



## Instantaneous Inventory

Gain ICs

## INSTANTANEOUS WIRELESS

Perhaps the most succinct figure of merit for summation of all efficiencies in wireless transmission is the ratio of carrier frequency to bitrate, the closer to 1 the better. In that regard, an exciting new breakthrough in wireless communication developed by Gain ICs, instantaneous Wireless (iW), comes in at 2 cycles/bit with 2 constellations in contrast to comparable bitrate of 256 QAM (IEEE 802.11ac) at 57 cycles/bit. iW improves wireless transmission 28 times by this indicator, with the latest QAM, 5G, being 20 times; iW also makes other quantum advances possible as well, significantly improving wireless communication and creating entirely new wireless applications as depicted in Figure 1.

Contemporary methods of radio frequency (RF) transmission involve down conversion to an immediate frequency (IF) or direct conversion which down converts to base frequencies directly (zero IF). iW, Figure 2, eliminates both down conversions (direct and IF) reducing reception to essential operations only at the received frequency: amplify, filter and demodulate. This reduces receiver noise by orders of magnitude allowing iW to transmit further, with less bit energy, and at essentially zero bit error rate (BER), while achieving 256 QAM bitrates and far surpassing other quadrature modulation methods.

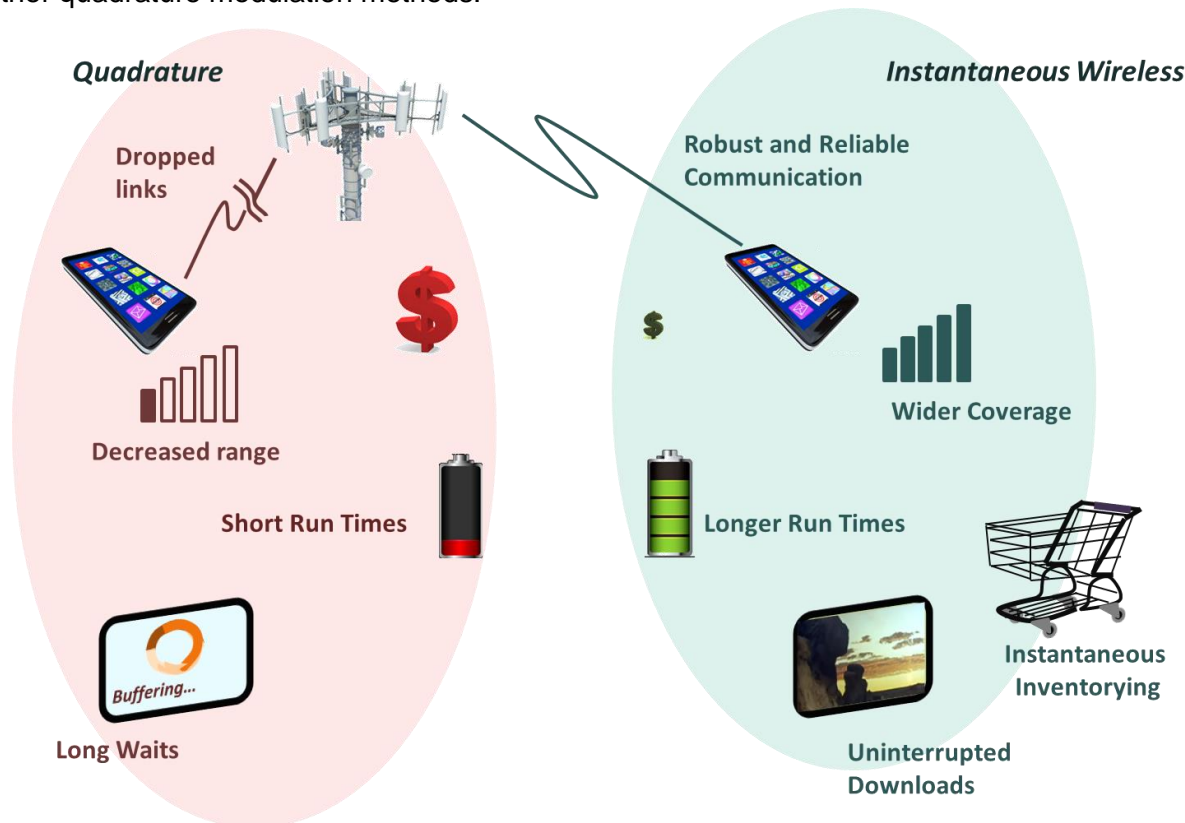
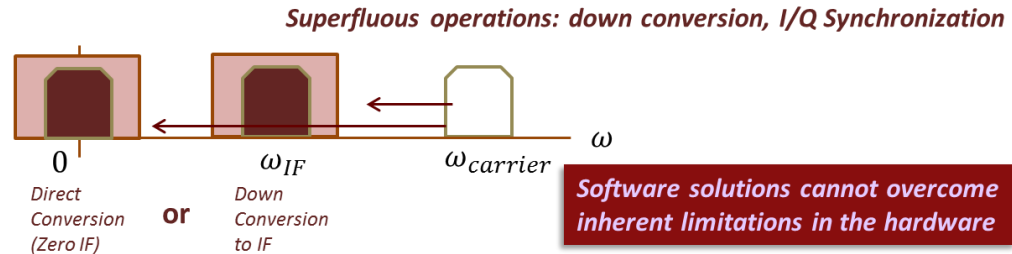


