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FSFR-Series — Fairchild Power Switch (FPS™) for Half-Bridge Resonant Converters

Features

- Variable Frequency Control with 50% Duty Cycle for Half-bridge Resonant Converter Topology
- High Efficiency through Zero Voltage Switching (ZVS)
- Internal UniFET™s with Fast-Recovery Type Body Diode ($t_r < 160\text{ns}$).
- Fixed Dead Time (350ns) Optimized for MOSFETs
- Up to 300kHz Operating Frequency
- Pulse Skipping for Frequency Limit (Programmable) at Light-Load Condition
- Remote On/Off Control Using Control Pin
- Protection Functions: Over-Voltage Protection (OVP), Over-Load Protection (OLP), Over-Current Protection (OCP), Abnormal Over-Current Protection (AOCP), Internal Thermal Shutdown (TSD)

Applications

- PDP and LCD TVs
- Desktop PCs and Servers
- Adapters
- Telecom Power Supplies
- Audio Power Supplies

Description

The FSFR-series include highly integrated power switches designed for high-efficiency half-bridge resonant converters. Offering everything necessary to build a reliable and robust resonant converter, the FSFR-series simplifies designs and improves productivity, while improving performance. The FSFR-series combines power MOSFETs with fast-recovery type body diodes, a high-side gate-drive circuit, an accurate current controlled oscillator, frequency limit circuit, soft-start, and built-in protection functions. The high-side gate-drive circuit has a common-mode noise cancellation capability, which guarantees stable operation with excellent noise immunity. The fast-recovery body diode of the MOSFETs improves reliability against abnormal operation conditions, while minimizing the effect of the reverse recovery. Using the zero-voltage-switching (ZVS) technique dramatically reduces the switching losses and efficiency is significantly improved. The ZVS also reduces the switching noise noticeably, which allows a small-sized Electromagnetic Interference (EMI) filter.

The FSFR-series can be applied to various resonant converter topologies, such as: series resonant, parallel resonant, and LLC resonant converters.

Related Resources

[AN-4151 — Half-Bridge LLC Resonant Converter Design Using FSFR-Series Fairchild Power Switch \(FPS™\)](#)

Ordering Information

Part Number	Package	Operating Junction Temperature	$R_{DS(ON_MAX)}$	Maximum Output Power without Heatsink ($V_{IN}=350\sim400V$) ^(1,2)	Maximum Output Power with Heatsink ($V_{IN}=350\sim400V$) ^(1,2)
FSFR2100U	9-SIP	-40 to +130°C	0.51Ω	180W	400W
FSFR2000			0.67Ω	160W	350W
FSFR1900			0.85Ω	140W	300W
FSFR1800			0.95Ω	120W	260W
FSFR1700			1.25Ω	100W	200W
FSFR1600			1.55Ω	80W	160W
FSFR1800L	9-SIP(L-Forming)	-40 to +130°C	0.95Ω	120W	260W
FSFR1700L			1.25Ω	100W	200W
FSFR1600L			1.55Ω	80W	160W

Notes:

- The junction temperature can limit the maximum output power.
- Maximum practical continuous power in an open-frame design at 50°C ambient.

Application Circuit Diagram

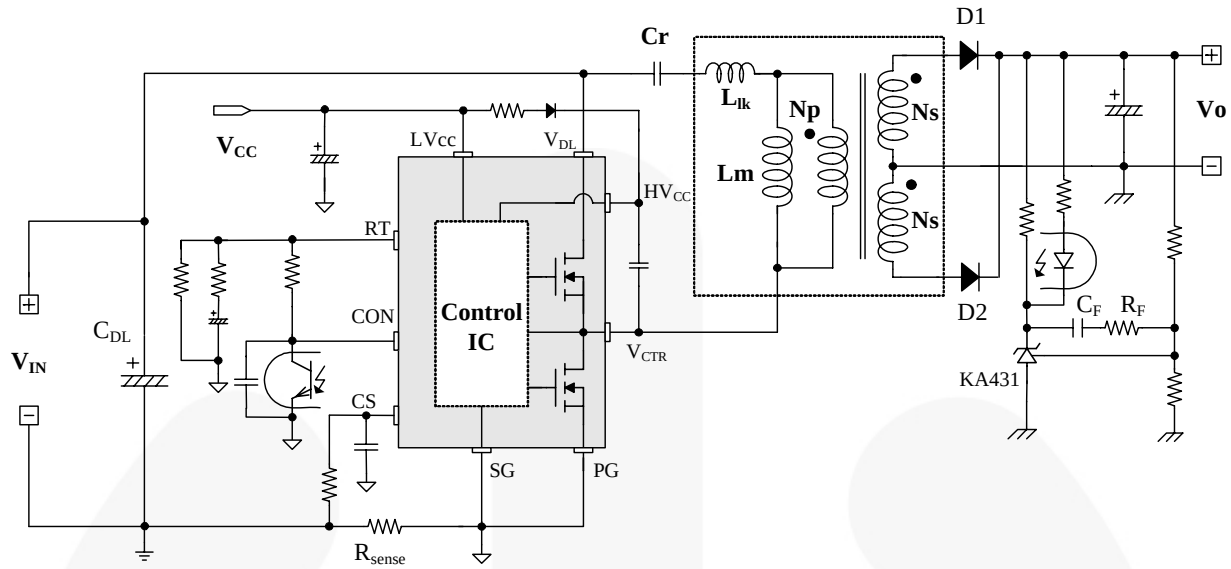


Figure 1. Typical Application Circuit (LLC Resonant Half-Bridge Converter)

