Keywords: ISM, RF, radio frequency, impedance matching, transmitter, remote keyless entry, RKE, wireless remote, ASK, FSK, drain efficiency, battery life, high transmit power, 433.92MHz, European frequency, ETSI

APPLICATION NOTE 5281

Flexible Configuration of the MAX7060 ASK/FSK ISM-RF Transmitter

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Apr 03, 2012

Abstract: This application note illustrates the flexibility of the MAX7060 ASK/FSK transmitter. While the currently available evaluation kit (EV kit) has been optimized for the device's use in a specific frequency band (i.e., 288MHz to 390MHz), this document addresses how the EV kit circuitry can be modified for improved operation at 433.92MHz, a frequency commonly used in Europe. Two alternative match and filter configurations are presented: one for optimizing drain efficiency, the other for achieving higher transmit power. Features and capabilities of earlier Maxim industrial, scientific, and medical radio-frequency (ISM-RF) transmitters are provided, allowing comparison of the MAX7060 to its predecessors. Several design guidelines and cautions for using the MAX7060 are discussed.

Introduction

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

The MAX7060 ASK/FSK transmitter is an IC that is all about flexibility. First of all, it is flexible in frequency, with a fractional-N PLL capable of operating either from 285MHz to 420MHz (with a 15MHz crystal), or from 304MHz to 448MHz (with a 16MHz crystal), in steps as fine as $f_{XTAL}/4096$. This allows transmission at all major industrial, scientific, and medical system (ISM) frequencies below 450MHz, including ones that might only be available in certain geographic areas. The fractional-N architecture also allows for extremely accurate FSK modulation, allowing data rates of up to 70kbps Manchester-coded.

The MAX7060 is also flexible in transmit power, designed with an integrated voltage digital-to-analog converter (VDAC) to provide an exponentially scaled voltage to the power amplifier (PA). When the IC is operated with a sufficient V_{DD}, the VDAC enables nearly 30dB of adjustment range in approximate 1dB steps. This power-stepping capability can also be used for envelope shaping when transmitting ASK, thereby facilitating conformance to regulatory requirements in both the U.S. and overseas markets.

Flexible PA matching is available by means of a programmable capacitor, which is selectable from 0 to 7.5pF in increments of 0.25pF. During system testing, the transmitter performance at a given operating point (transmit frequency and PA code) can be optimized by finding the "cap code" (i.e., capacitance code) that minimizes current drain and/or maximizes efficiency for that set of conditions. It also permits the PA load to be tuned as necessary to adapt to changes in the operating environment.

With the frequency, power, and PA capacitor all controllable via SPI commands, a microcontroller can be used to programmatically choose between multiple preoptimized combinations, allowing hopping between ISM frequencies. Conversely, if operating in a system where SPI control is not desirable, the IC has built-in pin-strapping capability, where one of 24 possible frequency/power combinations is implemented by connecting six of the IC pins either to the supply or to the ground.

In addition to these two choices (SPI control vs. no SPI control), the MAX7060 offers an innovative method of programmability in which the same combinations available in manual mode with no SPI control (i.e., pin-strapped) can be programmed by writing into only one register (the emulation register). This approach drastically reduces programming complexity and code space for the master microprocessor while still maintaining the flexibility and programmability features of the MAX7060.

The power-supply configuration of the MAX7060 is also flexible. The IC is able to operate on voltages from 2.1V to 3.6V, as might be provided by a coin-cell battery, or from a 4.5V to 5.5V supply, which activates an internal regulator. The regulator provides approximately 3.2V to most of the core IC circuit blocks, while the VDAC operates from the higher supply to achieve maximum linearity of the transmit power control characteristic.

With all these capabilities built into the MAX7060, only a handful of external passive components are needed to implement a full-featured transmitter with a small PCB footprint. However, as the rest of this document will demonstrate, the proper selection of those few passives plays a large part in tailoring the performance of the MAX7060 to the demands of a particular application.

The Present State of Affairs

First, a Little History...

The original application for the MAX7060 required operation exclusively in the domestic (i.e., North American) market, targeting multiple frequencies from 288MHz to 390MHz. Consequently, the manner in which the MAX7060 evaluation (EV) kit (MAX7060EVKIT) components were chosen tended to favor operation within that target band. When the MAX7060EVKIT operates with a 15MHz crystal and with the matching/filter components as shown in the EV kit data sheet, the MAX7060 is capable of delivering up to +15dBm into a 50Ω load across the frequency band of 288MHz to 390MHz, while conforming to the FCC Part 15 requirement of -20dBc for harmonics.

Alternatively, with a 16MHz crystal on the EV kit, the MAX7060 is capable of operating from 304MHz to 448MHz, which includes 433.92MHz, a common frequency used both in the U.S. and in Europe. However, if one were to take a stock MAX7060EVKIT and program it for 433.92MHz, it would quickly be evident that the efficiency is poor and that the harmonics, while still passing FCC Part 15, fail to meet the requirements of the European Telecommunications Standards Institute (ETSI) *unless* the TX output is reduced by selecting a lower PA code. ***Essentially, the original EV kit presents the MAX7060 in a less than favorable light for anyone wishing to operate at 433.92MHz, particularly in the European market.***

This application note is intended to correct this perception by more fully explaining the MAX7060's true capabilities.

What's on the Original EV Kit

Figure 1 represents the matching and filter networks as they exist on the MAX7060 EV kit. The harmonic filter is composed of C56, L2, and C55. C4 and L1, along with the parasitic capacitance of the IC package and PCB traces, designated in the figure as CparPA, create the PA match. Additional components C7, R3A, and C10 are for supply bypassing, creating an AC ground at the top end of L1. In this way, L1 can be viewed as parallel with CparPA for the purpose of this analysis.

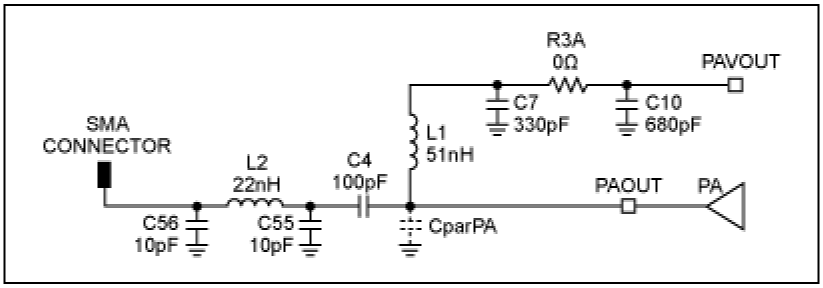

Figure 1. Simplified diagram of the MAX7060EVKIT match and filter networks.

For operation in a 50Ω system, one design approach is to make the harmonic filter symmetric such that the impedance at the filter output remains 50Ω. C4 may then be used to create an impedance transformation, which presents a larger real load to the PA at the point where the reactance of L1 and that of the capacitive effects cancel each other. (For an example of this approach, see Appendix A.)

However, to allow the MAX7060 to tune across the low frequencies in the domestic band, C4 in the stock EV kit was chosen as 100pF. As a result, C4 only acts as a coupling capacitor, which transfers the low-impedance load at the harmonic filter directly to the PA. At the PA, this load appears across the parallel LC formed by L1 and CparPA. Since the Q of a parallel RLC circuit can be represented as:

$$Q = \frac{R}{2\pi fL} \qquad \text{(Eq. 1)}$$

And since L1 is 51nH, the inductive reactance at 339MHz would be around 109Ω, resulting in a Q of less than 0.5. As intended, this combination achieves broadband tuning and high power output.

