ZETEX

Applications Note 9
Issue 4 July 2002

Zetex Variable Capacitance Diodes

Neil Chadderton

Introduction

The advent of varactor diodes has made a huge impact in many areas of electronic design, which is only too evident in todays consumer products. Formerly, where bulky or unreliable mechanical methods were used, the size, reliability and excellent tracking abilities of the varactor has led to smaller, cheaper and more elaborate circuitry, previously impossible to attain.

Zetex manufacture an extensive range of Variable Capacitance diodes that are processed using ion-implantation techniques to assure accurate doping levels, and hence produce the exacting junction profiles necessary for high performance devices. An overall capacitance range of approximately 1pF to 200pF assures a broad applications base, enabling designs operating from kHz and extending into the microwave region. Product variability within specification is comparable to, or better than, competitors devices; the Hyperabrupt series, for example, are available to 5% tolerance on nominal capacitance, due to close targeting during fabrication. Furthermore, Zetex are capable of matching (either to device type or customer specifications) or banding on capacitance parameters, as required. They are available in surface mount packages that exhibit low inductance ensuring a wide frequency application, and assure environmental endurance and mechanical reliability.

This application note gives some basic background information, examines the important parameters and specifications for the Zetex range of devices, and suggests a few application circuit examples.

Background

The varactor diode is a device that is processed so to capitalise on the properties of the depletion layer of a P-N diode. Under reverse bias, the carriers in each region (holes in the P type and electrons in the N type) move away from the junction, leaving an area that is depleted of carriers. Thus a region that is essentially an insulator has been created, and can be compared to the classic parallel plate capacitor model. The effective width of this depletion region increases with reverse bias, and so the capacitance decreases. Thus the depletion layer effectively creates a voltage dependent junction capacitance, that can be varied between the forward conduction region and the reverse breakdown voltage.

Different junction profiles can be produced that exhibit different Capacitance-Voltage characteristics. The Abrupt junction type for example, shows a small range of capacitance due to its diffusion profile, and as a consequence of this is capable of high Q and low distortion, while the Hyperabrupt variety allows a larger change in capacitance for the same range of reverse bias. So called Hyper-hyperabrupt, or octave tuning variable capacitance diodes show a large change in capacitance for a relatively small change in bias voltage.This is particularly useful in battery powered systems where the available bias voltage is limited.The varactor can be modelled as a variable capacitance (Cjv), in series with a resistance (Rs). (Please refer to Figure 1).

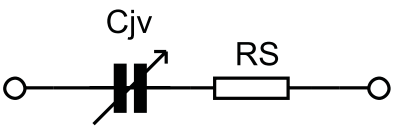

Figure 1
Common Model for the Varactor Diode.

The capacitance, Cjv, is dependent upon the reverse bias voltage, the junction area, and the doping densities of the semiconductor material, and can be described by:

$$Cjv = \frac{Cj0}{\left(1+ {}^{Vr}\!/\!{}_{\varphi}\right)^{N}}$$

Where:

Cj0 = Junction capacitance at 0V
Cjv = Junction capacitance at applied bias voltage Vr
Vr = Applied bias voltage
φ = Contact Potential
N = Power law of the junction or slope factor.

The series resistance exists as a consequence of the remaining undepleted semiconductor resistance, a contribution due to the die substrate, and a small lead and package component, and is foremost in determining the performance of the device under RF conditions.

This follows, as the quality factor, Q, is given by:

$$Q = \frac{1}{2\pi f C_{jv} R_s}$$

Where:

Cjv = Junction capacitance at applied bias voltage Vr
Rs = Series Resistance
f = Frequency

So, to maximise Q, R_S must be minimised. This is achieved by the use of an epitaxial structure so minimising the amount of high resistivity material in series with the junction.

NOTE: Zetex has produced a set of SPICE models to enable designers to simulate their circuits in SPICE, PSPICE and similar simulation packages. The models use a version of the above capacitance equation and so the model parameters may also be of interest for other software packages. Information is also provided to allow inclusion of parasitic elements to the model. These models are available on request, from any Zetex sales office.