Block Diagram

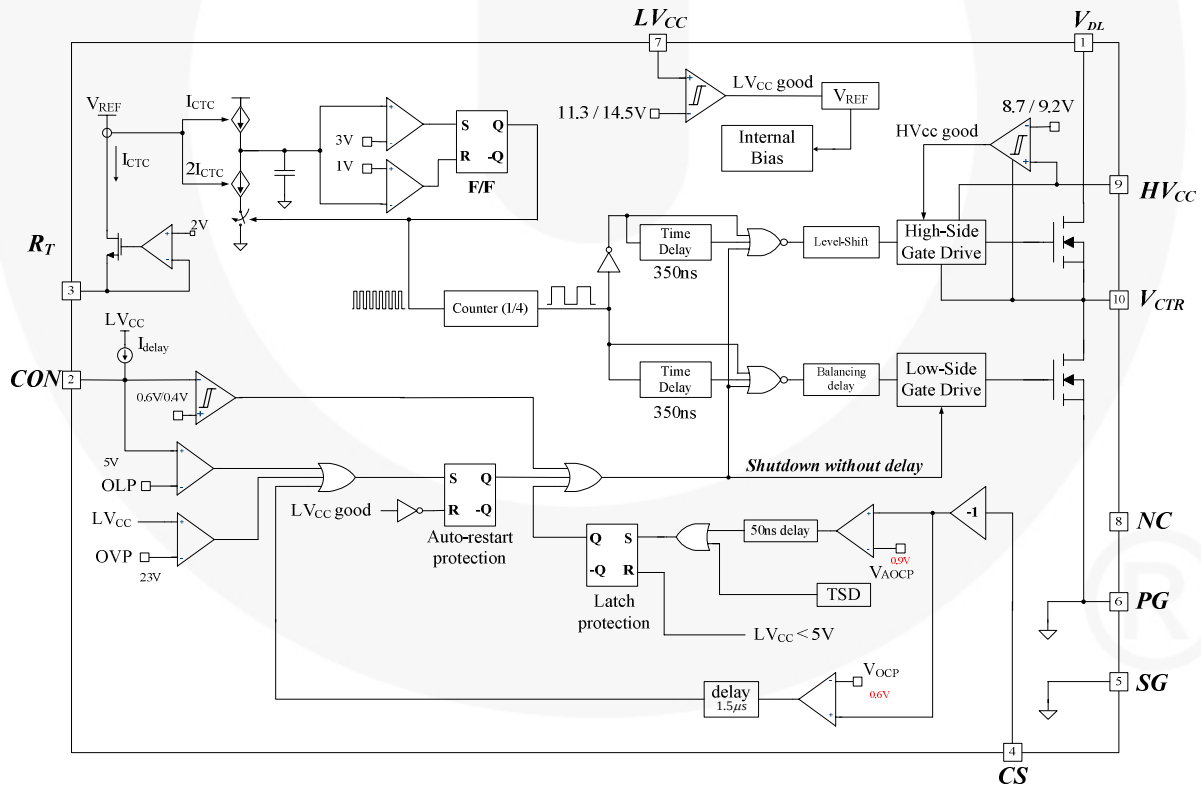


Figure 2. Internal Block Diagram

Pin Configuration

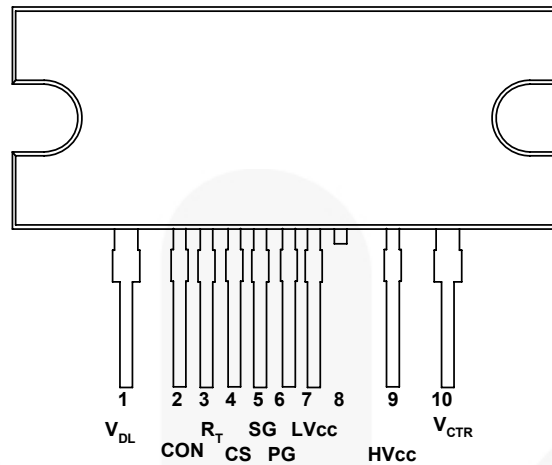


Figure 3. Package Diagram

Pin Definitions

Pin #	Name	Description
1	V_{DL}	This is the drain of the high-side MOSFET, typically connected to the input DC link voltage.
2	CON	This pin is for enable/disable and protection. When the voltage of this pin is above 0.6V, the IC operation is enabled. When the voltage of this pin drops below 0.4V, gate drive signals for both MOSFETs are disabled. When the voltage of this pin increases above 5V, protection is triggered.
3	R_T	This pin programs the switching frequency. Typically, an opto-coupler is connected to control the switching frequency for the output voltage regulation.
4	CS	This pin senses the current flowing through the low-side MOSFET. Typically, negative voltage is applied on this pin.
5	SG	This pin is the control ground.
6	PG	This pin is the power ground. This pin is connected to the source of the low-side MOSFET.
7	LV_{CC}	This pin is the supply voltage of the control IC.
8	NC	No connection.
9	HV_{CC}	This is the supply voltage of the high-side gate-drive circuit IC.
10	V_{CTR}	This is the drain of the low-side MOSFET. Typically, a transformer is connected to this pin.

Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only. $T_A=25^{\circ}\text{C}$ unless otherwise specified.

Symbol	Parameter	Min.	Max.	Unit
V_{DS}	Maximum Drain-to-Source Voltage ($V_{DL}-V_{CTR}$ and $V_{CTR}-PG$)	500		V
LV_{CC}	Low-Side Supply Voltage	-0.3	25.0	V
HV_{CC} to V_{CTR}	High-Side V_{CC} Pin to Low-Side Drain Voltage	-0.3	25.0	V
HV_{CC}	High-Side Floating Supply Voltage	-0.3	525.0	V
V_{CON}	Control Pin Input Voltage	-0.3	LV_{CC}	V
V_{CS}	Current Sense (CS) Pin Input Voltage	-5.0	1.0	V
V_{RT}	R_T Pin Input Voltage	-0.3	5.0	V
dV_{CTR}/dt	Allowable Low-Side MOSFET Drain Voltage Slew Rate		50	V/ns
P_D	Total Power Dissipation ⁽³⁾	FSFR2100U	12.0	W
		FSFR2000	12.0	
		FSFR1900	11.8	
		FSFR1800	11.7	
		FSFR1700	11.6	
		FSFR1600	11.5	
T_J	Maximum Junction Temperature ⁽⁴⁾		+150	$^{\circ}\text{C}$
	Recommended Operating Junction Temperature ⁽⁴⁾	-40	+130	
T_{STG}	Storage Temperature Range	-55	+150	$^{\circ}\text{C}$
MOSFET Section				
V_{DGR}	Drain Gate Voltage ($R_{GS}=1\text{M}\Omega$)	500		V
V_{GS}	Gate Source (GND) Voltage		± 30	V
I_{DM}	Drain Current Pulsed ⁽⁵⁾	FSFR2100U	32	A
		FSFR2000	31	
		FSFR1900	26	
		FSFR1800	23	
		FSFR1700	20	
		FSFR1600	18	

Continued on the following page...

Absolute Maximum Ratings (Continued)

Symbol	Parameter		Min.	Max.	Unit	
MOSFET Section (Continued)						
I _D	Continuous Drain Current	FSFR2100U	T _C =25°C		10.5	A
			T _C =100°C		6.5	
		FSFR2000	T _C =25°C		9.5	
			T _C =100°C		6.0	
		FSFR1900	T _C =25°C		8.0	
			T _C =100°C		5.0	
		FSFR1800	T _C =25°C		7.0	
			T _C =100°C		4.5	
		FSFR1700	T _C =25°C		6.0	
			T _C =100°C		3.9	
		FSFR1600	T _C =25°C		4.5	
			T _C =100°C		2.7	
Package Section						
Torque	Recommended Screw Torque		5~7		kgf·cm	

Notes:

- Per MOSFET when both MOSFETs are conducting.
- The maximum value of the recommended operating junction temperature is limited by thermal shutdown.
- Pulse width is limited by maximum junction temperature.

Thermal Impedance

T_A=25°C unless otherwise specified.

Symbol	Parameter		Value	Unit
θ _{JC}	Junction-to-Case Center Thermal Impedance (Both MOSFETs Conducting)	FSFR2100U	10.44	°C/W
		FSFR2000	10.44	
		FSFR1900	10.56	
		FSFR1800	10.68	
		FSFR1700	10.79	
		FSFR1600	10.89	

Electrical Characteristics

T_A=25°C unless otherwise specified.