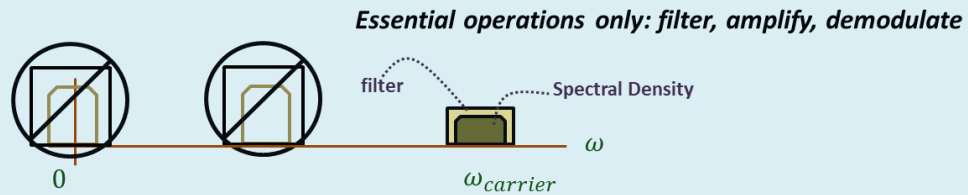
Figure 1. iW improves existing wireless applications and enables entirely new ones, like instantaneous checkout.

## Quadrature Architectures



- Higher spectral density to increase bitrates and ameliorate increased noise
- Prolonged latencies

## Instantaneous Wireless (iW)

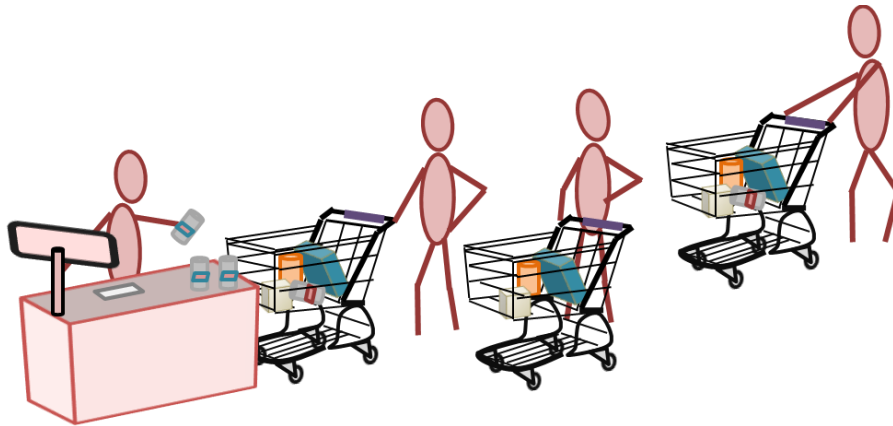


- Lower spectral density with optimally high bitrates and intrinsically low noise
- Instantaneous, negligible latencies

Figure 2. Simplify RF reception to filter, amplify and demodulate only.

## iW QUANTUM ADVANCES

By eliminating down conversion entirely, iW achieves the same high bitrates of significantly more complex modulation schemes, like 256 QAM, with only 2 fast constellations. The resulting large reduction in noise translates into far greater reliability and greater transmission distances while also keeping transmit power substantially lower. This enables entirely new wireless applications, like true item-level tagging: placing a barcode sized antenna on all items in a grocery store which can transmit into the meter range while keeping power low and communication immediate to enable instantaneous checkout without removing items from a grocery cart (see diagram in Figure 3). This same tag can be utilized for instantaneous inventory, leading to substantial cost reductions and increased accuracy throughout the world's supply chains, transportation and shipping industries. Other wireless communication can also achieve greater link spectral efficiencies with iW, increasing the number of constellations while remaining still a fraction of the constellation sizes required by quadrature for similar bitrates.



*Simultaneously read prices on hundreds of items  
Eliminate queues and manual operations*



**Instantaneous Checkout**

Figure 3. True item-level tagging.

## iW INSTANTANEOUS COMMUNICATION

Another salient iW advance is instantaneous communication. iW demodulation occurs within 10 ns which is millions of times faster than typical methods as shown in Figure 4. This eliminates interference from multipath reflections, as demodulation occurs much faster than the travel time of most reflected waves thus preventing overlap with the direct wave. This also translates into instantaneous (undetectable) frequency hopping for significantly increased security while not degrading effective bitrate by long transition times.

The largest advantage to item level tagging is 10,000,000 times faster inventorying. Because of a 1,000,000 times faster turn-around time and taking 100 ns per identify operation given fast bitrates approaching transmit frequency, iW tagging can scan through an inventory of 10,000 items, identifying any such items which exists within range of reader, all within a millisecond. Current RFID tagging, in contrast, with the much more complex and cumbersome EPC Gen 2 specification would take 2.78 hours to achieve the same, assuming they could even transmit into the meter range with barcode sized antennae which they cannot.

