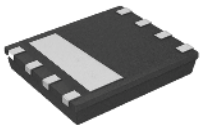
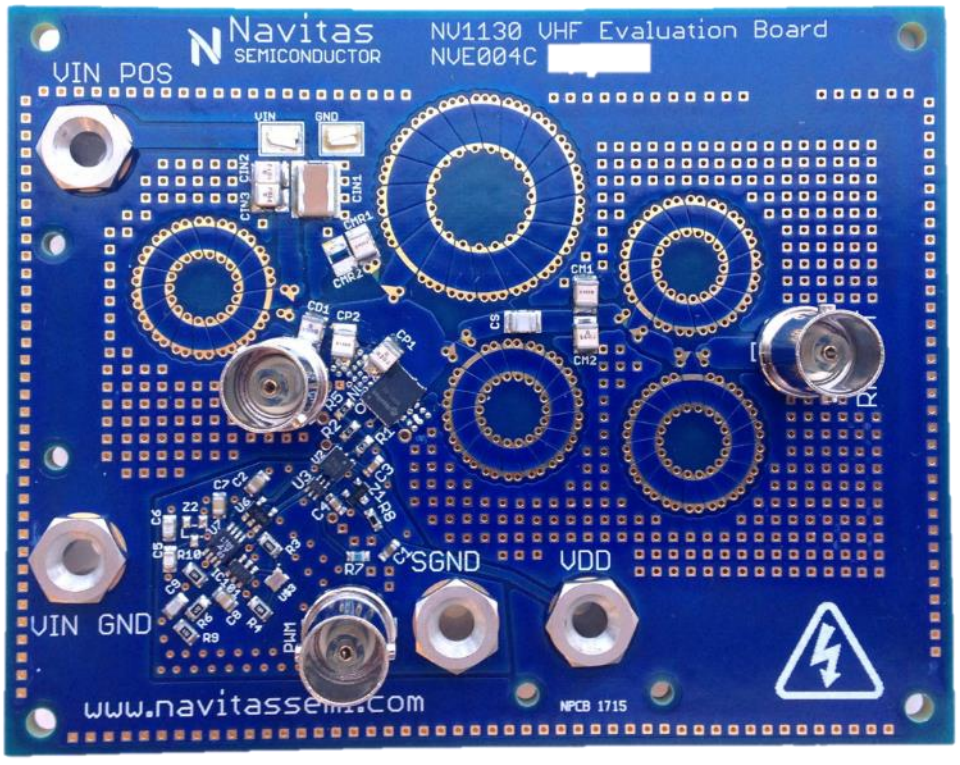
VHF Φ2 DC-AC Demo Boards

(This user's guide covers both NVE004C-A (27MHz) and NVE004C-B (40MHz) class Φ2 inverter demo boards with NV1130)

User Guide UG002

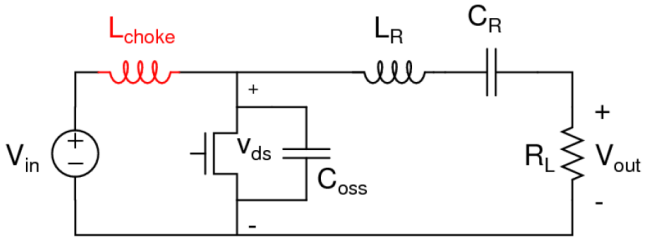




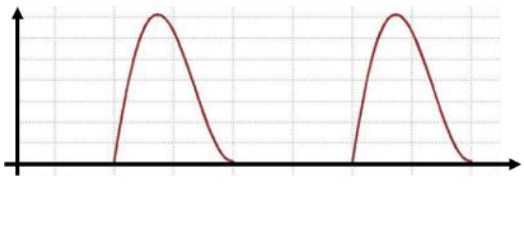
Description:

The NV1130 is a 650V 130mΩ eMode GaN Power IC with extremely low gate charge and output capacitance. The Φ2 demonstration board demonstrates how this performance enables efficient VHF power conversion.

Class E amplifiers (N. Sokal & A. Sokal (1975)) enable very high-frequency switching but FET voltage stress is high (4x V_{IN}), meaning high FET losses as Rds(on) increases with voltage.



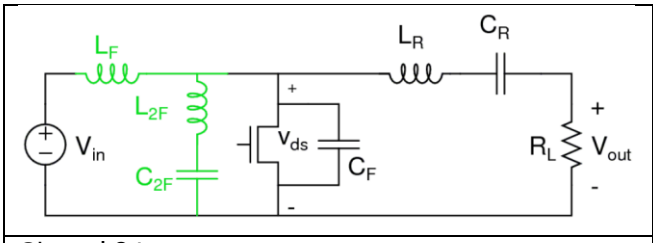
Class E Inverter



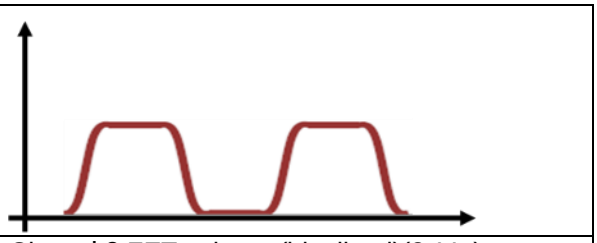
Class E FET voltage (4x V_{IN})

The class Φ2 converter (Rivas, Han, Leitermann, Sagneri, Perrault (2008)) removes the 2nd harmonic (the "Φ2") to limit FET voltage stress to 2x V_{IN}. As class Φ2 can now uses lower voltage FETs, it is more efficient and can process more power.

For more information, please refer to MIT Open Access Article:
http://dspace.mit.edu/handle/1721.1/86922



Class Φ2 Inverter



Class Φ2 FET voltage (idealized)(2xV_{IN})

Additional benefits of the Φ2 over Class E include:

- Replacing the DC choke with a simple multi-resonant network, eliminating the link between FET capacitance and power (C_F is now chosen as part of the network).
- Elimination of bulk inductance allowing smaller, even 'air core' inductors, with fast transient performance.

Due to industry-leading on-state and switching performance metrics ($R_{DS(ON)}$ x Q_g and $R_{DS(ON)}$ x Q_{OSS}), Navitas GaN Power ICs enable new benchmarks in VHF conversion.

