

Locator beacon design for victims in distress

The design requirements of a beacon intended to be used for victims in distress needs to be simple yet effective. This Beacon-On-Demand design includes a GPS system along with Tx/Rx implementation and achieves performance requirements.

By Fred Mohamadi

A multiband radar beacon locates victims in distress during search and rescue missions. The beacon can also help provide ordinance's accurate delivery by aircraft to immediate or pre-planned targets, and it can be used for en route navigation or pathfinder functions to guide aircraft to obscure or poorly visible targets. Another function of the beacon is to help outline a drop zone so that supplies, military personnel or heavy equipment can drop at precise ground points.

Currently, portable transponders lack the flexibility of coding programmability, on-demand functionality and highly efficient power use. The new Beacon-On-Demand (BOD) offers that flexibility and includes a GPS system with Tx/Rx implementation.

In a typical operation, an interrogator asset enables the function of the BOD. The interrogator asset is equipped with a special transponder receiver. It receives the beacon signal, recognizes the pulse code and places the BOD location as a symbol on the radar screen. Azimuth and distance are determined by the direction of the radar and time delay of the response pulse. The codes can be customized for a variety of applications to meet specific mission-related requirements.

When the BOD receives a radar signal in I-band (8-10 GHz) or J-band (10-20 GHz), it intelligently discriminates and creates a reply pulse train in the received band coded for the radar to identify and locate the transponder. The transmitter function of the BOD can be easily modified and delivered with or without a frequency offset from the radar frequency. Thus, it could be used without a special transponder receiver if desired.

Although the current design is based on two standard 9 VDC Alkaline batteries, it can also be modified for use with standard watch batteries for a smaller footprint.

The human factor in designing the BOD is crucial as well. It should be easy to operate, yet simple enough to maintain and repair because it uses widely available off-the-shelf components, including the replaceable integrated multichip module. An integrated in-field test unit ensures that BOD is fully operational prior to the mission. It should have a robust design to be upgradeable with a GPS modular add-on unit that can be inserted into the BOD main portable unit.

Figure 1 shows the product design concept for the beacon-on-demand. The small footprint (15.2 cm x 5.2 cm x 2 cm) includes a compact pocket size transmitter and receiver that operates with two 9 V batteries. A modular upgrade for a GPS interface has also been considered for the design of a high-end BOD. The near-PCMCIA size BOD is versatile in compactness at no compromise to the performance due to the unique

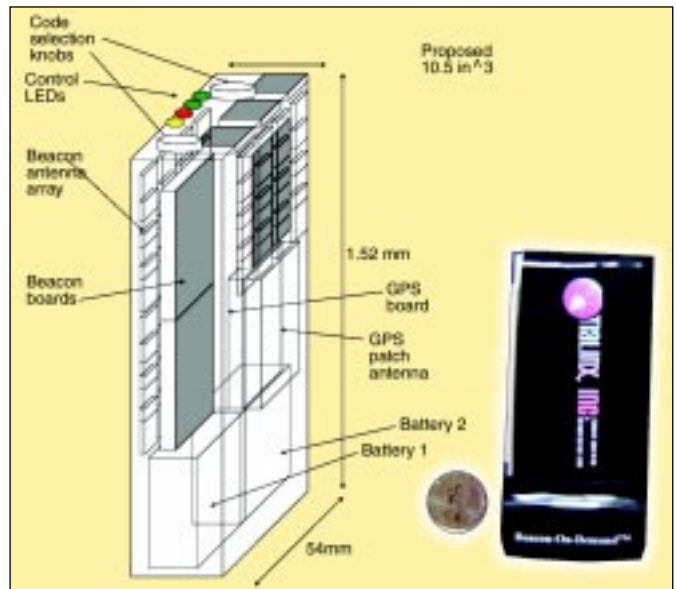


Figure 1. Product diagram of the Beacon-on-demand.