Symbol	Parameter		Test Conditions	Min.	Typ.	Max.	Unit
MOSFET Section							
BV _{DSS}	Drain-to-Source Breakdown Voltage		I _D =200μA, T _A =25°C	500			V
			I _D =200μA, T _A =125°C		540		
R _{DS(ON)}	On-State Resistance	FSFR2100U	V _{GS} =10V, I _D =6.0A		0.41	0.51	Ω
		FSFR2000	V _{GS} =10V, I _D =5.0A		0.53	0.67	
		FSFR1900	V _{GS} =10V, I _D =4.0A		0.74	0.85	
		FSFR1800	V _{GS} =10V, I _D =3.0A		0.77	0.95	
		FSFR1700	V _{GS} =10V, I _D =2.0A		1.00	1.25	
		FSFR1600	V _{GS} =10V, I _D =2.25A		1.25	1.55	
t _{rr}	Body Diode Reverse Recovery Time ⁽⁶⁾		di _{Diode} /dt=100A/μs				ns
		FSFR2100U	V _{GS} =0V, I _{Diode} =12.0A		120		
		FSFR2000	V _{GS} =0V, I _{Diode} =9.5A		125		
		FSFR1900	V _{GS} =0V, I _{Diode} =8.0A		140		
		FSFR1800	V _{GS} =0V, I _{Diode} =7.0A		160		
		FSFR1700	V _{GS} =0V, I _{Diode} =6.0A		160		
		FSFR1600	V _{GS} =0V, I _{Diode} =5.0A		65		
Supply Section							
I _{LK}	Offset Supply Leakage Current	H-V _{CC} =V _{CTR} =600V/500V				50	μA
I _{QHVCC}	Quiescent HV _{CC} Supply Current	(HV _{CC} UV+) - 0.1V			50	120	μA
I _{QLVCC}	Quiescent LV _{CC} Supply Current	(LV _{CC} UV+) - 0.1V			100	200	μA
I _{OHVCC}	Operating HV _{CC} Supply Current (RMS Value)	f _{OSC} =100KHz, V _{CON} > 0.6V			6	9	mA
		No Switching, V _{CON} < 0.4V			100	200	μA
I _{OLVCC}	Operating LV _{CC} Supply Current (RMS Value)	f _{OSC} =100KHz, V _{CON} > 0.6V			7	11	mA
		No Switching, V _{CON} < 0.4V			2	4	mA

Continued on the following page...

Electrical Characteristics (Continued)

T_A=25°C unless otherwise specified.

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
UVLO Section						
LV _{CC} UV+	LV _{CC} Supply Under-Voltage Positive Going Threshold (LV _{CC} Start)		13.0	14.5	16.0	V
LV _{CC} UV-	LV _{CC} Supply Under-Voltage Negative Going Threshold (LV _{CC} Stop)		10.2	11.3	12.4	V
LV _{CC} UVH	LV _{CC} Supply Under-Voltage Hysteresis			3.2		V
HV _{CC} UV+	HV _{CC} Supply Under-Voltage Positive Going Threshold (HV _{CC} Start)		8.2	9.2	10.2	V
HV _{CC} UV-	HV _{CC} Supply Under-Voltage Negative Going Threshold (HV _{CC} Stop)		7.8	8.7	9.6	V
HV _{CC} UVH	HV _{CC} Supply Under-Voltage Hysteresis			0.5		V
Oscillator & Feedback Section						
V _{CONDIS}	Control Pin Disable Threshold Voltage		0.36	0.40	0.44	V
V _{CONEN}	Control Pin Enable Threshold Voltage		0.54	0.60	0.66	V
V _{RT}	V-I Converter Threshold Voltage	R _T =5.2KΩ	1.5	2.0	2.5	V
f _{OSC}	Output Oscillation Frequency		94	100	106	KHz
DC	Output Duty Cycle		48	50	52	%
f _{SS}	Internal Soft-Start Initial Frequency	f _{SS} =f _{OSC} +40kHz, R _T =5.2KΩ		140		KHz
t _{SS}	Internal Soft-Start Time		2	3	4	ms
Protection Section						
I _{OLP}	OLP Delay Current	V _{CON} =4V	3.6	4.8	6.0	μA
V _{OLP}	OLP Protection Voltage	V _{CON} > 3.5V	4.5	5.0	5.5	V
V _{OV}	LV _{CC} Over-Voltage Protection	L-V _{CC} > 21V	21	23	25	V
V _{AOCP}	AOCP Threshold Voltage	ΔV/Δt=-0.1V/μs	-1.0	-0.9	-0.8	V
t _{BAO}	AOCP Blanking Time ⁽⁶⁾	V _{CS} < V _{AOCP} ; ΔV/Δt=-0.1V/μs		50		ns
V _{OCP}	OCP Threshold Voltage	V/Δt=-1V/μs	-0.64	-0.58	-0.52	V
t _{BO}	OCP Blanking Time ⁽⁶⁾	V _{CS} < V _{OCP} ; ΔV/Δt=-1V/μs	1.0	1.5	2.0	μs
t _{DA}	Delay Time (Low Side) Detecting from V _{AOCP} to Switch Off ⁽⁶⁾	ΔV/Δt=-1V/μs		250	400	ns
T _{SD}	Thermal Shutdown Temperature ⁽⁶⁾		110	130	150	°C
I _{SU}	Protection Latch Sustain LV _{CC} Supply Current	LV _{CC} =7.5V		100	150	μA
V _{PRSET}	Protection Latch Reset LV _{CC} Supply Voltage		5			V
Dead-Time Control Section						
D _T	Dead Time ⁽⁷⁾			350		ns

Notes:

6. This parameter, although guaranteed, is not tested in production.
7. These parameters, although guaranteed, are tested only in EDS (wafer test) process.

Typical Performance Characteristics

These characteristic graphs are normalized at $T_A=25^\circ\text{C}$.