This DC-AC VHF inverter is a building block demonstrator. By Adding an isolation transformer and resonant rectifier, a compact, isolated, DC-DC power supply is possible. Please reference to MIT's papers for additional information.

Start-up Sequence:

1. Connect V_{DD} bias supply, input voltage (V_{IN}), 50Ω load, PWM signal generator and scope probes.
2. Apply V_{DD} (set to 6V, 100mA).
3. Apply PWM input (Max 5% duty cycle, 10kHz, 5V output).
4. Gradually turn on V_{IN} from 0V to 150V_{DC}.
5. Monitor V_{DS} voltage:
    a. Multiply scope reading by 10-11x, based on probe input capacitance,
    b. The correct reading should be about 300-320V peak to peak voltage,
    c. Due to PWM action, use Normal mode for scope triggering.

Power-down Sequence:

1. Turn off V_{IN} first.

Caution:

1. Make sure 5% or less PWM is applied to avoid load overheating
2. Avoid probing other circuit nodes due to sensitivity to parasitic.

Operation Conditions:

	PARAMETER		Value	UNITS
V_{IN}	Input Voltage		150	V
V_{DD}	Bias Voltage		6	V
PWM	Signal Generator (0-5V, high Z output) duty cycle		5	%
F_{SW}	Switching Frequency	NVE004C-A	27.12	MHz
		NVE004C-A	40	MHz
P_{OUT}	Output Power (max)	NVE004C-A at 150V_{IN}	150	W
		NVE004C-A at 150V_{IN}	100	W

Fig. 1:
Board set-up

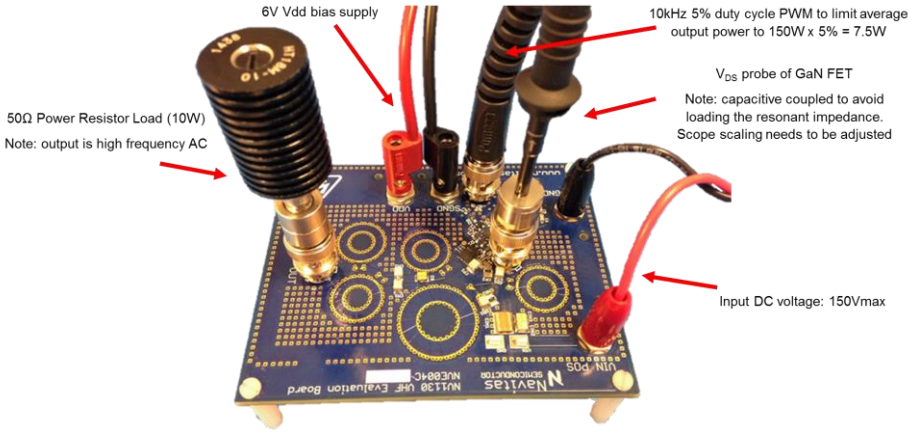


Fig. 2:
V_{DD} power supply and PWM input

Caution: Note peak and average power rating of demo board.
The PWM controls the enable pin of the driver, so the inverter operates in burst mode to limit average output power and protect the 50Ω load.
(100W x 5% = 5W
(150W x 5% = 7.5W)

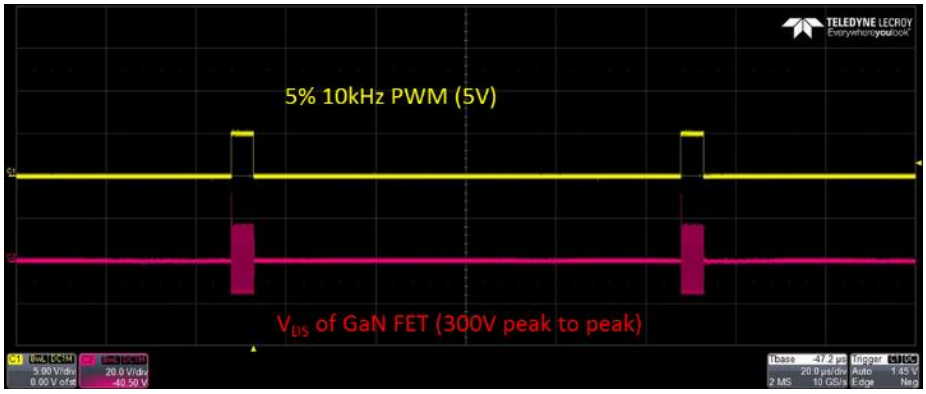


Fig. 3:
High voltage output load connection using 50Ω RF resistor (10W).
Tee adapter enables output voltage measurement and load connection.
http://www.pasternack.com/10-watts-bnc-male-rf-load-up-to-4-ghz-pe6034-p.aspx

http://www.pasternack.com/bnc-male-female-female-tee-adapter-pe9174-p.aspx

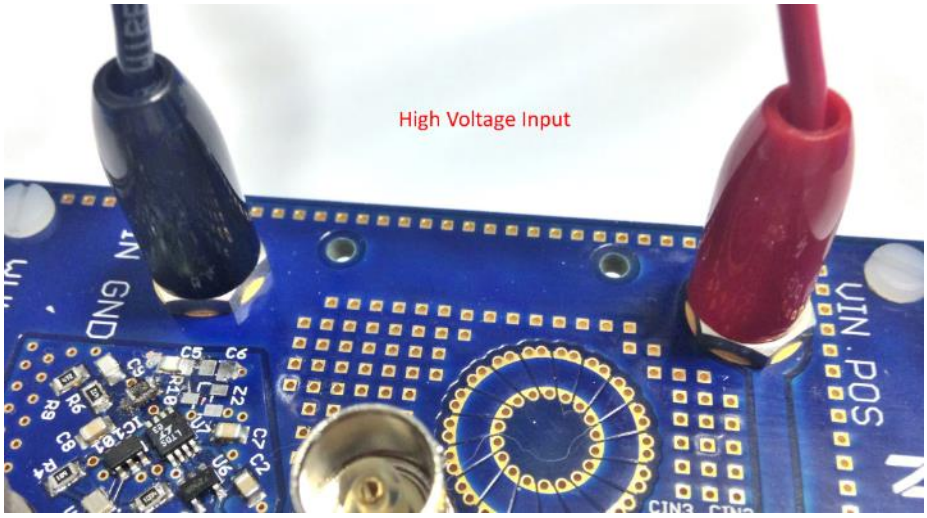
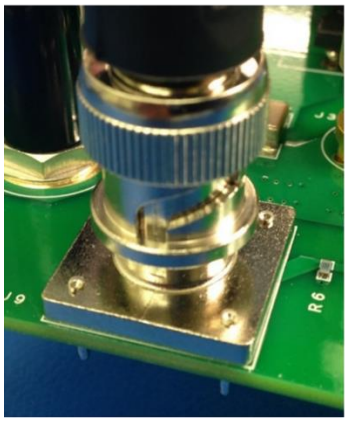
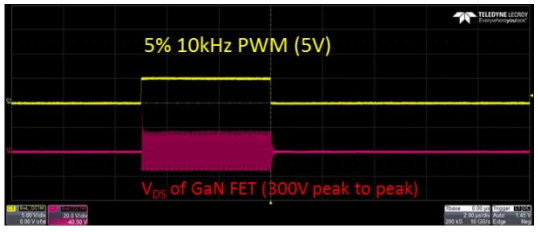


