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# FSFR-XS 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<sup>™</sup> with Fast-Recovery Body Diode
- Fixed Dead Time (350 ns) Optimized for MOSFETs
- Up to 300 kHz Operating Frequency
- Auto-Restart Operation for All Protections with External LV<sub>CC</sub>
- Protection Functions: Over-Voltage Protection (OVP), 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

#### Description

The FSFR-XS series includes 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-XS series simplifies designs while improving productivity and performance. The FSFR-XS series combines power MOSFETs with fast-recovery type body diodes, a highside 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 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 reverse recovery. Using the zero-voltage-switching (ZVS) technique dramatically reduces the switching losses and significantly improves efficiency. The ZVS also reduces the switching noise noticeably, which allows a smallsized Electromagnetic Interference (EMI) filter.

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

#### **Related Resources**

<u>AN4151 — Half-Bridge LLC Resonant Converter Design</u> <u>Using FSFR-Series Fairchild Power Switch (FPS<sup>TM</sup>)</u>

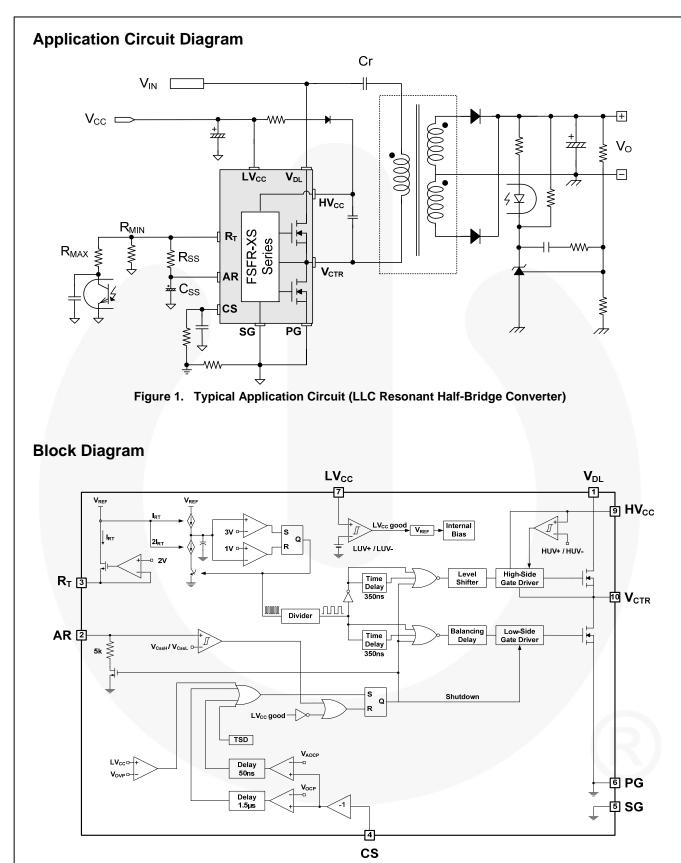
Part Number	Package	Operating Junction Temperature	R <sub>ds(on_max)</sub>	Maximum Output Power without Heatsink (V <sub>IN</sub> =350~400 V) <sup>(1,2)</sup>	Maximum Output Power with Heatsink (V <sub>IN</sub> =350~400 V) <sup>(1,2)</sup>
FSFR2100XS	- 9-SIP	-40 to +130°C	0.51 Ω	180 W	400 W
FSFR1800XS			0.95 Ω	120 W	260 W
FSFR1700XS			1.25 Ω	100 W	200 W
FSFR1600XS			1.55 Ω	80 W	160 W
FSFR2100XSL			0.51 Ω	180 W	400 W
FSFR1800XSL	9-SIP		0.95 Ω	120 W	260 W
FSFR1700XSL	L-Forming		1.25 Ω	100 W	200 W
FSFR1600XSL			1.55 Ω	80 W	160 W