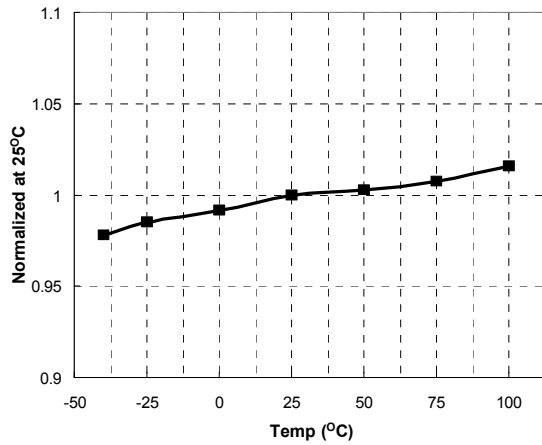


Figure 4. Low-Side MOSFET Duty Cycle vs. Temperature

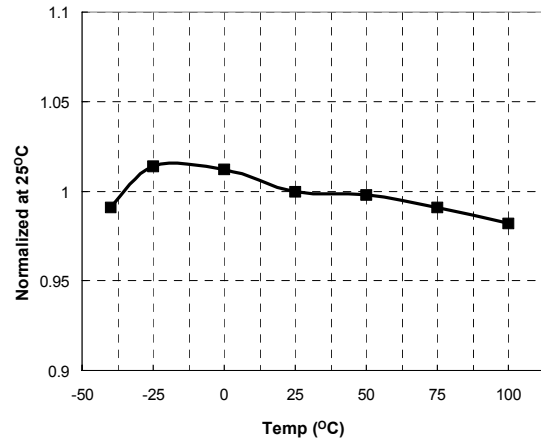


Figure 5. Switching Frequency vs. Temperature

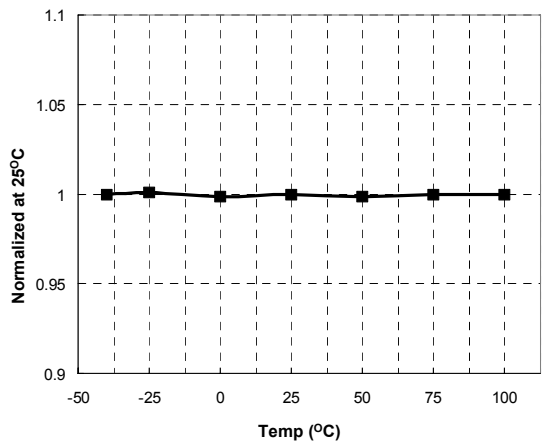


Figure 6. High-Side V_{CC} (HV_{CC}) Start vs. Temperature

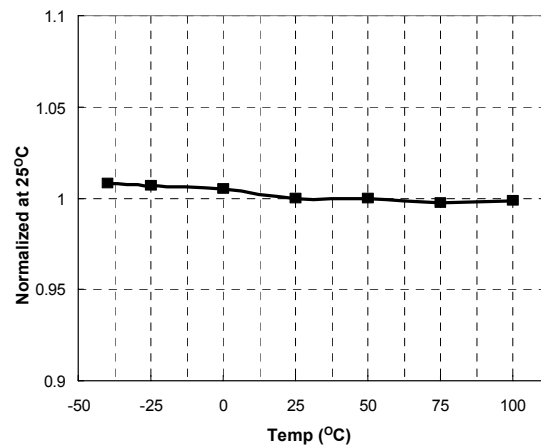


Figure 7. High-Side V_{CC} (HV_{CC}) Stop vs. Temperature

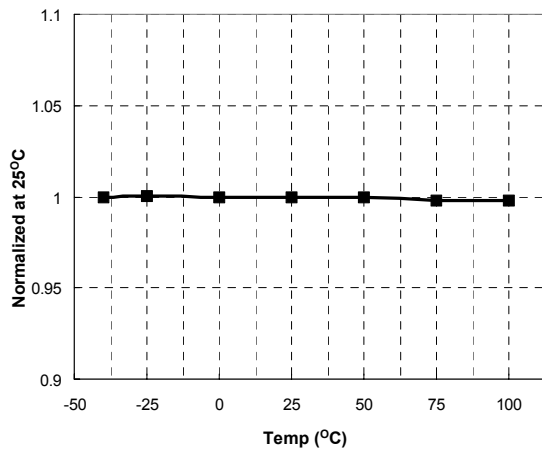


Figure 8. Low-Side V_{CC} (LV_{CC}) Start vs. Temperature

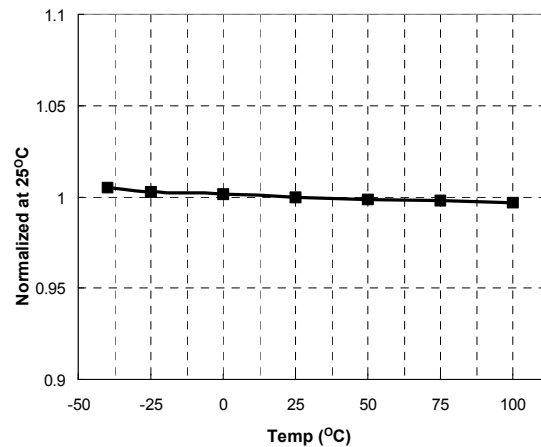


Figure 9. Low-Side V_{CC} (LV_{CC}) Stop vs. Temperature

Typical Performance Characteristics (Continued)

These characteristic graphs are normalized at $T_A=25^\circ\text{C}$.