Instantaneous communication also provides greater accuracy in tracking locations through a novel 2-way distancing owing to immediate response from responding node, all the triangulation calculations can be done at a single initiating node with all timing taken from a single clock. Thus iW enables position sampling for cases requiring this, as well as inventory sampling.



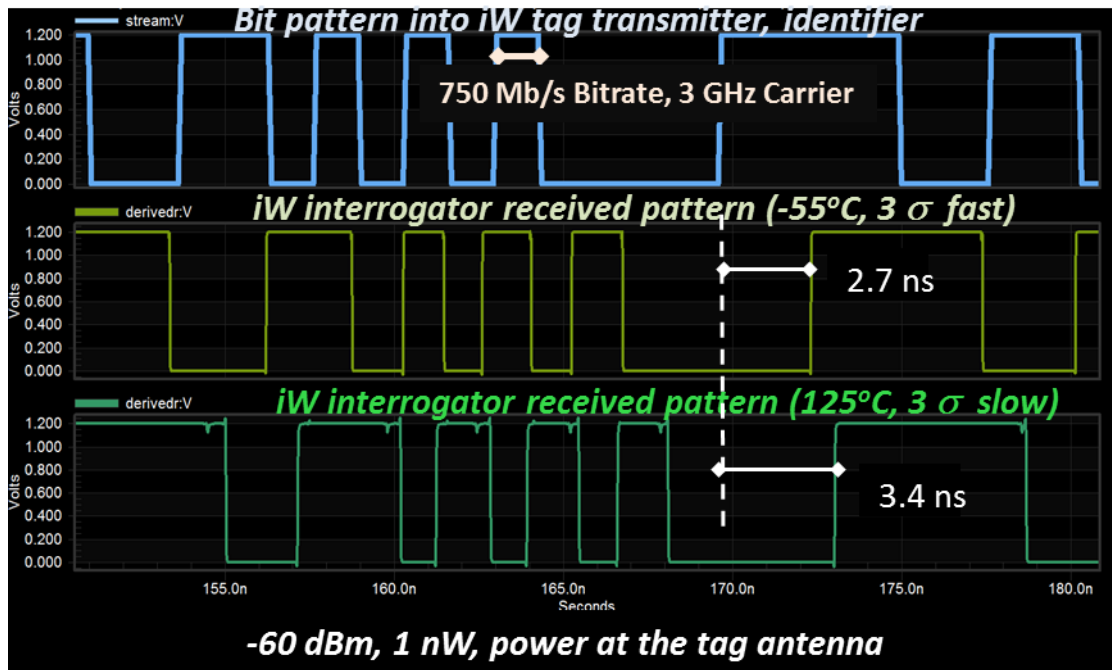
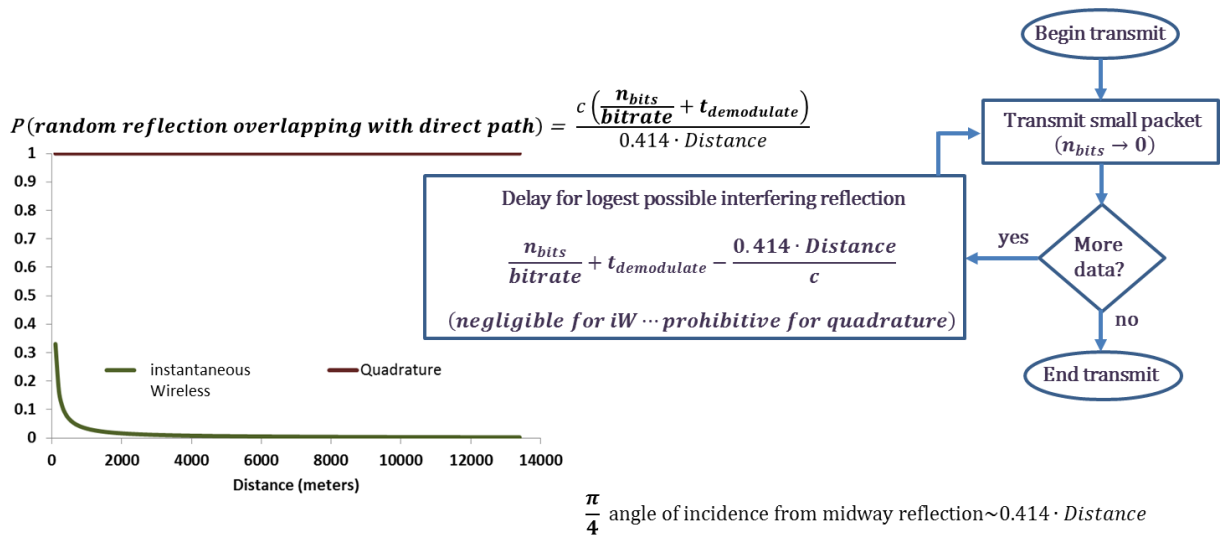


Figure 4. Negligible latencies from transmit to receive, transmitter and receiver adjacent to each other.