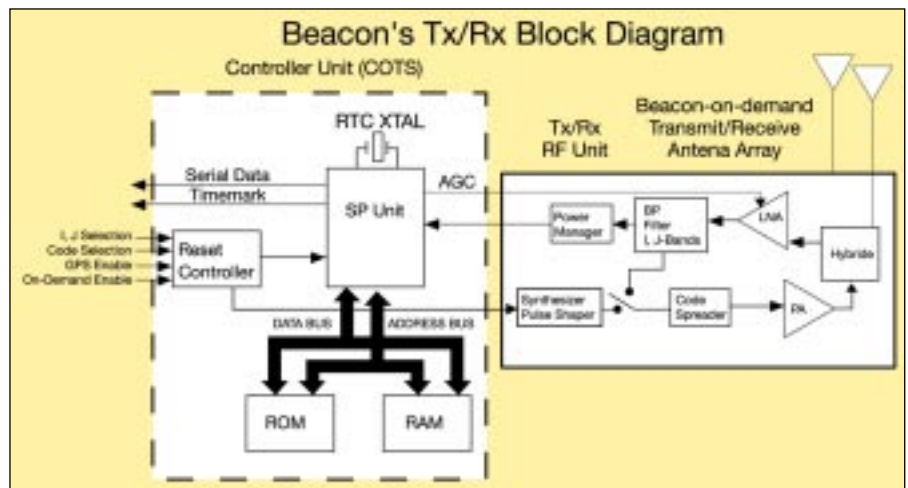


Figure 2. Tx/Rx function block diagram of the BOD.

power manager unit and simple and yet innovative system/antenna/circuit design.

Figure 2 presents the block diagram of the proposed transmit/receive (Tx/Rx) RF chip as part of a complete BOD system design. In an "echo = loop-back = on-demand" mode, the received signal from an interrogator asset will be demodulated by an envelop detector and the edge of the received pulse will be synchronized to the code spreader. The received (unmodulated

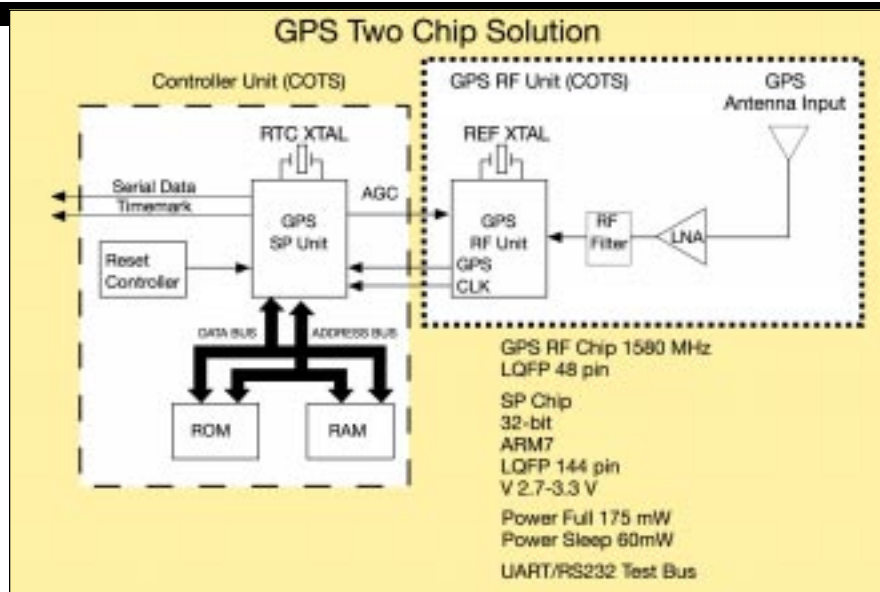


Figure 3. GPS module system block diagram of the Beacon-on-demand.

signal) will be amplified and a desired code will be spread over the amplified signal and transmitted back to the interrogator. The unique method of synchronization and code spreading is the key factor in design of a robust, low-power and low-component-count chip.

An ultra low-power controller/signal processor chip (below 100 mW at full speed) available from many vendors is used to address the signal processing and pulse repetition frequency (PRF) and pulse width. In a “stand-alone” mode, the desired code is modulated with the selected PRF and transmitted to the receiver asset. An optional GPS RF unit (available in COTS) is also designed to be used with the unit sharing the same controller and signal-processing chip [1-4].

Figure 3 describes the functionality and actual implementation of the GPS module that is currently available as an off-the shelf item. The GPS unit consumes about 170 mW at full operation, 65 mW in sleep mode and 24 mW in deep sleep mode.

