Keywords: RF, ISM, transmitter, RKE, RF remote control, short range radio

APPLICATION NOTE 5023

ISM Transmitter Has Constant Transmitter Power for Varying Supply Voltage

Jan 09, 2012

Abstract: In battery-powered RF transmitters such as garage door openers and remote keyless entry for cars, as the battery drains, the transmit power typically falls. This application note demonstrates that combining a high-efficiency step-up, or boost, voltage converter with an ISM transmitter will keep the transmitted power constant (under 0.5dB variation) over the battery voltage range. Performance data will show that the battery life for constant transmit power is up to 2 times that of a transmitter whose power drops as the battery voltage drops. The AC voltage ripple produced by the voltage converter does not degrade the quality of the amplitude-shift keying (ASK) data link and does not violate U.S. and European radio emission standards relating to short-range radio links.

Introduction

Click here for an overview of the wireless components used in a typical radio transceiver.

Short-range transmitters are used for many applications in unlicensed ISM frequency bands such as 433.05MHz to 434.79MHz in Europe, 260MHz to 470MHz in the United States, and similar frequency ranges in parts of Asia. Most of these applications require small transmitters (e.g., automobile key fobs, garage door and gate openers, security alarm sensors) that use battery power.

As a battery runs down, its voltage decreases which, in turn, reduces the radiated power of most inexpensive, low-current-drain transmitters. This depletion of radiated power happens because many short-range transmitters such as the Maxim MAX1472 use a switched amplifier for the best efficiency (See Maxim application note 3589, "Power Amplifier Theory for High-Efficiency Low-Cost ISM-Band Transmitters"), and the transmitted power of a switched amplifier decreases roughly as the square of the supply voltage. This means that a transmitter powered by a battery whose voltage drops from 3V to 1.8V over its lifetime will reduce its transmitted power to about 35% of its beginning power. In fact there will be between 4dB and 5dB of transmission power loss.

This application note shows that combining a high-efficiency step-up, or boost, voltage converter (the MAX1947) with an ISM transmitter (MAX1472) will keep the transmitted power constant (under 0.5dB variation) over the battery voltage range. This configuration will also reduce the battery life by no more than 15%. The article also shows that the AC-voltage ripple produced by the voltage converter does not degrade the quality of the amplitude-shift keying (ASK) data link nor does it violate U.S. and European radio emission standards for short-range radio links.

The Investigation

The objectives of this investigation were:

- Determine whether adding a voltage converter to a transmitter would maintain constant transmitter power over a typical battery voltage range.
- Determine the effect of the voltage converter on the overall efficiency of the transmitter system.
- Show the trade-off between constant transmitter power and battery life.
- Measure the effects of the voltage-converter AC ripple on the quality of the radio link.

Evaluation (EV) kits for the transmitter and voltage converter were used to measure how well constant transmitter power and high efficiency can be achieved. The transmitter used was the MAX1472, which operates in the 300MHz to 450MHz frequency range. Its supply voltage range is 2.1V to 3.6V and it typically transmits 10mW, or +10dBm while drawing about 10mA of DC current from a 2.7V supply. The specific frequency used for these tests was 433.92MHz, which is permitted in both Europe and the U.S. The voltage converter used was the MAX1947, a step-up DC-DC converter with an input (battery) voltage range of 0.7V to 3.6V. This converter uses an external inductor and capacitor with internal switching to charge the inductor, then transfer the energy to the capacitor and load resistance. The MAX1947 has factory-selected output voltages of 1.8V, 2.5V, 3.0V, and 3.3V. The MAX1947ETA33 (3.3V output) was used for these measurements. For input voltages higher than the output voltage, the MAX1947 automatically passes them with no effect.

The MAX1472EVKIT was modified by changing the passive components in its antenna-matching network to produce +10dBm of transmitter power with a 3.3V supply. Only one simple modification was made to the MAX1947EVKIT: the 1.8V output IC that is the standard value for the kit was replaced with a 3.3V output IC. The EV kits were connected and the input voltage to the MAX1947 (representing the battery voltage) came from a laboratory power supply with a current meter in series. An oscilloscope, power meter, and spectrum analyzer were used to collect data in addition to the voltage and current measurements.

In addition to the above combined EV kits, two other Maxim transmitter EV kits were used as performance references: a MAX1472 "Standard" EV kit that produces +10dBm of transmitter power with a 2.7V supply; and a MAX7060EVKIT, a frequency- and power-adjustable transmitter whose transmitter power is SPI programmable.

In the first set of tests, voltage, current, and transmitter power measurements were made on four different transmitter configurations. Power and supply current versus voltage was plotted, efficiency calculations made, and estimated effects on battery lifetime calculated.

In the second set of tests, the ripple voltage on the MAX1947's output supply was recorded on an oscilloscope while the MAX1472 transmitter drew power from the MAX1947.

In the third set of tests the spectrum of the RF signal transmitted from the MAX1472 was recorded for the expected operating range of input (battery) voltages. An ASK radio link was established with a MAX7033EVKIT ASK receiver to determine the effect of the voltage converter ripple on the link performance.

Summary of Results

Transmitter Power vs. Battery Voltage

Four power amplifier (PA) configurations were compared for their ability to maintain a steady transmitter power output with the least amount of supply current drain. Because the supply current varies with battery voltage as the battery discharges, the current drain of the configurations was compared by calculating the lifetime of a typical battery (or a set of batteries) under a 100% duty-cycle current drain.

Baseline configuration: MAX1472 matched for +10dBm Tx power at 2.7V.

No measurements were made for this configuration, because it is the standard configuration in the MAX1472EVKIT and typical data is given in the Typical Operating Characteristics (TOCs) of the MAX1472 data sheet. The performance at the relevant battery (supply) voltages is given in **Table 1** below.

Table 1. Tx Power and Current vs. Voltage of the MAX1472 with a 2.7V +10dBm Match

V_{IN}	V_{PA}	Tx (mW)	Tx (dBm)	I_{TOT} (mA)	I_{PLL} (ma)	PA Efficiency (%)	Total Efficiency (%)
2.1	2.1	5.50	7.40	7.70	1.50	42.21%	33.99%
2.4	2.4	7.94	9.00	8.70	1.60	46.62%	38.04%
2.7	2.7	10.96	10.40	9.70	1.70	50.76%	41.87%
3.0	3.0	13.49	11.30	10.60	1.80	51.10%	42.42%
3.3	3.3	16.60	12.20	11.30	1.90	53.50%	44.50%
3.6	3.6	19.95	13.00	12.60	1.97	52.14%	43.99%

Table 1 illustrates the transmitter's power variation with battery voltage that the DC-DC converter should eliminate. The transmitter power drops 5.6dB when the battery voltage drops from 3.6V to 2.1V, which are the maximum and minimum specified voltages for the MAX1472. The specified Tx power of +10dBm occurs near the middle of the voltage range. Consequently, too much power is transmitted when the battery is fresh and not enough power is transmitted when the battery is near the end of its life.

