

DIRECTED ENERGY, INC. TECHNICAL NOTE

“Stand Alone” RF Power Capabilities Of The DEIC420 MOSFET Driver IC at 3.6, 7, 10, and 14 MHZ.

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Abstract

The DEIC420 MOSFET driver IC is evaluated as a “stand alone” RF source at 3.6, 7, 10, and 14 MHZ. To create up to 47W of CW RF all that is required is a clock oscillator, RF resonant tank, and associated output matching circuitry. This module can be used as a medium power RF source for amateur radio use, a laboratory RF source, a source of sine wave gate drive, and many other applications where a compact RF source is required.

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FIGURE 1: DEIC420 GATE DRIVER IC

Introduction

The DEIC420 is a 20A_{pk} high-speed MOSFET gate drive IC available from DEI/IXYS. It is compact and self-contained requiring only VCC, a 5V TTL clock signal, and appropriate heat sinking to produce a pulsed RF output signal. The addition of a simple L/C resonant tank and an impedance matching network produces a sine wave output to a standard 50Ω load. With the addition of a keying circuit and additional harmonic filtering the IC can be utilized as an Amateur Radio CW source for operation through at least 20 Meters (14MHZ).

Theory of Operation

When gated via the TTL input or clock, the DEIC420 converts the input to a high-current sub-10ns rise time output pulse via multiple totem-pole stages. This output signal is designed to drive a low impedance capacitive load like a MOSFET gate. In this application, the IC drives a low impedance series-resonant tank and appropriate matching circuitry to ultimately drive a 50Ω load.