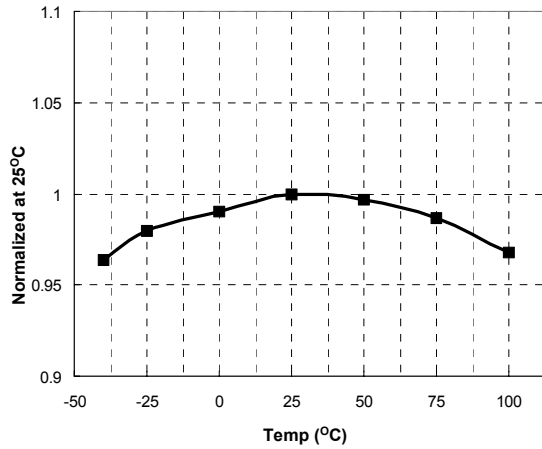


Figure 10. OLP Delay Current vs. Temperature

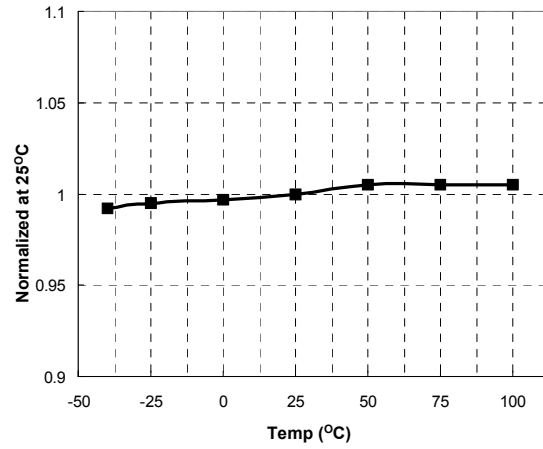


Figure 11. OLP Protection Voltage vs. Temperature

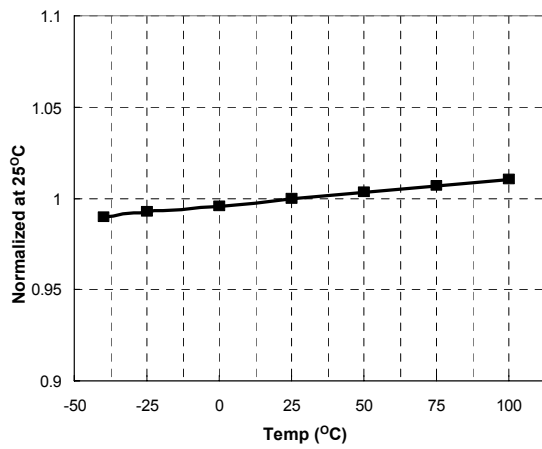


Figure 12. LVCC OVP Voltage vs. Temperature

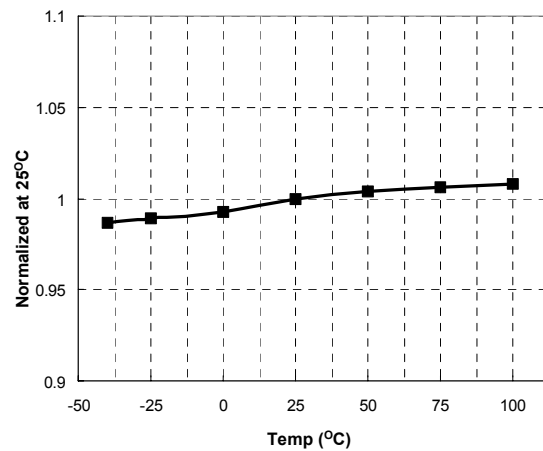


Figure 13. R_T Voltage vs. Temperature

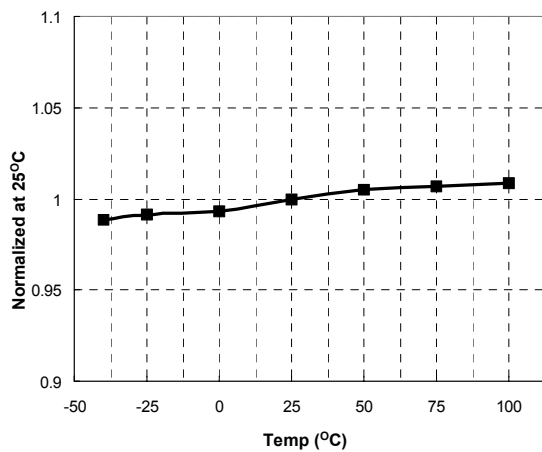


Figure 14. CON Pin Enable Voltage vs. Temperature

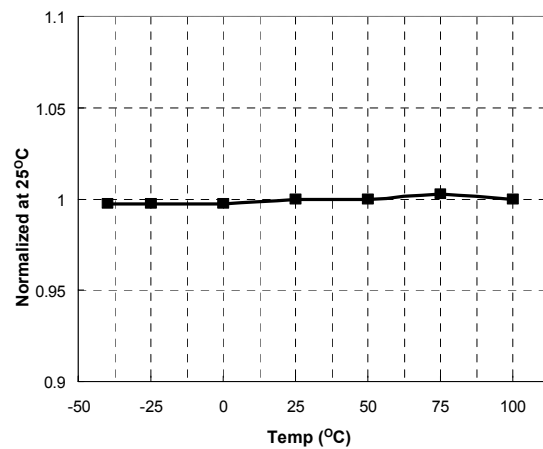


Figure 15. OCP Voltage vs. Temperature

Functional Description

1. Basic Operation: FSFR-series is designed to drive high-side and low-side MOSFETs complementarily with 50% duty cycle. A fixed dead time of 350ns is introduced between consecutive transitions, as shown in Figure 16.

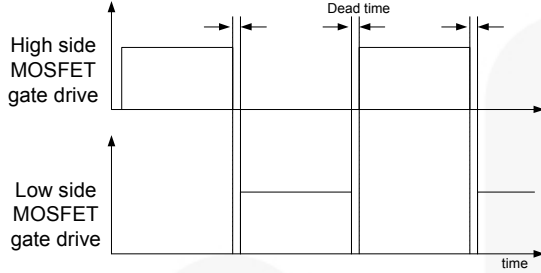


Figure 16. MOSFETs Gate Drive Signal

2. Internal Oscillator: FSFR-series employs a current-controlled oscillator, as shown in Figure 17. Internally, the voltage of R_T pin is regulated at 2V and the charging/discharging current for the oscillator capacitor, C_T , is obtained by copying the current flowing out of R_T pin (I_{CTC}) using a current mirror. Therefore, the switching frequency increases as I_{CTC} increases.

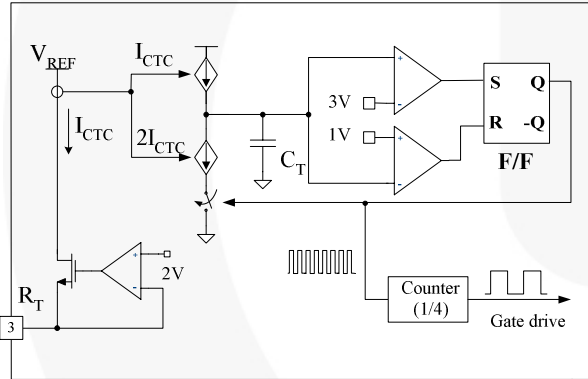


Figure 17. Current Controlled Oscillator

3. Frequency Setting: Figure 18 shows the typical voltage gain curve of a resonant converter, where the gain is inversely proportional to the switching frequency in the ZVS region. The output voltage can be regulated by modulating the switching frequency. Figure 19 shows the typical circuit configuration for R_T pin, where the opto-coupler transistor is connected to the R_T pin to modulate the switching frequency.

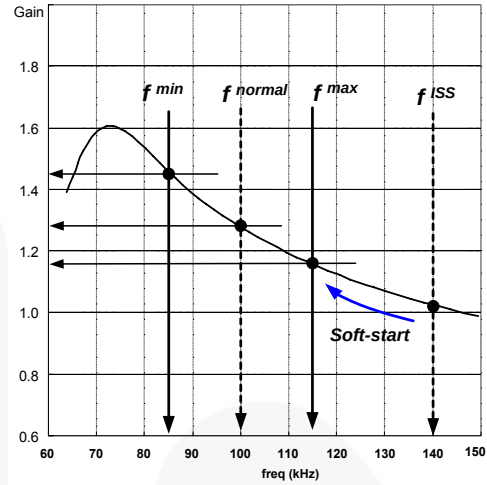


Figure 18. Resonant Converter Typical Gain Curve

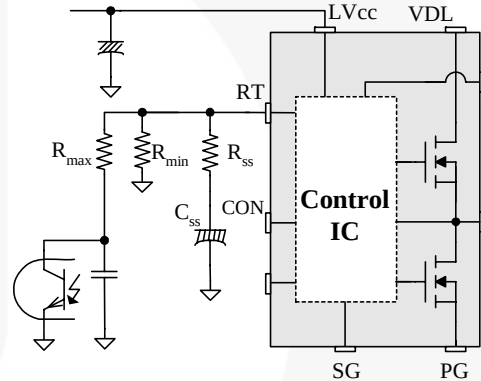


Figure 19. Frequency Control Circuit

The minimum switching frequency is determined as:

$$f_{\min} = \frac{5.2k\Omega}{R_{\min}} \times 100(\text{kHz}) \quad (1)$$

Assuming the saturation voltage of opto-coupler transistor is 0.2V, the maximum switching frequency is determined as:

$$f_{\max} = \left(\frac{5.2k\Omega}{R_{\min}} + \frac{4.68k\Omega}{R_{\max}} \right) \times 100(\text{kHz}) \quad (2)$$

To prevent excessive inrush current and overshoot of output voltage during startup, increase the voltage gain of the resonant converter progressively. Since the voltage gain of the resonant converter is inversely proportional to the switching frequency, the soft-start is implemented by sweeping down the switching frequency from an initial high frequency (f^{ISS}) until the output voltage is established. The soft-start circuit is made by connecting R-C series network on the R_T pin, as shown

in Figure 19. FSFR-series also has an internal soft-start for 3ms to reduce the current overshoot during the initial cycles, which adds 40kHz to the initial frequency of the external soft-start circuit, as shown in Figure 20. The initial frequency of the soft-start is given as:

$$f_{ISS} = \left(\frac{5.2k\Omega}{R_{min}} + \frac{5.2k\Omega}{R_{SS}} \right) \times 100 + 40 \text{ (kHz)} \quad (3)$$

It is typical to set the initial frequency of soft-start two ~ three times the resonant frequency (f_o) of the resonant network.