Antenna and multichip-module substrate implementation

As illustrated in Figure 4a, a T-shaped dipole antenna element may be used to form the antenna element. Each T-shaped antenna element may be formed using a metal layer of a standard semiconductor process. T-shaped antenna elements are excited using vias that extend through insulating layers and through a ground plane to drive transistors formed on a RF layer separated from a substrate by an insulating layer. Two T-shaped antenna elements also may be excited by the RF unit to form a dipole pair. To provide polarization diversity, two dipole pairs may be arranged such that the transverse arms (not shown) in a given dipole pair are orthogonally arranged with respect to the transverse arms in the remaining dipole pair. Depending on the desired operating frequencies, each T-shaped antenna element may have multiple transverse arms. The length of each transverse arm is proportional to the quarter wavelength for the desired operating frequency.

Figure 5 presents the electromagnetic field simulation results for a 24-pair antenna array (comb type) operating at 8 to 20 GHz range [5]. The array and substrate area occupies volume of 9 cm by 2.4 cm by 5 mm.

The unique packaging of the part enables the use of flexible substrate such that a low dielectric substrate can be used for enhanced wideband coupling of the antenna to the transmitted power. Bands of flexible substrate will enable the use of the array suitable for many applications that require conformity. The phase

steering will provide such a function if a flat environment was desired.

Additionally, the modulator and code generator are also mounted on the same substrate that embeds in the flexible substrate. The chip is connected to the antenna elements using metal vias. A grounded metallic layer shields the chip from the antenna array.

A PTFE (Teflon)-based or similar flexible substrate with $\epsilon_r = 2$ results in an array beamwidth of $\sim 60^\circ$ and 12 dBi of gain, launching a 1 V signal to a 50-ohm load. The coverage bandwidth of the antenna is 12 GHz flat with S11 being better than -20 dB.

Signal shaping and antenna array

Separating the design into two adjacent channels optimizes designs to achieve flatter and effective filtering capabilities. A unique, simple two-stage integrated amplifier and microstrip-based flat band signal shaping with low-power consumption has been designed (Figure 6 a). Reflection coefficient and gain

at desired ranges of the frequency are shown in Figure 6b and 6c. The implementations of the microstrip-based filters, inductive coils and active devices are in a Si-Based process (CMOS or SiGe). Design criteria of 25 dB gain (S21) and -15 dB or better reflection (S11) were chosen.

BOD system-level architecture

Figure 7 presents the proposed system block diagram that has been used for simulations.

Interrogator signal source (echo or on-demand mode): An interrogator asset initiates transmitting radar pulses with 1 millisecond period and 0.2-microsecond width. Rise and fall times are

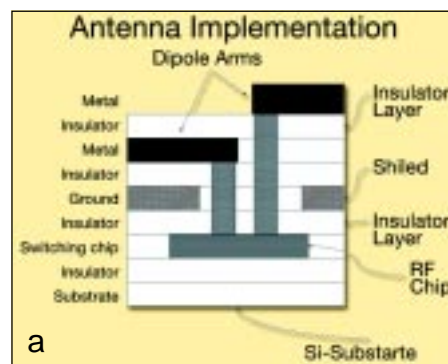
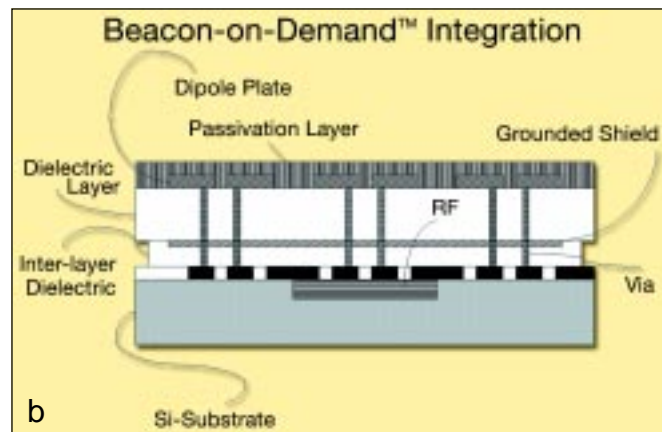


Figure 4. Demonstration of dipole array design. (a) Cross section of the antenna. (b) Integrated implementation.