Fig. 4:
High voltage input connection.
Max 150V.





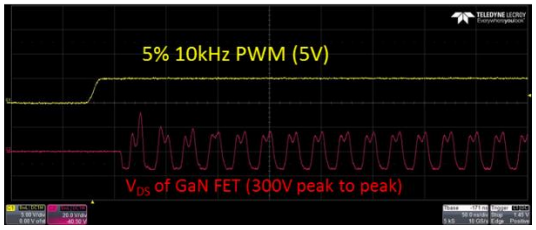


Fig. 5:
PWM signal generator connection.
Max 5% 10kHz

Fig. 6:
Probe location to measure FET V_{DS}

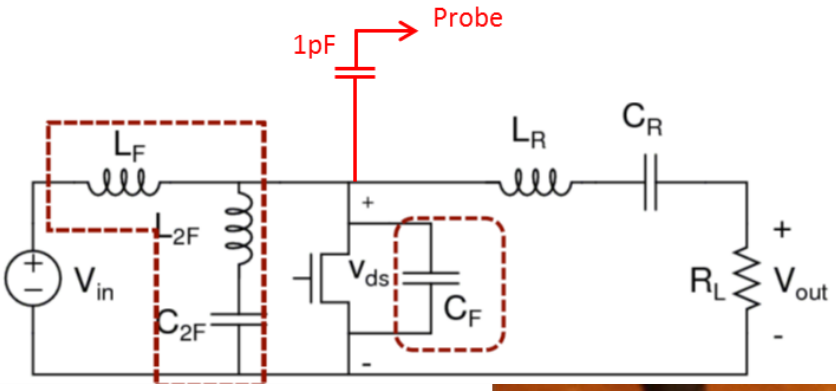


Fig. 7:
Probes:
Probe/BNC adapter (left) is preferred technique (cleaner waveform)

http://www.amazon.com/TEKTRONIX-013022600-PROBE-TIP-ADAPTER/dp/B00DJS6XLA

http://www.caltestelectronics.com/ctitem/35-35mm-probe-accessories/CT3655

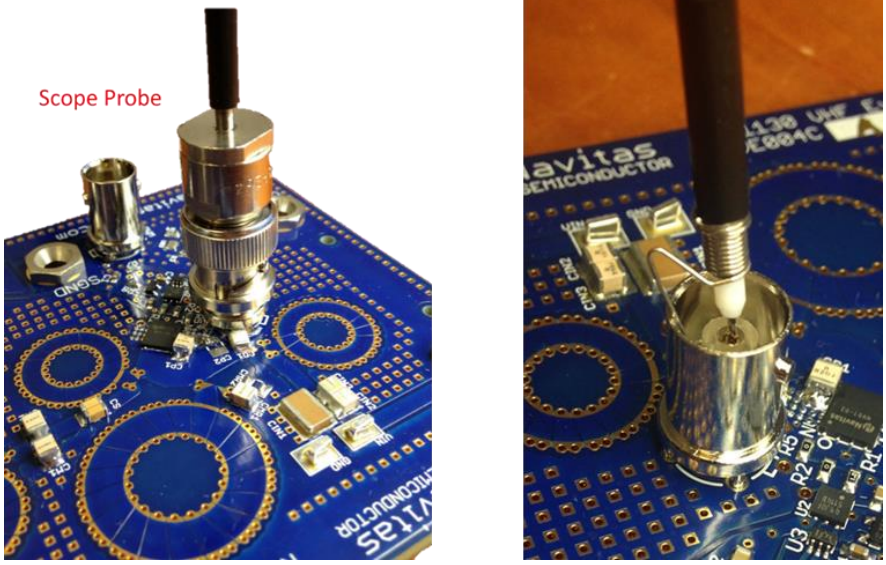


Fig. 8:
Probe capacitance interferences with resonant capacitor C_F if used directly to probe V_{DS}.

Use a 1pF decoupling capacitor to limit the overall probe impact to less than 1pF. The decoupling capacitor and probe capacitor form a capacitor network. The V_{DS} reading needs to be rescaled. At 150V_{IN}, V_{DS} peak to peak voltage should be around 320V. Due to the decoupling capacitor, the DC component of V_{DS} is removed. Use peak to peak voltage to judge V_{DS} magnitude. Note: the 50Ω load can be directly probed using a T-adaptor. No decoupling capacitor is needed.