Important Parameters

This section reviews the important characteristics of varactor diodes with particular reference to the Zetex range of variable capacitance diodes.

The characteristic of prime concern to the designer is the Capacitance-Voltage relationship, illustrated by a C-V curve, and expressed at a particular voltage by Cx, where x is the bias voltage. The C-V curve summarises the range of useful capacitance, and also shows the shape of the relationship, which may be relevant when a specific response is required. Figures 2a, 2b and 2c show families of C-V curves for the 830 hyperabrupt series, 930 hyper-hyperabrupt series and the 950 low voltage hyperabrupt series. Obviously, the choice of device type depends upon the application, but aspects to consider include: the range of frequencies the circuit must operate with, and hence an appropriate capacitance range; the available bias voltage; and the required response.

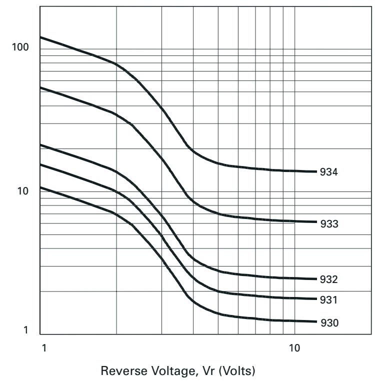

Figure 2b
Typical Capacitance-Voltage Characteristics for the 930 Series

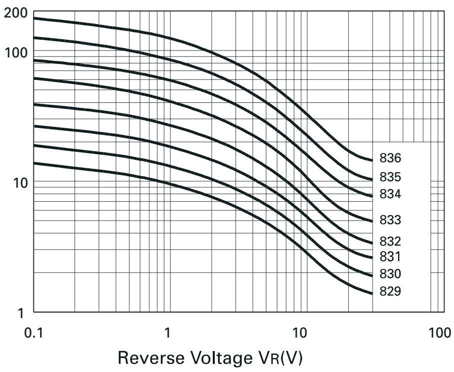

Figure 2a
Typical Capacitance-Voltage Characteristics for the 830 Series

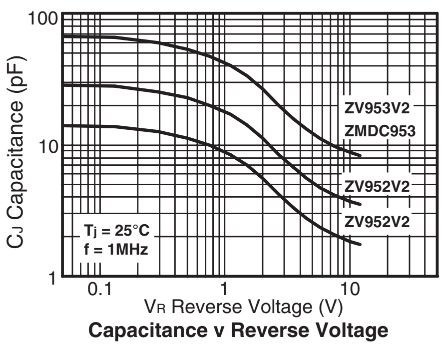

Figure 2c
Typical Capacitance-Voltage Characteristics for the 950 Series

The capacitance ratio, commonly expressed as Cx/Cy (where x and y are bias voltages), is a useful parameter that shows how quickly the capacitance changes with applied bias voltage. So, for an Abrupt junction device, a C2/C20 figure of 2.8 may be typical, whereas a C2/C20 ratio of 6 may be expected for a Hyperabrupt device. This feature of the Hyperabrupt variety can be particularly important when assessing devices for battery-powered applications, where the bias voltage range may be limited. In this instance, the 930 series that feature a better than 2:1 tuning range for a 0 to 6V bias may be of particular interest.

The quality factor, Q, at a particular condition is a useful parameter in assessing the performance of a device with respect to tuned circuits, and the resulting loaded Q.

Zetex guarantee a minimum Q at test conditions of 50MHz, and a relatively low V_R of 3 or 4V, and ranges 100 to 450 depending on device type (see Product Range Tables).

The specified V_R is very important in assessing this parameter, because as well as the C-V dependence as detailed previously, a significant part of the series resistance (Rs), is due to the remaining undepleted epitaxial layer, which is also dependant upon V_R. This Rs-V_R relationship is shown in Figure 3 for the ZC830, ZC833 and ZC836 Hyperabrupt devices, measured at frequencies of 470MHz, 300MHz and 150MHz respectively, and also serves to illustrate the excellent performance of Zetex Variable Capacitance Diodes at VHF and UHF.