But Something Is Left Out...

By inspecting Figure 2, it becomes evident why operation at 433.92MHz is problematic for the matching scheme of the stock EV kit. The fact that the European market uses a frequency nearly 100MHz higher than the domestic band center makes it unlikely that a single match can optimally cover both markets. To make matters worse, the harmonic filter must be configured to attenuate the 2nd harmonic of 288MHz, which has also resulted in partial attenuation of the fundamental at 433.92MHz.

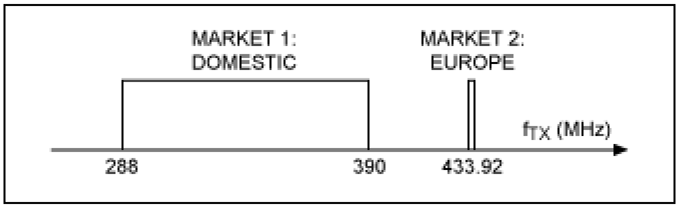

Figure 2. Relative positions of domestic and European low-band frequencies.

All things considered, it is little wonder that the MAX7060 data sheet shows performance at 315MHz, which appears far more impressive than performance at 433.92MHz. However, just as many other Maxim ISM-RF EV kits have been optimized for operation at either 315MHz (the most common domestic frequency) or 433.92MHz, it is indeed possible to modify the match and filter components of the MAX7060EVKIT to achieve similar goals.

Examples of Improved Performance at 433.92MHz

Alternate Match/Filter Method #1: +10dBm with Higher Drain Efficiency

Within the data sheets of the Maxim ISM-RF product family, an often-quoted operating point is +10dBm transmitted power with a supply voltage of 2.7V. This data point is based on the assumption that customers who are implementing coin-cell-powered solutions need to maintain highly efficient transmit operation to conserve battery life. While such operation was not the original focus of the MAX7060, it is not uncommon for potential users to ask how the IC performs in comparison to far simpler transmitters such as the MAX1472, MAX1479, MAX7044, and the MAX7057. If one were to take the MAX7060 data sheet numbers for 433.92MHz operation at face value, the answer would appear to be, "quite poorly." But the story does not need to end there.

Figure 3 shows the component values used to achieve a more efficient +10dBm TX output when using a 2.7V supply. Because the MAX7060 is very similar to the MAX7057, this alternate configuration of the MAX7060EVKIT uses the match/filter networks from the MAX7057's typical application circuit as a starting point. It proved to be a very good starting point indeed, with only the value of C4 needing further adjustment. In the modified match, C4 is 15pF, which creates an upward step in impedance such that the PA is loaded with an effective resistance of over 100Ω. As a result, for a given voltage swing at the PA, a lower output power is produced.

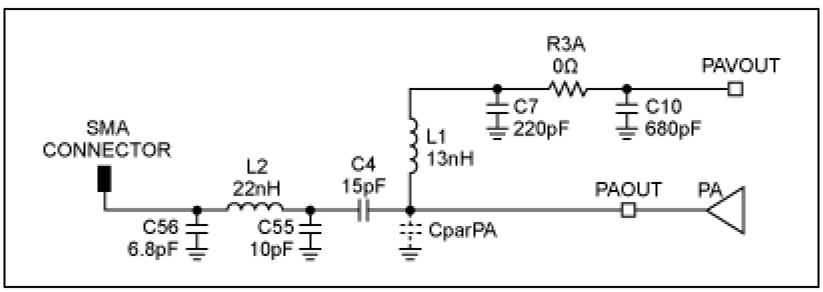

Figure 3. Diagram of the MAX7060 match and filter for improved efficiency at +10dBm.

The effect of raising the resistance presented to the PA (frequently referred to as Ropt, i.e., the optimal resistance to achieve a given TX power) is shown in **Figure 4**. PA codes 0 through 28 (0hex through 1Chex) always produce higher power with the old match than with the new one. However, when the desired output of +10dBm is reached, the new match requires far less operating current (**Figure 5**), corresponding to an improvement in overall efficiency (**Figure 6)**.

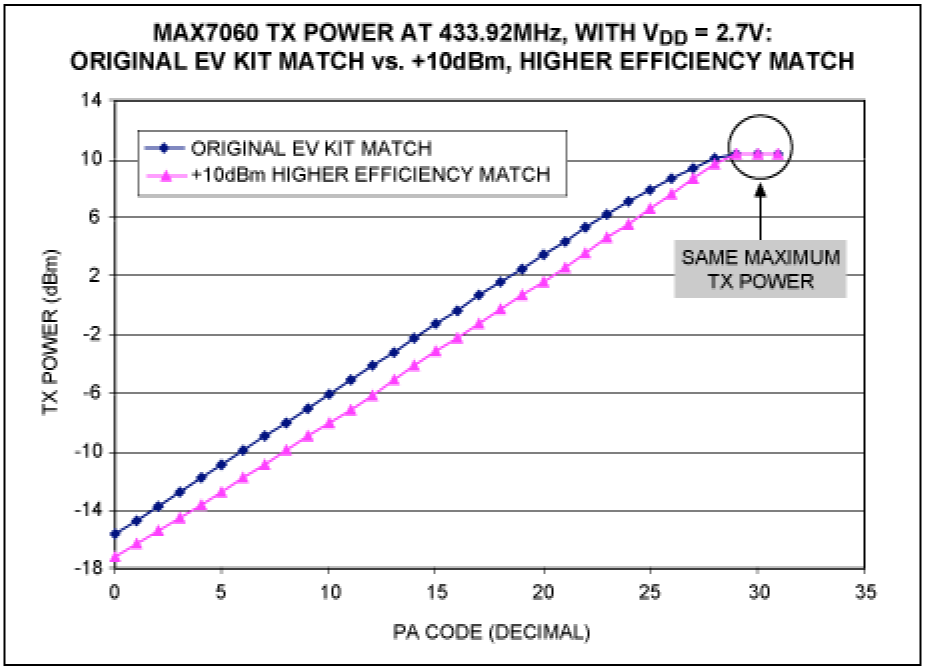

Figure 4. TX power comparison, original match vs. new match/filter for +10dBm.

