is not intended to limit the claimed processes to any order except as may be specified in the claims. Accordingly, the invention is limited only by the following claims and equivalents thereto.

CLAIMS

What is claimed is:

1. A method comprising:

transmitting, by a multimode radio frequency identification (RFID) reader device, a wide pattern millimeter wave radiofrequency beam towards a scan area;

receiving, by the multimode RFID reader device, reflected millimeter wave radiofrequency beams from the scanned area and re-radiated millimeter wave radiofrequency beams from one or more RFID tags located within the scanned area;

determining, by the RFID reader device, a spatial location for each of the one or more RFID tags located within the scanned area from a radar image generated based on the reflected millimeter wave radiofrequency beams and the re-radiated millimeter wave radiofrequency beams; and

transmitting, by the RFID reader device, a narrow millimeter wave beam towards at least one of the RFID tags located within the scanned area based on the determined spatial location, wherein the narrow millimeter wave beam is configured to power an integrated circuit or sensor located on and to communicate with the at least one of the RFID tags.

2. A multimode RFID reader device comprising:

a millimeter wave radiofrequency device configured to transmit and receive electromagnetic radiation through a beam steered antenna array coupled to the millimeter wave frequency device;

an RFID control computing device coupled to the millimeter wave frequency device and the beam steered antenna array, the RFID control computing device comprising a memory coupled to a processor which is configured to be capable of executing programmed instructions comprising and stored in the memory to:

transmit in a synthetic aperture radar (SAR) mode a wide pattern millimeter wave radiofrequency beam towards a scan area and determine a spatial location for one or more RFID tags located within the scanned area from a radar image generated based on reflected millimeter wave radiofrequency beams and re-radiated millimeter wave radiofrequency beams resulting from the transmission of the wide pattern millimeter wave radiofrequency beam; and

transmit in a transponder mode a narrow millimeter wave beam towards at least one of the RFID tags based on the determined spatial location to power an integrated circuit or sensor located on and to communicate with the at least one of the RFID tags.

3. A multimode RFID system comprising:

a multimode RFID reader device comprising:

a millimeter wave radiofrequency device configured to transmit and receive electromagnetic radiation through a beam steered antenna array coupled to the millimeter wave frequency device;

an RFID control computing device coupled to the millimeter wave frequency device and the beam steered antenna array, the RFID control computing device comprising a memory coupled to a processor which is configured to be capable of executing programmed instructions comprising and stored in the memory to:

transmit in a synthetic aperture radar (SAR) mode a wide pattern millimeter wave radiofrequency beam towards a scan area and determine a spatial location for one or more RFID tags located within the scanned area from a radar image generated based on reflected millimeter wave radiofrequency beams and re-radiated millimeter wave radiofrequency beams resulting from the transmission of the wide pattern millimeter wave radiofrequency beam; and

transmit in a transponder mode a narrow millimeter wave beam towards at least one of the RFID tags based on the determined spatial location to power an integrated circuit or sensor located on and to communicate with the at least one of the RFID tags;

a plurality of RFID tags configured to provide re-radiated millimeter wave frequency beams in response to the SAR mode of the RFID reader device.