Constant Transmitter Power Using a DC-DC Converter

This investigation will show that a step-up, or boost converter can be combined with a standard Maxim transmitter to achieve a constant +10dBm transmit power. The boost converter chosen for the combination was the MAX1947 with a factory-set 3.3V output. Hence, the two most commonly used batteries for portable devices (a CR2032 coin cell, two AAA batteries in series) will have battery voltages below the converter's output voltage. If the battery voltage exceeds 3.3V, the MAX1947 simply passes the voltage through.

MAX1472 Matched for +10dBm Tx Power at 3.3V

Since the supply voltage applied to the MAX1472 transmitter was 3.3V, the matching network on the MAX1472EVKIT must be changed to produce a transmitted signal at +10dBm. Table 1 shows that the standard match produces a transmitted signal that is +12.2dBm, which is too high and will draw too much current. **Figure 1** shows the component values for the 2.7V +10dBm match in the 433MHz EV kit and the modified component values chosen to achieve approximately +10dBm with a 3.3V supply.

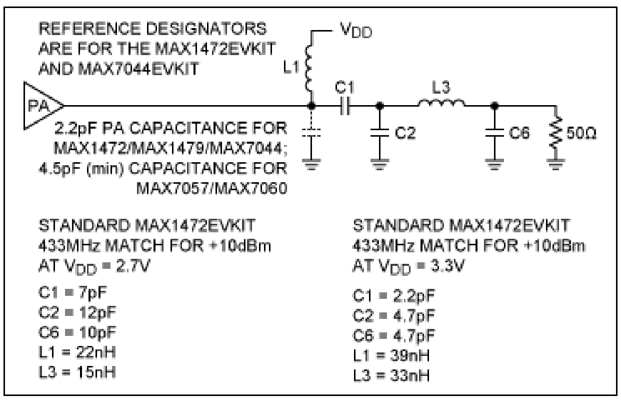


Figure 1. Matching networks for the MAX1472 using 2.7V and 3.3V power supplies.

Table 2 has the same format as Table 1, but it shows the transmitted power and current drain versus supply voltage for the 3.3V +10dBm match.

Table 2. Tx Power and Current vs. Voltage of the MAX1472 with a 3.3V +10dBm Match

V_{IN}	V_{PA}	Tx (mW)	Tx (dBm)	I_{TOT} (mA)	I_{PLL} (ma)	PA Efficiency (%)	Total Efficiency (%)
2.1	2.1	3.25	5.12	4.73	1.68	50.76%	32.73%
2.4	2.4	4.44	6.47	5.36	1.78	51.63%	34.48%
2.7	2.7	5.74	7.59	5.97	1.87	51.86%	35.62%
3.0	3.0	7.16	8.55	6.59	1.97	51.67%	36.22%
3.3	3.3	8.71	9.40	7.23	2.06	51.05%	36.50%
3.6	3.6	10.38	10.16	8.17	2.16	47.95%	35.28%

Table 2 shows that this new matching network produces +9.4dBm at 3.3V, which is slightly lower than the +10dBm target but sufficient for this investigation. Further adjustments in the matching network component values could be made to raise the transmit power slightly and to achieve better rejection of the second and third harmonics of the 434MHz carrier. At least 46dB of harmonic rejection is needed to satisfy European emission regulations; the circuit topology of Figure 1 can achieve this with proper selection of component values.

Notice that the current drain at each supply voltage is lower than it is for the 2.7V match. Note too that the power at 2.1V is just +5.2dBm instead of +7.4dBm for the 2.7V match. There is still about 5dB reduction in transmit power when the battery voltage drops from 3.6V to 2.1V.

MAX1472 Matched for 3.3V When Combined with MAX1947 Step-Up Converter

Combining the MAX1472 and the MAX1947 for a functional test was made easy by using EV kits for each device. To identify the signal names and describe the connections, schematics of both EV kits are shown in **Figure 2**. A picture of the connections made on the bench (**Figure 3**) illustrates the simplicity of combining these two EV kits.

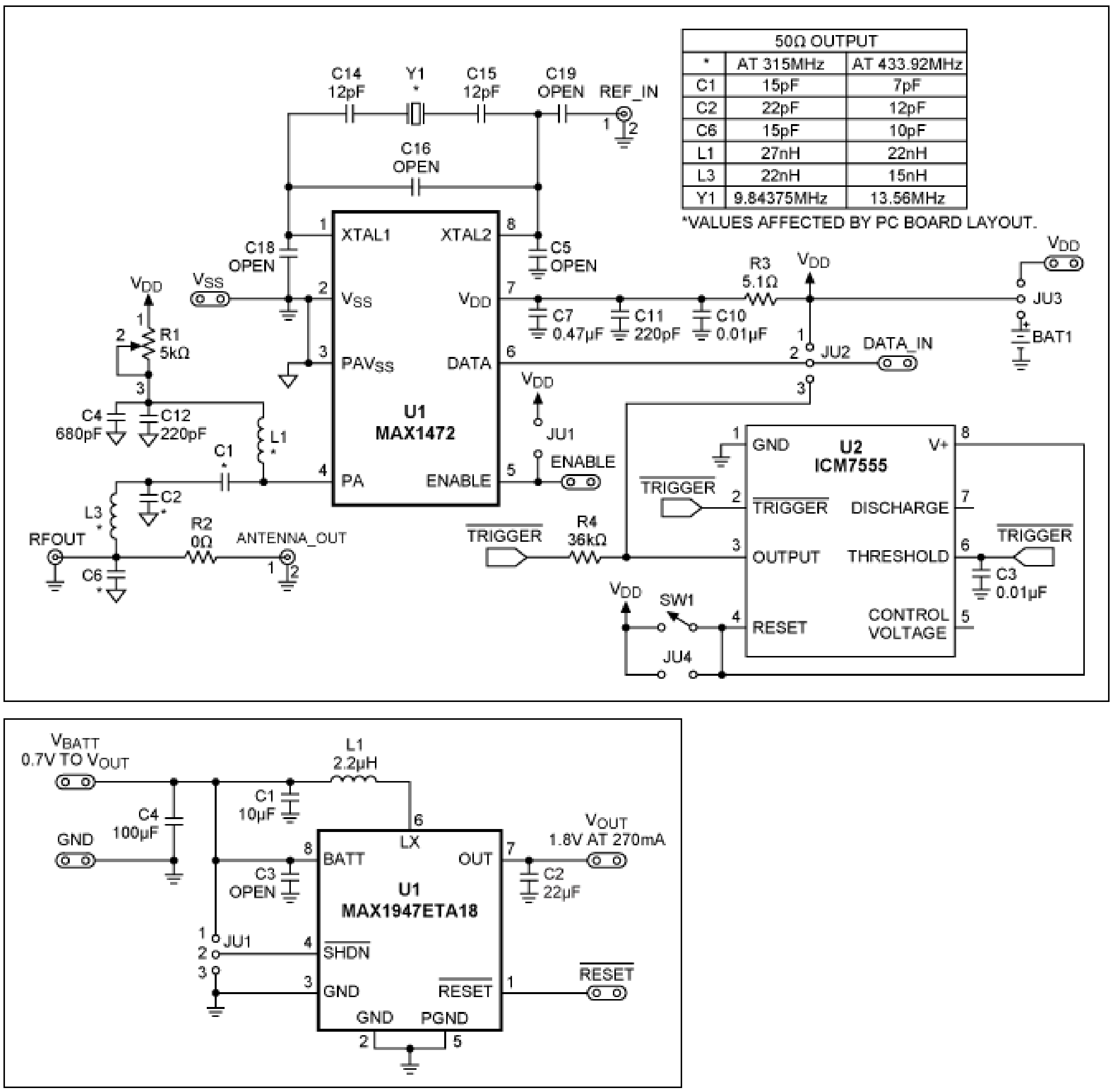
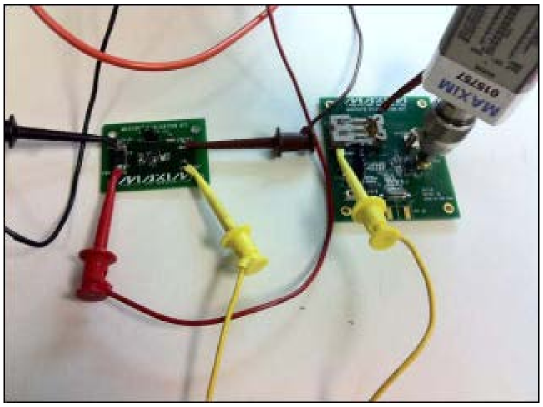