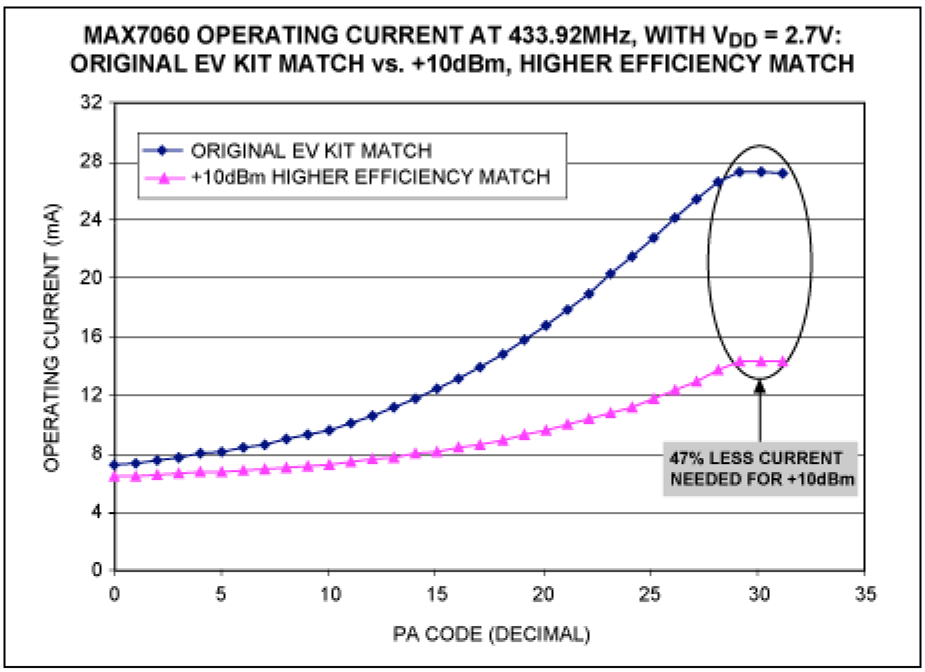

Figure 5. Decreased operating current with new match/filter for +10dBm.

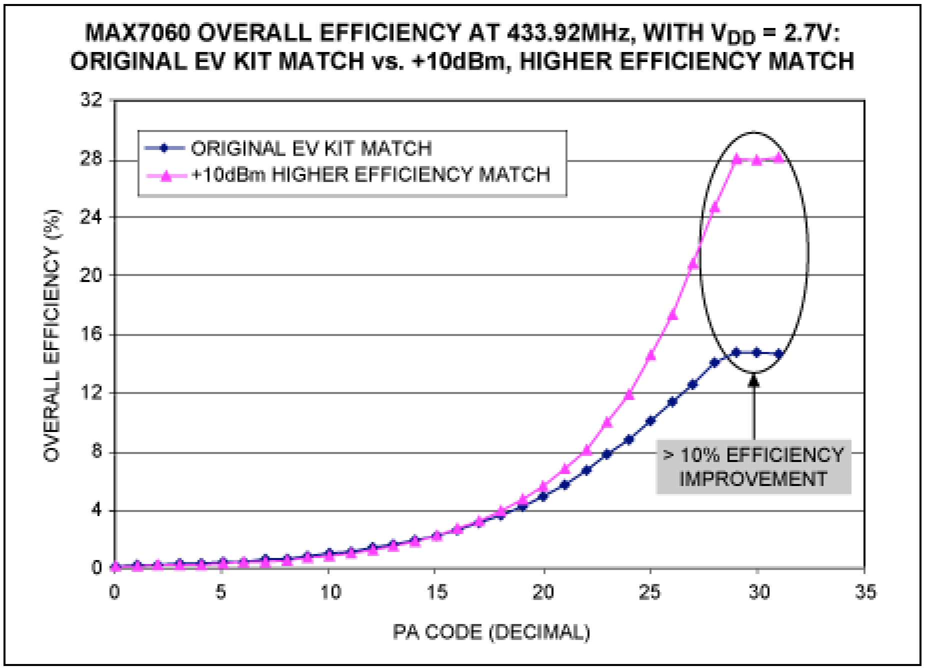

Figure 6. Improved overall efficiency with new match/filter for +10dBm.

When discussing the efficiency of a transmitter IC, it must be pointed out that there is a distinction between the overall efficiency of the IC (as shown in Figure 6) and the efficiency of just the PA output device by itself. Overall efficiency (Equation 2) is calculated using the total operating current of the IC, and thus includes contributions from the crystal oscillator, PLL, PA predriver, interface circuitry, and the final stage FET.

$$\text{Overall Efficiency} = \frac{\text{(TX Power in mW)}}{[\text{(PA Current + Non–PA Current)} \times V_{DD}]} \qquad \text{(Eq. 2)}$$

However, if the current through the final stage FET can be isolated (by testing with an ammeter in place of R3A in the circuit diagram) and the VDAC simultaneously monitored at the PAVOUT pin, Equation 3 can be used to show that an optimized match is producing near 50% drain efficiency.

$$\text{Drain Efficiency} = \frac{\text{(TX Power in mW)}}{\text{(PA Current} \times \text{VDAC Voltage)}} \qquad \text{(Eq. 3)}$$

The contributions of all other circuit blocks are fixed in the overall efficiency calculation and their currents cannot be modified or controlled by the user. Improvements in efficiency can only be made in the PA match and filter, as we have done in Alternate Match/Filter Method #1.

Alternate Match/Filter Method #2: +14dBm with ETSI-Compliant Harmonics

In contrast to the scenario just presented, in which conservation of battery power was crucial, there are other applications in which high transmit power is desired and a supply voltage between +4.5V and +5.5V will be available. In these cases, it is desirable to feed the 5V supply to the V_{DD5} pin and allow the internal voltage regulator of the MAX7060 to provide approximately 3.2V to the other circuit blocks. Under these conditions, the VDAC is biased by the 5V supply, resulting in the ability to maintain excellent power control linearity (≈1dB/code) nearly to the end of the code range. (See the Typical

Operating Characteristics section in the MAX7060 data sheet.)

Since the original EV kit match did not allow full-power operation at 433.92MHz with ETSI compliance, it seemed worthwhile to attempt a separate match with robust TX output (up to +14dBm), but with harmonic levels which would conform to ETSI standards. It should be noted that while the maximum allowable transmission at 433.92MHz is only +10dBm in Europe, ***the measurements are taken with an antenna attached***, and most small antennas (certainly including PCB trace antennas) are inefficient radiators. With a PA capable of +14dBm, the MAX7060 can partially compensate for such a lossy antenna. Conversely, if a much more efficient antenna were available, the PA output can simply be reduced in 1dB steps until the composite (transmitter + antenna) output falls under +10dBm.

Figure 7 shows the component values used to achieve the +14dBm, ETSI-compliant match. The input pi filter has been altered, and a spreadsheet analysis of the original and modified filters suggests that this filter should no longer attenuate 433.92MHz as the original did. When operated over the domestic band (i.e., 288MHz to 390MHz), the original filter presented an output impedance (at the C55/C4 junction) of between 35Ω and 65Ω, while the impedance at 433.92MHz fell into a considerably higher region, leading to lower output power. The new combination results in about 40Ω of filter output impedance at 433.92MHz, effectively shifting the high-power capability up in frequency from where it had previously been. The new operating point also provides power at considerably lower current than the Typical Operating Characteristics in the data sheet reflect, as shown in **Figure 8** and **Figure 9**.

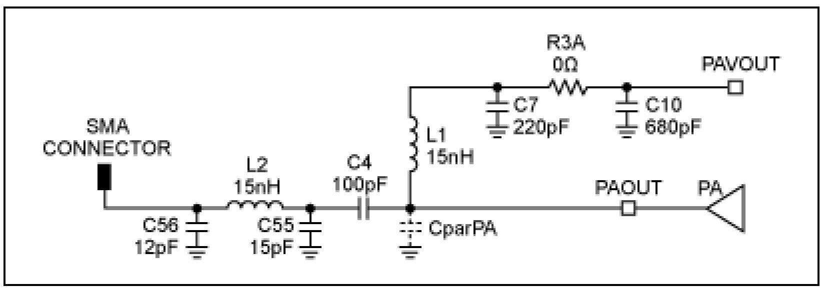

Figure 7. Diagram of the MAX7060 match and filter for +14dBm with ETSI compliance.