#### **Ordering Information**

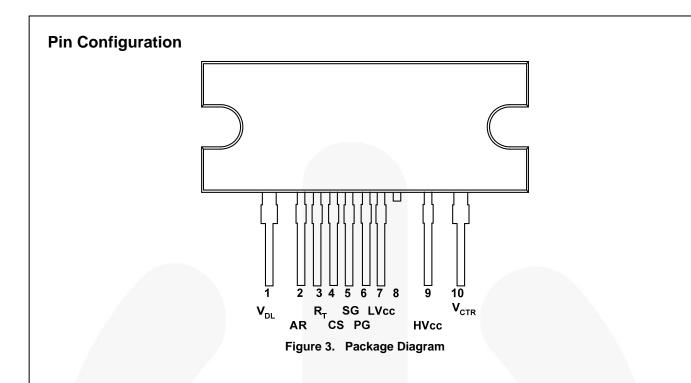
#### Notes:

1. The junction temperature can limit the maximum output power.

2. Maximum practical continuous power in an open-frame design at 50°C ambient.



FSFR-XS Series — Fairchild Power Switch (FPS<sup>™</sup>) for Half-Bridge Resonant Converter



## **Pin Definitions**

Pin #	Name	Description
1	V <sub>DL</sub>	This is the drain of the high-side MOSFET, typically connected to the input DC link voltage.
2	AR	This pin is for discharging the external soft-start capacitor when any protections are triggered. When the voltage of this pin drops to 0.2 V, all protections are reset and the controller starts to operate again.
3	R <sub>T</sub>	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 <sub>CC</sub>	This pin is the supply voltage of the control IC.
8	NC	No connection.
9	HV <sub>CC</sub>	This is the supply voltage of the high-side gate-drive circuit IC.
10	V <sub>CTR</sub>	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.  $T_A=25^{\circ}C$  unless otherwise specified.

Symbol	P	Parameter			Max.	Unit
V <sub>DS</sub>	Maximum Drain-to-Source	Maximum Drain-to-Source Voltage (V <sub>DL</sub> -V <sub>CTR</sub> and V <sub>CTR</sub> -PG)				V
LV <sub>CC</sub>	Low-Side Supply Voltage			-0.3	25.0	V
HV <sub>CC</sub> to V <sub>CTR</sub>	High-Side V <sub>CC</sub> Pin to Low-	Side Drain Voltag	е	-0.3	25.0	V
HVcc	High-Side Floating Supply	-0.3	525.0	V		
V <sub>AR</sub>	Auto-Restart Pin Input Voltage			-0.3	LV <sub>CC</sub>	V
Vcs	Current-Sense (CS) Pin In	Current-Sense (CS) Pin Input Voltage				V
V <sub>RT</sub>	R <sub>T</sub> Pin Input Voltage			-0.3	5.0	V
dV <sub>CTR</sub> /dt	Allowable Low-Side MOSF	ET Drain Voltage	e Slew Rate		50	V/ns
		F	SFR2100XS/L		12.0	
<b>D</b>	Tatal David Disaination <sup>(3)</sup>	F	SFR1800XS/L		11.7	
PD	Total Power Dissipation <sup>(3)</sup>	F	SFR1700XS/L		11.6	W
		F	SFR1600XS/L		11.5	
-	Maximum Junction Tempe	rature <sup>(4)</sup>			+150	
TJ	Recommended Operating	Recommended Operating Junction Temperature <sup>(4)</sup>			+130	°C
T <sub>STG</sub>	Storage Temperature Rang		-55	+150	°C	
OSFET Sec	tion					
V <sub>DGR</sub>	Drain Gate Voltage ( $R_{GS}$ =1 M $\Omega$ )			500		V
V <sub>GS</sub>	Gate Source (GND) Voltage				±30	V
		-		32		
	Drain Current Pulsed <sup>(5)</sup>	FSFR1800XS/L			23	1
I <sub>DM</sub>		FSFR1700XS/L			20	
		FSFR1600XS/L			18	
			T <sub>C</sub> =25°C		10.5	
		FSFR2100XS/L	T <sub>C</sub> =100°C		6.5	
			T <sub>C</sub> =25°C		7.0	
		FSFR1800XS/I	T <sub>C</sub> =100°C		4.5	
ID	Continuous Drain Current		T <sub>C</sub> =25°C		6.0	A
		FSFR1700XS/L	T <sub>c</sub> =100°C		3.9	1
			Tc=25°C		4.5	
		FSFR1600XS/I	- T <sub>c</sub> =100°C		2.7	D
ackage Sec	tion	1			-	
Torque	Recommended Screw Torque			5~7		kgf∙cm
- 1	Tresoniniended Gorew Torque					3. 5.1