Fig. 9: 27.12MHz board FET V_{DS} and Output waveforms

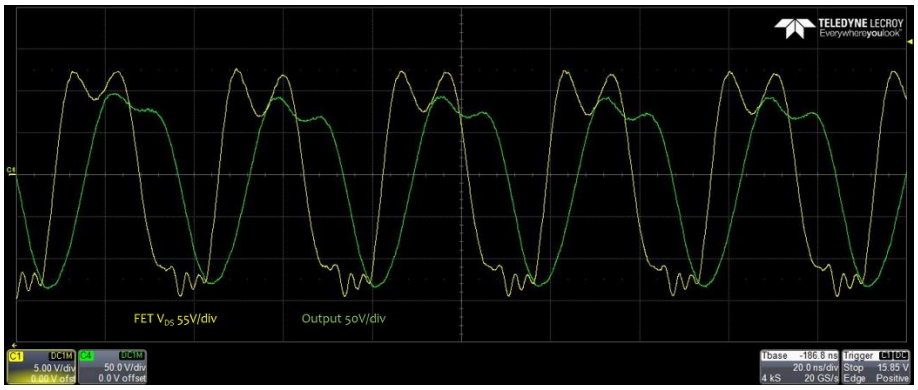


Fig. 10. Start-up.

Fig. 11: Pulse-modulated output power

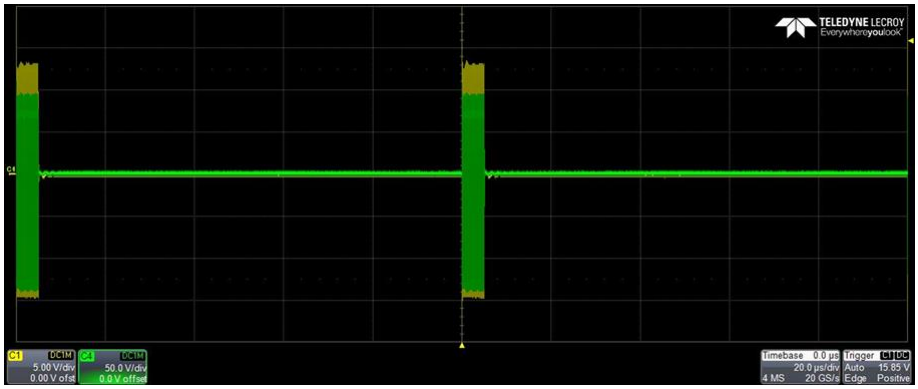


Fig. 12: Steady-state (V_{DS})