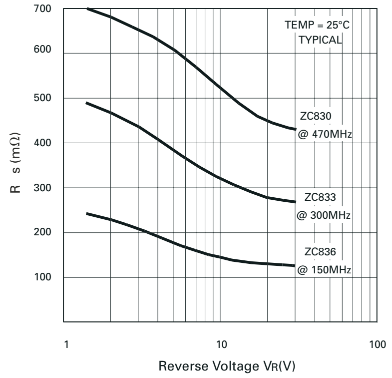

Figure 3
Typical R_S v V_R Relationship for ZC830 Series Diodes

ZETEX

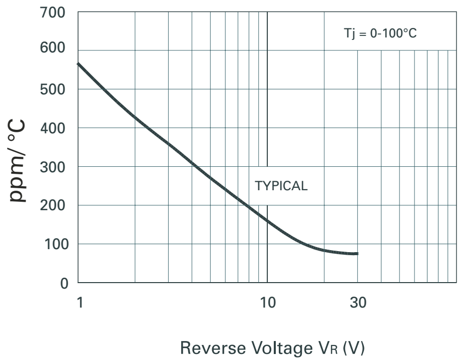

Figure 4a
Temperature Coeffcient of Capacitance v V_R for the ZC830 Series.

Also of interest, with respect to stability, is the temperature coefficient of capacitance, as capacitance changes with V_R, and is shown for the ranges in figures 4a, and 4b.

The reverse breakdown voltage, V(BR) also has a bearing on device selection, as this parameter limits the maximum V_R that may be used when biasing for minimum capacitance. Zetex variable capacitance diodes typically possess a V(BR) of 25V for the 830 series and 12V for the 930, 950 series.

The maximum frequency of operation will depend on the required capacitance and the series resistance (and hence useful Q), that is possessed by a particular device type, but also of consequence are the parasitic components exhibited by the device package. These depend on the size, material, and construction of the package. For example, the Zetex SOT-23 package has a typical stray capacitance of 0.08pF, and a total lead inductance of 2.8nH. These low values allow a wide frequency application, for example, the ZC830 and ZC930 series, configured as series pairs are ideal for low cost microwave designs extending to 2.5GHz and above.

Applications

Variable capacitance diodes can be used in any tuned circuit application where previously mechanical methods were utilised, and provide a size, cost and performance advantage. This section briefly examines some typical examples of varactor application.

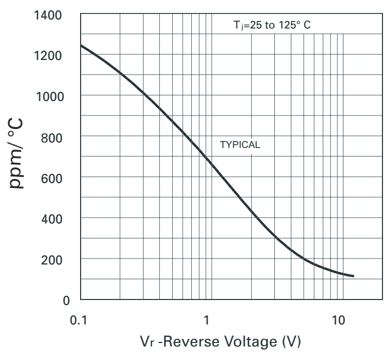

Figure 4b
Temperature Coefficient of Capacitance v V_R for the ZC930 Series.

The conventional simple tuned circuit of Figure 5a can also be effected by the varactor version as in Figure 5b, where capacitor C1 isolates the DC bias. The choice of varactor for such a circuit depends on the tuning range and hence capacitance, with particular attention being paid to the C-V region approaching 0V, as this may introduce non-linearity and poor Q. Another similar approach is to use the series configuration shown in Figure 5c which, while allowing a lower apparent diode

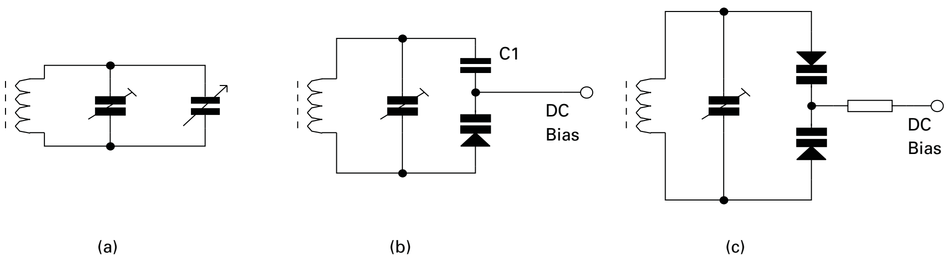

Figure 5
Basic Tuned Circuits.

capacitance, also prevents RF rectification at low values of diode bias therefore inhibiting generation of intermodulation products, and also simplifies bias requirements.