Notes:

3. Per MOSFET when both MOSFETs are conducting.

4. The maximum value of the recommended operating junction temperature is limited by thermal shutdown.

5. Pulse width is limited by maximum junction temperature.

## **Thermal Impedance**

 $T_A$ =25°C unless otherwise specified.

Symbol	Parameter			Unit
θ <sub>JC</sub>		FSFR2100XS/L	10.44	
	Junction-to-Case Center Thermal Impedance	FSFR1800XS/L	10.68	00.004
	(Both MOSFETs Conducting)	FSFR1700XS/L	10.79	°C/W
		FSFR1600XS/L	10.89	
θ <sub>JA</sub>	Junction-to-Ambient Thermal Impedance	FSFR XS Series	80	°C/W

## **Electrical Characteristics**

 $T_A=25^{\circ}C$  unless otherwise specified.

Symbol	Parameter		Test Conditions	Min.	Тур.	Max.	Unit
MOSFET S	ection						
BV <sub>DSS</sub>	Drain-to-Source Breakdown Voltage		I <sub>D</sub> =200 μΑ, Τ <sub>Α</sub> =25°C	500			- V
			I <sub>D</sub> =200 μΑ, Τ <sub>Α</sub> =125°C		540		
		FSFR2100XS/L	V <sub>GS</sub> =10 V, I <sub>D</sub> =6.0 A		0.41	0.51	Ω
P	On-State Resistance	FSFR1800XS/L	$V_{GS}$ =10 V, I <sub>D</sub> =3.0 A		0.77	0.95	
R <sub>DS(ON)</sub>	On-State Resistance	FSFR1700XS/L	V <sub>GS</sub> =10 V, I <sub>D</sub> =2.0 A		1.00	1.25	
		FSFR1600XS/L	V <sub>GS</sub> =10 V, I <sub>D</sub> =2.25 A		1.25	1.55	
	Body Diode Reverse Recovery Time <sup>(6)</sup>	FSFR2100XS/L	V <sub>GS</sub> =0 V, I <sub>Diode</sub> =10.5 A, dI <sub>Diode</sub> /dt=100A/µs		120		ns
		FSFR1800XS/L	V <sub>GS</sub> =0V, I <sub>Diode</sub> =7.0A, dI <sub>Diode</sub> /dt=100 A/µs		160		
t <sub>rr</sub>		FSFR1700XS/L	V <sub>GS</sub> =0 V, I <sub>Diode</sub> =6.0 A, dI <sub>Diode</sub> /dt=100 A/µs		160		
		FSFR1600XS/L	V <sub>GS</sub> =0 V, I <sub>Diode</sub> =4.5 A, dI <sub>Diode</sub> /dt=100 A/μs		90		
	Input Capacitance <sup>(6)</sup>	FSFR2100XS/L	V <sub>DS</sub> =25 V, V <sub>GS</sub> =0 V, f=1.0 MHz		1175		pF
C		FSFR1800XS/L			639		pF
CISS		FSFR1700XS/L			512		pF
		FSFR1600XS/L			412		pF
		FSFR2100XS/L	V <sub>DS</sub> =25 V, V <sub>GS</sub> =0 V, f=1.0 MHz		155		pF
C	Output Capacitance <sup>(6)</sup>	FSFR1800XS/L			82.1		pF
Coss		FSFR1700XS/L			66.5		pF
		FSFR1600XS/L			52.7		pF

Continued on the following page...