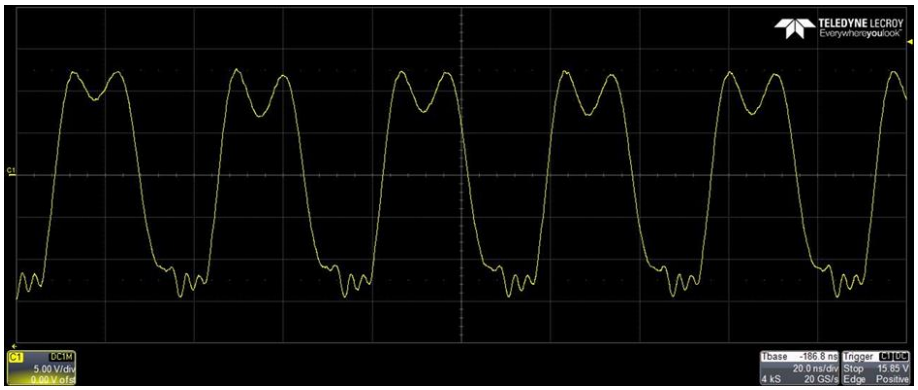


Fig. 13:
40MHz FET V_{DS} and Output waveforms

Fig. 14
V_{DS}

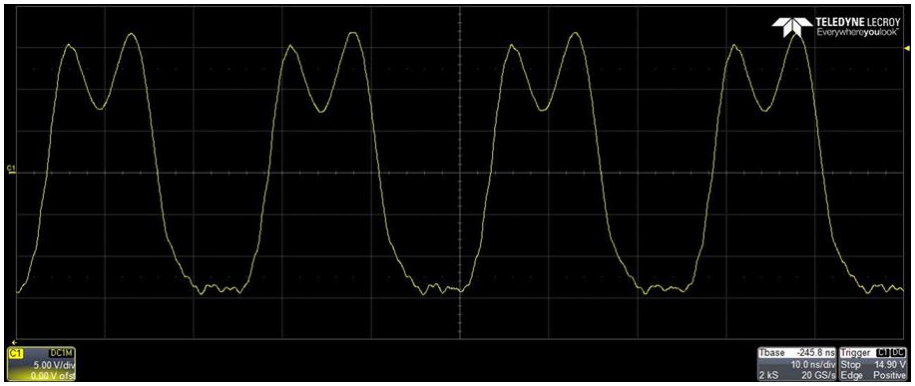


Fig. 15
Output

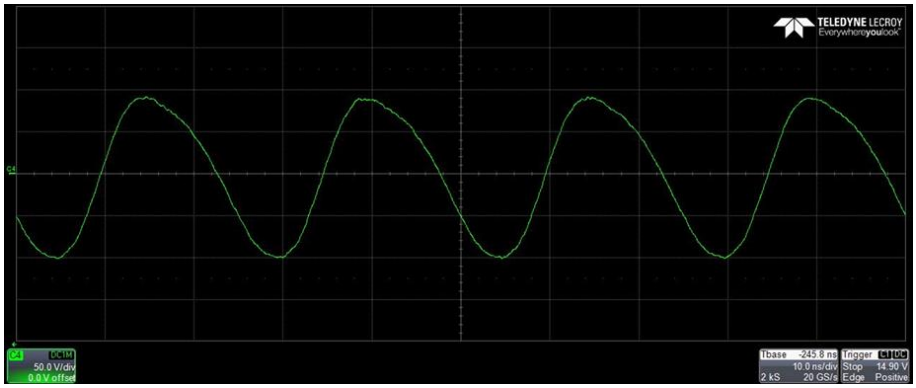


Fig. 16
Start-up
VDS, Output

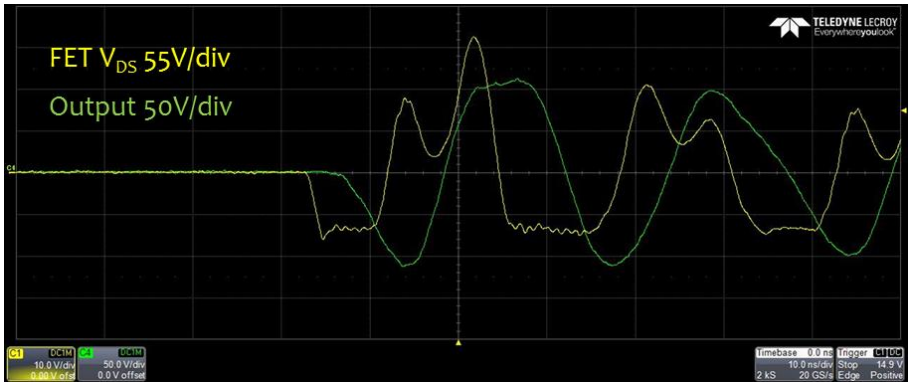
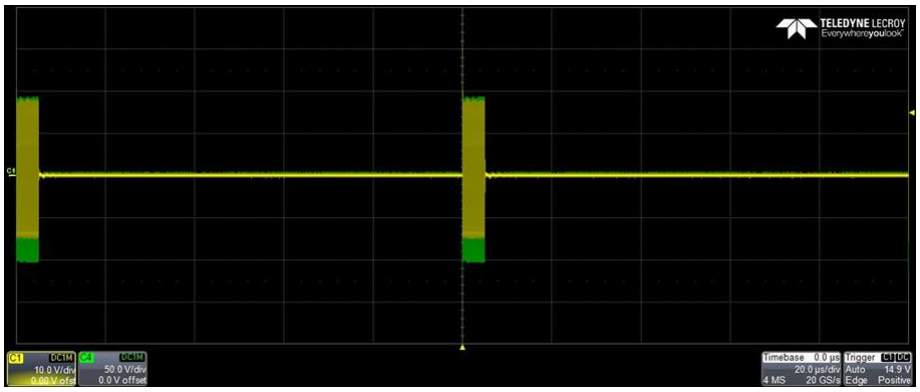


Fig. 17
Pulse-modulated output power



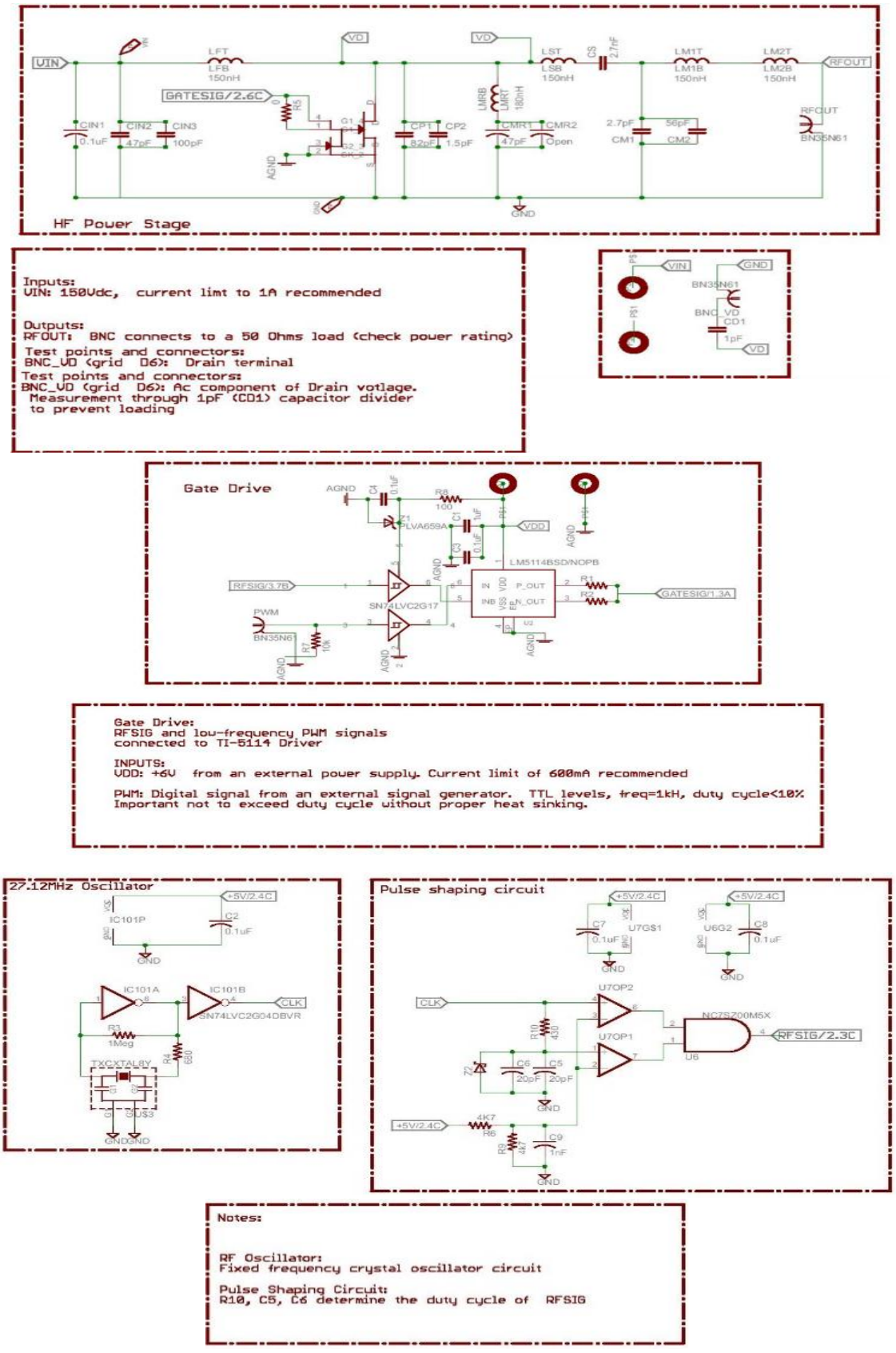
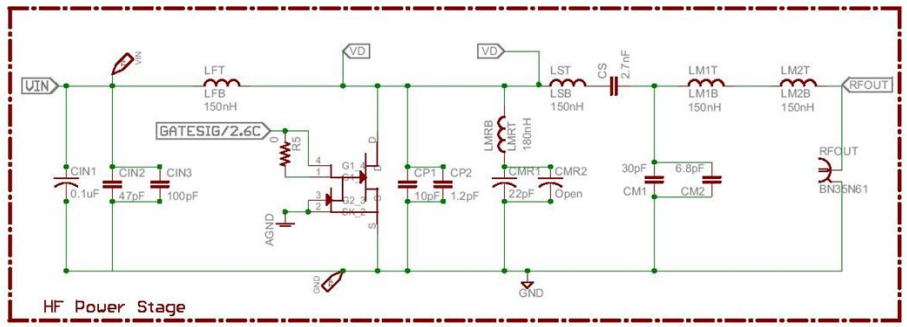