A practical front-end for an FM receiver is shown in Figure 6, with each stage being tuned by it's own diode. Multi-stage units are therefore possible without the severe tracking errors, and the massive size penalty inherent to mechanical mechanisms.

As the tuning is now controlled by a voltage, the inevitable inclusion of the microprocessor and memory in many modern receivers has allowed band-scanning and station storage by producing the control voltage

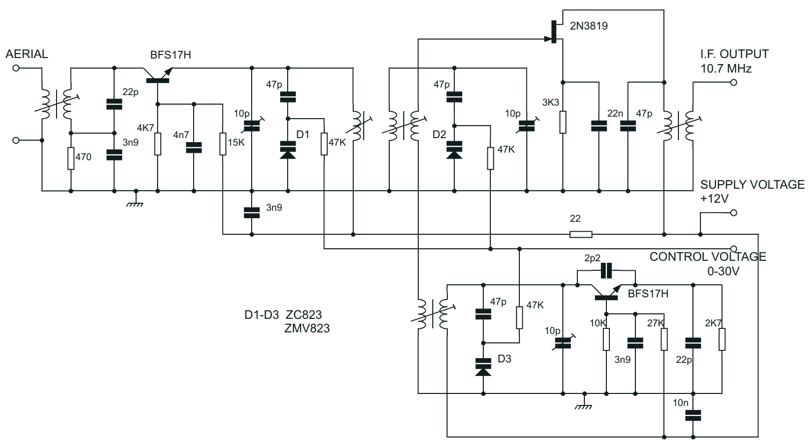

Figure 6
Typical FM receiver Front End employing Variable Capacitance Diodes.

automatically. It is noteworthy that the control voltage of any system must possess good voltage and temperature stability.

Perhaps the largest effect on consumer products due to the varactor has been the development of varactor based VHF and UHF tuners for televisions. These have enabled solid state non-mechanical designs that are smaller, more reliable and allow elaborate features such as remote control and station searching. Figure 7 shows a typical circuit of a UHF tuner incorporating varactor diodes. Stage matching is effected by the bias trimmers RV1-5, and allows adjustment remote from the actual tuning element; the mechanical equivalent being to add padding capacitance, or to bend the vanes on an air-spaced capacitor.

Such a tuner can, using the large capacitance range of Hyperabrupt varactor diodes, tune the whole channel range of bands IV and V (470MHz-850MHz).

Another common application for the varactor is as the frequency controlling element in a Voltage Controlled Oscillator (VCO). There are many applications for such circuits, either as stand alone units or as part of a phase locked loop in a frequency synthesiser. This latter method is commonly utilised in radio telecommunications and for the tuning stages in satellite receivers. Closely allied to these are functions such as frequency pulling on crystal oscillators, narrow band FM and temperature compensation of frequency within an oscillator, all of which can benefit from a varactor diode based design.