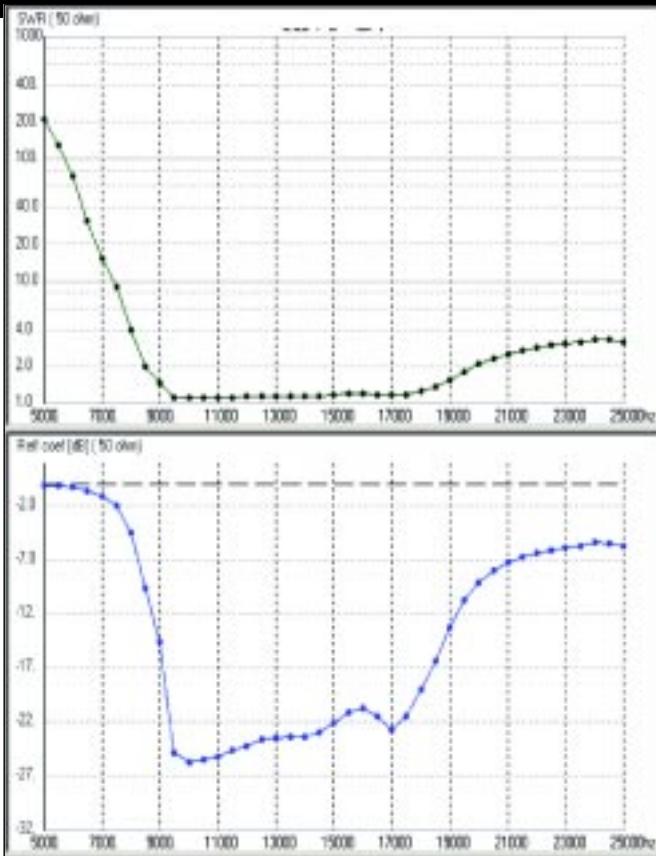


Figure 5a. Reflection coefficient and SWR of the proposed array for 8-20 GHz Tx/Rx.

selected to be 10 nanoseconds. The amplitude of the signal is chosen to be 1 V. The pulse train is then amplitude-modulated with a local oscillator of magnitude 10 mV and frequency of 10 GHz for the purpose of illustration. The signal is then amplified for 52 dB to simulate the transmitted signal power level from an interrogator asset. This example used 27 dB gain for the output power amplifier and 25 dBi gain of interrogator transmitter antenna gain.

Channel model: The communication between the interrogator asset and the BOD is modeled to be at 10 NM in the air. The attenuation associated with the environmental elements was about -116 dB, and the noise generated in the channel was modeled to be a white Gaussian (random seed is chosen to be 534345 for high- and low-frequency noise spectra) with -20 dB power and 20 dB signal-to-noise ratio (SNR). The details of link budgets are reflected for Rx (Table 1).

Receiver (echo mode application) model: The received signal is collected using an antenna array with 7 dBi gain and then amplified with a unique flat-band two-stage amplifier of Figure 6. The amplitude demodulator has a sensitivity of 1 V per volt and has been assumed to tolerate 3° phase shift. The demodulator is then used to recover the signal envelope (data) from the carrier and use the edge of the pulse width for synchronization of code spreader with the unmodulated signal in echo or on-demand mode. In a “stand-alone” mode, the knob selector determines selected PRF codes from memory module and its chosen PRF will dictate the operation of the transmitter.

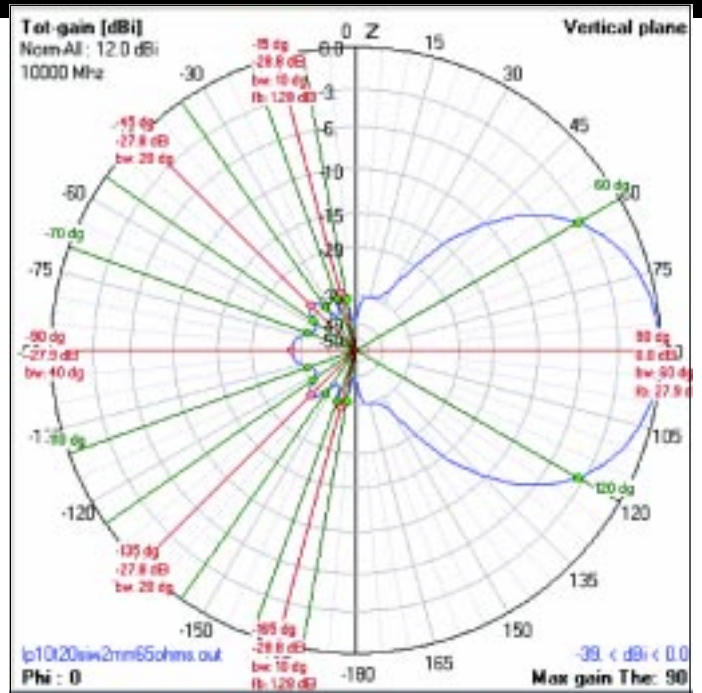


Figure 5b. Radiation pattern of the proposed array at 10GHz.