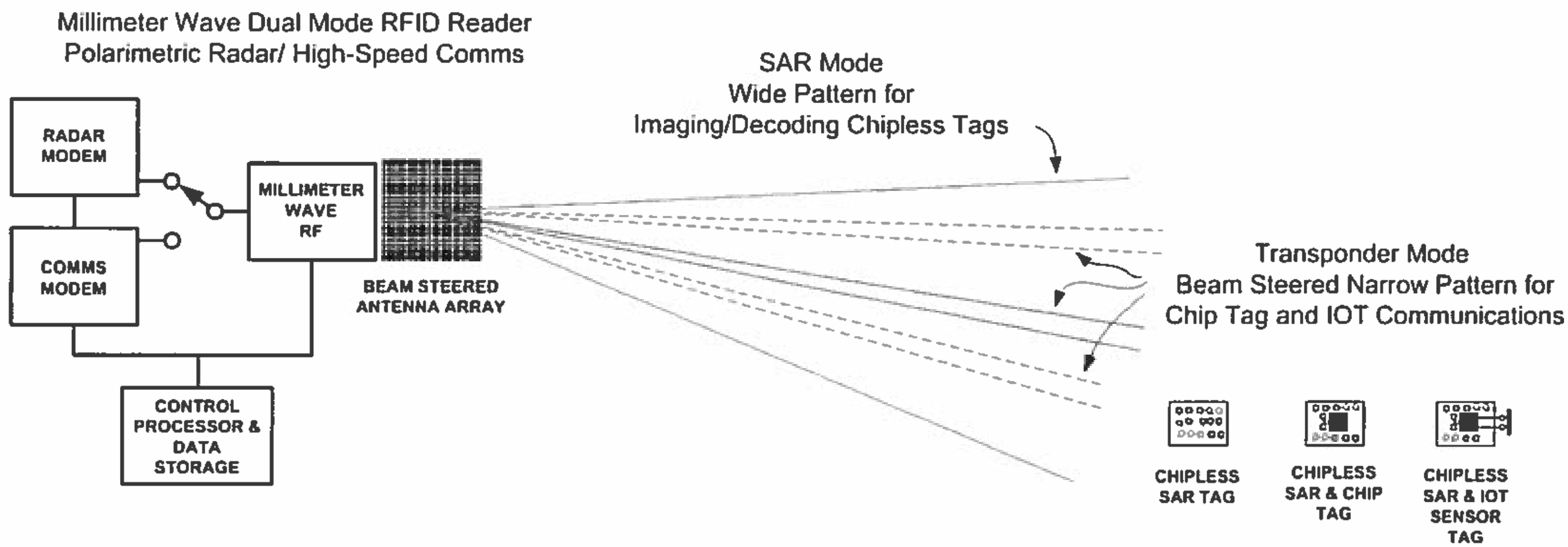


Figure 1 Dual Mode Millimeter Wave RFID System

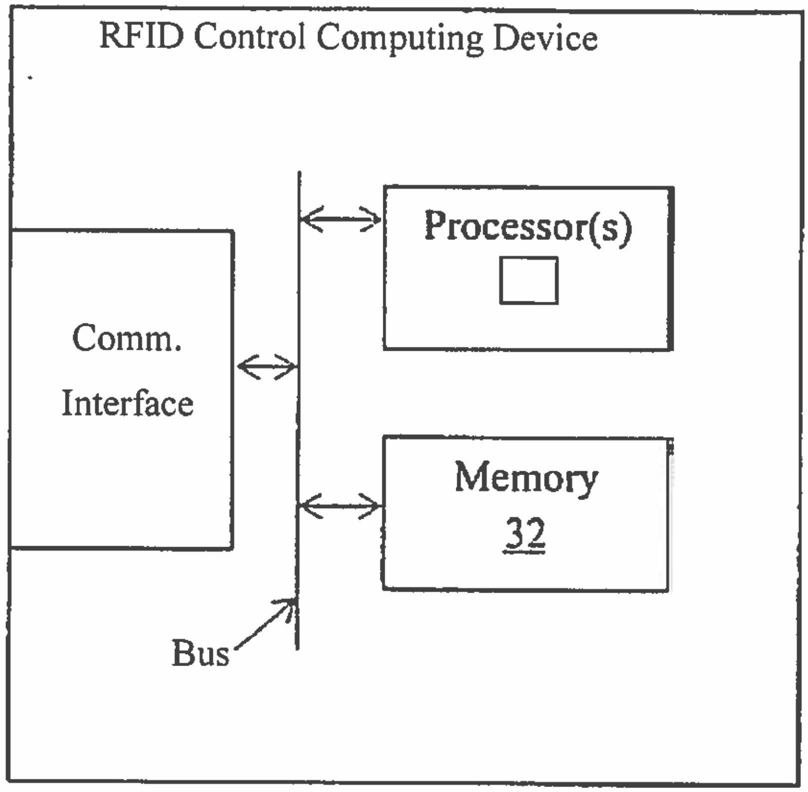
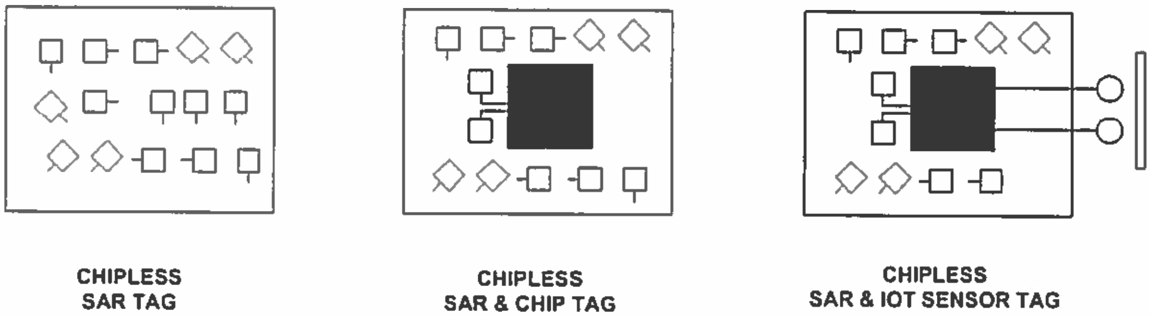

RFID Control Computing Device
Processor(s)
Comm.
Interface
Memory
32
Bus

Figure 2



(a) (b) (c)

Figure 3 RFID Tag Types for Use in the Dual Mode Millimeter Wave RFID System