Figure 2. Schematics for the MAX1472 and MAX1947 EV kits.



More detailed image (PDF, 888kB)
Figure 3. Laboratory setup of MAX1472 and MAX1947 EV kits.

The MAX1947 will boost DC voltages from as low as 0.7V to the 3.3V output. Therefore, the data shown in **Table 3** starts at input supply voltages as low as 1.8V, which is the lowest voltage available from commonly used battery configurations. This configuration offers an added bonus to users of the MAX1472 transmitter: the effective battery voltage range is extended from 2.1V down to 1.8V.

Table 3. Tx Power and Current vs. Voltage for the MAX1472 with a MAX1947 Step-up Converter

V_{IN}	V_{PA}	Tx (mW)	Tx (dBm)	I_{TOT} (mA)	I_{PLL} (ma)	PA Efficiency (%)	Total Efficiency (%)
1.8	3.34	8.79	9.44	15.79	4.52	43.33%	30.93%
2.1	3.34	9.06	9.57	13.66	3.83	43.88%	31.57%
2.4	3.36	9.10	9.59	11.93	3.36	44.24%	31.78%
2.7	3.36	9.18	9.63	10.33	2.92	45.90%	32.93%
3.0	3.39	9.27	9.67	9.28	2.62	46.39%	33.29%
3.2	3.41	9.42	9.74	8.78	2.48	46.72%	33.52%
3.3	3.44	9.55	9.80	8.61	2.42	46.75%	33.61%
3.4	3.38	9.23	9.65	7.56	2.19	50.53%	35.89%
3.6	3.61	10.30	10.13	8.24	2.26	47.86%	34.74%

Constant Tx Power Using the MAX7060

Users of Maxim's 300MHz to 450MHz transmitters can already set a constant transmit power over the supply voltage range by using the MAX7060. The MAX7060 is a programmable transmitter that can be controlled through an SPI or individual pins to change transmit frequencies, transmit power, and modulation characteristics. By designing a proper matching network and choosing a single power setting, it is possible to transmit a signal whose power varies slightly or not at all.

So why, one can ask, is it important to use another Maxim transmitter to achieve constant power? The answer is straightforward: because the MAX7060 serves applications that require advanced performance, such as frequency agility, frequent power adjustment, and extra transmit power (+13dBm vs. +10dBm). The trade-off between the more powerful abilities of the MAX7060 and the simpler MAX1472 is total current drain. The MAX7060 has many more features and better performance than the MAX1472, but draws more power. Consequently, the MAX7060 is best for applications where power supplies are more robust and durable than small inexpensive batteries. This now leads to another possibility: a simple but important feature such as constant power over battery voltage can be added to the MAX1472.

The variation in transmit power and the current drain versus battery voltage of the MAX7060 is presented to show a reference point in the trade-off between low-transmit-power variation and high current drain. The combined results for the four amplifier configurations (the MAX1472 with a 2.7V match, the MAX1472 with a 3.3V match, the MAX1472 and MAX1947, and the MAX7060) illustrate the difference in performance.

Table 4 has the same format as Tables 1, 2, and 3. It shows the transmit power and the current drain as a function of the battery voltage for the MAX7060. The Tx power setting on the MAX7060 was fixed at 2dB below the maximum power setting. This setting keeps the power nearly constant (< 1dB decrease) as battery voltages increase from 2.4 to 3.6V, losing another 1dB when the voltage drops to 2.1V.

Table 4. Tx Power and Current vs. Voltage of the MAX7060 with a 2.7V Match

V_{IN}	V_{PA}	Tx (mW)	Tx (dBm)	I_{TOT} (mA)	I_{PLL} (ma)	PA Efficiency (%)	Total Efficiency (%)
2.1	0x1C	6.46	8.10	12.06	4.38	40.03%	25.49%
2.4	0x1C	8.65	9.37	13.63	4.62	40.00%	26.44%
2.7	0x1C	9.57	9.81	14.42	4.90	37.24%	24.59%
3.0	0x1C	9.77	9.90	15.01	5.13	32.97%	21.70%
3.3	0x1C	9.77	9.90	15.50	5.42	29.38%	19.11%
3.6	0x1C	10.00	10.00	16.10	5.66	26.61%	17.25%

Comparison of Transmitter Power and Load-Current Variation

Figures 4 and **5** display the Tx power and current drain information from the four previous tables. It is clear that the MAX7060 and the MAX1472 and MAX1947 combination exhibit the smallest variation in Tx power over the supply voltage range. Because the MAX1947 can work at 1.8V, the MAX1472 and MAX1947 data is extended down to 1.8V.