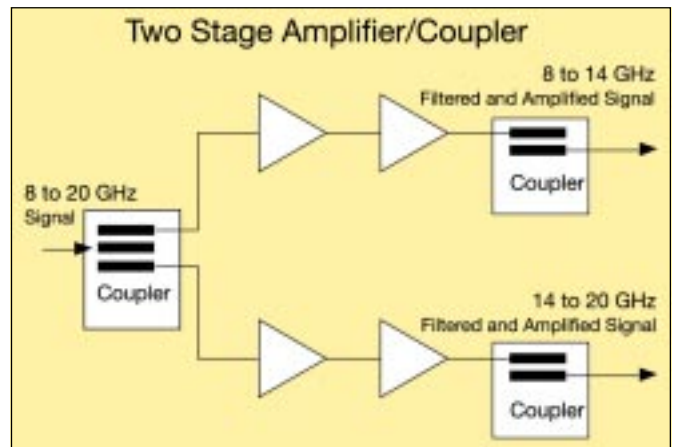


Figure 6a. Two-stage flat bandwidth amplifier with integrated filtering.

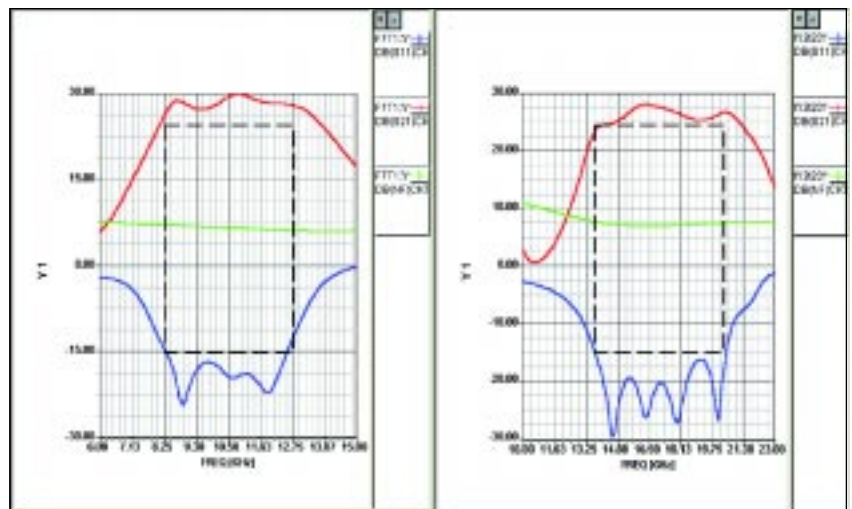


Figure 6b. S11, S21 and NF for 8-14 GHz. Figure 6c. S11, S21 and NF for 14-20 GHz.

Table 1. Interrogator Transmitter to BOD Receiver Link Power Budget

BOD Received Signal from Interrogator Asset Transmitter				
Frequency	8000	10000	20000	MHz
Distance	10	10	10	Miles
Free space wavelength	37.5	30.0	15.0	mm
Substrate	Si	Si	Si	
Permittivity	11.7	11.7	11.7	
Antenna elements	1	1	1	
Available receiver BW (%)	5	5	5	%
Available bandwidth	400	2000 to 10000	1000	MHz
Maximum data rate	4	4	4	Kbps
Launched signal from transmitter asset	500.0	500.0	500.0	W
Ps = Asset TX power	27.0	27.0	27.0	dB
G = Asset TX antenna gain	25.0	25.0	25.0	dBi
EIRP	52.0	52.0	52.0	dBw
FSL = Free space loss	-134.7	-136.6	-142.6	dBw
Gr = MMRB receiver antenna gain	7.0	7.0	7.0	dBi
Pr = Received carrier power	-75.7	-77.6	-83.6	dBw
Received power in dBm	-45.7	-47.6	-53.6	dBm
Reshaped signal gain - connection loss	25.0	25.0	25.0	dB
Received modulated signal to code spreader	-20.7	-22.6	-28.6	dBm
Amplifier gain	25.0	25.0	25.0	dB
Multiplier and amplifier gain	20.0	20.0	20.0	dB
Coded signal	24.3	22.4	16.4	dBm
Available process gain for pseudo-random coding	50.0	50 to 54	54.0	dB
Noise temperature (highest point of operation)	360	360	360	Deg K
Receive bandwidth	6000	6000	12000	MHz
Noise energy	-165	-165	-162	dBw
Received carrier SNR after antenna/filter	89.6	87.6	78.6	dB
Additional channel loss in bad storm	10	10	10	dB
Received carrier SNR in bad storm	79.6	77.6	68.6	dB