## Electrical Characteristics (Continued)

 $T_A {=} 25^\circ C$  unless otherwise specified.

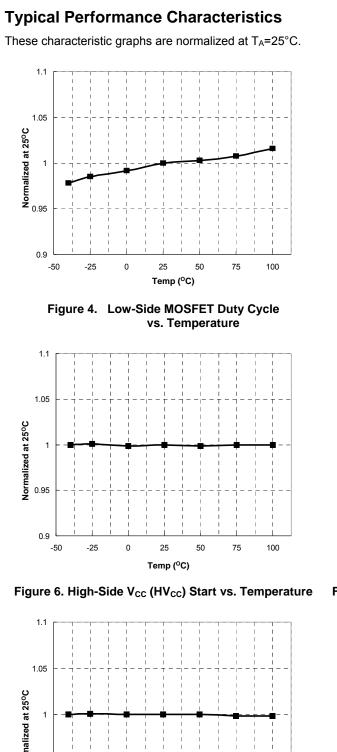
Symbol	Parameter	Test Conditions	Min.	Тур.	Max.	Unit
Supply Sec	tion					1
I <sub>LK</sub>	Offset Supply Leakage Current	HV <sub>CC</sub> =V <sub>CTR</sub> =500 V			50	μA
$I_QHV_{CC}$	Quiescent HVcc Supply Current	(HV <sub>CC</sub> UV+) - 0.1 V		50	120	μA
I <sub>Q</sub> LV <sub>CC</sub>	Quiescent LVcc Supply Current	(LV <sub>CC</sub> UV+) - 0.1 V		100	200	μA
I <sub>0</sub> HV <sub>cc</sub>	Operating HV <sub>cc</sub> Supply Current	f <sub>OSC</sub> =100 KHz		6	9	mA
IOI IV CC	(RMS Value)	No Switching		100	200	μA
I <sub>o</sub> LV <sub>cc</sub>	Operating LV <sub>cc</sub> Supply Current	f <sub>OSC</sub> =100 KHz		7	11	mA
IOL V CC	(RMS Value)	No Switching		2	4	mA
UVLO Sect	ion					
LV <sub>CC</sub> UV+	LV <sub>CC</sub> Supply Under-Voltage Positive Go	11.2	12.5	13.8	V	
LV <sub>cc</sub> UV-	LV <sub>CC</sub> Supply Under-Voltage Negative Going Threshold (LV <sub>CC</sub> Stop)			10.0	11.1	V
LV <sub>cc</sub> UVH	LV <sub>CC</sub> Supply Under-Voltage Hysteresis			2.50		V
HV <sub>cc</sub> UV+	HV <sub>cc</sub> Supply Under-Voltage Positive Going Threshold (HV <sub>cc</sub> Start)			9.2	10.2	V
HV <sub>cc</sub> UV-	HV <sub>CC</sub> Supply Under-Voltage Negative Going Threshold (HV <sub>CC</sub> Stop)			8.7	9.6	V
HV <sub>cc</sub> UVH	HV <sub>CC</sub> Supply Under-Voltage Hysteresis		0.5		V	
Oscillator &	Feedback Section				•	
V <sub>RT</sub>	V-I Converter Threshold Voltage		1.5	2.0	2.5	V
f <sub>OSC</sub>	Output Oscillation Frequency	R <sub>T</sub> =5.2 KΩ	94	100	106	KHz
DC	Output Duty Cycle		48	50	52	%
f <sub>SS</sub>	Internal Soft-Start Initial Frequency	f <sub>SS</sub> =f <sub>OSC</sub> +40 kHz, R <sub>T</sub> =5.2 KΩ		140		KHz
tss	Internal Soft-Start Time		2	3	4	ms
Protection	Section					
V <sub>CssH</sub>	Beginning Voltage to Discharge Css		0.9	1.0	1.1	V
$V_{CssL}$	Beginning Voltage to Charge C <sub>SS</sub> and Restart		0.16	0.20	0.24	V
V <sub>OVP</sub>	LV <sub>CC</sub> Over-Voltage Protection	LV <sub>CC</sub> > 21 V	21	23	25	V
VAOCP	AOCP Threshold Voltage		-1.0	-0.9	-0.8	V
t <sub>BAO</sub>	AOCP Blanking Time <sup>(6)</sup>	V <sub>CS</sub> < V <sub>AOCP</sub>		50		ns
V <sub>OCP</sub>	OCP Threshold Voltage		-0.64	-0.58	-0.52	V
t <sub>BO</sub>	OCP Blanking Time <sup>(6)</sup>	V <sub>CS</sub> < V <sub>OCP</sub>	1.0	1.5	2.0	μs
t <sub>DA</sub>	Delay Time (Low Side) Detecting from	Delay Time (Low Side) Detecting from V <sub>AOCP</sub> to Switch Off <sup>(6)</sup>		250	400	ns
T <sub>SD</sub>	Thermal Shutdown Temperature <sup>(6)</sup>		120	135	150	°C
	Control Section	-1		1	1	I
DT	Dead Time <sup>(7)</sup>			350		ns