### Eliminate Multipath Interference

Because iW demodulation times are so immediate, demodulation occurs before any reflected wave has a chance to interfere, whereas the much longer demodulation times of quadrature, like QAM, have a high probability of overlapping and hence contending with the direct path. By breaking up communication packets into bursts, multipath interference can be eliminated entirely by iW with very little impact to bitrate as demonstrated in Figure 5.



$$\text{bitrate}_{iW} \rightarrow \infty \text{ and } t_{\text{demodulate } iW} \rightarrow 0$$



$$t_{\text{demodulate Quadrature}} \rightarrow \infty$$



Figure 5. The probability of multipath reflections overlapping with direct path goes to zero for iW and one for quadrature.

## INCREASED RELIABILITY AND RANGE

To achieve greater bitrates, conventional RF communication has evolved to 256 and above QAM, which creates a high number of constellations and counterproductively increases receiver noise. The higher QAM bitrates come at the high cost of substantially reduced transmission ranges and increased BER, or increased re-transmissions, which then ironically reduce the overall or effective bitrate.

In contrast to QAM, iW increases the bitrate to those achieved by QAM while decreasing constellation size by 128 times to 2 constellations. iW also greatly reduces the noise by eliminating down conversion and amplitude modulation. Because of the decreased constellations and the orders of magnitude reduction in noise, iW maintains reliability while achieving expected bitrates of modern day communications systems. This is shown in Figure 6 by the  $10^7$  increase in bit energy required by QAM to achieve the same BER as iW reaches at equivalent bitrates. In addition to these benefits, iW increases transmission range substantially over quadrature transmission. iW range exceeds that of 256 QAM by 20 times or more using equal transmission power. With 7 times less transmitted energy, iW still transmits 12 times further than 256 QAM given equal average bit energy, and 40 times further when taking advantage of much lower iW BER, as shown in Figure 7. This case is for short-range transmissions, but the same ratios of improvement apply in long-range transmission also when using larger antennae and higher transmitted power.

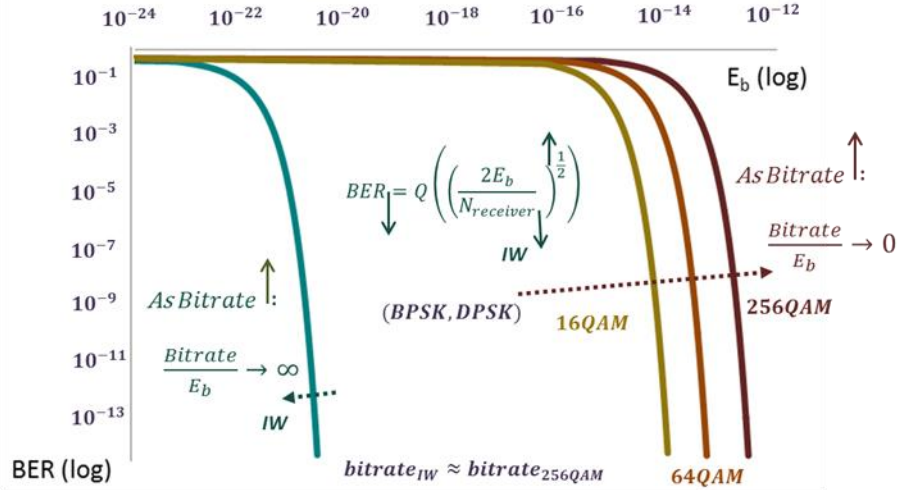


Figure 6. At same bitrate, iW reduces BER eliminating the bitrate to reliability tradeoff of quadrature modulations.