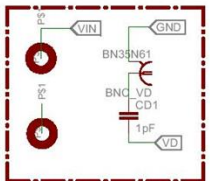
Fig. 18: NVE004C-A 27MHz Schematic

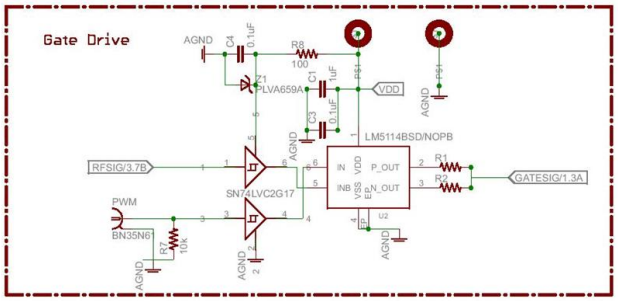
Fig. 19: NVE004C-B 40MHz Schematic



Inputs:
VIN: 150Vdc, current limt to 1A recommended

Outputs:
RFOUT: BNC connects to a 50 Ohms load (check power rating)
Test points and connectors:
BNC_VD (grid D6): Drain terminal
Test points and connectors:
BNC_VD (grid D6): Ac component of Drain votlage.
Measurement through 1pF (CD1) capacitor divider
to prevent loading

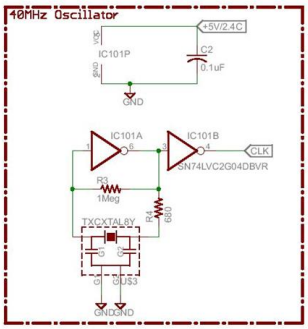


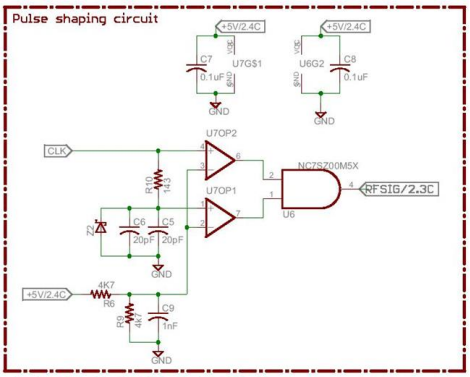


Gate Drive:
RFSIG and low-frequency PWM signals
connected to TI-5114 Driver

INPUTS:
VDD: +6V from an external power supply. Current limit of 600mA recommended

PWM: Digital signal from an external signal generator. TTL levels, freq=1kH, duty cycle<10%
Important not to exceed duty cycle without proper heat sinking.





Notes:

RF Oscillator:
Fixed frequency crystal oscillator circuit

Pulse Shaping Circuit:
R10, C5, C6 determine the duty cycle of RFSIG

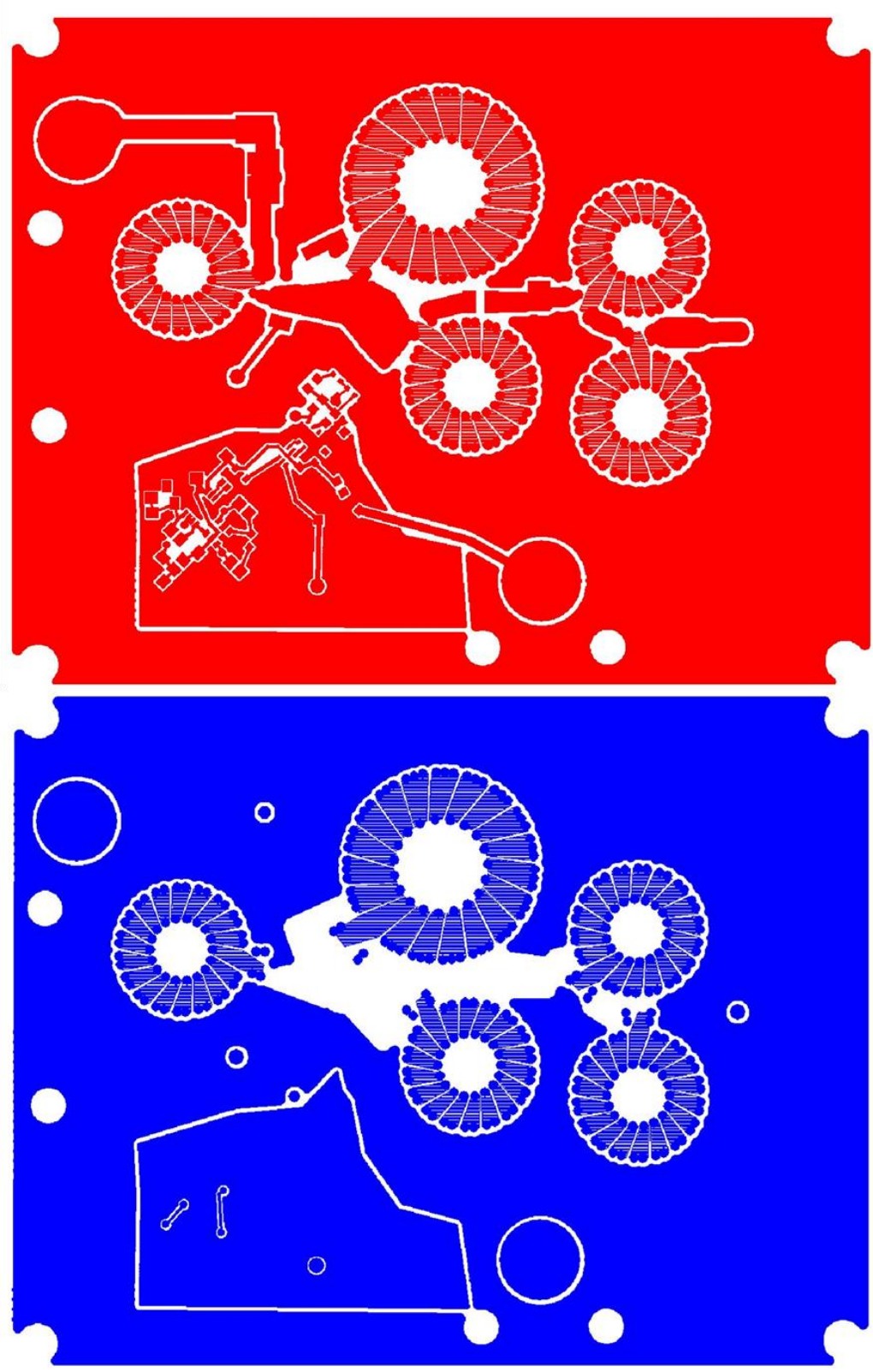


Fig. 20: PCB top and bottom layers

Fig 21: NVE004C-A 27MHz Bill OF Materials

Part	Value	Device	Package	Description	Manufacturer	Mr. Part No.
CIN1	0.1uF, 500V	C1825C104KCRACTU	1825	X7R Multi-layer Ceramic Capacitor	Kemet	C1825C104KCRACTU
CIN2	47pF	47pF RF Ceramic	C1210	HF Filtering	ATC	
CIN3	100pF	100pF RF Ceramic	C1210	HF Filtering	ATC	
CP1	82pF	20pF RF Ceramic	C1210	Paralell Tuning Capacitor	ATC	
CP2	1.5pF	1.5pF RF Ceramic	C1210	Paralell Tuning Capacitor	ATC	
CMR1	47pF	47pF RF Ceramic	C1210	2nd Harmonic Resonant Capacitor	ATC	
CMR2	None	None	C1210	2nd Harmonic Resonant Capacitor	ATC	
CM1	2.7pF	2.7pF RF Ceramic	C1210	Matching Network Capacitor	ATC	
CM2	56pF	56pF RF Ceramic	C1210	Matching Network Capacitor	ATC	
CD1	1.0pF	1.0pF RF Ceramic	C1210	Drain Measuring Point		
CS	2.7nF	C1210C272KCGACTU	C1210	Inverter Series Blocking Capacitor	Kemet	C1210C272KCGACTU
C1	1uF, 25V	GRM188R61E105KA12D	C0603	Ceramic Capacitor	Murata	GRM188R61E105KA12D
C2	0.1uF, 25V	C0805C104K3RACTU	C0805	Ceramic Capacitor	Kemet	C0805C104K3RACTU
C3	0.1uF, 25V	GRM188R71E104KA01D	C0603	Ceramic Capacitor	Murata	GRM188R71E104KA01D
C4	0.1uF, 25V	GRM188R71E104KA01D	C0603	Ceramic Capacitor	Murata	GRM188R71E104KA01D
C5	20pF, 16V	C0805C200J4GAC7800	C0805	Duty cycle control	Murata	C0805C200J4GAC7800
C6	20pF, 16V	C0805C200J4GAC7800	C0805	Duty cycle control	Murata	C0805C200J4GAC7800
C7	0.1uF, 25V	C0805C104K3RACTU	C0805	Ceramic Capacitor	Kemet	C0805C104K3RACTU
C8	0.1uF, 25V	C0805C104K3RACTU	C0805	Ceramic Capacitor	Kemet	C0805C104K3RACTU
C9	1nF, 25V	08053A102KAT2A	C0805	Ceramic Capacitor	Kemet	08053A102KAT2A
TP1		TPOINTMIN	TPSMDM	SMT/THM Test Point	Keystone Electronics	5015
TP2		TPOINTMIN	TPSMDM	SMT/THM Test Point	Keystone Electronics	5015
SGND				BANANA JACK		
VDD				BANANA JACK		
VIN GND				BANANA JACK		
VOUT GND				BANANA JACK		
Q1		NV1130	QFN	650V Mosfet	Navitas Semiconductor	
R1	1, 1/10w, 5%	ERJ-3RQF1R0V	R0603	Resistor	Panasonic	ERJ-3RQF1R0V
R2	0, 1/10w, 5%	ERJ-3GEY0R00V	R0603	Resistor	Panasonic	ERJ-3GEY0R00V
R3	1M, 1/8w, 5%	ERJ-6ENF1004V	R0805	Resistor	Panasonic	ERJ-6ENF1004V
R4	680, 1/8w, 5%	ERJ-6GEYJ681V	R0805	Resistor	Panasonic	ERJ-6GEYJ681V
R5	0, 1/10w, 5%	ERJ-3GEY0R00V	R0603	Resistor	Panasonic	ERJ-3GEY0R00V
R6	4k7, 1/8w, 5%	ERJ-6GEYJ472V	R0805	Resistor	Panasonic	ERJ-6GEYJ472V
R7	10k, 1/10w, 5%	ERJ-3GEYJ103V	R0603	Resistor	Panasonic	ERJ-3GEYJ103V
R8	100, 1/10w, 5%	ERJ-3GEYJ101V	R0603	Resistor	Panasonic	ERJ-3GEYJ101V
R9	4k7, 1/8w, 5%	ERJ-6GEYJ472V	R0805	Resistor	Panasonic	ERJ-6GEYJ472V
R10	430, 1/8w, 5%	ERJ-6GEYJ431V	R0805	Resistor	Panasonic	ERJ-6GEYJ431V
RFOUT	Female BNC	5-1634503-1	BNC	RF for 50 OHM Load	TE Connectivity AMP Connectors	5-1634503-1
PWM	Female BNC	5-1634503-1	BNC	PWM Input	TE Connectivity AMP Connectors	5-1634503-1
Drain	Female BNC	5-1634503-1	BNC	Drain Measuring Point	TE Connectivity AMP Connectors	5-1634503-1
Z1		PLVA650A,215	SOT23	5.0 Zener Diode 250mW	NXP Semiconductors	PLVA650A,215
Z2		None				
U2		LM5114BSD/NOPB	6-WDFN	MOSFET Driver	Texas Instruments	LM5114BSD/NOPB
U3		SN74LVC2G17	SC70	Dual Buffer	Texas Instruments	SN74LVC2G17
IC101		SN74LVC2G04DBVR	SOT23	Dual Inverter	Texas Instruments	SN74LVC2G04DBVR
U$3		8Y-27.120MEEQ-T		Clock	TXC	8Y-27.120MEEQ-T
U6		NC7SZ00M5X	SOT23-5	NAND	Fairchild	NC7SZ00M5X
U7		LT1720CMS8#PBF	8-MSOP	Rail-Rail Comparitor	Linear	LT1720CMS8#PBF