6. This parameter, although guaranteed, is not tested in production.

7. These parameters, although guaranteed, are tested only in EDS (wafer test) process.

FSFR-XS Series — Fairchild Power Switch (FPS<sup>™</sup>) for Half-Bridge Resonant Converter

6



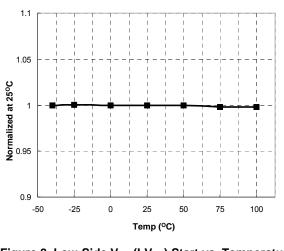


Figure 8. Low-Side V<sub>CC</sub> (LV<sub>CC</sub>) Start vs. Temperature

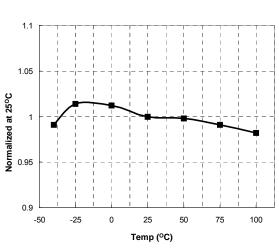


Figure 5. Switching Frequency vs. Temperature

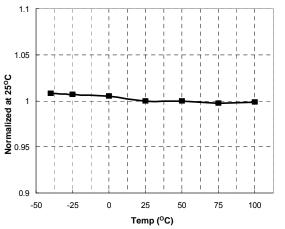
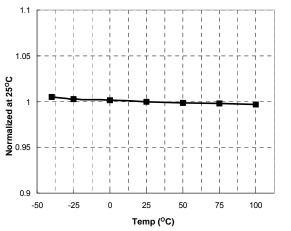
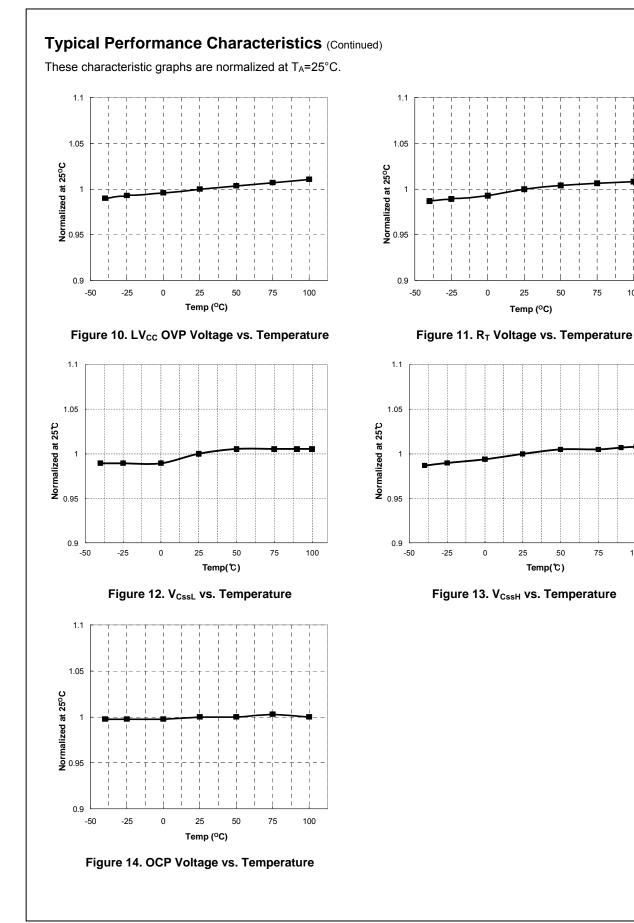