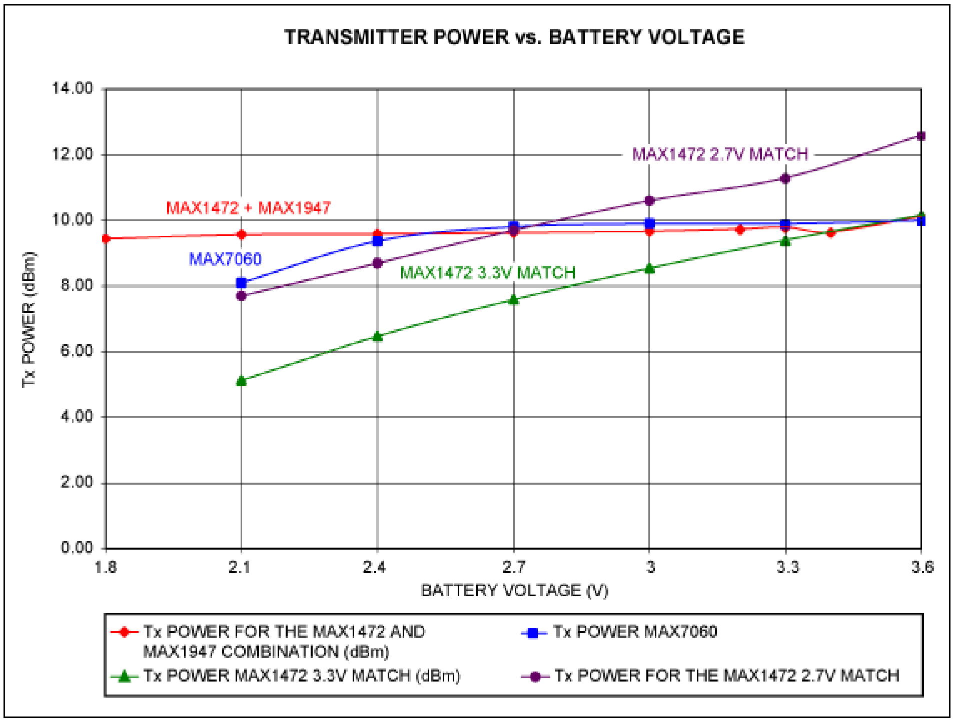


Figure 4. Transmitter power vs battery voltage for four transmitter configurations.

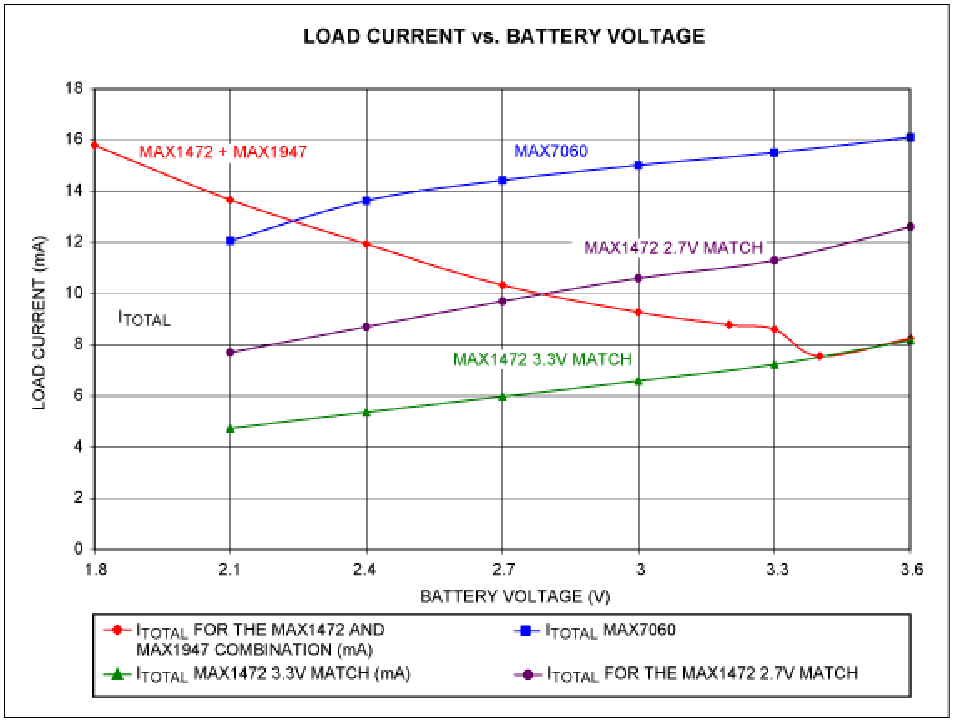


Figure 5. DC current drain vs. battery voltage for four transmitter configurations.

Figure 5 shows the cost in added current drain of keeping the transmit power variation low. The MAX7060 has the highest current drain, in part because it is a higher Tx power device. The MAX1472 with the 3.3V match has the lowest current versus battery-voltage characteristic. It also has the same current drain at 3.3V and above as the MAX1472 and MAX1947 combination, because the MAX1947 converter is bypassing the supply voltage with minimal current drain. The most relevant current-drain curves to compare are those for the MAX1472 with the 2.7V match and the MAX1472 and MAX1947 combination. Both implementations produce the targeted +10dBm Tx power at 2.7V (the middle of the battery range) and draw almost identical currents at 2.7V. It is interesting, however, that the load current of the "baseline" transmitter (the MAX1472 with the +10dBm 2.7V match) grows with increasing battery voltage while the constant power transmitter (the MAX1472 and MAX1947 combination) drops with increasing battery voltage. This behavior suggests that both implementations will have similar battery lifetimes.

Battery Life Example: Three Transmitter Configurations with Two AAA Batteries

Battery specifications for an Energizer® E92 alkaline AAA battery were used with the current-drain information on the transmitter configurations described in this note. The objective was to compare the effect of the configurations on battery life. The capacity of this particular AAA battery is about 1200mAh for steady currents under 25mA, decreasing to under 1000mAh for steady currents over 100mA. Battery companies elaborate on this single-number specification by showing test results from industry-standard usage profiles such as those shown in **Figure 6**.

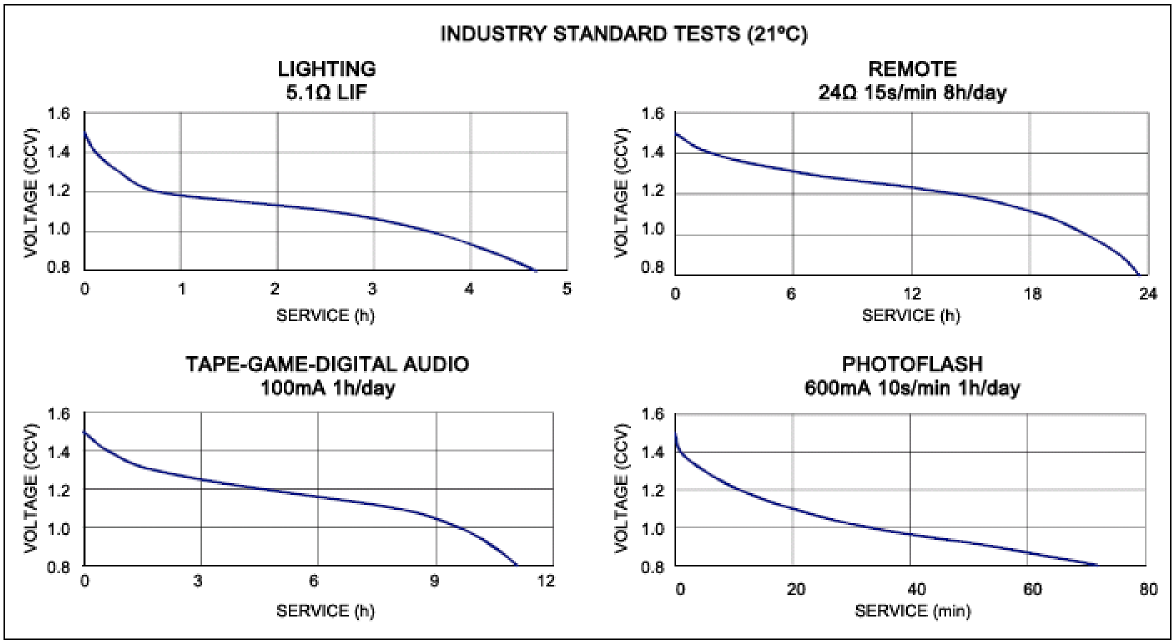


Figure 6. Industry-standard battery life test data for an Energizer E92 AAA battery.