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CIN2	47pF	47pF RF Ceramic	C1210	HF Filtering	ATC	
CIN3	100pF	100pF RF Ceramic	C1210	HF Filtering	ATC	
CP1	10pF	10pF RF Ceramic	C1210	Paralell Tuning Capacitor	ATC	
CP2	1.2pF	1.2pF RF Ceramic	C1210	Paralell Tuning Capacitor	ATC	
CMR1	22pF	22pF RF Ceramic	C1210	2nd Harmonic Resonant Capacitor	ATC	
CMR2	Open	Open	C1210	2nd Harmonic Resonant Capacitor	ATC	
CM1	30pF	30pF RF Ceramic	C1210	Matching Network Capacitor	ATC	
CM2	6.8pF	6.8pF RF Ceramic	C1210	Matching Network Capacitor	ATC	
CD1	1.0pF	1.0pF RF Ceramic	C1210	Drain Measuring Point		
CS	2.7nF	C1210C272KCGACTU	C1210	Inverter Series Blocking Capacitor	Kemet	C1210C272KCGACTU
C1	1uF, 25V	GRM188R61E105KA12D	C0603	Ceramic Capacitor	Murata	GRM188R61E105KA12D
C2	0.1uF, 25V	C0805C104K3RACTU	C0805	Ceramic Capacitor	Kemet	C0805C104K3RACTU
C3	0.1uF, 25V	GRM188R71E104KA01D	C0603	Ceramic Capacitor	Murata	GRM188R71E104KA01D
C4	0.1uF, 25V	GRM188R71E104KA01D	C0603	Ceramic Capacitor	Murata	GRM188R71E104KA01D
C5	20pF, 16V	C0805C200J4GAC7800	C0805	Duty cycle control	Murata	C0805C200J4GAC7800
C6	20pF, 16V	C0805C200J4GAC7800	C0805	Duty cycle control	Murata	C0805C200J4GAC7800
C7	0.1uF, 25V	C0805C104K3RACTU	C0805	Ceramic Capacitor	Kemet	C0805C104K3RACTU
C8	0.1uF, 25V	C0805C104K3RACTU	C0805	Ceramic Capacitor	Kemet	C0805C104K3RACTU
C9	1nF, 25V	08053A102KAT2A	C0805	Ceramic Capacitor	Kemet	08053A102KAT2A
TP1		TPOINTMIN	TPSMDM	SMT/THM Test Point	Keystone Electronics	5015
TP2		TPOINTMIN	TPSMDM	SMT/THM Test Point	Keystone Electronics	5015
SGND				BANANA JACK		
VDD				BANANA JACK		
VIN GND				BANANA JACK		
VOUT GND				BANANA JACK		
Q1		NV1130	QFN	650V Mosfet	Navitas Semiconductor	
R1	1, 1/10w, 5%	ERJ-3RQF1R0V	R0603	Resistor	Panasonic	ERJ-3RQF1R0V
R2	0, 1/10w, 5%	ERJ-3GEY0R00V	R0603	Resistor	Panasonic	ERJ-3GEY0R00V
R3	1M, 1/8w, 5%	ERJ-6ENF1004V	R0805	Resistor	Panasonic	ERJ-6ENF1004V
R4	680, 1/8w, 5%	ERJ-6GEYJ681V	R0805	Resistor	Panasonic	ERJ-6GEYJ681V
R5	0, 1/10w, 5%	ERJ-3GEY0R00V	R0603	Resistor	Panasonic	ERJ-3GEY0R00V
R6	4k7, 1/8w, 5%	ERJ-6GEYJ472V	R0805	Resistor	Panasonic	ERJ-6GEYJ472V
R7	10k, 1/10w, 5%	ERJ-3GEYJ103V	R0603	Resistor	Panasonic	ERJ-3GEYJ103V
R8	100, 1/10w, 5%	ERJ-3GEYJ101V	R0603	Resistor	Panasonic	ERJ-3GEYJ101V
R9	4k7, 1/8w, 5%	ERJ-6GEYJ472V	R0805	Resistor	Panasonic	ERJ-6GEYJ472V
R10	143, 1/8w, 5%	ERJ-6ENF1430V	R0805	Duty cycle control	Panasonic	ERJ-6ENF1430V
RFOUT	Female BNC	5-1634503-1	BNC	RF for 50 OHM Load	TE Connectivity AMP Connectors	5-1634503-1
PWM	Female BNC	5-1634503-1	BNC	PWM Input	TE Connectivity AMP Connectors	5-1634503-1
Drain	Female BNC	5-1634503-1	BNC	Drain Measuring Point	TE Connectivity AMP Connectors	5-1634503-1
Z1		PLVA650A,215	SOT23	5.0 Zener Diode 250mW	NXP Semiconductors	PLVA650A,215
Z2		TBD				
U2		LM5114BSD/NOPB	6-WDFN	MOSFET Driver	Texas Instruments	LM5114BSD/NOPB
U3		SN74LVC2G17	SC70	Dual Buffer	Texas Instruments	SN74LVC2G17
IC101		SN74LVC2G04DBVR	SOT23	Dual Inverter	Texas Instruments	SN74LVC2G04DBVR
U$3		8Y-40.000MAAV-T		Clock	TXC	8Y-40.000MAAV-T
U6		NC7SZ00M5X	SOT23-5	NAND	Fairchild	NC7SZ00M5X
U7		LT1720CMS8#PBF	8-MSOP	Rail-Rail Comparitor	Linear	LT1720CMS8#PBF