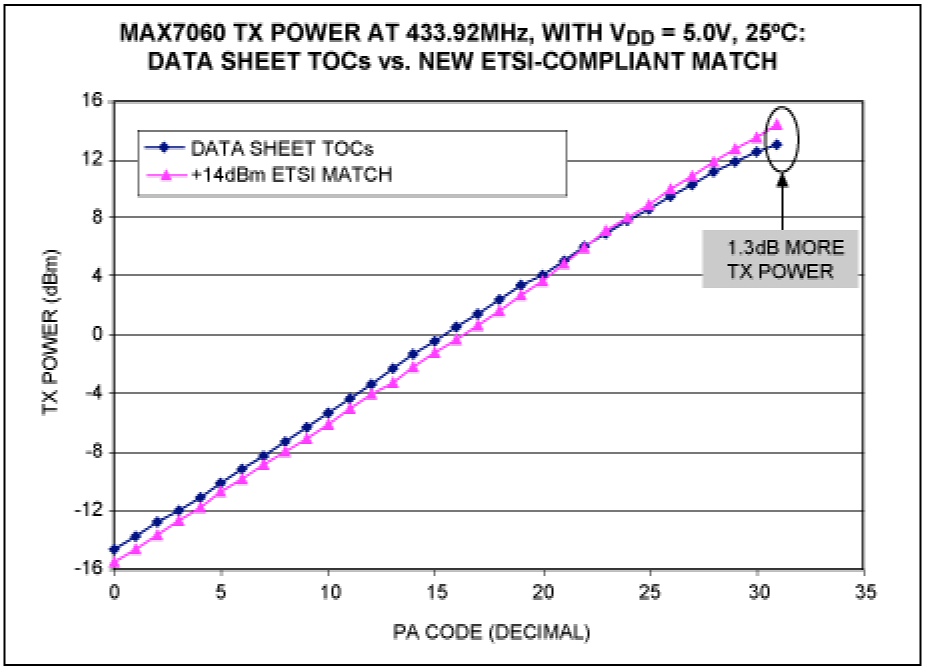

Figure 8. Improved power with match/filter for +14dBm with ETSI compliance.

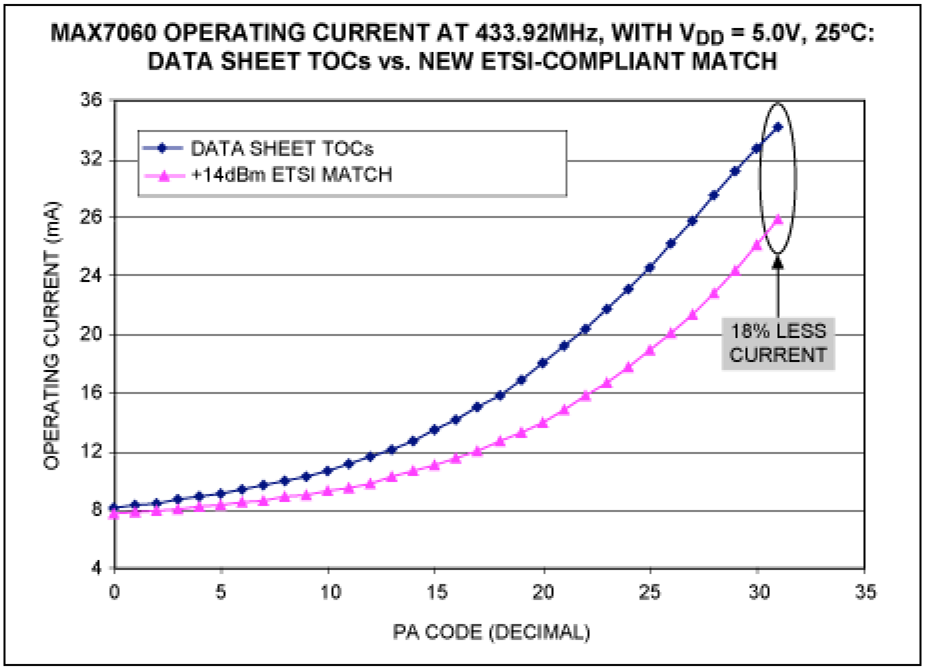

Figure 9. Decreased operating current with match/filter for +14dBm with ETSI compliance.

Only a minor improvement in harmonic attenuation has been achieved with the new filter, but a more significant improvement has taken place at the PA, where L1 has dropped by more than a factor of three. This translates to a tripling of the Q as long as the R reflected into the PA circuit stays the same. (See Equation 1.) Better harmonic rejection is the result.

Both of the alternate match/filter combinations described above are attempts to enhance 433.92MHz operation and clearly, the MAX7060 is capable of far better performance than the original EV kit match allows. However, it should be noted that neither of the proposed solutions are necessarily the optimum that can be achieved, but they provide insights into what steps might be taken the next time there is a new requirement. Interestingly, the +14dBm match/filter which meets ETSI requirements at 433.92MHz will also perform very impressively at 315MHz ***as long as one makes use of the variable capacitor at the PA output to adjust for the lower frequency of operation***. In the experiments performed thus far, setting the cap[4:0] bits to 16hex (corresponding to an additional 5.5pF of shunt C at the PAOUT pin) allows TX power of up to +15dBm at 315MHz, while meeting FCC harmonics, and at efficiencies only slightly less than with the original match.

Feature Comparison Between Maxim ISM-RF Transmitters: Why the MAX1472 vs. the MAX7060 Isn't a Fair Fight

The first transmitter in the Maxim ISM-RF product line was the MAX1472. When it comes to simplicity and efficiency, it is an impressive device, producing +10.3dBm from a 2.7V supply while drawing only 9.6mA operating current, with a scant 1.7mA of that being non-PA current. However, it also lacked features that customers later needed:

- The phase noise did not meet ETSI standards for full-power operation. (The MAX1479 was developed to address that shortcoming.)
- It was only capable of ASK modulation. (The MAX1479 added FSK modulation.)
- It could not support higher output power levels. (The MAX7044 was developed to deliver +13dBm.)
- The fixed-ratio PLL only allowed the frequency to be changed by replacing the crystal. (The MAX7057 incorporated a fractional-N PLL.)
- The low-power crystal LO required the use of crystals with small (4.5pF) load capacitance. (The MAX7057 improved upon this with a stronger LO.)
- The only way to vary transmit power was to vary the supply voltage.

The MAX7060 was subsequently developed to address these limitations as well as to incorporate features not available in earlier Maxim ISM-IF transmitters. But such improvements have come with a price, in the form of extra operating current and consequently, reduced overall efficiency.

Table 1 shows the available features of each of the ICs mentioned above, along with operational data from their respective data sheets. In the case of the MAX7060, the data used for comparison comes from the higher-efficiency match/filter described earlier in this application note, not from the MAX7060 data sheet.