There are two advantages to using this profile of battery voltage versus time. First, all of the current-drain conditions shown in these tests are higher than the 5mA to 20mA that are typically drawn in the Maxim ISMRF transmitters. Nonetheless, the Tape-Game Digital Audio test draws 100mA for an hour a day. The high-current drain for one hour is offset by the low duty cycle, so the average current drawn per day is slightly over 4mA. This produces a profile of battery voltage versus time that should have the same shape as one that arises from a steady 10mA current drain.

Another advantage of using this profile is that one hour on the horizontal axis is equivalent to 100mAh of capacity (Figure 6 and **Figure 7**). Therefore, the horizontal axis can be relabeled to show a plot of battery capacity used up as a function of battery voltage. For example, when the battery voltage drops from 1.5V to 1.4V, roughly 75mAh has been consumed. When the voltage drops to 1.0V, roughly 975mAh has been consumed.

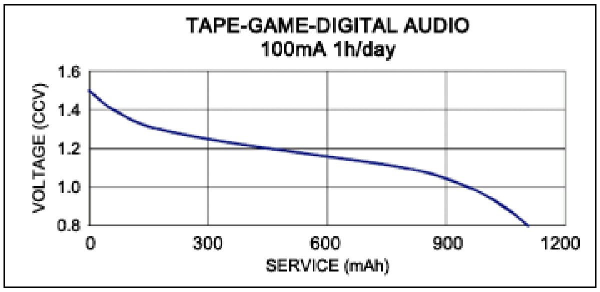


Figure 7. Battery capacity used vs. battery voltage.

The above information was used with the battery current versus battery voltage for each receiver configuration shown in Figure 5 and Tables 1 through 4 to create **Tables 5** and **6**, both tied to the battery voltage.

Table 5. Battery Capacity Available per Voltage Range, Two Series AAA Batteries

Battery Voltage Range (V)	Cumulative Battery Capacity Used (mAh)	Incremental Battery Capacity Used (mAh)
3.0 to 2.7	100	100
2.7 to 2.4	450	350
2.4 to 2.1	900	450

2.1 to 1.8	1050	150

Table 6. Transmitter Current Drain per Voltage Range, Three Tx Configurations

Battery Voltage Range (V)	Current Drain (mA)		
	MAX1472, 2.7V +10dBm Match	MAX1472 and MAX1947	MAX7060, 2.7V +10dBm Match
3.0 to 2.7	10.15	9.81	14.72
2.7 to 2.4	9.20	11.13	14.03
2.4 to 2.1	8.20	12.80	12.85
2.1 to 1.8		14.73	

Table 5 assumes that two AAA batteries are connected in series, doubling the voltage range and maintaining the same battery profile. The second column in the table divides the total battery capacity of 1050mAh according to the distribution of Figure 7 into intervals for every 0.3V of battery range from 3.0V to 1.8V. The important number for battery-life calculations is the Incremental capacity in the far right column. Table 6 has the same current drain information as Tables 1, 3, and 4, except that the current for each voltage range is the average of the current at the high and low voltage in that range.

The battery life of each transmitter configuration over its voltage range can now be calculated by dividing the incremental battery capacity for each 0.3V range by the current drain in that voltage range (mAh/mA = h = hours) and adding up the hours. The results of these calculations are shown in **Tables 7** through **10**.

Table 7. Battery-Life Comparison of Three Transmitter Configurations

Battery Voltage Range (V)	Incremental Battery Capacity Used (mAh)	Current in mA MAX1472, 2.7V +10dBm Match	Calculated Battery Life (h)	Current in mA MAX1472 and MAX1947	Calculated Battery Life (h)	Current in mA MAX7060, 2.7V +10dBm Match	Calculated Battery Life (h)
3.0 to 2.7	100	10.15	9.85	9.81	10.20	14.72	6.80
2.7 to 2.4	350	9.20	38.04	11.13	31.45	14.03	24.96
2.4 to 2.1	450	8.20	54.88	12.80	35.17	12.85	35.03
2.1 to 1.8	150			14.73	10.19		

Table 7 is useful because, for each 300 mV battery voltage interval, it converts the average current drawn by each configuration into the incremental life of the battery as its voltage drops through that interval. This information can be adapted to make comparisons of useful battery life depending on the definition of "useful." Three examples are given below. The first two examples define the useful battery range by the ability of each configuration to maintain a minimum transmitter power. The last example removes the minimum transmitter power restrictions and compares the number of hours that it takes for each configuration to reach its minimum operating voltage.

Before comparing the battery lifetimes, it is important to point out that the lifetime hours computed in these exercises are used solely for comparison purposes. They are much lower than the lifetime of these configurations in a typical operation because they are derived from the curve in Figure 7, which is based on drawing 100mA of current from the batteries for an hour each day. A more realistic operating profile for products based on these transmitters is an active current drain of 10mA to 15mA for perhaps 30 seconds a day (as in remote keyless entry, garage door openers, and security alarm sensors) and a standby current drain of about 5µA. This would increase the lifetime hours calculated below by a factor of 500 to 1000, depending on the standby current.

Battery Life for +10dBm (min) Transmitter Power

The transmitter power curves in Figure 4 show that the baseline configuration in Table 7, which is the MAX1472 connected directly to a battery and impedance-matched to produce +10dBm at 2.7V, fails to satisfy the minimum requirement of +10dBm transmitter power when the battery voltage falls below 2.7V. Figure 4 also shows that the MAX7060 configuration maintains a +10dBm transmitter power until the battery voltage falls below 2.4V. Therefore, **Table 8**, which is a modified version of Table 7, shows that the useful battery life of the MAX1472 and MAX1947 combination is 87 hours, compared to 31.75 hours for the MAX7060 and 9.85 hours for the MAX1472 alone.

Table 8. Battery Life Comparison For Minimum Tx Power of +10 dBm

Battery Voltage Range (V)	Incremental Battery Capacity Used (mAh)	Current in mA MAX1472, 2.7V +10dBm Match	Calculated Battery Life (h)	Current in mA MAX1472 and MAX1947	Calculated Battery Life (h)	Current in mA MAX7060, 2.7V +10dBm Match	Calculated Battery Life (h)
3.0 to 2.7	100	10.15	9.85	9.81	10.20	14.72	6.80
2.7 to 2.4	350	Tx Power Falls Below +10dBm		11.13	31.45	14.03	24.96
2.4 to 2.1	450			12.80	35.17	Tx Power Falls Below +10dBm	
2.1 to 1.8	150			14.73	10.19		
Useful Battery Life (Hrs)		**9.85**		**87.00**			**31.75**

Battery Life for +9dBm (min) Transmitter Power

Table 9 shows the battery life comparison when the minimum transmitter power requirement is relaxed to +9dBm. Now the MAX1472 directly connected to the battery can operate down to 2.4V, which increases its useful battery life to 47.9 hours. The MAX7060 can operate down to 2.1V, its minimum operating voltage. This improves its battery life to 66.78 hours. Neither configuration approaches the 87 hours of the MAX1472 and MAX1947 combination.