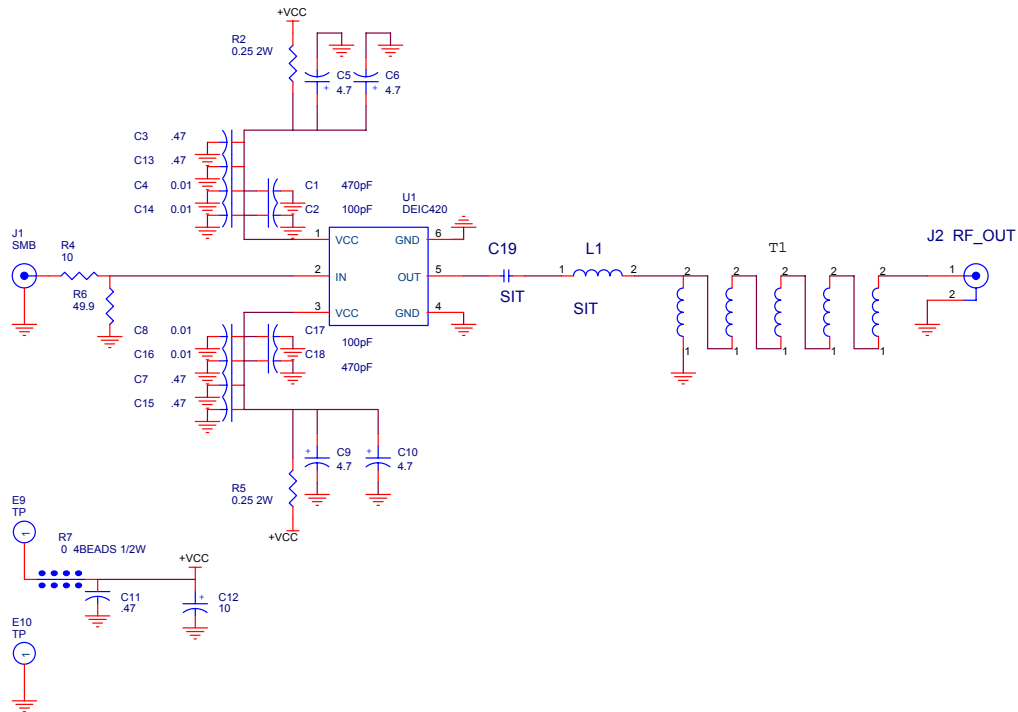


FIGURE 2: DEIC420 RF DRIVER SCHEMATIC DIAGRAM

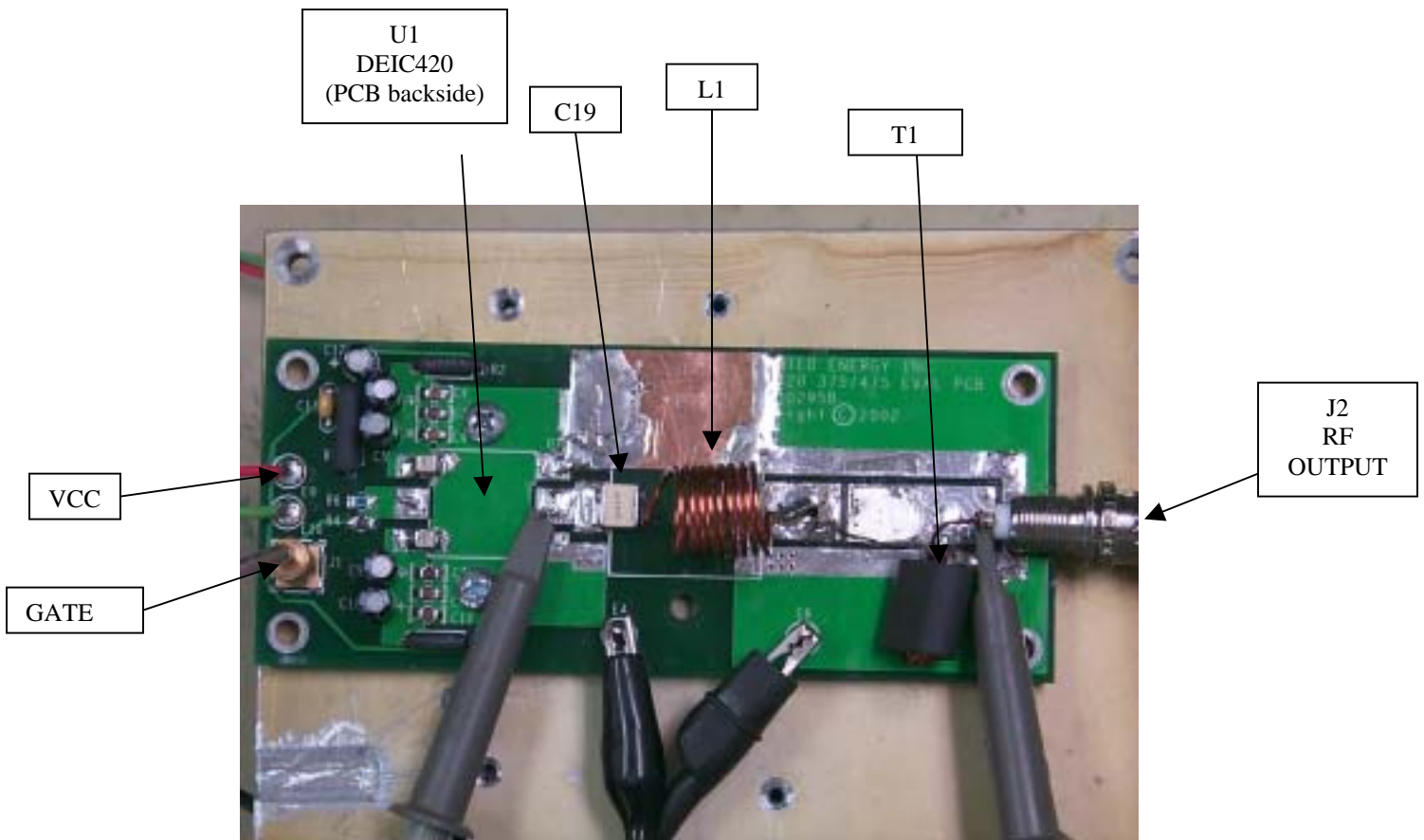


FIGURE 3: DEIC420 DRIVER MODULE TOP-VIEW

Circuit Description

The circuit in FIGURE 2 was implemented using a DEI EVIC420 gate drive evaluation board, shown in FIGURE 3. The EVIC420 provides a convenient means of mounting and interconnecting to the DEIC420 gate driver IC. The DEIC420 is mounted on the back (solder side) of the EVIC420.

The DEIC420 will operate with a VCC supply from 8-28VDC with an absolute maximum of 30V. The magnitude of the output pulse is directly related to the applied level of VCC. The voltage should be applied to the “E9” connection as shown in FIGURE 2. Resistors R2 and R5 decouple the IC from the power supply. In addition, please notice the variety and quantity of the bypass capacitors. Since the output is a square pulse containing many harmonics, it is very important that enough bypassing at low, medium, and high frequencies be used to ensure a fast rise time and adequate peak current to drive the load. Capacitors C3-C10, C15, and C16 perform this function.

When a 5V TTL compatible 50% Duty Cycle clock of the required frequency is applied to J1, U1 drives its output pin in the same direction (non-inverting) as the driving signal to the level of applied VCC. This pulse is capable of a 20A_{pk} and 4A_{rms} output current to the load.

C19 presents a DC block to prevent DC from flowing to the load. In addition, C19 and L1 form a series resonant “tank”. The function of the tank is to provide a low impedance at the operating frequency f_0 , while inhibiting harmonic current flow. The result is a sine wave output voltage at the fundamental switching frequency.

Transformer T1 is a multi-filar autotransformer used to match the DEIC420 output to the 50Ω load. As the output power is <50W the transformer is wound on one single Fair-Rite #286100202 balun core. Depending on the intended frequency of operation, 5 or 6 strands of AWG 22 enameled solid magnet wire are twisted tightly together to form the autotransformer. This method ensures tight coupling between windings for the best high frequency response. As shown in TABLE 1, separate tank component values for each of four frequencies were used.

Frequency (f _o)	C19 (pF)	L1 (nH)	Q	Load Impedance R _L	T1 Z ratio
3.6MHZ	2700	723	8	≈2Ω	1:25
7.0MHZ	1200	430	5	≈2Ω	1:25
10.0	1000	258	8	≈2Ω	1:25
14.1MHZ	780	164	10	≈1.4Ω	1:36

TABLE 1: RF TANK COMPONENT VALUES

Circuit performance

FIGURE 4 shows the RF output power of the test module. Over 40W is available at 3.6, 7, and 10 MHz, and 35 watts at 14 MHz. The output power is limited by the DEIC420 maximum ratings. The maximum rated output current is 4A_{rms}, maximum VCC is 30V, and maximum dissipated power is 100W at 25°C. This testing used 28V VCC and 4.5A DC input current to the DEIC420 as the maximum for safe device operation.