In case of echo mode, the design process ensures the return signal from the BOD is at the same frequency as the received one from interrogator asset and the BOD acts to relay (re-transmit) the signal with spreading the code on. This unique ultra-low power design removes the need for sophisticated PLL and tuner circuits that are expensive and consume high power. A unique design of a coding module enables significant processing gain to be available for generation of interrogators with advanced anti-jamming capability (Table 1).

Transmitter model (on-demand and stand-alone): Shown in Figure 7 is also the block diagram of the transmitter portion of the BOD to address code spreading and to re-send the re-shaped received pulse trains back to the interrogator. This simulation has assumed an 8-bit sequencer that generates the codes at 10 to 40 MHz. Codes can alternatively be read from a pre-programmed fixed (on the chip) or replaceable memory stick. The depth of the sequencer can be modified for final design.

The transmitted signal is assumed to be about 2W and a worst case of 0 dB antenna gain has been assumed (our design has a 12 dB gain). A processing gain of 50 dB is available using pseudo-random cod-

ing that is discussed later. This additional gain is effective in addressing losses of bad storms, extreme temperatures and degraded receiver assets over time.

Coding system: The code with a binary bit pattern of 1010 (10 decimal) has been repeatedly spread (bit sequence of 10101010....) to the pulse width of the synchronized pulse train (replica of the interrogator's pulse train).

The multiplier transistor block spreads the binary pattern to the width of the pulse train as shown in the output signal of Figure 7. The spread code is then amplified and delivered to the antenna for transmission. In one example two different code types can be spread over a 200-nanosecond pulse width. A pattern of choice can be the 11001100 code or an alternate pattern corresponding to an 11110000 code.

Alternative coding system: Modification to the coding system can be performed with more sophisticated designs. A maximal length pseudo noise (PN) code and carrier frequency can be used coherently as having a common reference signal. This coherency provides required accuracy for the condition that each 350 Mcps (Mega-chips per second) in one design and 35 Mcps in alternate design with lower resolution requirement. For the case of 350

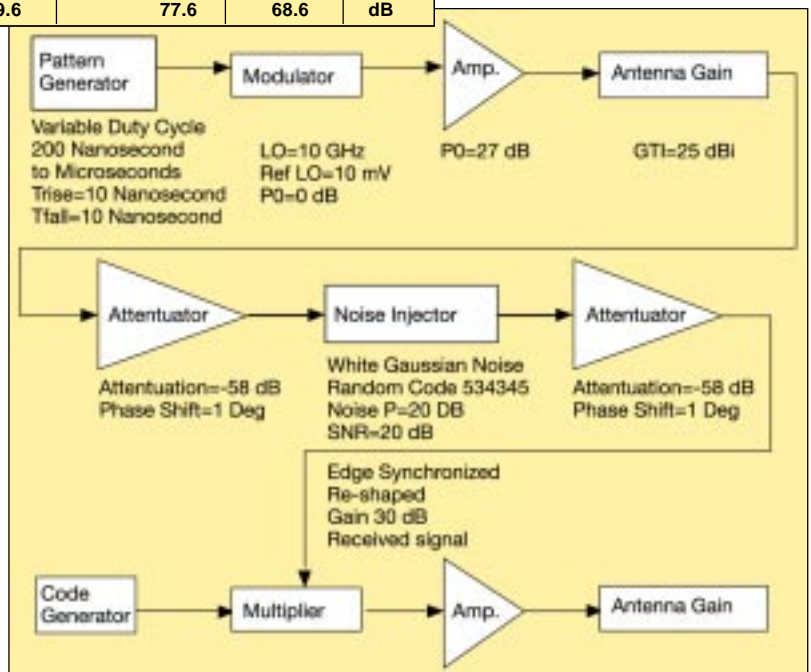


Figure 7. Interrogator and Beacon-on-demand system diagram.