Figure 7. High-Side V<sub>CC</sub> (HV<sub>CC</sub>) Stop vs. Temperature





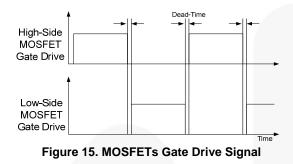


100

100

#### **Functional Description**

**1. Basic Operation**. FSFR-XS series is designed to drive high-side and low-side MOSFETs complementarily with 50% duty cycle. A fixed dead time of 350 ns is introduced between consecutive transitions, as shown in Figure 15.



**2.** Internal Oscillator: FSFR-XS series employs a current-controlled oscillator, as shown in Figure 16. Internally, the voltage of  $R_T$  pin is regulated at 2 V and the charging / discharging current for the oscillator capacitor,  $C_T$ , is obtained by copying the current flowing out of the  $R_T$  pin ( $I_{CTC}$ ) using a current mirror. Therefore, the switching frequency increases as  $I_{CTC}$  increases.

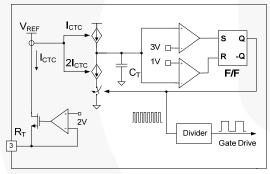


Figure 16. Current-Controlled Oscillator

**3. Frequency Setting**: Figure 17 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 18 shows the typical circuit configuration for the  $R_T$  pin, where the opto-coupler transistor is connected to the  $R_T$  pin to modulate the switching frequency.

The minimum switching frequency is determined as:

$$f^{\min} = \frac{5.2k\Omega}{R_{\min}} \times 100(kHz) \tag{1}$$

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

$$f^{\max} = \left(\frac{5.2k\Omega}{R_{\min}} + \frac{4.68k\Omega}{R_{\max}}\right) \times 100(kHz) \tag{2}$$

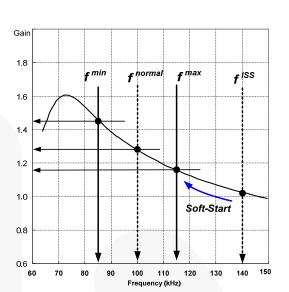


Figure 17. Resonant Converter Typical Gain Curve

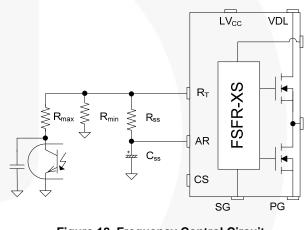


Figure 18. Frequency Control Circuit

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 ( $f^{/SS}$ ) until the output voltage is established. The soft-start circuit is made by connecting R-C series network on the R<sub>T</sub> pin, as shown in Figure 18. FSFR-XS series also has a 3ms internal soft-start to reduce the current overshoot during the initial cycles, which adds 40 kHz to the initial frequency of the external soft-start circuit, as shown in Figure 19. The initial frequency of the soft-start is given as:

$$f^{ISS} = \left(\frac{5.2k\Omega}{R_{\min}} + \frac{5.2k\Omega}{R_{SS}}\right) \times 100 + 40 \ (kHz) \tag{3}$$