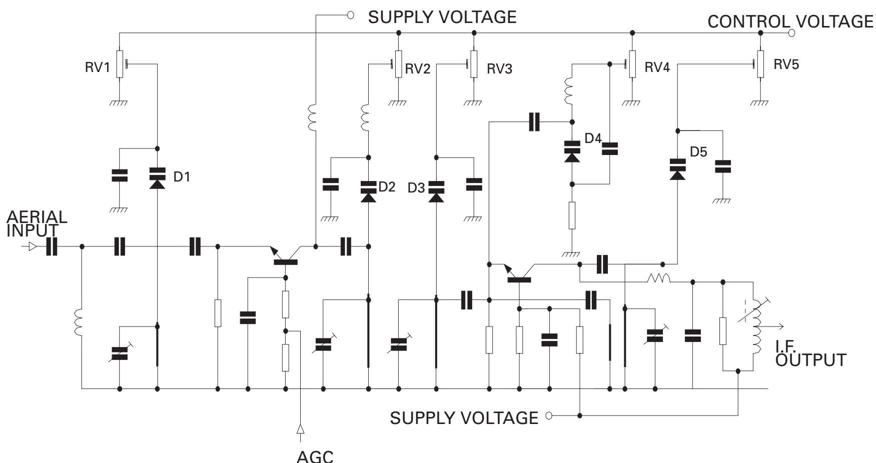

Figure 7
Typical UHF Variable Capacitance Diode Tuner Module

D1 - D5 - ZC831 or ZMV831 or ZV831V

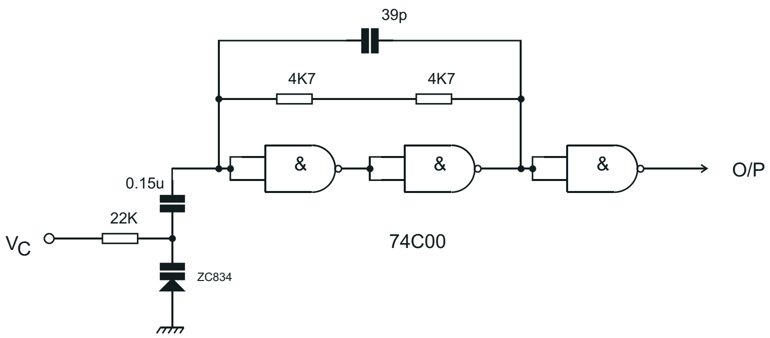

Figure 8
Basic Form of VCO using Logic Gates.

In its basic form, and for a square wave output, a common method of providing a VCO is to use logic gates coupled as shown in Figure 8; this particular design giving a 1 to 1.25MHz range. For a transistor design, a VCO can be realised by modifying the Clapp configuration as shown in Figure 9. For this example, the frequency can be varied over a 75 to 150MHz range for a 0-30V control voltage.

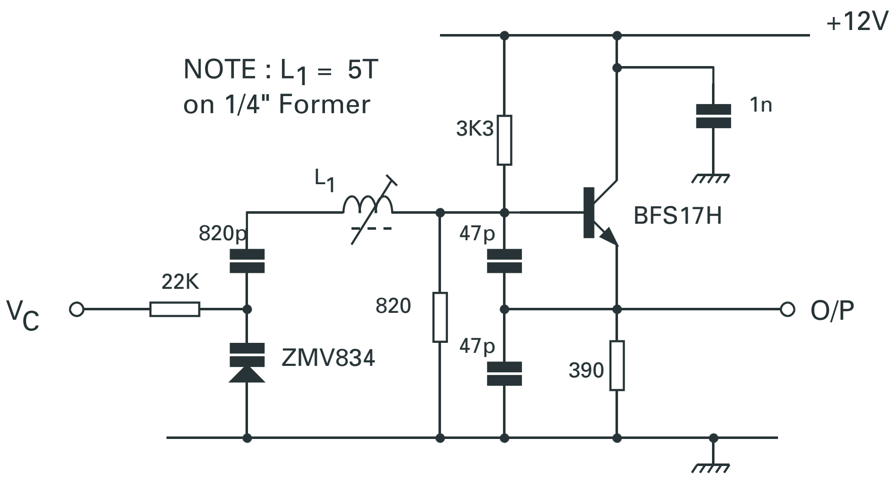

Figure 9
Transistor Effected VCO using Clapp Configuration.