### iW $E_b$ Modeling

Both device noise and on-die supply noise were modeled for the cascade and range plots in Figures 6 and 7. The same noise (1) was used for both iW and QAM to ensure equivalent comparison. Device parameters define the most dominant device noise at higher frequencies, thermal noise, summed with on-die supply noise for overall Gaussian or white noise.

$$\sigma_w = 1.373 \sqrt{\frac{kT}{K' \frac{W}{L} I_D}} + \sigma_{supply} \quad (1)$$

iW modulated signal is (2). By taking the derivative of (2) and the value at  $\frac{3}{4}$  of the period, corresponding to the rising edge of the signal, the standard deviation amplitude noise is converted into standard deviation phase noise (3).

$$i_w(t) = \begin{cases} \sqrt{2rE_b f_b} \cos(2\pi f_i t), & 0 \leq t < \frac{1}{2f_b} \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

where:

$$f_i = f_c + (2i - 3)f_d \quad \text{for } i = 1, 2$$

$$f_b \sim \text{modulation frequency}, \frac{f_c}{4}$$

$$f_d \sim \text{modulation amplitude}$$

$$f_c \sim \text{carrier frequency}$$

Using (3), the standard deviation of noise, and (4) the mean, the BER, using the Q function, for iW becomes (5).

$$\sigma_{\delta_t} = \frac{\sigma_w}{2\pi f_c \sqrt{2rE_b f_b}} \quad (3)$$

$$\mu = -\frac{1}{f_d} \quad (4)$$

$$BER_{iw} = Q \left( \frac{2\pi f_c \sqrt{rE_b f_c}}{f_d \left( \sqrt{\frac{kT}{K' \frac{W}{L} I_D}} + \frac{\sigma_{supply}}{1.373} \right)} \right) \quad (5)$$

### QAM $E_b$ Modeling

Similarly for QAM, the modulated signal is (6).

$$qam_m(t) = \begin{cases} 2\sqrt{\frac{2rE_b f_s}{\sqrt{m}}} (a_i \cos(2\pi f_c t) - b_i \sin(2\pi f_c t)), & 0 \leq t < \frac{1}{2f_m} \\ 0, & otherwise \end{cases} \quad (6)$$

where:

$$a_i, b_i = \frac{|i|}{i} \left( \frac{\sqrt{m}}{2 \left( \frac{\sqrt{m}}{2} - |i| + 1 \right)} - \frac{1}{2} \right) \quad for \ i = \pm 1, \pm 2, \dots, \pm \frac{\sqrt{m}}{2}$$

$$f_s \sim \text{symbol rate} \approx \frac{f_c}{5 \log_2 m}$$

$$f_b = f_s \log_2 m$$

$$f_c \sim \text{carrier frequency}$$

Converting amplitude noise to phase noise, same as was done with iW, yields standard deviation (7) and mean (8). The resulting BER, used to generate QAM cascade plots, is (9) where the actual value is doubled, as down conversion effectively doubles the noise under typical conditions.

$$\sigma_{\delta_t} = \frac{\sigma_w}{2\pi f_c} \sqrt{\frac{\sqrt{m}}{2rE_b f_s}} \quad (7)$$

$$\mu = -\frac{1}{\sqrt{m} f_c} \quad (8)$$

$$BER_{qam_m} = Q \left( \frac{0.45\pi \sqrt{rE_b f_c \log_2 m}}{m^{\frac{3}{4}} \left( \sqrt{\frac{kT}{K' \frac{W}{L} I_D}} + \frac{\sigma_{supply}}{1.373} \right)} \right) \quad (9)$$

To keep average bit energy ( $E_b$ ) at  $1 \times 10^{-14}$  (needed to achieve acceptable BER for QAM), the power supply noise was modeled at 2 mW. This is optimistic considering typical on-die supply noise. As observable from the graphs, the BER of QAM stops transmitting data as supply noise increases, whereas iW continues to operate with 0 BER even above a high 100 mW supply noise. Device noise was also kept the same for both iW and QAM. This resulted in a negative effect on the BER of QAM but had a negligible effect on the BER of iW. In essence, iW is much





more immune to noise. In contrast, QAM is very sensitive to noise and completely breaks down under typical noise profiles unless transmit power is increased dramatically. These are commonly known deficiencies in real world implementations of QAM, and lead to other expensive and complex solutions such as beamforming. iW achieves far greater performance with significantly increased simplicity and lower costs.

The equations for effectively received average bit energy, for QAM and iW in Figures 7, are (10) and (11). Using Friis transmission equation, and signal space minus the respective noise for both, the much smaller signal space and the increased noise of QAM relative to iW, where m is the number of constellations (256 compared with 2), is readily observable. The same power transmitted for iW spreads to half the power for each of the two phase-synchronized QAM signals. Increased reliability and transmission range while still achieving desired bitrates are industry-changing breakthroughs that iW offers in place of QAM.

$$E_{b_{receive\ qam}} = \left( \frac{1}{f_{b_{qam}}} \right) \left( \frac{2P_{transmit\ qam}}{m} - \frac{1}{r} \left( 3(4) \left( 1.373 \left( \frac{kT}{\sqrt{K' \frac{W}{L} I_D}} \right)^{\frac{1}{2}} + \sigma_{supply} \right) \right)^2 \right) \left( \frac{\lambda}{4\pi Distance} \right)^2 G_o^2 \quad (10)$$

$$E_{b_{receive\ iw}} = \left( \frac{1}{f_{b_{iw}}} \right) \left( \frac{2P_{transmit\ iw}}{m} - \frac{1}{r} \left( 3 \left( 1.373 \left( \frac{kT}{\sqrt{K' \frac{W}{L} I_D}} \right)^{\frac{1}{2}} + \sigma_{supply} \right) \right)^2 \right) \left( \frac{\lambda}{4\pi Distance} \right)^2 G_o^2 \quad (11)$$