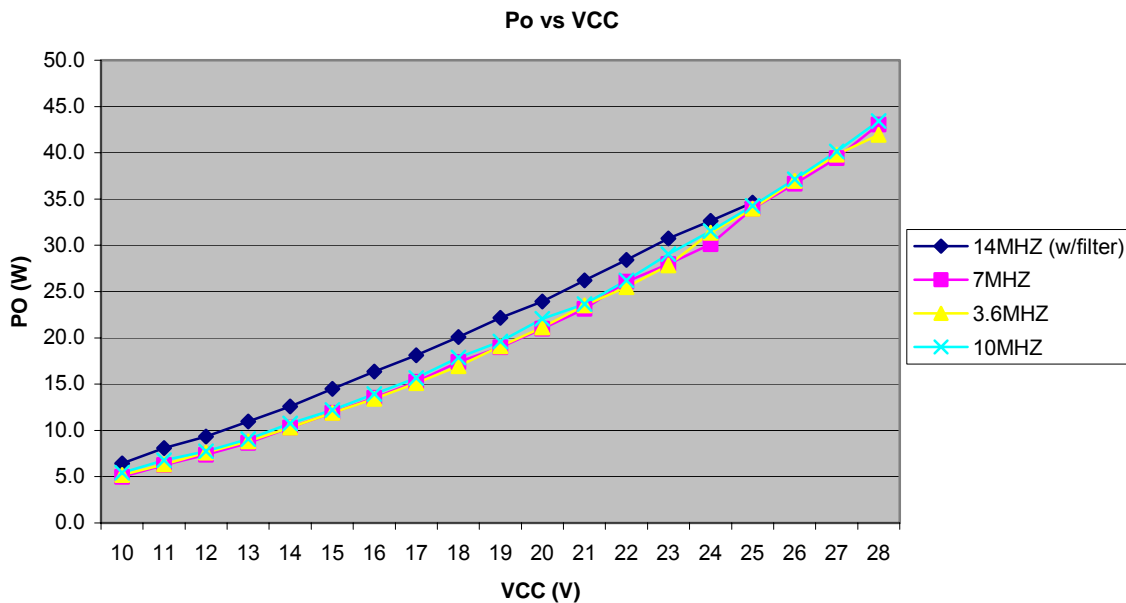


FIGURE 4: DEIC420 OUTPUT POWER

FIGURES 5 through 12 show the output waveforms and harmonic spectra for each of four test frequencies. We see in FIGURE 5 an output sine wave with a 45.79 V_{rms} amplitude corresponding to 41.9W into a 50Ω load. In addition, we see a 34 V_{pk} 50% Duty Cycle square wave on channel 2 representing the DEIC420 output signal driving the resonant tank. FIGURE

6 is a spectrum analyzer plot showing a “worst case” third harmonic level @ -34.5 dBc at the output level shown in FIGURE 5. Similarly, this display of test data is repeated for the other test frequencies at 7, 10, and 14 MHz.