It is typical to set the initial frequency of soft-start two to three times the resonant frequency ( $f_0$ ) of the resonant network. The soft-start time is three to four times the RC time constant. The RC time constant is:

$$\tau = R_{SS} \bullet C_{SS} \tag{4}$$

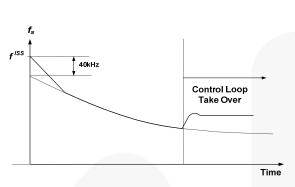


Figure 19. Frequency Sweeping of Soft-Start

4. Self Auto-Restart: The FSFR-XS series can restart automatically even though any built-in protections are triggered with external supply voltage. As can be seen in Figure 20 and Figure 21, once any protections are triggered, the M1 switch turns on and the V-I converter is disabled.  $C_{SS}$  starts to discharge until  $V_{Css}$  across  $C_{SS}$  drops to  $V_{CssL}$ . Then, all protections are reset, M1 turns off, and the V-I converter resumes at the same time. The FSFR-XS starts switching again with soft-start. If the protections occur while  $V_{Css}$  is under  $V_{CssL}$  and  $V_{CssH}$  level, the switching is terminated immediately,  $V_{Css}$  continues to increase until reaching  $V_{CssH}$ , then  $C_{SS}$  is discharged by M1.

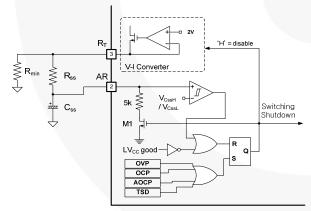


Figure 20. Internal Block of AR Pin

After protections trigger, FSFR-XS is disabled during the stop-time,  $t_{stop}$ , where  $V_{Css}$  decreases and reaches to  $V_{CssL}$ . The stop-time of FSFR-XS can be estimated as:

$$t_{STOP} = C_{SS} \bullet \{ (R_{SS} + R_{MIN}) || 5k\Omega \}$$
(5)

The soft-start time,  $t_{s/s}$  can be set as Equation (4).

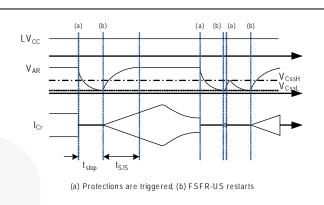


Figure 21. Self Auto-Restart Operation

**5. Protection Circuits**: The FSFR-XS series has several self-protective functions, such as Over-Current Protection (OCP), Abnormal Over-Current Protection (AOCP), Over-Voltage Protection (OVP), and Thermal Shutdown (TSD). These protections are auto-restart mode protections, as shown in Figure 22.

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 10 V or AR signal is HIGH, the protection is reset. The FSFR-XS resumes normal operation when  $LV_{CC}$  reaches the start voltage of 12.5 V.

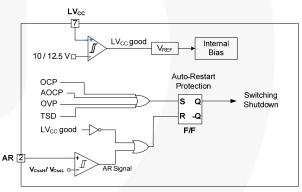


Figure 22. Protection Blocks

**5.1 Over-Current Protection (OCP)**: When the sensing pin voltage drops below -0.58 V, OCP is triggered and the MOSFETs remain off. This protection has a shutdown time delay of 1.5 µs to prevent premature shutdown during startup.

**5.2 Abnormal Over-Current Protection (AOCP)**: If the secondary rectifier diodes are shorted, large current with extremely high di/dt can flow through the MOSFET before OCP is triggered. AOCP is triggered without shutdown delay if the sensing pin voltage drops below -0.9 V.

**5.3 Over-Voltage Protection (OVP)**: When the LV<sub>CC</sub> reaches 23 V, OVP is triggered. This protection is used when auxiliary winding of the transformer to supply V<sub>CC</sub> to the FPS<sup>m</sup> is utilized.

**5.4 Thermal Shutdown (TSD)**: The MOSFETs and the control IC in one package makes it easier for the control IC to detect the abnormal over-temperature of the MOSFETs. If the temperature exceeds approximately 130°C, thermal shutdown triggers.

**6.** Current Sensing Using a Resistor: FSFR-XS series senses drain current as a negative voltage, as shown in Figure 23 and Figure 24. Half-wave sensing allows low power dissipation in the sensing resistor, while full-wave sensing has less switching noise in the sensing signal.