Mcps, the chip contains approximately 40 cycles of the 14 GHz carrier, and that the zero-phase point of each chip corresponds to the zero-phase point of one cycle of the 14 GHz carrier. This locking of the modulation and the carrier is necessary for the technique that follows, and in practice is easy to achieve by simply phase-locking both clocks to a common high-stability master system reference oscillator (Ref_Clk) in the master PLL (please refer to the February 2004 article of *RF Design* by this author). There are three components of information in the waveform: (a) the integer chip value (which particular chip has arrived), (b) the sub-chip code phase value (exactly where within an integer chip the arrival occurs), and (c) the carrier phase value (the carrier phase at the instant of arrival). Together, these components provide proper resolution to a high degree of accuracy for interrogator while receiving very weak signals from beacon at distances far away.

The worst-case measurement is at maximum range, so the allowable error is one chip divided by 15,000 chips (15 km range times 1 chip/m), or 66 ppm. This is the upper error limit for the interrogator. As the receiver bandwidth narrows, the achievable update rate decreases. Alternatively, a 50 km range may have 20 ppm allowable 1chip/m resolution. This implies that the worst-case timing accuracy requirement for the entire ranging system is, therefore, 20 ppm, which is well within the accuracy of any reasonable high-quality reference oscillator with sophisticated interrogator or receiver assets.

For a complex realization, (PN) sequences are used which employ good correlation properties. Using SNR and update rate tables [6-8] and assuming identification code is BPSK modulated, a 14 GHz carrier frequency and a 10 dB Eb/N0 translates to a 10^{-5} BER. Assuming a 10 dB SNR inside the PLL, then a 128 KHz signal translates to 2.7 microsecond of update time. A more restrictive design of 1.28 KHz signal, requires 30 dB PLL tracking (update rate of 270 microsecond). The SONET requirement is a locking/tracking capability of 60 bit (at 12.5 Gbps) without any transition. Past experiences of suppliers of SONET and Ethernet PLL chips have met this challenge of tracking with update time requirement of 80 microseconds.

For simple implementation, a maximal length sequences can be applied with a length of 40 bits. The code sequence is generated using a quartz oscillator that is connected to CMOS shift registers. The feedback loops of these shift registers define the code.

Power management unit

Operation of the power management unit is crucial to secure capability of communication between interrogator asset and the BOD. The system design is based on optimized power consumption by the power management unit. The chip takes advantage of the highest voltage swing only at the input low-noise amplifier (LNA) and output power amplifier (PA). All

logical functions and signal processing (controller unit, synchronization of pulse edge, coding and code selection including interface to GPS, multiplier, pulse width and PRF manager, and synthesizer) will be designed with a low-voltage 1.2 V module to save power consumption. The exact power saving as a result of these hardware enhancements in the chip will significantly increase the lifetime of the operation.

Echo, loop-back, or on-demand mode of operation: The unique design of the antenna array enables transmitter and receiver from the same antenna. The Tx/Rx function in echo mode is shut down until the power detection unit identifies interrogator asset's detected radar scans signal. The power management unit comprises an energy conversion unit that collects RF signal and after rectifying it, delivers it to a large storage capacitor. The collected energy is then compared to a reference level to start the operation of transmit and alternates between Rx and Tx

mode to perform the echo mode.

Stand-alone mode of operation: In a stand-alone mode, all the functions of Rx within the BOD chip are shut down with the exception of the power management unit that encompasses a timer. This programmed timer is responsible for managing the proper timing required for burst cycle (PRF), duty cycle (pulse width) and proper wake-up mode procedures during Tx operation. The key element is function of the power management unit. Amplifiers and the synthesizer should reach steady state condition prior

to the full functionality of Tx and Rx. The GPS function has also been modeled to be active with 10-minute intervals (on/off) with a power consumption of 175 mW active and 60 mW in sleep mode.

Implementation

The aforementioned units: power management, Rx and Tx, code generator, synthesizer for generating PRF and pulse duration are readily available in COTS for a breadboard design. The unique design and integration of these functions into a single chip allow interface to a memory module and interface to a GPS unit to receive position data. Furthermore, microstrip filters using the Si substrate will result in further compactness and miniaturization of the BOD. RFD

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