Table 1. Feature Comparison of Maxim ISM-RF Transmitter ICs					
Feature	**MAX1472**	**MAX1479**	**MAX7044**	**MAX7057**	**Rematched MAX7060**
ASK Modulation	X	X	X	X	X
FSK Modulation		X		X	X
ETSI-Compliant Phase Noise		X		X	X
Frequency Agility (Frac-N)				X	X
10pF C Load on Crystals				X	X
TX Power of +13dBm or More			X		X
Load Tuning				X	X
Operate from +3V or +5V Supply					X
Adjustable TX Power					X
TX Performance at 433.92MHz					
Nominal TX Power at 2.7V (dBm)	+10.3	+9.2	+12.5	+9.2	+10.4
Op Current, ASK, 100% Duty Cycle (mA)	9.6	11.4	14.0	12.4	14.8
Op Current, ASK, 0% Duty Cycle (mA)	1.7	3.3	1.9	4.5	4.9

Before comparing the drain efficiency between the MAX1472 and the MAX7060 based on the data in Table 1, a few additional factors need to be considered:

- The predriver current of the MAX1472 is around 0.5mA and is turned off when the PA is disabled. Thus the MAX1472 PA FET is actually drawing 7.4mA of current (i.e., 9.6mA - 1.7mA - 0.5mA).
- The predriver current of the MAX7060 is around 1.5mA and is turned off when the PA is disabled. Thus the MAX7060 PA FET is actually drawing 8.4mA of current (i.e., 14.8mA - 4.9mA - 1.5mA).
- While the PA inductor of the MAX1472 is connected directly to the 2.7V supply, L1 of the MAX7060 circuit is connected to PAVOUT, which has been measured at 2.45V (flattened out, similar to the power characteristic shown in Figure 4) when the IC is operated from a 2.7V supply.

If Equation 3 is now applied to these two sets of numbers (i.e., the TX power and the current), the MAX1472 achieves 53.6% drain efficiency while the MAX7060 achieves 53.3%. ***The largest discrepancy between the two devices is the overall efficiency calculations.*** Using Equation 2, the feature-rich MAX7060 can only achieve 27.4% overall efficiency, as compared to 41.3% for the MAX1472. The drain efficiency of the MAX7060 could be slightly improved by further optimizing the "Alternate Match/Filter Method #1", but there is no overcoming the "efficiency penalty" that comes with the increased functionality and flexibility which have been designed into the MAX7060.

Additionally, if the need for high output and maximum power control range demands that the MAX7060 be configured to operate from a +5V supply, the efficiency penalty will include the internal voltage regulator. The presence of 5V as V_{DD} in the denominator of Equation 2 (rather than 2.7V as in the example above) causes the overall efficiency to be even lower. In this sense, it is not fair to compare the efficiency figures from the two new matching schemes presented, as each alternative was meant for a specific purpose: to optimize drain efficiency (i.e., battery life) or to achieve high transmit power. We simply cannot have it both ways.

Applying the MAX7060: Best Practices

In the previous section, we discussed certain tradeoffs and comparisons. Several additional general guidelines and cautions are helpful to keep in mind when designing with the MAX7060.

Don't Forget to Use the PA Capacitance

There are several mistakes one could make involving the variable PA capacitance. The first is not taking advantage of the PA capacitance at all. In single-frequency operation, it would be possible to achieve optimal performance without changing the cap code, but as soon as multiple-frequency operation is desired, failure to utilize the cap[4:0] bits will result in less than optimal efficiency. It could also increase the risk of regulatory issues, as a mistuned PA load might not attenuate harmonics well enough.

In applications where the MAX7060 operates at more than one frequency, the best approach is to assume that some amount of PA capacitance will be applied when operating at the lowest frequency, and then progressively removed at higher frequencies. With the match/filter combinations attempted thus far, it appears that best operation at 433.92MHz is achieved with little or no additional PA capacitance. Conversely, a shift down to a much lower frequency (i.e., 315MHz) necessitates applying a large portion of the PA capacitance (i.e., 5.5pF out of 7.5pF, as was the case for Alternate Match/Filter #2). ***Note: If the match and filter components were chosen to optimize performance at 315MHz with a cap code of zero, it will be impossible for that same match/filter combination to work optimally at any higher transmit frequency.*** This is the second mistake.

During bench characterization of the MAX7060, a set of experiments was performed in which the PA capacitance was used to fine tune the transmit power, allowing a nearly constant output level to be maintained at the same PA code over five frequencies from 288MHz to 390MHz (i.e., the domestic band of the original match). By applying a predetermined amount of PA capacitance at each frequency, the output flatness could be kept within a few tenths of 1dB. Similarly, it might be desirable to operate over multiple frequencies with optimal drain efficiency at each point by choosing a set of cap codes for that criterion.

However, in either case, the ability to determine an optimal combination requires measurement of TX power, harmonic levels, VDAC output, and PA current while the cap code varies over its entire range. The results from such a set of measurements is shown in **Figure 10** and **Figure 11**, which were taken from an EV kit using the Alternate Match/Filter Method #1, but operating at 315MHz. (Recall that both alternate matches aim for optimization at 433.92MHz rather than 315MHz.)

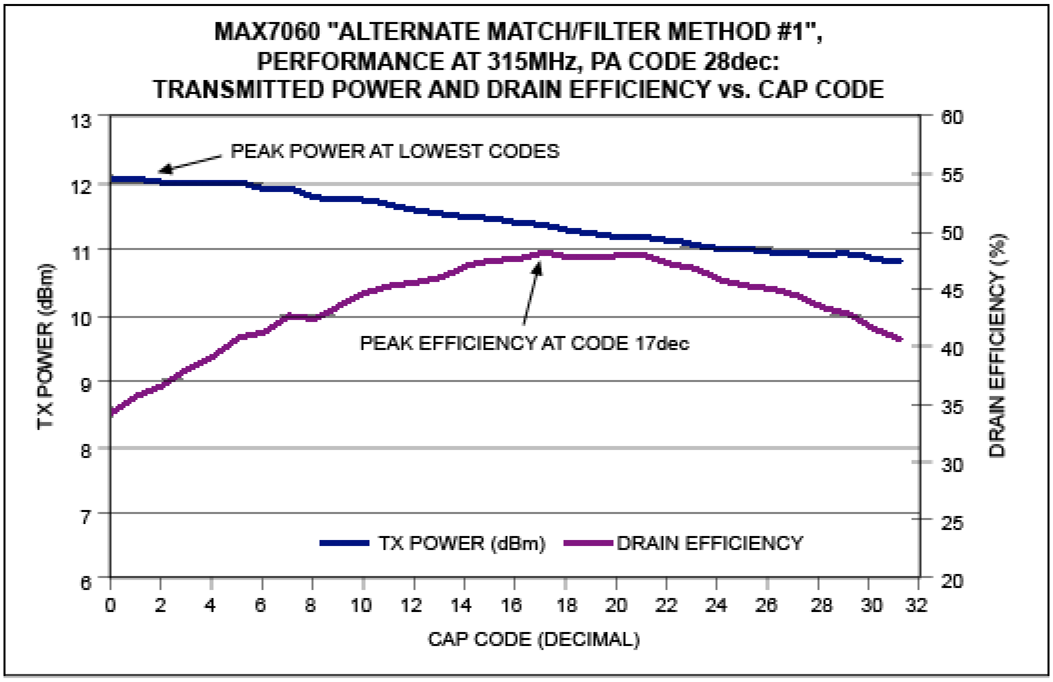

Figure 10. TX power and drain efficiency vs. cap code at 315MHz, using Alternate Match/Filter Method #1.