Table 9. Battery Life Comparison for Minimum Tx Power of +9dBm

Battery Voltage Range (V)	Incremental Battery Capacity Used (mAh)	Current in mA MAX1472, 2.7V +10dBm Match	Calculated Battery Life (h)	Current in mA MAX1472 and MAX1947	Calculated Battery Life (h)	Current in mA MAX7060, 2.7V +10dBm Match	Calculated Battery Life (h)
3.0 to 2.7	100	10.15	9.85	9.81	10.20	14.72	6.80
2.7 to 2.4	350	9.20	38.04	11.13	31.45	14.03	24.96
2.4 to 2.1	450	Tx Power Falls Below +9dBm		12.80	35.17	12.85	35.03
2.1 to 1.8	150			14.73	10.19		
Useful Battery Life (Hrs)		**47.90**		**87.00**			**66.78**

Battery Life to Minimum Device Supply Voltage

Table 10 shows that when all transmitter power restrictions are removed, the MAX1472 directly connected to the battery provides the longest battery life (102.77 hours). However, its Tx power drops below +8dBm at the low end of its voltage range. The MAX1472 and MAX1947 combination provides 87 hours of battery life, which is 85% of the lifetime attained with the MAX1472 alone. The MAX7060 maintains at least +9dBm of transmitter power, but provides 66.78 hours of battery life (about 77% of the MAX1472 and MAX1947 combination) because it is designed for higher Tx power and uses a less efficient way to achieve constant Tx power.

Table 10. Battery Life Comparison over Full Voltage Range

Battery Voltage Range (V)	Incremental Battery Capacity Used (mAh)	Current in mA MAX1472, 2.7V +10dBm Match	Calculated Battery Life (h)	Current in mA MAX1472 and MAX1947	Calculated Battery Life (h)	Current in mA MAX7060, 2.7V +10dBm Match	Calculated Battery Life (h)
3.0 to 2.7	100	10.15	9.85	9.81	10.20	14.72	6.80
2.7 to 2.4	350	9.20	38.04	11.13	31.45	14.03	24.96
2.4 to 2.1	450	8.20	54.88	12.80	35.17	12.85	35.03
2.1 to 1.8	150			14.73	10.19		
Useful Battery Life (Hrs)		**102.77**		**87.00**			**66.78**

These measurements show that adding a step-up DC-DC converter to a simple ISM transmitter like the MAX1472 can maintain constant transmit power (within 0.5dB) over a wide battery voltage range, while sacrificing just 15% of battery life compared to a simple MAX1472 transmitter whose Tx power drops by 4dB over the battery lifetime. Given that most applications for these transmitters have duty cycles that are so low that the standby current in the device accounts for a significant part of the battery life, the practical reduction in battery life is likely to be even lower.

Results: Power-Supply Ripple and the Quality of an ASK Radio Link

Up until now, only the trade-off between DC current drain and the variation of Tx power has been addressed. It is not too surprising that combining an efficient (> 80%) step-up converter with a transmitter that has a carefully chosen impedance match can produce a constant power transmitter with a slightly higher average current drain over the life of a battery. Of equal, if not greater, importance is the effect of the AC ripple created by the voltage converter on the quality of the transmitted signal and the integrity of the ASK communication link.

The DC-DC converter used for this investigation is a step-up, or boost, converter that uses an external inductor temporarily connected to ground to draw current from the battery. After that, the inductor is switched over to the load with a smoothing capacitor in parallel. The frequency and duty cycle of the switching function depends on the inductor, capacitor, and the current being drawn. There are many categories of high-efficiency (> 80%) DC-DC converters, and they are known for high-AC ripple voltages compared to the less-efficient linear regulators.

This series of tests characterized the ripple (V_{P-P} and frequency) and determined its effect on the transmitted signal.

Ripple on 3.3V Transmitter Supply Voltage versus Input (Battery) Voltage

An EV kit with a MAX1947ET33 (3.3V output supply voltage) was connected to a MAX1472EVKIT as shown in Figure 3. The battery-voltage input to the MAX1947 was varied from 1.8V to 3.3V (above 3.3V, the MAX1947 just passes the input voltage). A scope probe was connected to the OUT test point of the MAX1947EVKIT and the ripple properties at each supply (V_{BATT})

setting were recorded. **Table 11** shows the peak-to-peak amplitude and the period of the ripple. The ripple waveform is a sawtooth, which is characteristic of an hysteretical converter that uses a threshold-feedback process instead of a duty-cycle-controlled converter.

Table 11. AC Ripple Characteristics of the MAX1947 Output Voltage Loaded with a MAX1472 Transmitter Battery Voltage Peak-to-Peak Ripple Amplitude (mV) Ripple Period (µs)

Battery Voltage	Peak-to-Peak Ripple Amplitude (mV)	Ripple Period (µs)
1.8	75	45
2.1	100	70
2.4	100	80
2.7	100	120
3.0	160	180
3.3	220	330

The ripple amplitude increases from about 75mV to 150mV as the input voltage is increased; the frequency decreases from about 20kHz to 5kHz. The ripple amplitude can be reduced by changing the load capacitor value. **Figures 8** and **9** show ripple traces at battery voltages of 1.8V and 3.0V (where the step-up ratio is highest and lowest).

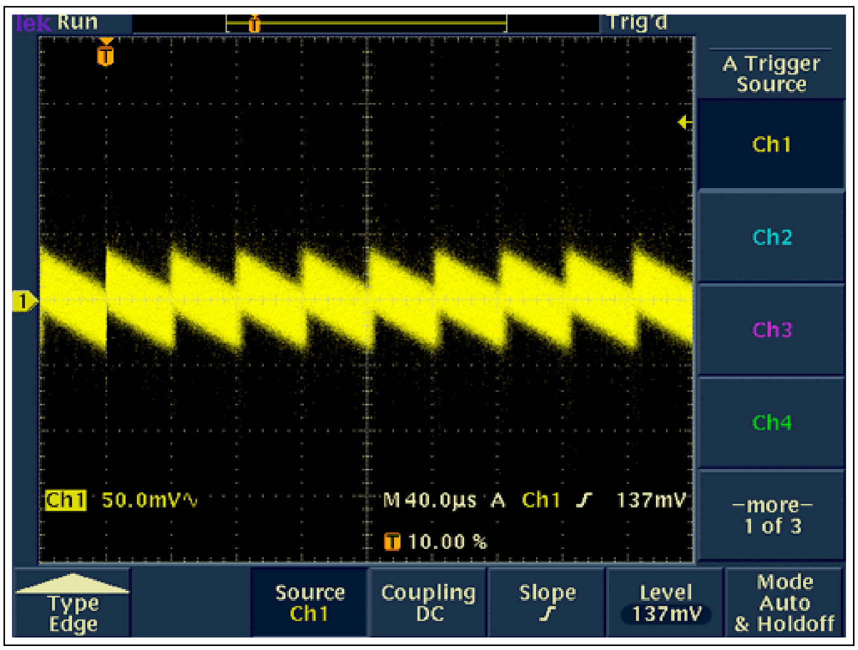


Figure 8. DC-DC converter output ripple voltage for a 1.8V to 3.3V conversion.