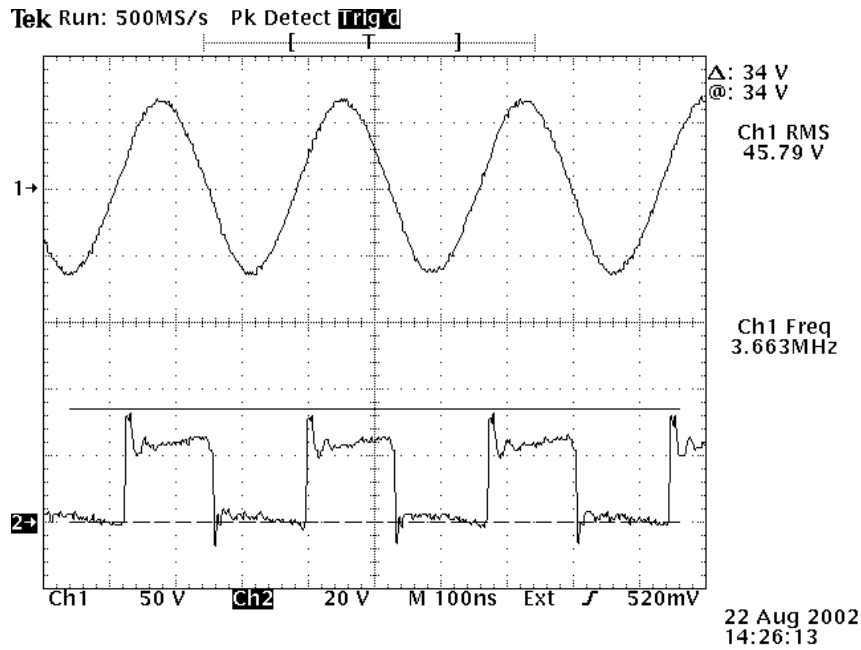


FIGURE 5: DEIC420 3.6 MHZ OUTPUT WAVEFORMS

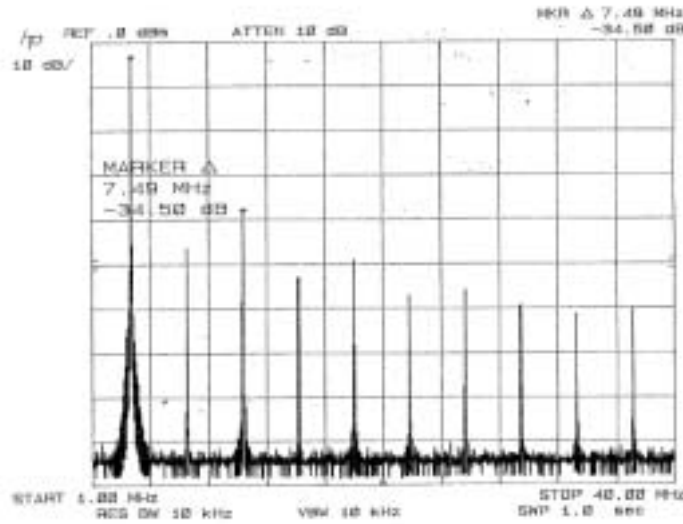


FIGURE 6: DEIC420 3.6 MHZ SPECTRUM

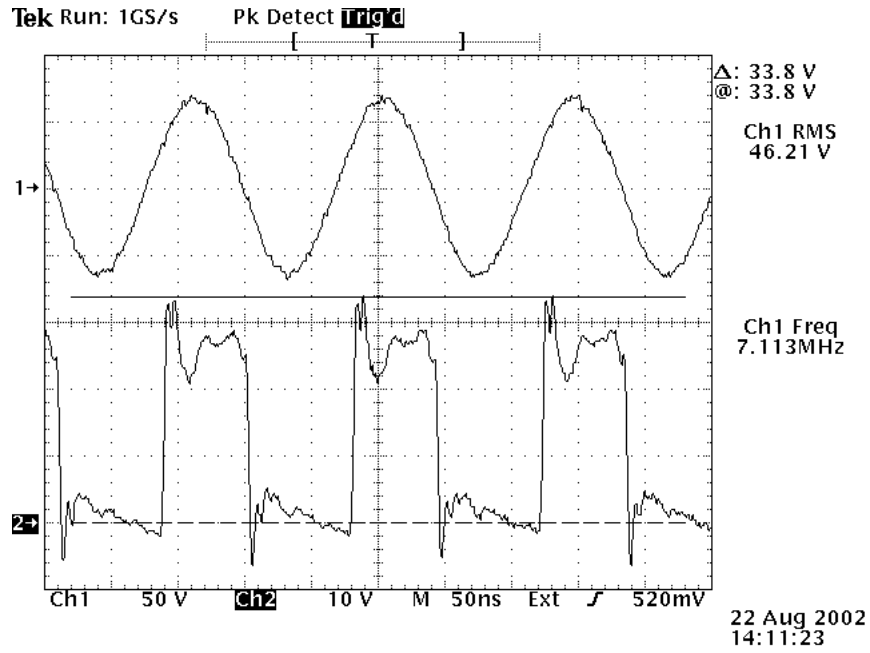


FIGURE 7: DEIC420 7 MHZ OUTPUT WAVEFORMS

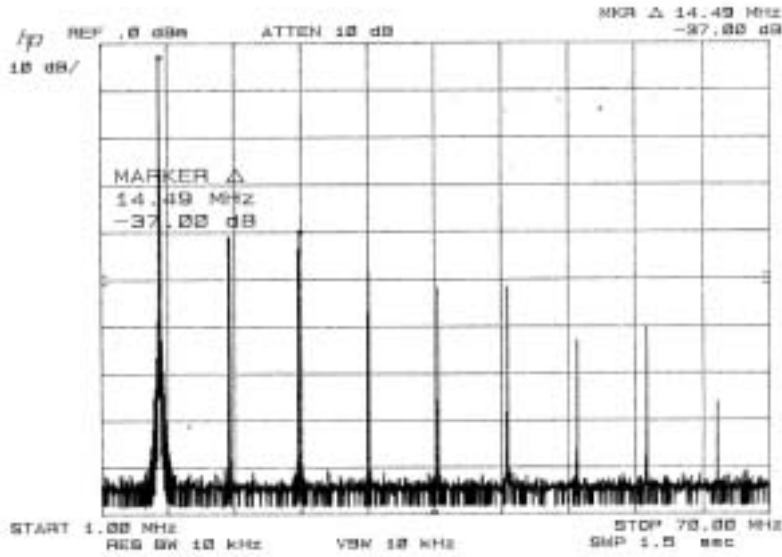


FIGURE 8: DEIC420 7.0 MHZ SPECTRUM

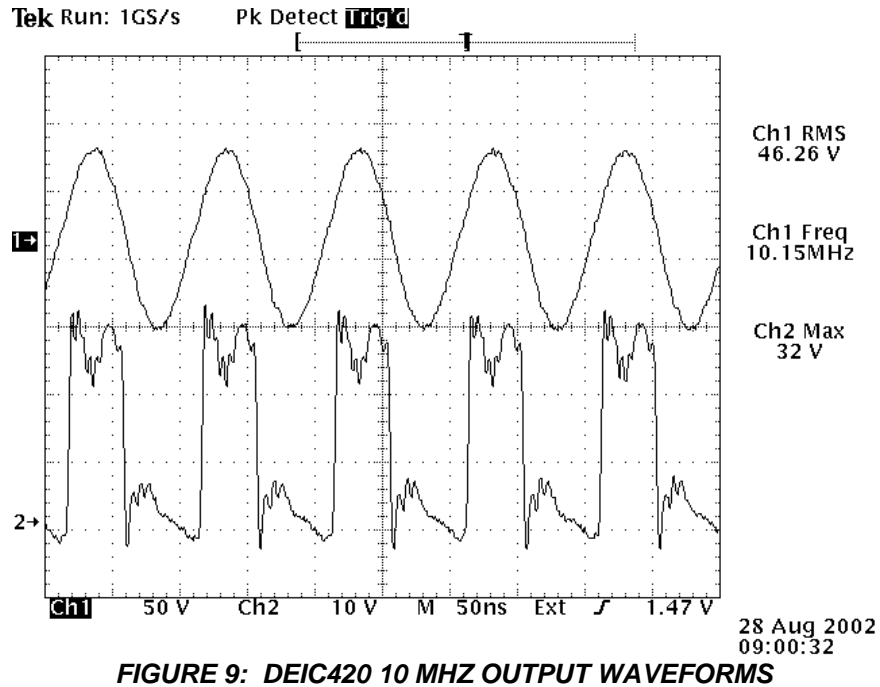


FIGURE 9: DEIC420 10 MHZ OUTPUT WAVEFORMS

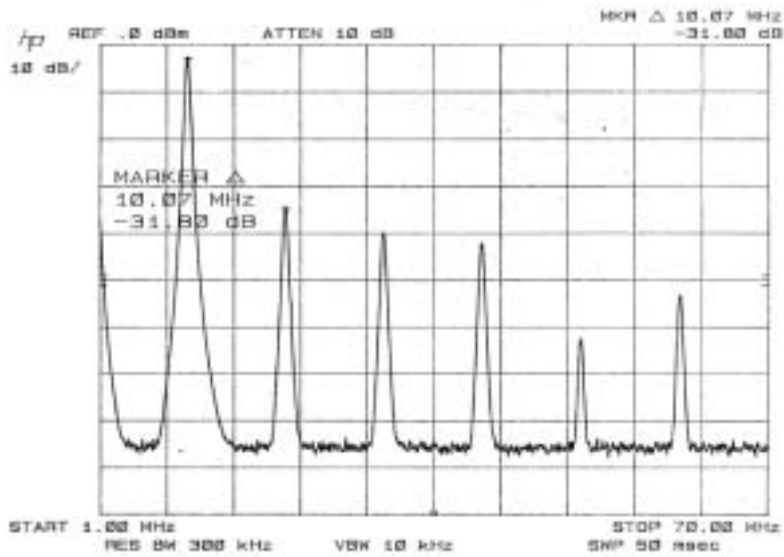