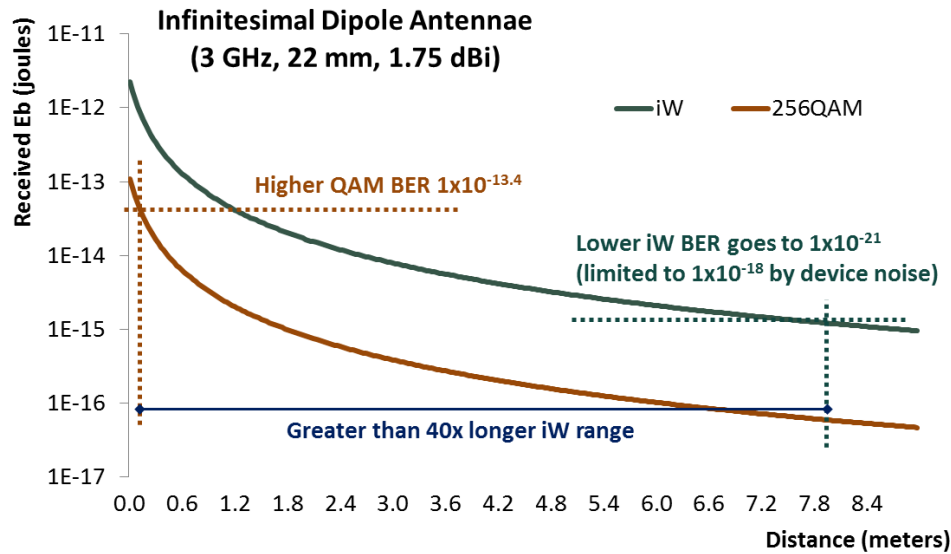


Figure 7. Greater transmit range achieved by iW at 1/5<sup>th</sup> the power and essentially 0 BER.

iW, by increasing range by 12 times to 3 meters, overcomes one of the chief impediments of current RFID to achieve the ability to read items from a shopping cart without removing them from the shopping cart, as in Figure 8. Another limitation of current RFID is cost, and iW overcomes this by reducing die area to a fraction of that used by quadrature architectures, to where an iW tag rivals the cost of barcodes while eliminating all the manual operations



associated with barcodes. The manual operation of scanning each item by hand at a checkout counter, when calculating the cost of cashiers, costs 5.5 cents per item scanned. That cost alone roughly equates to the die cost of an iW tag, not even considering the cost saving iW enables throughout the entire supply chain. The 5 times lower power of iW, instantaneous startup time and communication, and high bitrate also reduce the size of the power management needed for ubiquitous passive tags. The instantaneous communication of iW also eliminates multipath interference and allows a serial scan through an inventory of hundreds of thousands of items in a matter of seconds to identify any matching items in a grocery cart.

Figure 9 demonstrates that the efficiencies of iW relative to the most comparable existing communication method, 256 QAM, cover 144 times greater area with the typical donut radiation pattern of dipole antennae, transmits more reliably and orders of magnitude faster.