The soft-start time is three to four times of the RC time constant. The RC time constant is as follows:

$$T_{SS} = R_{SS} \cdot C_{SS} \quad (4)$$

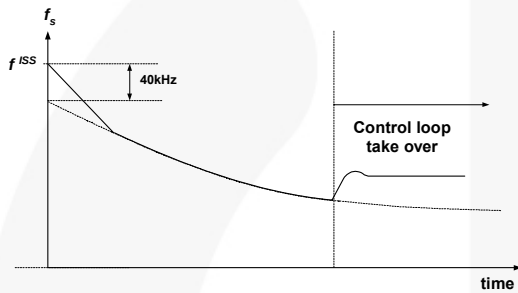


Figure 20. Frequency Sweeping of Soft-start

4. Control Pin: The FSFR-series has a control pin for protection, cycle skipping, and remote on/off. Figure 21 shows the internal block diagram for control pin.

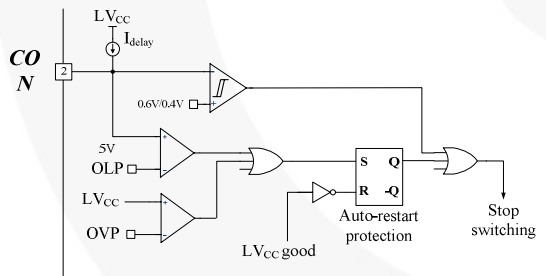


Figure 21. Internal Block of Control Pin

Protection: When the control pin voltage exceeds 5V, protection is triggered. Detailed applications are described in the protection section.

Pulse Skipping: FSFR-series stops switching when the control pin voltage drops below 0.4V and resumes switching when the control pin voltage rises above 0.6V. To use pulse-skipping, the control pin should be connected to the opto-coupler collector pin. The frequency that causes pulse skipping is given as:

$$f_{SKIP} = \left(\frac{5.2k\Omega}{R_{min}} + \frac{4.16k\Omega}{R_{max}} \right) \times 100 \text{ (kHz)} \quad (5)$$

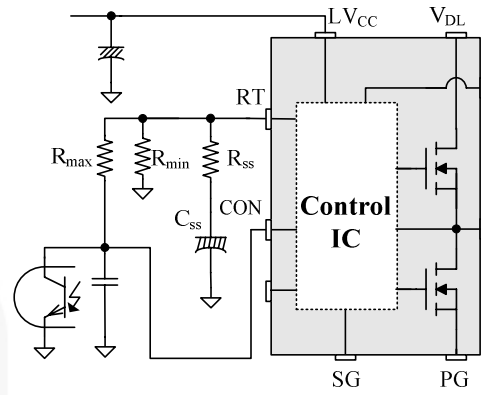


Figure 22. Control Pin Configuration for Pulse Skipping

Remote On / Off: When an auxiliary power supply is used for standby, the main power stage using FSFR-series can be shut down by pulling down the control pin voltage, as shown in Figure 23. R1 and C1 are used to ensure soft-start when switching resumes.

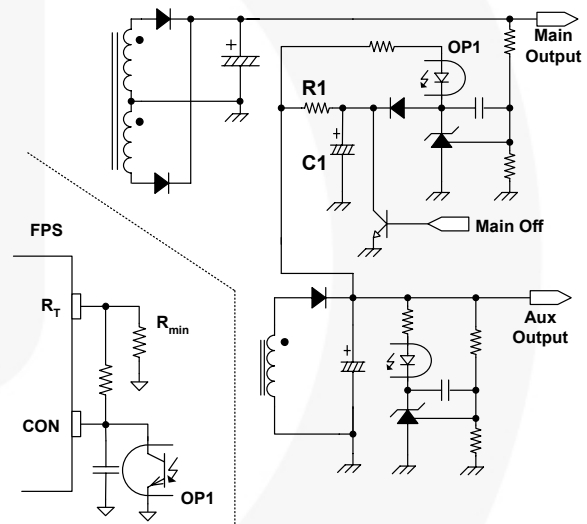


Figure 23. Remote On / Off Circuit

4. Current Sensing Method

Current Sensing Using Resistor: FSFR-series senses drain current as a negative voltage, as shown in Figure 24 and Figure 25. Half-wave sensing allows low power dissipation in the sensing resistor, while full-wave sensing has less switching noise in the sensing signal.

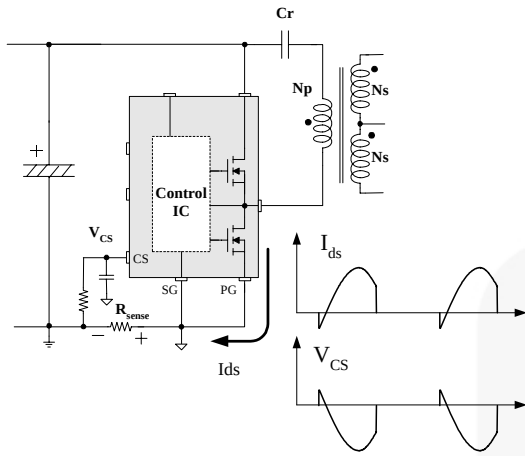


Figure 24. Half-Wave Sensing

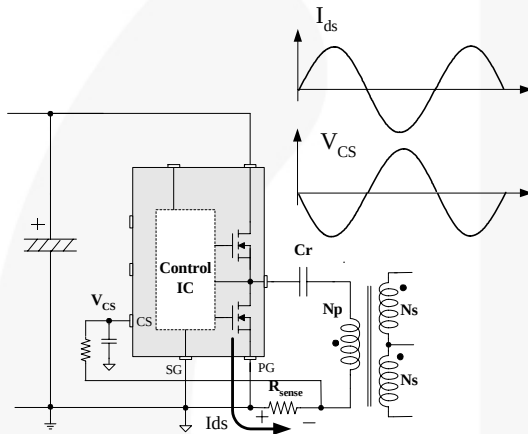


Figure 25. Full-Wave Sensing

Current Sensing Using Resonant Capacitor Voltage: For high-power applications, current sensing using a resistor may not be available due to the severe power dissipation in the resistor. In that case, indirect current sensing using the resonant capacitor voltage can be a good alternative because the amplitude of the resonant capacitor voltage (V_{Cr}^{p-p}) is proportional to the resonant current in the primary side (I_p^{p-p}) as:

$$V_{Cr}^{p-p} = \frac{I_p^{p-p}}{2\pi f_s C_r} \quad (6)$$

To minimize power dissipation, a capacitive voltage divider is generally used for capacitor voltage sensing, as shown in Figure 26.