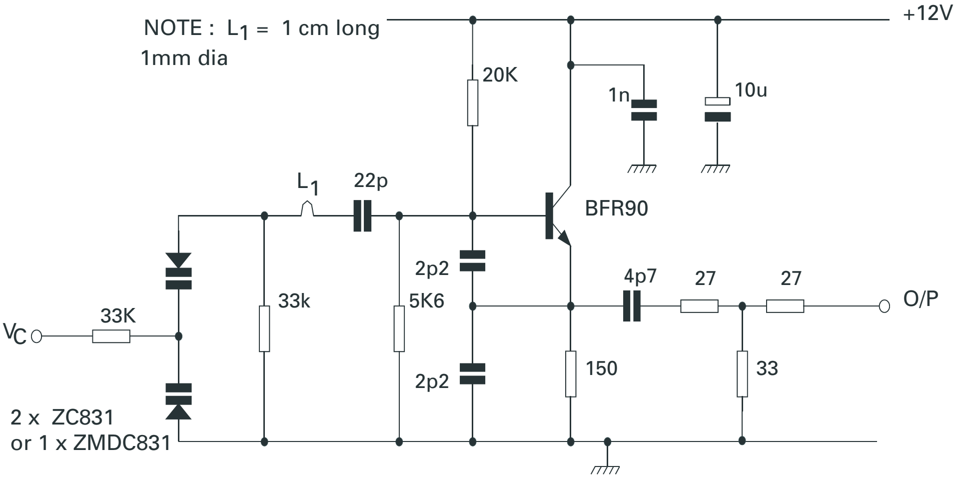

Figure 10
1GHz VCO Producing -5dBm with a 10dB PAD into 50Ω.

Figure 10 shows a similar configuration for a 1GHz VCO. Obviously at this frequency, circuit construction is critical and capable of producing large tuning range changes. For this example, the transistor was mounted in a slot in a small ground plane configured board, and the other components supported by short leads. This produced a signal level of -5dBm with a 10dB PAD into 50 ohms. The second harmonic was observed at -35dB down from the fundamental.

Other techniques using lumped components and Zetex variable capacitance diodes are capable of output at 1.5-2.5GHz, typically for tuning units for satellite receivers.

Low Phase Noise Capability

Due to the geometric features employed in the Zetex range of variable capacitance diodes, these products exhibit extremely low values of leakage current (typically less than 20 pA which enables excellent low phase noise performance within VCXO circuitry.

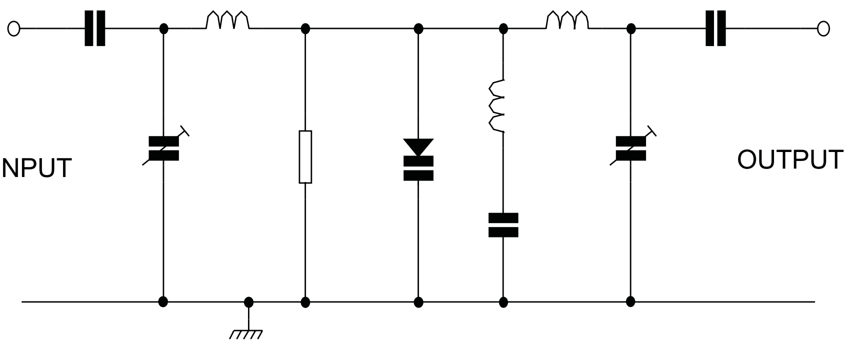

Figure 11a
Varactor Tripler with Marching Input and Output Stages.

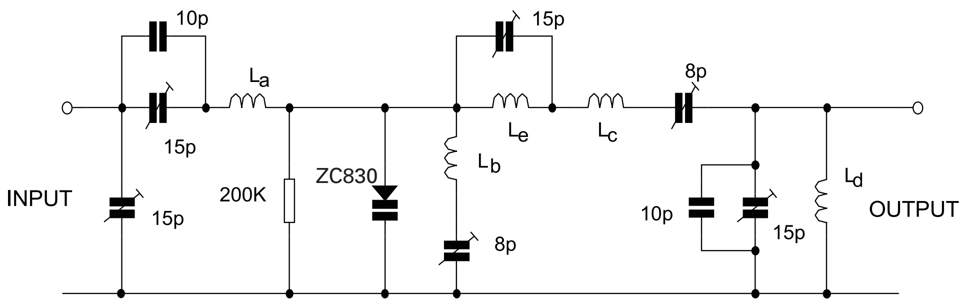

Figure 11b
Varactor Tripler with Bandpass Filtered Output and a Trap for the Fundamental.

The varactor diode also enables frequency multipliers to be produced that exhibit very high conversion efficiency, a zero DC power requirement, and low component count. Figure 11a shows the general appearance of a varactor tripler, and consists of input and output matching, and a trap for the unwanted second harmonic. Figure 11b shows a similar circuit for a 100-300MHz tripler using a ZC830, and includes a bandpass filtered output and a trap for the fundamental.