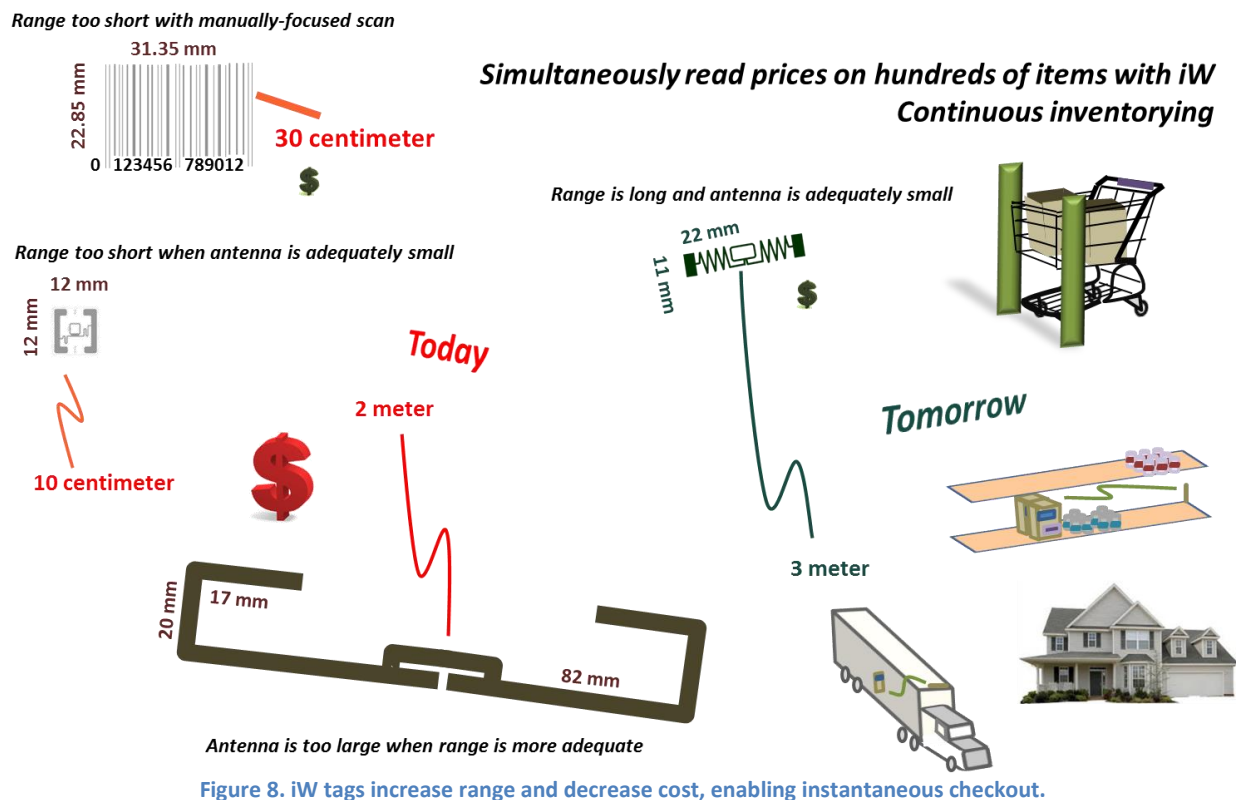


Figure 8. iW tags increase range and decrease cost, enabling instantaneous checkout.