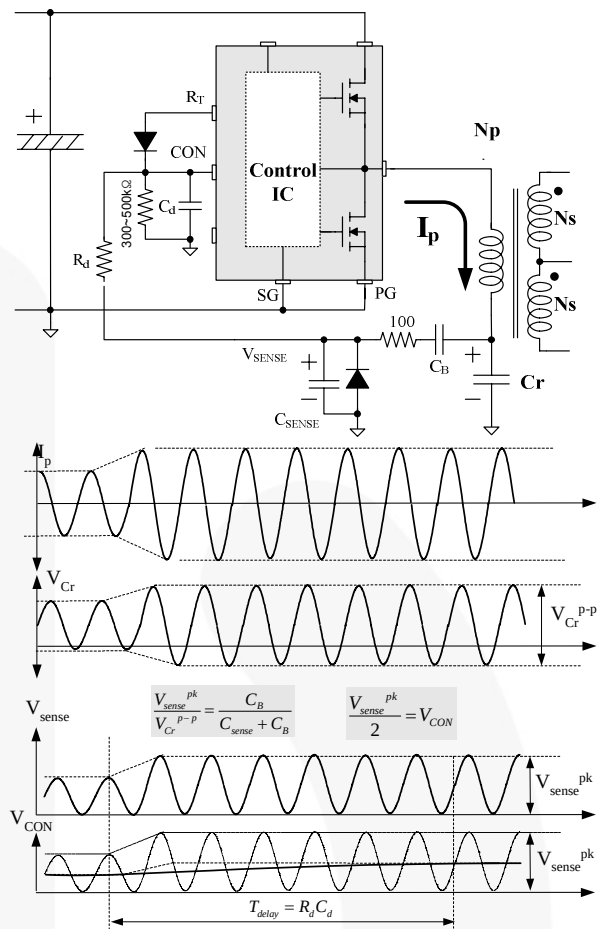


Figure 26. Current Sensing Using Resonant Capacitor Voltage

5. Protection Circuits: The FSFR-series has several self-protective functions, such as Overload Protection (OLP), Over-Current Protection (OCP), Abnormal Over-Current Protection (AOCP), Over-Voltage Protection (OVP), and Thermal Shutdown (TSD). OLP, OCP, and OVP are auto-restart mode protections; while AOCP and TSD are latch-mode protections, as shown in Figure 27.

Auto-restart Mode Protection: Once a fault condition is detected, switching is terminated and the MOSFETs remain off. When LV_{CC} falls to the LV_{CC} stop voltage of 11.3V, the protection is reset. The FPS resumes normal operation when LV_{CC} reaches the start voltage of 14.5V.

Typical Application Circuit (Half-Bridge LLC Resonant Converter)

Application	FPS™ Device	Input Voltage Range	Rated Output Power	Output Voltage (Rated Current)
LCD TV	FSFR2100U	400V (20ms Hold-up Time)	192W	24V-8A

Features

- High efficiency (>94% at 400V_{DC} input)
- Reduced EMI noise through zero-voltage-switching (ZVS)
- Enhanced system reliability with various protection functions

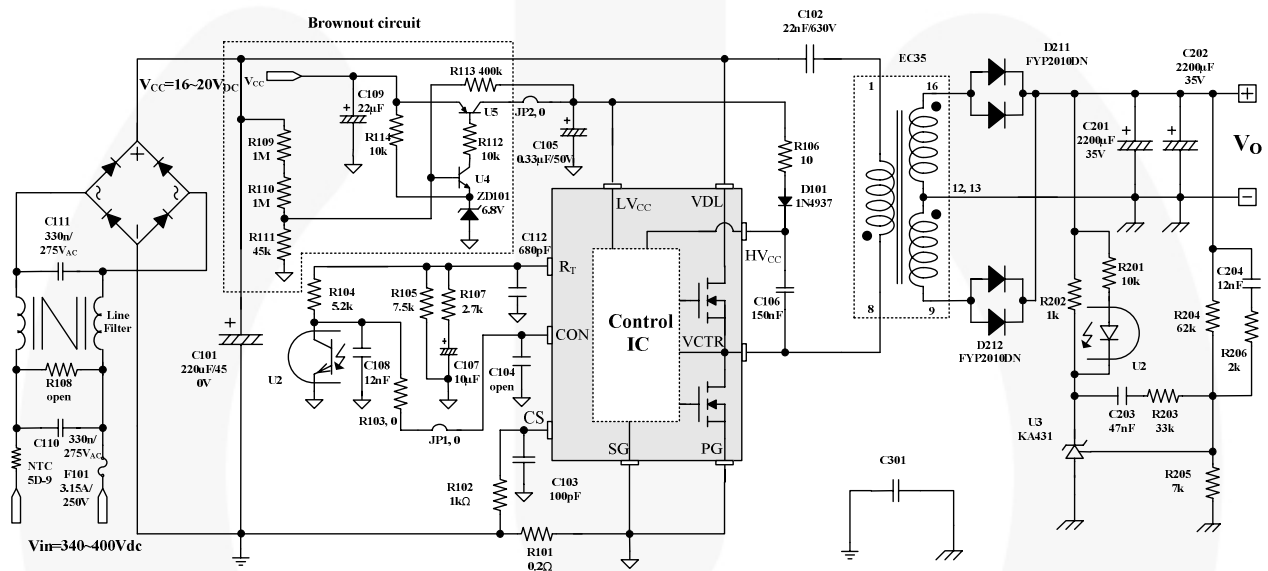


Figure 29. Typical Application Circuit

Typical Application Circuit (Continued)

Usually, LLC resonant converters require large leakage inductance value. To obtain a large leakage inductance, sectional winding method is used.

- Core: EER3542 ($A_e=107 \text{ mm}^2$)
- Bobbin: EER3542 (Horizontal)