FIGURE 10: DEIC420 10 MHZ SPECTRUM

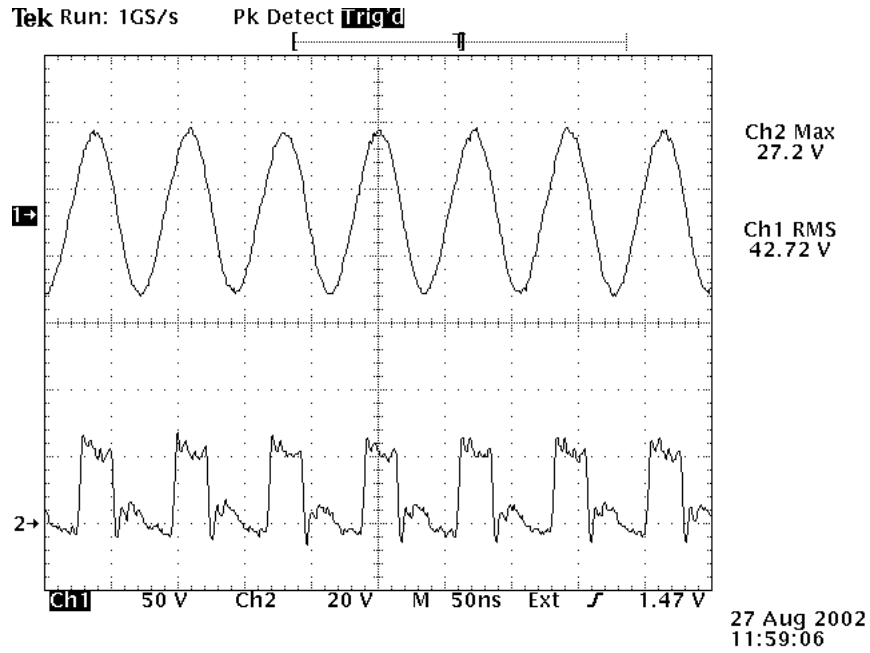


FIGURE 11: DEIC420 14.0 MHZ OUTPUT WAVEFORMS

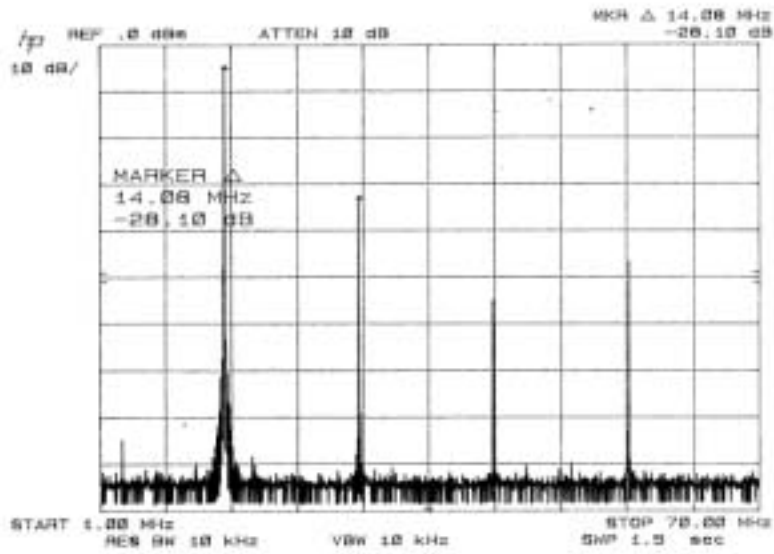


FIGURE 12: DEIC420 14.0 MHZ SPECTRUM (NO FILTER)

FIGURE 13 displays the test module DC to RF conversion efficiencies for each test frequency. Efficiency varies from a low of 30% to a high of 56%. Higher operating frequencies result in lower efficiency.