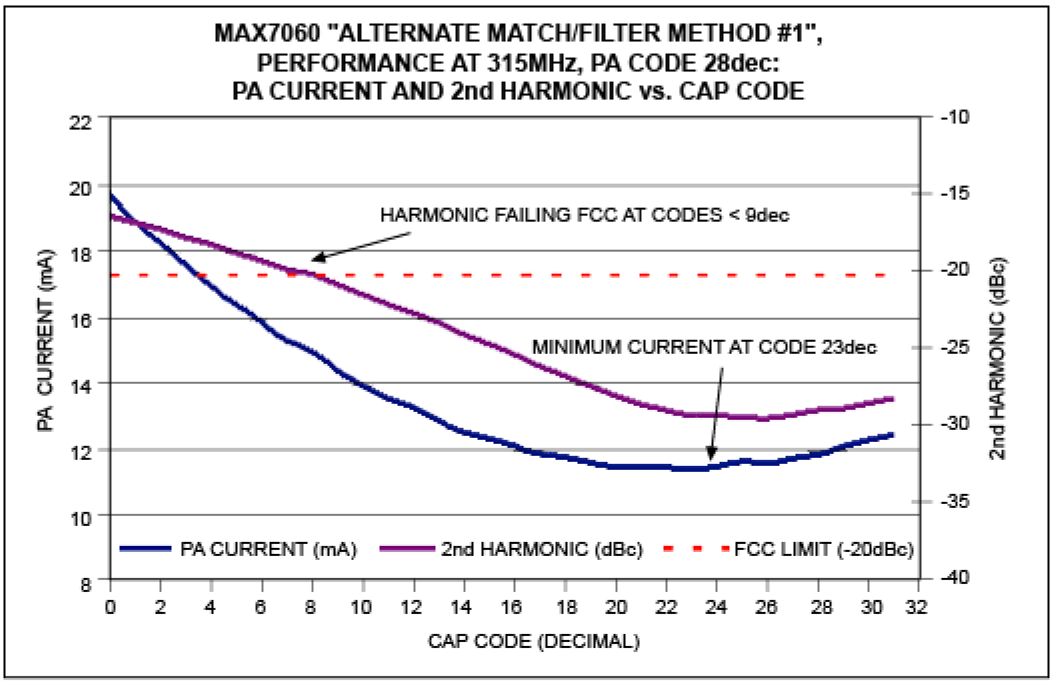

Figure 11. PA current and 2nd harmonic vs. cap code at 315MHz, using Alternate Match/Filter Method #1.

The inherent trade-offs visible from these results are as follows:

- Although an additional 0.5dB to 1dB of output power might seem to be available by operating at low cap codes, those same operating points consume considerable extra current and fail to meet FCC

harmonics.
- Best harmonic performance seems to correlate well with the lowest current, but neither of these optimum points provides the highest drain efficiency.

Since a compromise must be made, a general recommendation for operation at 315MHz with this particular match would involve using cap codes between 15dec and 23dec. In this range, the harmonics are well in spec, the efficiency is not too far from its peak value, and the current is close to its minimum value. **Conversely, it should be obvious from the example that choosing maximum TX power as the metric of highest importance, while disregarding what is occurring with the current, drain efficiency, and harmonic performance would constitute a third mistake with significant consequences.**

Because the load-tuning capability of the MAX7060 is a rather unique feature, experimentation is strongly recommended to determine how it might best be utilized in a given application environment.

Don't Expect the Best of Both Worlds (at the Same Time)

The alternate matches presented in this document highlight a difference that bears further discussion: One can choose to aim for high TX output and power control linearity, or one can choose to aim for efficient operation at lower (coin-cell) supply voltages, but both goals cannot be achieved simultaneously. There are fundamental reasons why this is true.

In order to be capable of high output power, the final stage FET of the MAX7060 is larger than in any of the earlier ISM-RF transmitters, with the exception of the MAX7044. Even so, when switched on, the FET exhibits a resistance (i.e., Rsw) of approximately 13Ω. This finite resistance represents an unavoidable power loss. As noted earlier in this document, to transmit at high power, a low value of Ropt (less than 50Ω) must be presented to the PA. Since in this case the value of Rsw is a significant percentage of Ropt, drain efficiency is impacted. (For a general discussion of the theory behind switched-mode PAs, see application note 3589, "Power Amplifier Theory for High-Efficiency Low-Cost ISM-Band Transmitters.")

Another impact to efficiency occurs due to the presence of the VDAC, which is positioned between the raw supply (i.e., whatever is connected to the V_{DD5} pin) and the PA inductor. The VDAC has a finite output resistance, and I^2R loss associated with this resistance will be greater for high-power matches, which draw more current through the PA.

In contrast, in lower voltage applications where the MAX7060 is matched for higher efficiency, Ropt is much larger than Rsw, thus reducing the impact of the switch loss. At the same time, lower current drawn through the PA results in lower VDAC losses. However, values of V_{DD} that are lower than 3.6V result in the power control characteristic flattening out. (See Figure 4 where the supply is 2.7V and the VDAC output is below 2.6V.) In general, as V_{DD} is lowered from 3.6V to 2.1V in 300mV steps, one extra PA code is lost from the control range for each step, though the rest of the characteristic (from the flat area on down) remains impressively linear.

While the Typical Operating Characteristics in the data sheet display the control range at the V_{DD} limits of 3.6V and 2.1V, in real-world applications where the MAX7060 is powered from a nominal 3V coin cell (e.g., model CR2032), the battery voltage will be approximately 2.7V for the majority of its lifetime. To target operation under such conditions, the upper codes of the control range must be sacrificed in the interest of efficient transmitter operation, and consequently, longer battery life.

Be Aware of Frequency-Dependent Effects

Because the MAX7060 is well-suited for applications where hopping between two or more frequencies is desired, some frequency-sensitive factors must be kept in mind. First, because the impedance/admittance values of the match/filter network are frequency dependent, the same combination of passive components will always cause a larger Ropt to be presented to the PA at the higher frequency. When the frequencies are closer together (e.g., 315MHz and 345MHz), the amount of shift in Ropt is small, but when spacing between frequencies is larger (e.g., 315MHz and 433.92MHz), the amount of shift in Ropt is 23% for the Alternate Match/Filter Method #1 and 49% for Alternate Match/Filter Method #2. ***Thus, the output levels attainable at 433.92MHz will always be less than those for 315MHz***, though both alternate matches allow them to be closer together than the original EV kit match did.

In practice, the difference in power levels can end up being partially offset by the fact that small antennas that are typical in ISM-RF applications tend to be less efficient radiators at low frequencies and better ones at high frequencies. (For more information, see application notes 3401, "Matching Maxim's 300MHz to 450MHz Transmitters to Small Loop Antennas" and 4302, "Small Antennas for 300MHz to 450MHz Transmitters.") However, along with the decrease in output, there is a secondary impact to the overall efficiency because PLL current increases at higher frequencies. Once again, while the alternate matches have improved performance at 433.92MHz, performance will always be slightly less than what can be achieved at 315MHz.