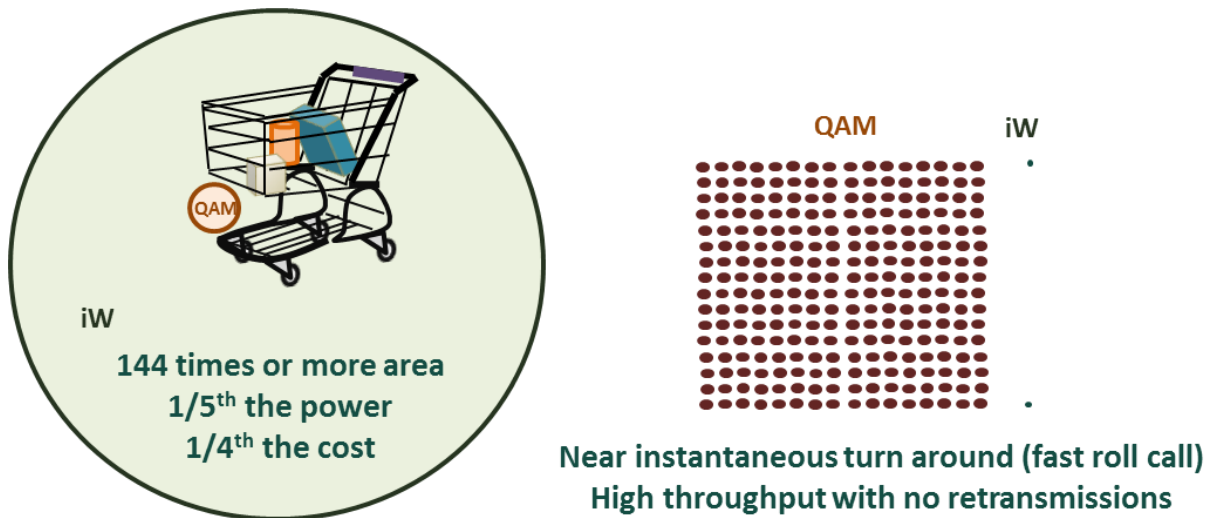


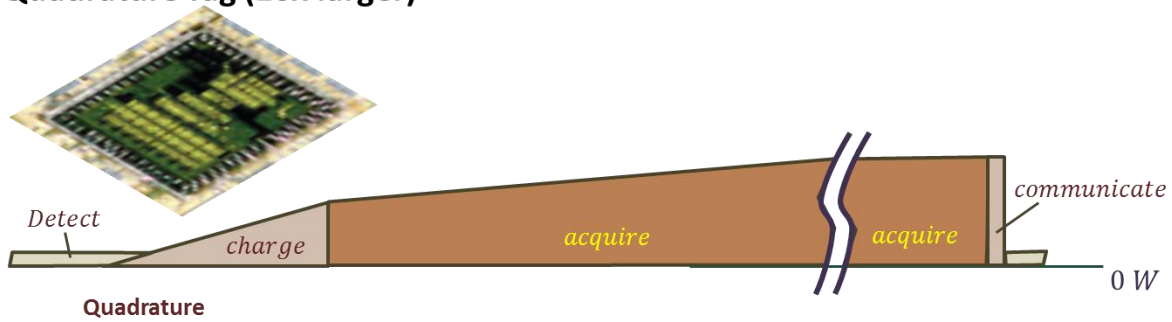
Figure 9. iW efficiencies provide 144 times more coverage at 1/5th the power, greater reliability and faster inventory.

## REDUCED POWER AND COST

In the case of passive tags, power reduction becomes paramount. iW, with a million times faster, or instantaneous, startup and at roughly 1/10<sup>th</sup> the area of QAM from eliminating all the circuitry associated with down conversion, consumes a small fraction of the static power consumed by QAM. A tenth the die size also means iW tags can now rival barcode costs, whereas existing tags are significantly more expensive, per unit die costs being the dominant tag cost.

Figure 10 shows the two cases QAM can take to address power, both with adverse outcomes relative to iW. QAM can either burn power for the long startup times of QAM,  $t_{acquire}$ , or burn power while off to allow for a faster startup time. iW eliminates this tradeoff, due to instantaneous startup, inherently minimizing the on time to be only communicating while on, with essentially zero  $t_{acquire}$ . These power efficiencies aid passive tag implementation by large orders of magnitude, requiring much less energy harvesting and hence smaller die even then, shown Table 1.

## Quadrature Tag (10x larger)



## iW Tag



Figure 10. Minimal power usage of iW facilitates passive tags.

Table 1. Energy per tag.

Modes	Quadrature (Joules)	Instantaneous Wireless (Joules)	Ratio iW to Quadrature
Detect, 1/2 hour off	18	0.0018	$1 \times 10^{-5}$
Charge	$500 \times 10^{-9}$	$5 \times 10^{-9}$	$1 \times 10^{-2}$
Acquire	1	$0.8 \times 10^{-9}$	$0.8 \times 10^{-9}$
Communicate	$170 \times 10^{-9}$	$17 \times 10^{-9}$	$1 \times 10^{-1}$
<b>System-level</b>			
Active transceiver (with detect)	18	0.00018	$1 \times 10^{-5}$
Active transceiver (without detect)	1	$17 \times 10^{-9}$	$17 \times 10^{-9}$
Passive transceiver	1	$22 \times 10^{-9}$	$22 \times 10^{-9}$

## iW IMPROVEMENT

In the case of short-range transmission, on-die supply noise is kept low (2 mW) to ensure 256 QAM operates with BER below 1. Table 2 demonstrates the tradeoff between transmit power and range. Even using 5 times less transmission power and at infinitely greater reliability than QAM, iW still achieves 12 times or greater range with all other factors held constant. The reliability is  $10^7$  greater for iW with BER always near 0 compared with the struggle to keep QAM noise low enough to even function.



Table 2. Overall improved transmission of iW.

Performance	iW	QAM256	iW Improvement
Transmit Frequency (Hz)	3 G	3 G	
Bitrate (bps)	750 M	600 M	1.25x
Range (m)	2.8	0.23	12x
Bit Error Rate, BER	0	$2.3 \times 10^{-9}$	$\infty$
Transmit Power (W)	0.3	1.5	5x
Transmitted $E_b$ (joules)	$5.6 \times 10^{-10}$	$3.5 \times 10^{-9}$	6.5x
Received $E_b$ (joules)	$1 \times 10^{-14}$	$1 \times 10^{-14}$	1x
Transition/Startup Time (s)	$8 \times 10^{-9}$	1	$125 \times 10^6 \times$

## QUANTUM ADVANCES ENABLE INSTANTANEOUS CHECKOUT

iW, a truly breakthrough technology in wireless communication, surpasses, often by orders of magnitude, quadrature architectures, now in common use, in all aspects of wireless communication. As such iW enables entirely new wireless applications antiquated wireless technologies cannot achieve, most notably instantaneous checkout. These instantaneous checkout capabilities are:

- Transmit 12x further, 2.76 meters versus current 10 centimeters (read tags while in cart)
  - Improvement can be greater than 40x when taking advantage of lower iW BER
- Reduce cost to rival barcode costs while eliminating manual operations
- Instantaneous communication to allow rapid scan through large inventory database
- Offer large efficiencies, optimal power reduction, to enable passive tag implementation
- Eliminate multipath interference while radiating energy to reflect off cans as a direct path