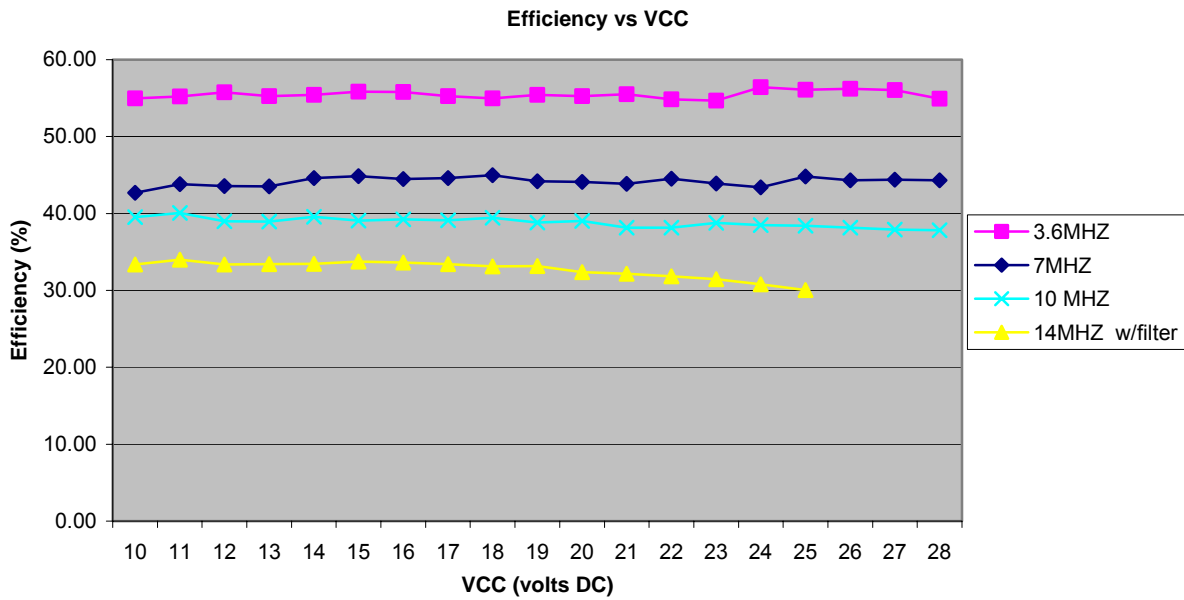


FIGURE 13: DEIC420 DC TO RF EFFICIENCIES

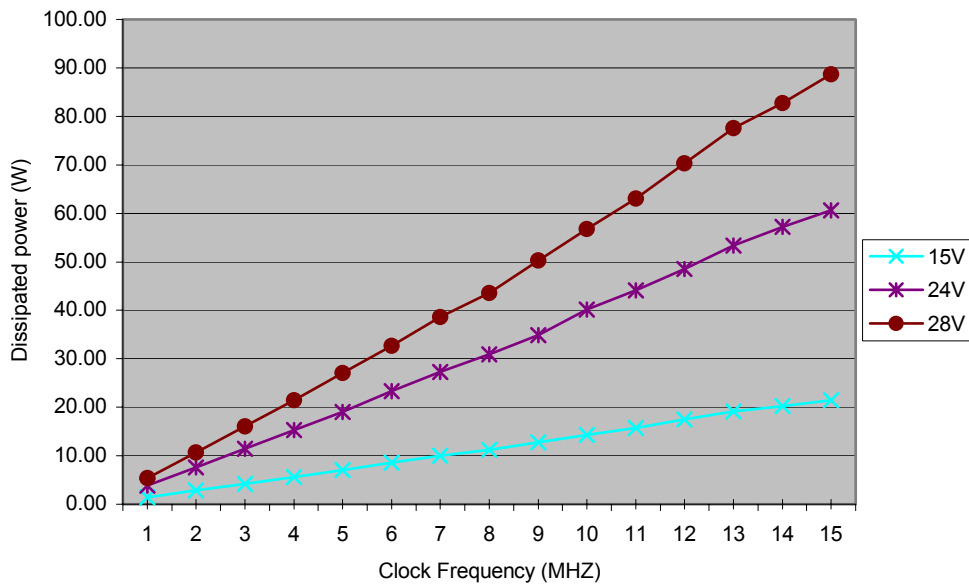


FIGURE 14: DEIC420 NO-LOAD DISSIPATION

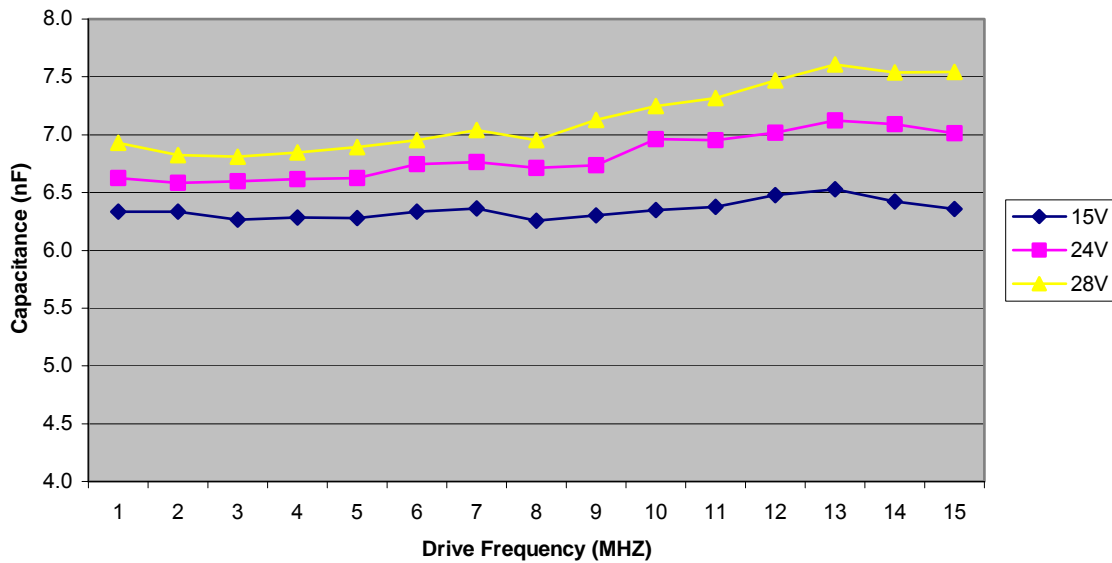


FIGURE 15: DEIC420 EQUIVALENT CAPACITANCE (NO-LOAD)

Testing shows the DEIC420 consumes non-trivial power with no load attached. FIGURE 14 is a graph of DEIC420 self-dissipation vs. frequency at 15V, 24V, and 28V VCC. This dissipation varies from 1-89W. No load was attached to the DEIC420. Power is required to drive the internal totem-pole pairs inside the IC. This dissipation is related to the power required to charge and discharge a capacitor, $P=C * V^2 * f_o$. The test data for FIGURE 14 was used to calculate the DEIC420 equivalent capacitance from the above formula. FIGURE 15 demonstrates a relatively consistent capacitance vs. both frequency and VCC. This confirms that internal capacitive loads dominate the DEIC420 losses. This power loss is part of the fundamental IC design and cannot be changed.