Be Aware of PCB and Component Dependencies

For the most part, data in the Typical Operating Characteristics of the MAX7060 data sheet and additional data presented here with the alternate matches have both used the PCB shown in the MAX7060 EV kit documentation. When designing the MAX7060 into new applications, care should be taken in the development and layout of the PCB per the guidelines described in tutorial 4636, "Avoid PC-Layout "Gotchas" in ISM-RF Products." Because the parasitic inductance and capacitance values associated with the application PCB are unlikely to be identical to those on the EV kit, some trial and error of the matching and filter components will need to be performed to attain optimization.

Use of high quality passive components are recommended to achieve maximum performance with the MAX7060. It is best to choose a particular manufacturer for all parts, particularly with chip inductors, because vendor-to-vendor variations in tolerance, Q, and parasitic parameters can lead to less than optimal results, even when choosing the same nominal value.

Use Care in Measurement Techniques

When taking measurements of the PA current by using a DMM in place of R3A, make sure to choose the range setting carefully. The mA scale on some meters present as much as 15Ω in series, which drops the available PA voltage by over 200mV in a high-power configuration such as the Alternate Match/Filter Method #2. Using the amps scale can present a far smaller series resistance. (Users should check the manual of their respective DMMs.)

When using a test arrangement where the PCB must be some distance from the bench top power supply, use feed cables of sufficient gauge to ensure that the voltage drop will be small. Alternately, use a bench top supply with remote sense capability, which allows the displayed voltage to be maintained at the load point on the PCB.

For transmit power measurements, placement of a 10dB, 50Ω attenuator in the coaxial connection stabilizes the impedance of the line and minimizes reflected energy, which could skew measurement results. (Remember to characterize the cable + attenuator loss so it can be calibrated out in the data.)

Appendix A. A MAX7060 Matching/Filter Network Example Using the Smith Chart

This section presents an example of how a match/filter network can be constructed for the MAX7060. In this example, a 50Ω impedance is maintained by the pi filter, and then transformed up to a 100Ω real impedance at the PA, which operates at 433.92MHz. The impedances encountered at various nodes of the network are shown on the Smith Chart. (For a tutorial on the development and usage of the Smith Chart, see application note 742, "Impedance Matching and the Smith Chart: The Fundamentals.")

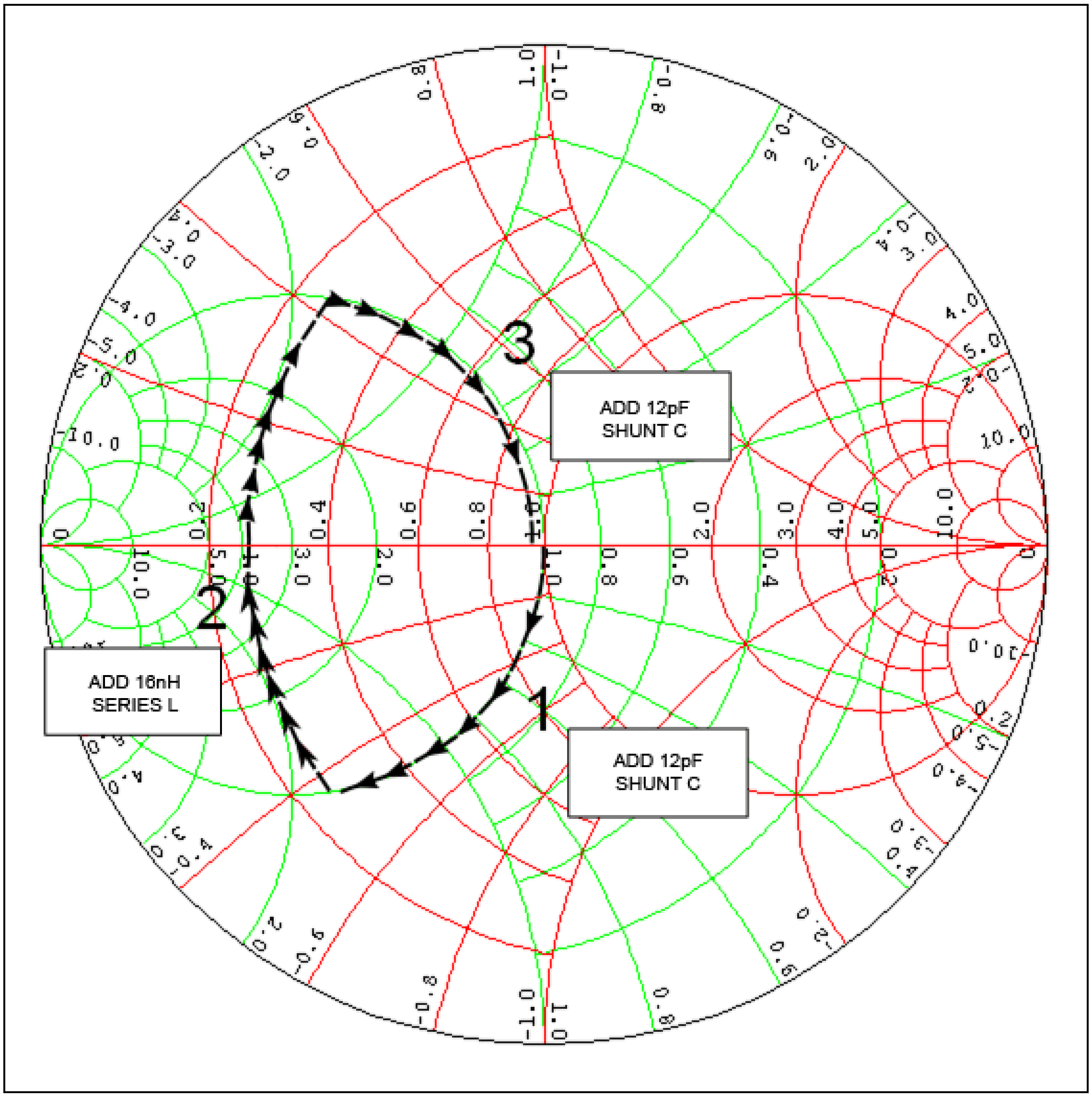

Figure A1. Impedance/admittance contours for a 50Ω pi filter at 433.92MHz.

Starting from the center of the chart (where 1 + j0Ω normalized represents a 50Ω termination at the SMA connector on the EV kit), **Figure A1** shows step-by-step the addition of a 12pF shunt capacitor (C56), a 16nH series inductor (L2), and another shunt 12pF capacitor (C55). This configuration results in an ending impedance of 47 + j1.5Ω, very similar to the 50Ω starting point. Note: The component values shown here are readily available ones. If it were possible to obtain 12.5pF capacitors, the ending impedance could be exactly 50Ω, but any amount of variation due to component tolerance will cause deviation from the ideal. Parasitic capacitances and inductances on the PCB will also result in imperfect matching, so wise design practice necessitates all theoretical matches to be verified on the application PCB.