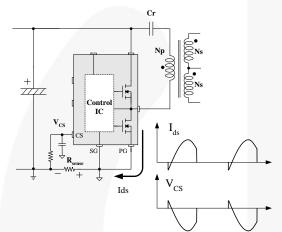
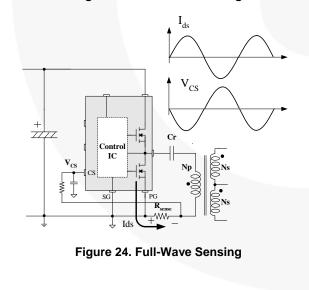


Figure 23. Half-Wave Sensing



7. PCB Layout Guidelines: Duty imbalance problems may occur due to the radiated noise from the main transformer, the inequality of the secondary side leakage inductances of main transformer, and so on. This is one of the reasons that the control components in the vicinity of R<sub>T</sub> pin are enclosed by the primary current flow pattern on PCB layout. The direction of the magnetic field on the components caused by the primary current flow is changed when the high- and low-side MOSFET turn on by turns. The magnetic fields with opposite directions induce a current through, into, or out of the R<sub>T</sub> pin, which makes the turn-on duration of each MOSFET different. It is strongly recommended to separate the control components in the vicinity of  $R_T$  pin from the primary current flow pattern on PCB layout. Figure 25 shows an example for the duty-balanced case.

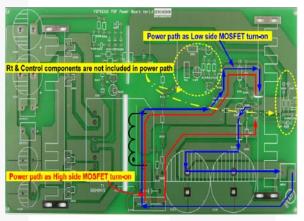
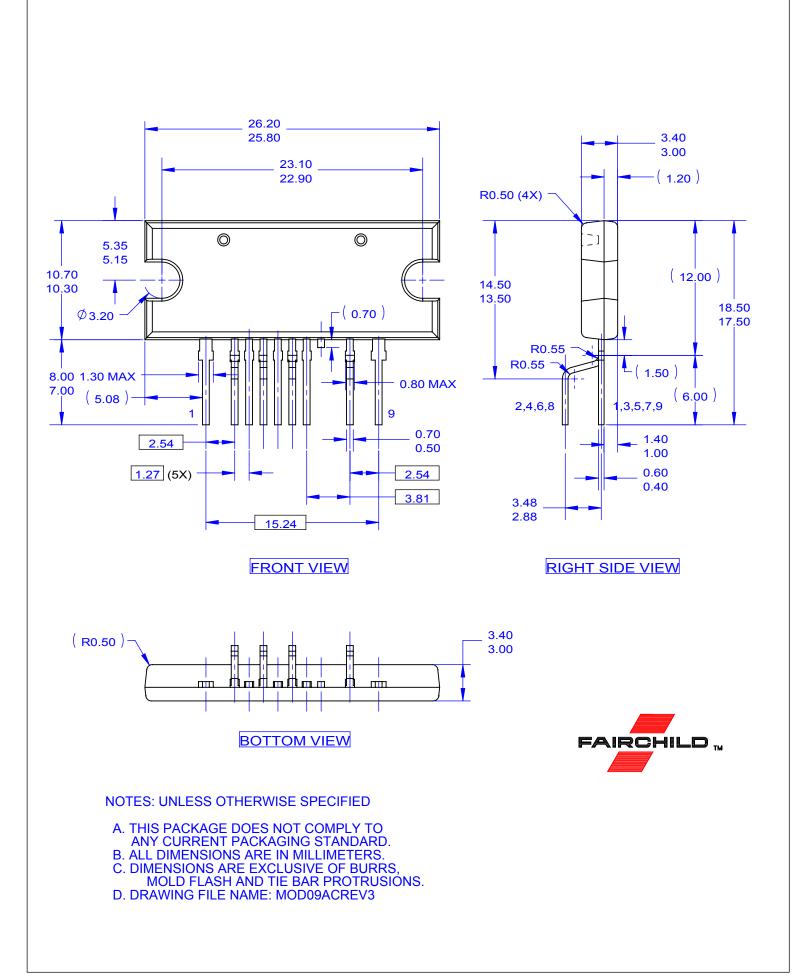


Figure 25. Example for Duty Balancing



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