The ultimate result of this loss is that the maximum efficiency of this RF module is limited by the system losses. Clearly for a goal of 50W output power at 28V and 15MHz, the absolute maximum efficiency will be $100 * P_o/P_{in}$ or $100 * (50/(50+50))$ or 50%. The actual overall efficiency will be less when you include other system losses.

f_o (MHZ)	P_{in} (W)	P_o (W)	η (%)	P_{loss} (W)
3.6	76.4	42	55	34.4
7	97.2	43	44.3	54.2
10	114.8	43.4	37.8	71.4
14	115.3	34.6	30.0	80.7

TABLE 2: SYSTEM EFFICIENCIES AND LOSSES

The P_{loss} column of TABLE 2 refers to the total system loss or the difference between P_{in} and P_o . TABLE 3 breaks this loss into sub-categories. This loss is composed of the DEIC420 switching loss (P_{switch}), the output transformer insertion loss (P_{tran}) and the tank circuit component losses (P_{tank}).

FIGURE 14 indicates the switching losses for each test frequency. Switching loss as described earlier is $SL (W) = C * V^2 * f_o$. Losses are 18.8, 38.6, 56.8, and 57.1 W for 3.6, 7, 10, and 14 MHz respectively.

Circuit losses dissipate the balance of the system loss. The circuit losses include the tank ESR and the output transformer insertion losses. At the 40 W level at 14MHz the measured tank loss was 0.1-0.25dB. This corresponds to 1-2.4W of tank dissipation. Note that the Tank losses are small relative to the switching and transformer losses.

f_o (MHZ)	P_{in} (W)	P_o (W)	P_{tank} (W)	P_{switch} (W)	P_{tran} (W)	P_{tran} (dB)
3.6	76.4	42	1	18.8	14.6	-1.3
7.0	97.2	43	1	38.6	14.6	-1.3
10.0	114.8	43.4	1	56.8	13.6	-1.2
14.1	115.3	34.6	2.4	57.1	21.2	-2.1

TABLE 3: SYSTEM LOSSES

Figures 6,8,10 and 12 display the output spectra for each frequency. TABLE 3 summarizes the results. Ideally, given the output is an odd function, the spectrum should contain only odd harmonic terms 1,3, 5.... The high harmonic level at 10 and 14 MHz is attributable to non-symmetry in the clock signal driving the DEIC420.

F_o (MHZ)	Harmonic level (dBc)	Harmonic #
3.6	-34.5	3
7	-37	3
10	-31.8	2
14	-28	2

TABLE 4: SYSTEM HARMONIC LEVELS

If this device is used as an RF transmitter for amateur radio or other use where an antenna is driven, there are spectral purity requirements. FCC standards require all spurious emissions be at least 40 dB down (-40dBc) from the fundamental on frequencies below 30 MHz and powers <500W. To ensure compliance at 14 MHz and as an example a 5 element low-pass filter was designed as shown in FIGURE 16.

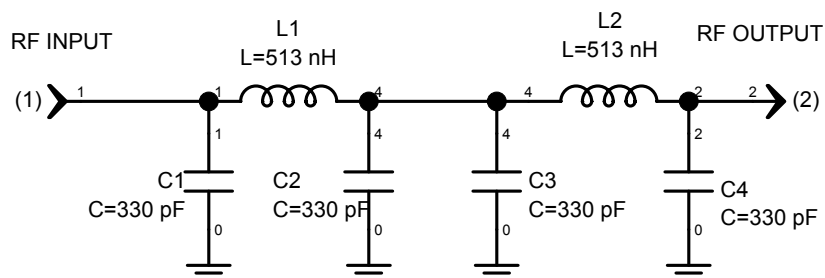


FIGURE 16: DEIC420 14 MHZ OUTPUT FILTER

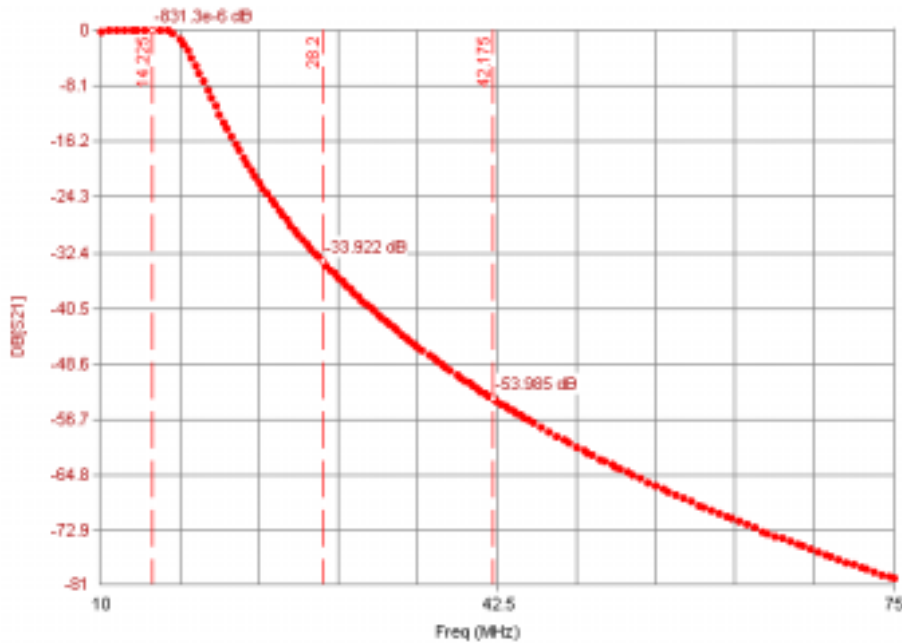


FIGURE 17: DEIC420 14 MHZ FILTER SIMULATION

FIGURE 17 describes the ideal filter response. The second harmonic attenuation is 34 dB and the third harmonic attenuation is 42dB.