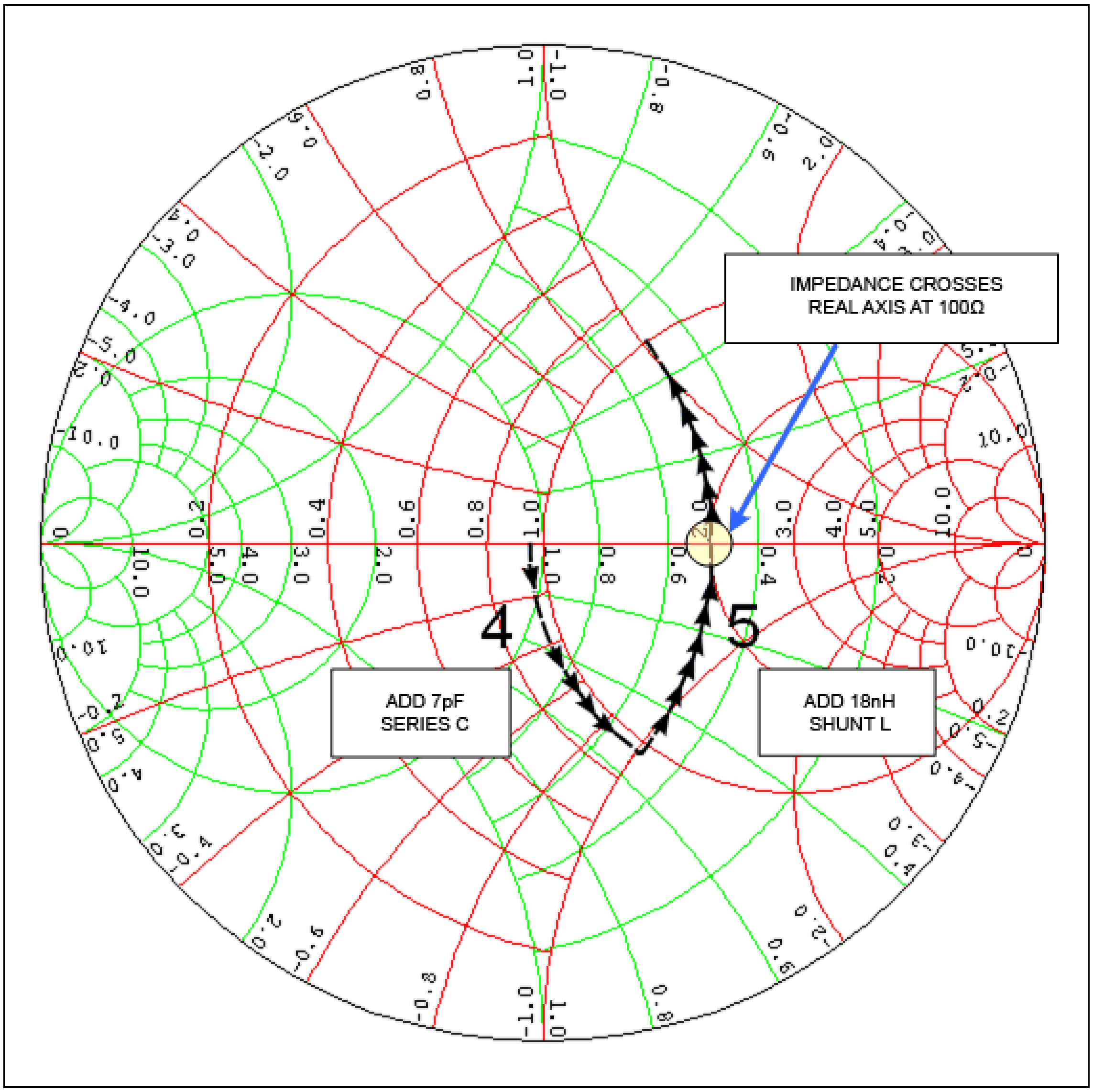

Figure A2. Impedance/admittance contours for a 50Ω to 100Ω transformation at 433.92MHz.

Continuing from the 47 + j1.5Ω output impedance of the pi filter, **Figure A2** shows the impedance transformation, which occurs by adding a series capacitor (C4) and a shunt inductor (L1). In this case, 7pF provides the necessary capacitive reactance to rotate the impedance counter clockwise until reaching the constant-conductance contour of a 100Ω shunt resistance. If L1 is now selected in such a way as to balance the susceptance presented by CparPA plus the amount reflected from the pi filter, the PA should experience a 100Ω real load. In graphical terms, we want the endpoint to land in the yellow circle of Figure A2. As was the case for the pi filter, it may be necessary to slightly adjust the values to reach an optimal result.

While the example presented here intentionally used component values that cause the input and output impedances of the pi filter to be the same, it should be clear that multiple options are possible including:

- If the series inductor had been made ***smaller***, the second shunt capacitor will cause the endpoint to land in a region of the chart where the real portion of the impedance is < 50Ω.
- If the series inductor had been made ***larger***, the second shunt capacitor will cause the endpoint to land in a region of the chart where the real portion of the impedance is > 50Ω.
- If the device connected at the input does not present a 50Ω impedance to begin with (as many antennas will not), the starting point for the match will no longer in the center of the chart. However, proper selection of C56, L2, and C55 can still result in a network that brings the impedance back to 50Ω at the filter output, allowing C4 and L1 to once again transform up to 100Ω for the PA load.

For more information on matching to the types of antennas typically encountered in ISM-RF applications, see application notes 3401, "Matching Maxim's 300MHz to 450MHz Transmitters to Small Loop Antennas" and 4302, "Small Antennas for 300MHz to 450MHz Transmitters."

Further Reading

For more information, please refer to these other Maxim application notes and tutorials:

Tutorial 742, "Impedance Matching and the Smith Chart: The Fundamentals."

Application note 1954, "Designing Output-Matching Networks for the MAX1472 ASK Transmitter."

Application note 3401,"Matching Maxim's 300MHz to 450MHz Transmitters to Small Loop Antennas."

Application note 3587,"FCC and ETSI Requirements for Short-Range UHF ASK-Modulated Transmitters."

Application note 3621,"Small Loop Antennas: Part 1—Simulations and Applied Theory."

Application note 3815, "Radiated Power and Field Strength from UHF ISM Transmitters."

Application note 4302, "Small Antennas for 300MHz to 450MHz Transmitters."

Tutorial 4636, "Avoid PC-Layout "Gotchas" in ISM-RF Products."

Related Parts		
MAX1472	300MHz-to-450MHz Low-Power, Crystal-Based ASK Transmitter	Free Samples
MAX1479	300MHz to 450MHz Low-Power, Crystal-Based +10dBm ASK/FSK Transmitter	Free Samples
MAX7044	300MHz to 450MHz High-Efficiency, Crystal-Based +13dBm ASK Transmitter	Free Samples

MAX7057	300MHz to 450MHz Frequency-Programmable ASK/FSK Transmitter	Free Samples
MAX7060	280MHz to 450MHz Programmable ASK/FSK Transmitter	Free Samples
MAX7060EVKIT	Evaluation Kit for the MAX7060	

More Information
For Technical Support: http://www.maximintegrated.com/support
For Samples: http://www.maximintegrated.com/samples
Other Questions and Comments: http://www.maximintegrated.com/contact

Application Note 5281: http://www.maximintegrated.com/an5281
APPLICATION NOTE 5281, AN5281, AN 5281, APP5281, Appnote5281, Appnote 5281