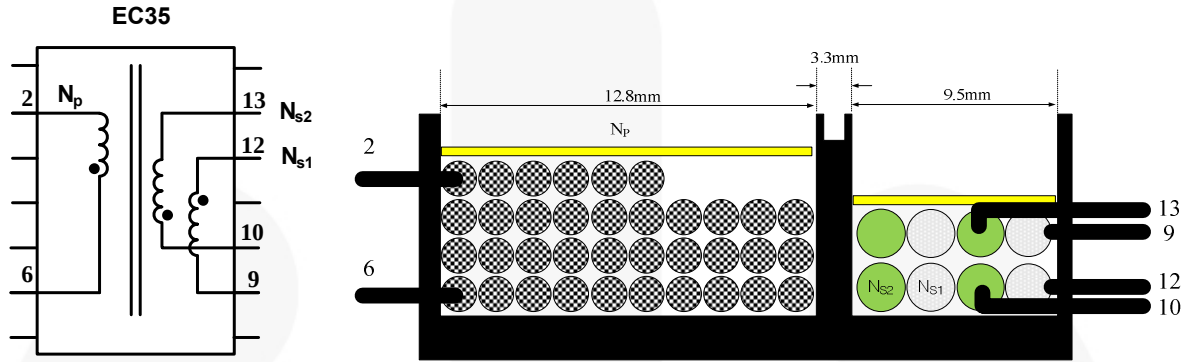
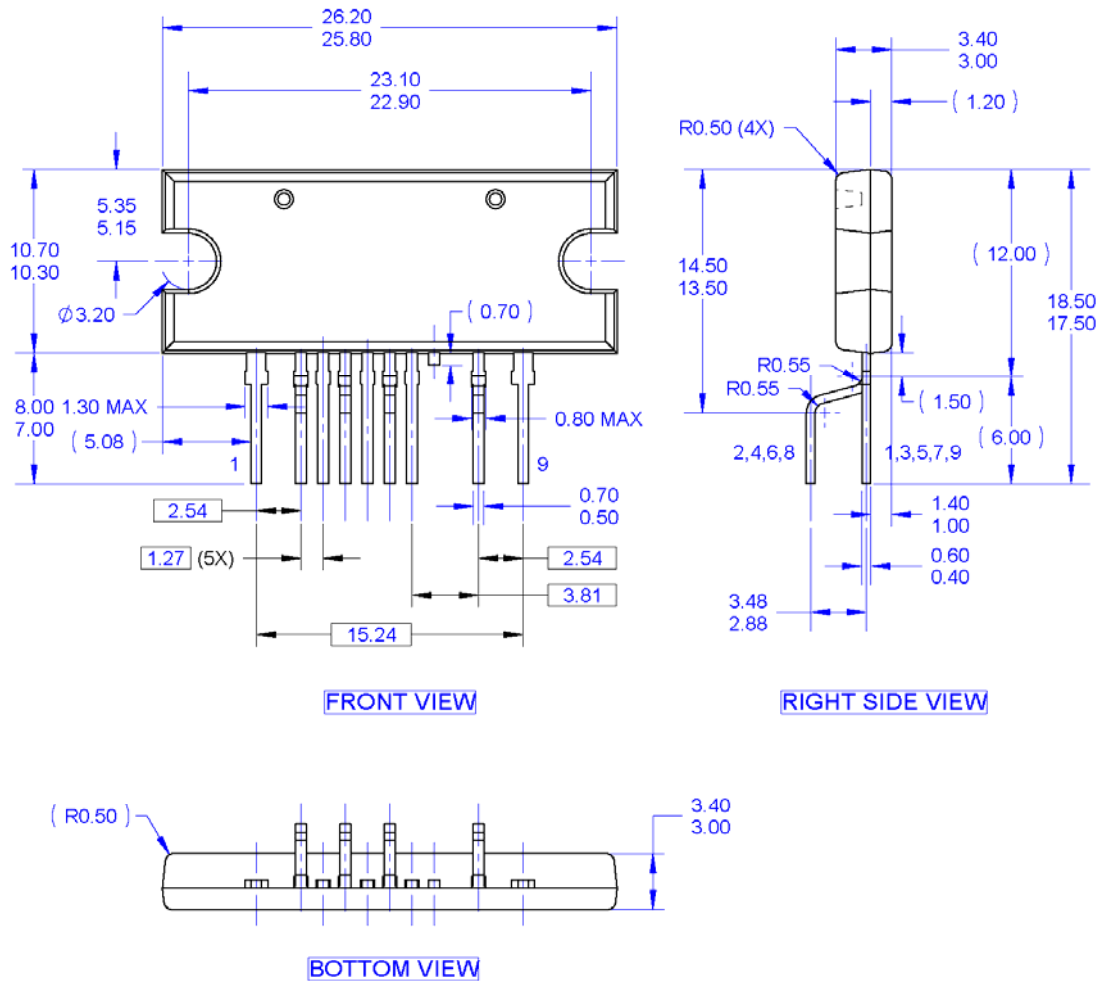


Figure 30. Transformer Construction

	Pins (S → F)	Wire	Turns	Note
N_p	8 → 1	0.12 ϕ ×30 (Litz Wire)	36	
N_{s1}	12 → 9	0.1 ϕ ×100 (Litz Wire)	4	Bifilar Winding
N_{s2}	16 → 13	0.1 ϕ ×100 (Litz Wire)	4	Bifilar Winding

	Pins	Specifications	Remark
Primary-Side Inductance (L_p)	1—8	630 μ H $\pm$ 5%	100kHz, 1V
Primary-Side Effective Leakage (L_r)	1—8	135 μ H $\pm$ 5%	Short One of the secondary Windings

Physical Dimensions



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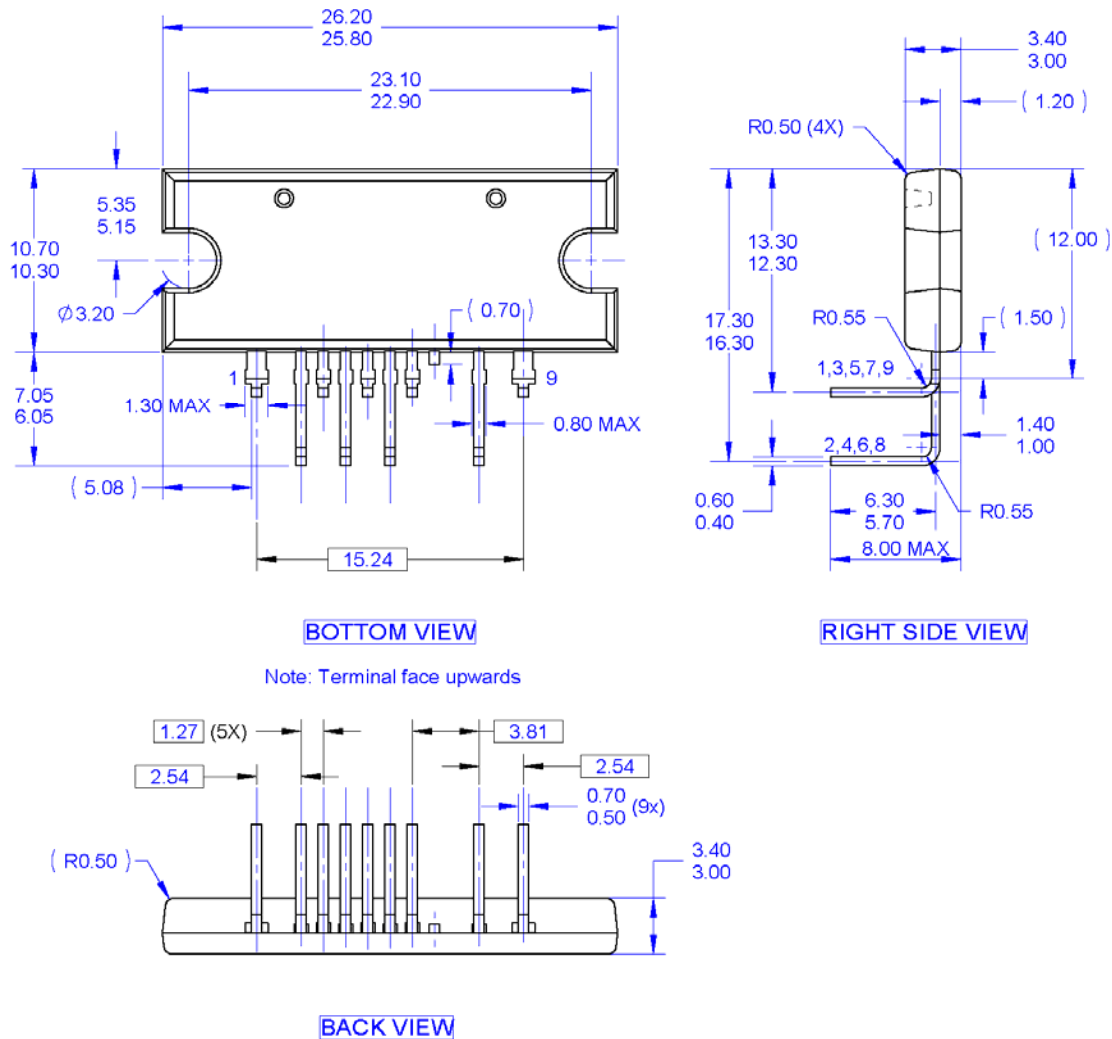
Figure 31. 9-SIP Package

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Figure 32. 9-Lead, SIP Module, L-Forming, 3.2x10.5x26mm Body

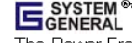
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