FIGURE 18: DEIC420 14 MHZ MODULE (WITH FILTER)

Next, a filter was added on the output of the RF module between the 50Ω T1 output and the RF output connector J2. FIGURE 18 shows the filter added to the RF module. Figure 19 shows the spectrum after the filter addition and TABLE 5 summarizes the filter improvements. Note the harmonic improvement is less than ideal. The ideal filter response assumes perfect 50Ω interface impedances. In addition, the circuit strays and component variation also can cause considerable deviation from ideal.

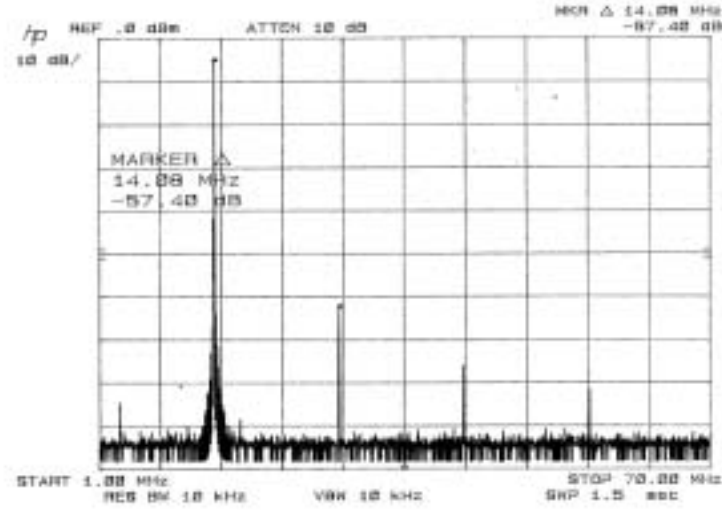


FIGURE 19: DEIC420 14 MHZ SPECTRUM (WITH FILTER)

$f_0=14\text{MHZ}$	2 nd (-dBc)	3 rd (-dBc)
No filter	28	48
With Filter	57	70
Difference	29	22

TABLE 5: 14 MHZ HARMONIC SPECTRA

Accuracy of test data

A Tektronix TDS 360 oscilloscope with P6131 probes was used for all monitoring and data recording. A Fluke 87 DMM was used for the DC voltage and current measurements. An HP 8568B Spectrum Analyzer was used for the harmonic data. Power measurements were done by calculating the $(V_{\text{rms}})^2 / 50\Omega$ value from the scope data into the Bird 8322 load. As a result, all harmonics are included in the power calculation and a perfect 50Ω is assumed. A variation of $\pm 10\%$ from an absolute power reference is possible. This data was taken to represent what could reasonably be duplicated in the average industry electronics lab. It is not intended as an exact indication of DEIC420 performance and customer results may vary.

Circuit implementation

It is important to use an adequate heat sink to remove the power dissipated in the DEIC420. Looking at TABLE 2, 80.7 W were dumped into the heat sink at 14 MHz. The DEIC420 is rated for 100W at 25°C case temperature. You should derate the DEIC420 power dissipation capability at $1/0.13^\circ\text{C} / \text{W}$ or $7.7\text{W} / ^\circ\text{C}$ to ensure the maximum junction temperature is not exceeded. Under no circumstances should the junction temperature be allowed to exceed 150°C.



FIGURE 20: T1, 25:1, MULTI-FILAR AUTOTRANSFORMER

FIGURE 20 shows T1, a 25:1 impedance ratio output matching transformer. This shows the construction and winding technique. As shown, the winding consists of one turn of five twisted magnet wires. Hence $5^2 = 25$ or 25:1 Z ratio. One wire starts on one side of the balun core and wraps through once to the other balun hole. This wire in turn solders to the start of the next wire, forming a sequence of series windings. The ARRL handbook listed in the references section has further information on transformer construction. If CW “key down” operation is desired, at least two cores should be used to help minimize transformer core losses and keep core heating to a minimum.

For Amateur CW applications, a clock oscillator at a standard “fixed” operating frequency in the 80, 40, 30, 20 meter bands is readily available or any adjustable and stable pulse generator can be used. A simple keyed buffer stage between the clock oscillator and the DEIC420 will allow CW operation.

Conclusion

The DEIC is a flexible IC originally designed for high frequency MOSFET gate drive applications. Given this simple circuit implementation, 35W of RF is readily obtainable anywhere from 3.6-14 MHz. Efficiency approaches 60% at the lower frequencies and power approaches 50W. Given some additional output filtering the module can easily be used as a “one IC” Amateur Radio CW transmitter. It can be easily adjusted to the frequency of interest and is not critical in tuning or operation. Lower frequencies (e.g. 1.8-2MHz) are readily available by just scaling the RF tank values. The reader is encouraged to experiment with the DEIC420 for use in his specific application.

DEIC420 ICs and the EVIC420 evaluation module are readily available for purchase from DEI. Please see the DEI web site at www.directedenergy.com for more information.

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Solid State Radio Engineering

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