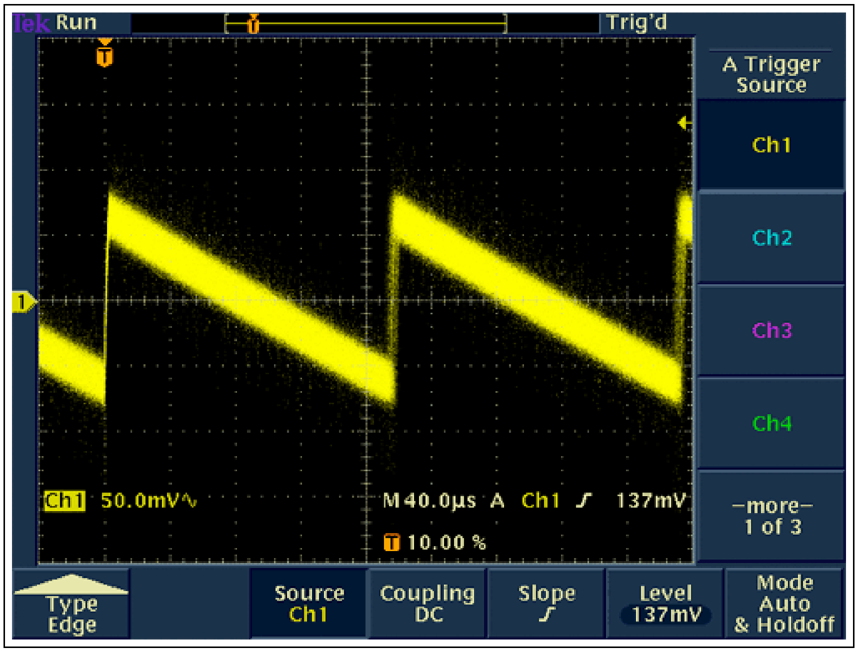


Figure 9. DC-DC converter output ripple voltage for a 3.0V to 3.3V conversion.

Ripple on the DC power supply of the transmitter has two potentially harmful effects on the radio link: first, a spreading of the transmitted frequency spectrum; and second, the transfer of the ripple from the power supply to the demodulated ASK spectrum in the receiver.

1. Frequency Spectrum of an Unmodulated Carrier

The spectrum of the unmodulated carrier was observed on a spectrum analyzer for each ripple condition in Table 11. The effect of the ripple is evident, but not significant, at frequencies up to 50kHz from the carrier. The effect of the ripple is nonexistent at frequencies more than 100kHz from the carrier. This behavior is consistent with the frequency and amplitude of the ripple. A 100mV$_{P-P}$ ripple on a 3.3V supply can look terrible, but the power associated with it is more than 30dB lower than the power associated with the carrier frequency. It is like having very weak AM on a carrier. The ripple does, indeed, raise the noise spectrum of an unmodulated carrier, but this increase is small and occurs at frequencies that are close to the carrier frequency and do not violate spurious emission restrictions. The largest increase occurs at a 2.4V input battery voltage, where the noise spectrum is 6dB higher within ±100kHz of the carrier, compared to battery voltages above 3.3V, where no DC-DC conversion takes place. **Figures 10** and **11** show the spectrum of the unmodulated carrier with battery voltages of 2.4V (worst spectral effect) and 3.4V (no ripple and no spectral effect).

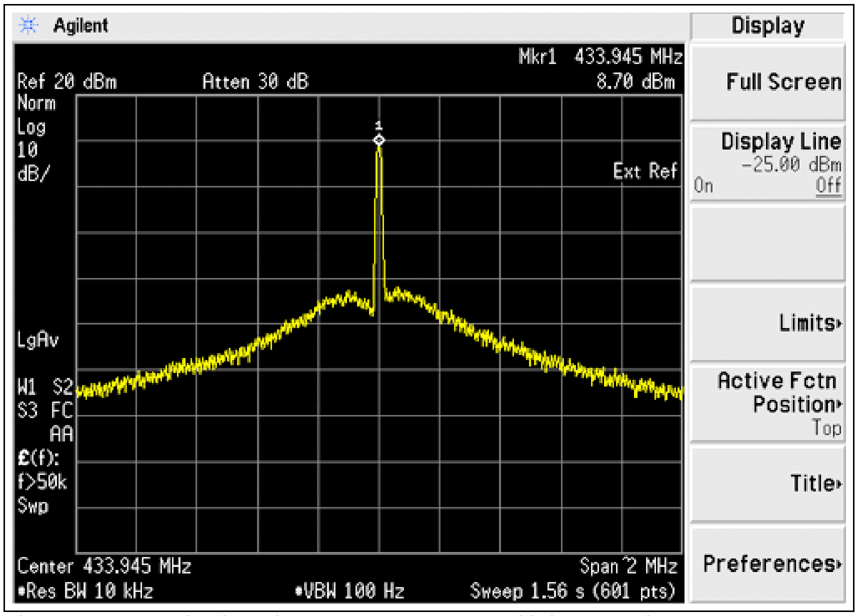


Figure 10. Transmitted continuous-wave spectrum with battery voltage = 2.4V.

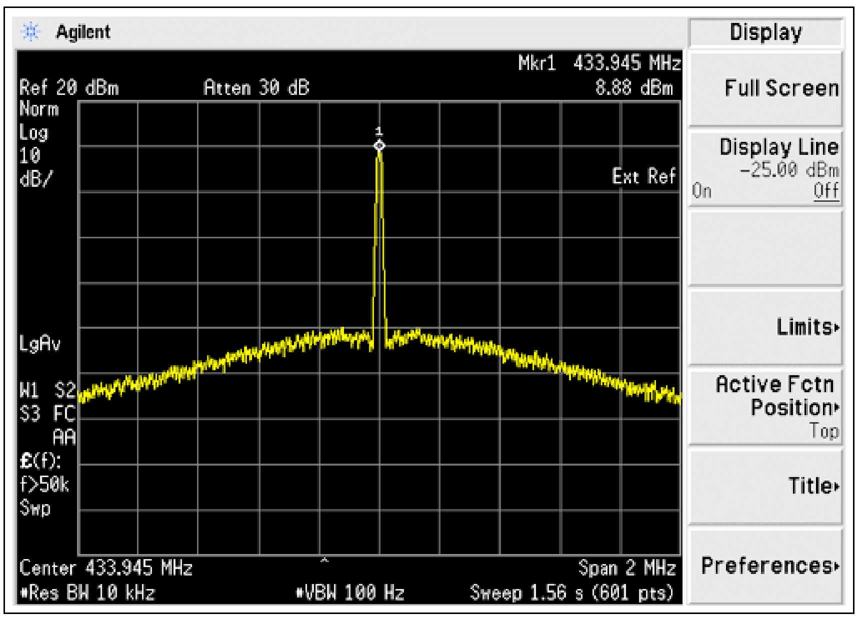


Figure 11. Transmitted continuous-wave spectrum with battery voltage = 3.4V.