Appendix

Zetex Variable Capacitance Diode Product Range.

The tables presented within this Appendix illustrate the standard abrupt, hyperabrupt and hyper-hyperabrupt ranges available with respect to datasheet characteristics and package style. In addition, Zetex can also supply to competitors' type numbers and customers' specific requirements.

SOD523	SOD323	SOT23	SOT323 DUAL	SOT23 DUAL	Capacitance V_R = 2V, f = 1MHz	Capacitance Ratio C2/C20 at f = 1MHz		Q V_R = 3V f = 50MHz
					TYP (pF)	Min	Max	Min
	ZMV829A	ZC829A			8.2	4.3	5.8	250
ZV829BV2 [(1)]	ZMV829B	ZC829B	ZMDC829B [(1)]		8.2	4.3	5.8	250
	ZMV830A	ZC830A			10.0	4.5	6.0	300
ZV830BV2 [(1)]	ZMV830B	ZC830B	ZMDC830B [(1)]		10.0	4.5	6.0	300
	ZMV831A	ZC831A			15.0	4.5	6.0	300
ZV831BV2	ZMV831B	ZC831B	ZMDC831B		15.0	4.5	6.0	300
	ZMV832A	ZC832A			22.0	5.0	6.5	200
ZV832BV2	ZMV832B	ZC832B	ZMDC832B		22.0	5.0	6.5	200
	ZMV833A	ZC833A		ZDC833A	33.0	5.0	6.5	200
	ZMV833B	ZC833B	ZMDC833B [(1)]		33.0	5.0	6.5	200
	ZMV834A	ZC834A		ZDC834A	47.0	5.0	6.5	200
	ZMV834B	ZC834B			47.0	5.0	6.5	200
	ZMV835A	ZC835A			68.0	5.0	6.5	100
	ZMV835B	ZC835B			68.0	5.0	6.5	100
		ZC836A			100.0	5.0	6.5	100
	ZMV836B	ZC836B			100.0	5.0	6.5	100

Note:
Suffix A diodes are 10% tolerance.
Suffix B diodes are 5% tolerance.
[(1)] Planned for future release. Please contact your local Zetex sales office for more details.

HIGH PERFORMANCE HYPER-HYPER ABRUPT

SOD523	SOT323	SOT23	Capacitance V_R = 1V, f=1MHz	Capacitance V_R = 2.5V, at f=1MHz		Capacitance VR = 4V f=1MHz	Q VR = 4V f=50MHz
			Min (pF)	Min	Max	Min (pF)	Min
ZV930V2 (1)	ZMV930	ZC930	8.70	4.30	5.50	2.90	200
ZV931V2	ZMV931	ZC931	13.50	6.50	7.80	4.00	300
ZV932V2	ZMV932	ZC932	17.00	8.50	10.50	5.50	200
ZV933V2	ZMV933	ZC933	42.00	18.00	27.00	12.00	150
	ZMV933A	ZC933A	42.00	20.25	24.75	12.00	150
	ZMV934	ZC934	95.00	40.00	65.00	25.00	80
	ZMV934A	ZC934A	95.00	47.25	57.75	25.00	80

(1) Planned for future release. Please contact your local Zetex sales office for more details.

LOW VOLTAGE HYPER ABRUPT

SOD523	SOT323 DUAL	Capacitance V_R = 0.5V, f = 1MHz	Capacitance V_R = 1.5V, f = 1MHz		Capacitance C0.5/C2.5 f = 1MHz	Q V_R = 0.5V f = 50MHz
		Min (pF)	Min	Max	Min	Min
ZV950V2	ZMDC950 (1)	9.5	6.3	7.8	2.0	250
ZV951V2 (1)	ZMDC951 (1)	15.0	9.4	11.6	2.0	250
ZV952V2	ZMDC952 (1)	19.00	12.7	15.7	2.0	250
ZV953V2	ZMDC953	45.0	30.0	37.0	2.0	200

(1) Planned for future release. Please contact your local Zetex sales office for more details.