2. Demodulated ASK at the Receiver

The effect on the demodulated ASK signal can be seen in two measurements. One is a zero-scan plot from a spectrum analyzer, in which the spectrum analyzer functions as a power detector. It is not surprising that a small ripple can be seen on the demodulated signal. The other measurement is the demodulated signal from an EV kit of the MAX7033 ASK receiver. A simple communication link was set up in the laboratory between the MAX1472EVKIT and the MAX7033EVKIT. No antennas were placed on either EV kit. The incidental coupling between the EV kits (very likely a combination of radiated power and coupling through test equipment on the bench) produced a signal well above sensitivity at the receiver. The scope trace of the demodulated 2kHz square-wave signal, which passed through the standard data filter on the EV kit, shows no trace of the ripple because the data filter rejects it. **Figure 12** shows the ripple on the detected signal in the spectrum analyzer. **Figure 13** shows the filtered demodulated signal on an oscilloscope.

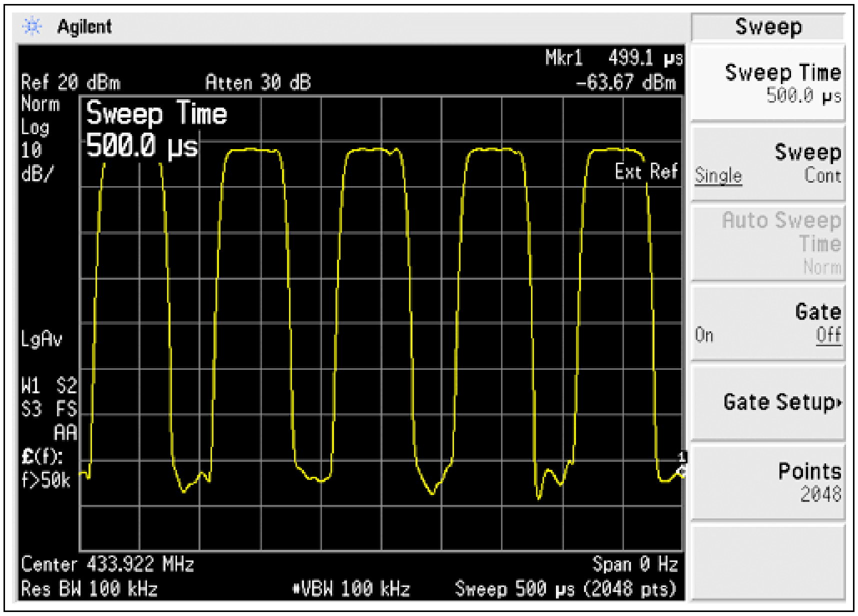


Figure 12. ASK signal from the constant power that the MAX1472 received on spectrum analyzer.

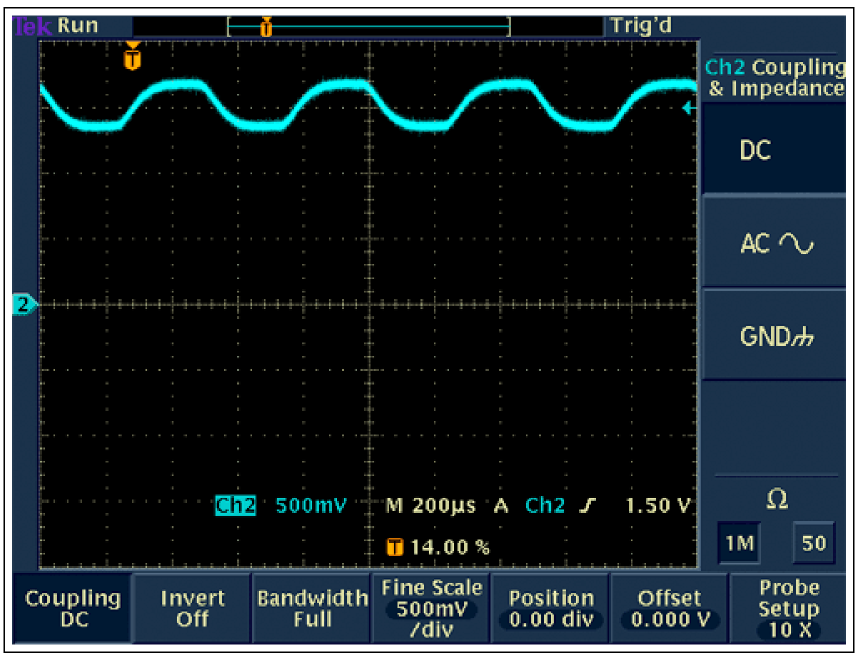


Figure 13. ASK signal from the constant power that the MAX1472 received on MAX7033.

These tests show that even strong power-supply ripple (100mV$_{P-P}$) does not appear to spread or raise the transmitted spectrum appreciably. Nor does it degrade the reception of a signal that is well above the sensitivity level. Although measurements at the sensitivity level could not be made, it appears that proper data filtering will prevent the ripple from degrading sensitivity.

Conclusions and Recommendations

The combination of the MAX1472 transmitter and the MAX1947 step-up converter achieves the desired objective of constant transmit power over the battery voltage range. In a situation where a minimum transmitter power of +10dBm is required, the useful battery life of the MAX1472 and MAX1947 combination is almost 9 times longer than that of a simple transmitter. Even if the minimum transmit power is allowed to drop to +9dBm, the useful battery life is almost doubled.

The efficiency of this combination is about 85% when compared to a simple transmitter whose transmitted power decreases by 4dB during a typical battery lifetime. It is manifested in the ratio of transmitter power to DC power, where the transmitter efficiency with the converter is about 85% of the efficiency without the converter. It is also manifested in the calculation of battery life, where the constant-transmit-power battery life is exactly 85% of the battery life when the transmit power drops with the battery voltage.

In situations where it is important to maintain transmitter power throughout battery life, the worst-case trade-off is a 15% reduction in battery life. In practice, this trade-off is less than 15% because most portable transmitter applications have a low duty cycle and the standby current will account for a substantial fraction of the battery drain.

The AC ripple, which is a byproduct of high-efficiency voltage converters, degrades the transmitter spectrum, but not enough to degrade the quality of an ASK radio link and not enough to violate FCC (in the U.S.) or ETSI (in Europe) emission limits. Furthermore, other types of high-efficiency voltage converters that exhibit much lower AC-ripple amplitude can be used, which will make the spectral contribution inconspicuous in most short-range radio links.

A two-chip solution, using the devices in this application note or similar devices, is available today. Both devices have a small footprint (3mm x 3mm) and the addition of the voltage converter to the existing transmitter circuit increases the external component count by only three. These two functional devices can be combined into a single IC, resulting in additional savings in cost, area, and component count.

Energizer is a registered trademark of Eveready Battery Company, Inc.

Related Parts		
MAX1472	300MHz-to-450MHz Low-Power, Crystal-Based ASK Transmitter	Free Samples
MAX1947	Low Input/Output Voltage Step-Up DC-DC Converter with Active-Low RESET	Free Samples