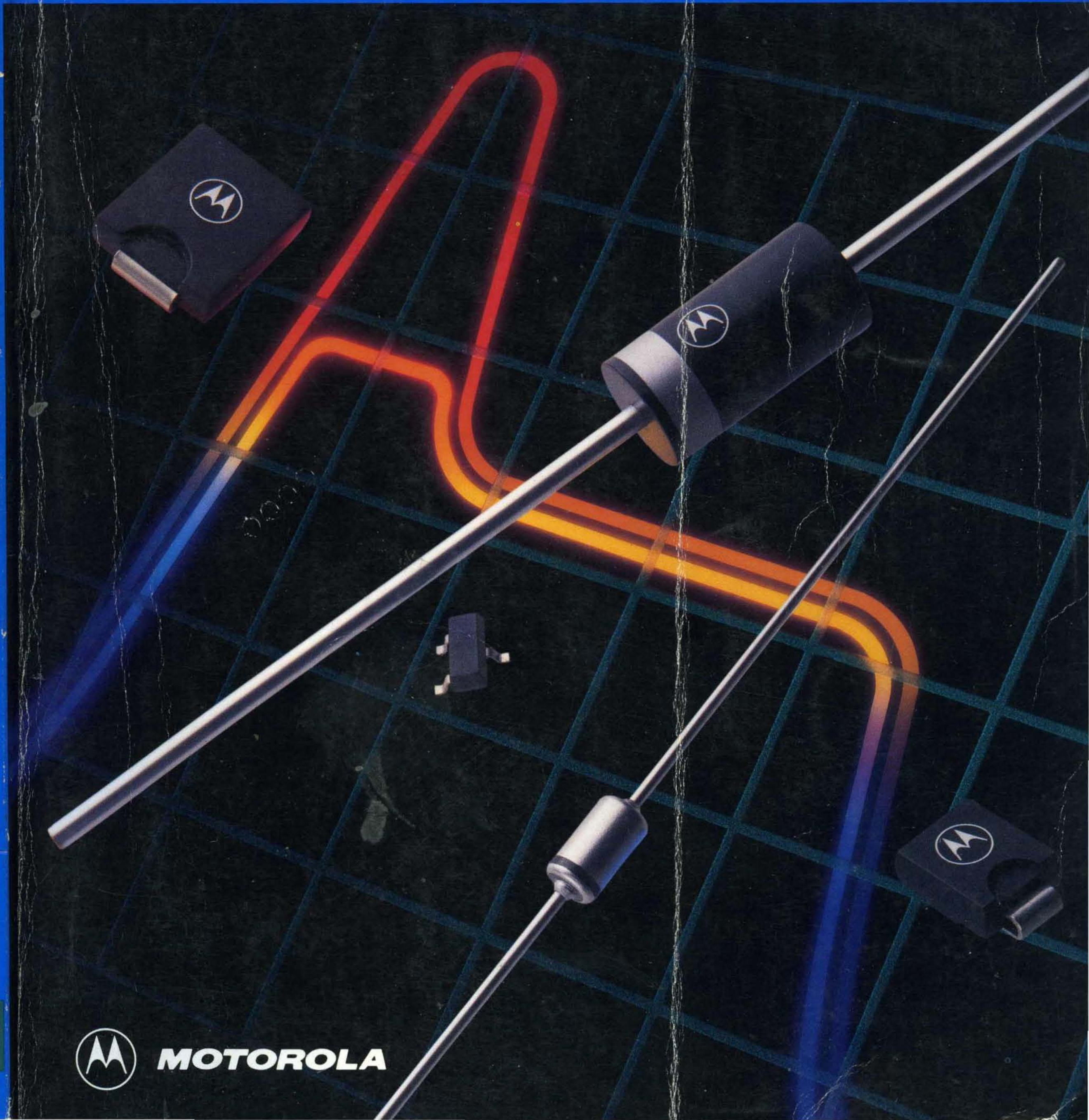
DL150

TVS/Zener

Device Data



MOTOROLA

MOTOROLA TVS / ZENER DEVICE DATA

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CF = consult factory representative

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CF = consult factory representative

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CF = consult factory representative

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1N4681	1N4681		4-2-30
1N4681C	1N4681C		4-2-30
1N4681D	1N4681D		4-2-30
1N4682	1N4682		4-2-30
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1N4745C	1N4745C		4-2-44
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1N5014A		3EZ5.6D5	4-2-53
1N5015		3EZ6.2D10	4-2-53
1N5015A		3EZ6.2D5	4-2-53
1N5016		3EZ6.8D10	4-2-53
1N5016A		3EZ6.8D5	4-2-53
1N5017		3EZ7.5D10	4-2-53
1N5017A		3EZ7.5D5	4-2-53
1N5018		3EZ8.2D10	4-2-53
1N5018A		3EZ8.2D5	4-2-53
1N5019		3EZ9.1D10	4-2-53
1N5019A		3EZ9.1D5	4-2-53
1N5020		3EZ10D10	4-2-53
1N5020A		3EZ10D5	4-2-53
1N5021		3EZ11D10	4-2-53
1N5021A		3EZ11D5	4-2-53
1N5022		3EZ12D10	4-2-53
1N5022A		3EZ12D5	4-2-53
1N5023		3EZ13D10	4-2-53
1N5023A		3EZ13D5	4-2-53
1N5024		3EZ14D10	4-2-53
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1N5025		3EZ15D10	4-2-53
1N5025A		3EZ15D5	4-2-53
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1N5026A		3EZ16D5	4-2-53
1N5027		3EZ17D10	4-2-53
1N5027A		3EZ17D5	4-2-53
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1N5032A		3EZ24D5	4-2-53
1N5033		3EZ24D5	4-2-53
1N5033A		3EZ24D5	4-2-53
1N5034		3EZ27D10	4-2-53
1N5034A		3EZ27D5	4-2-53
1N5035		3EZ30D10	4-2-54
1N5035A		3EZ30D5	4-2-53
1N5036		3EZ33D10	4-2-53
1N5036A		3EZ33D5	4-2-53
1N5037		3EZ36D10	4-2-53
1N5037A		3EZ36D5	4-2-53
1N5038		3EZ39D10	4-2-53
1N5038A		3EZ39D5	4-2-53
1N5039		3EZ43D10	4-2-53
1N5039A		3EZ43D5	4-2-53
1N5040		3EZ47D5	4-2-53
1N5040A		3EZ47D5	4-2-53
1N5041		3EZ47D5	4-2-53
1N5041A		3EZ47D5	4-2-53
1N5042		3EZ51D5	4-2-53
1N5042A		3EZ51D5	4-2-53
1N5043		3EZ51D10	4-2-53
1N5043A		3EZ51D5	4-2-53
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1N5225B	1N5225B		4-2-31
1N5225C	1N5225C		4-2-31
1N5225D	1N5225D		4-2-31
1N5226	1N5226A		4-2-31
1N5226A	1N5226A		4-2-31
1N5226B	1N5226B		4-2-31
1N5226C	1N5226C		4-2-31
1N5226D	1N5226D		4-2-31
1N5227	1N5227A		4-2-31
1N5227A	1N5227A		4-2-31
1N5227B	1N5227B		4-2-31
1N5227C	1N5227C		4-2-31
1N5227D	1N5227D		4-2-31
1N5228	1N5228A		4-2-31
1N5228A	1N5228A		4-2-31
1N5228B	1N5228B		4-2-31
1N5228C	1N5228C		4-2-31
1N5228D	1N5228D		4-2-31
1N5229	1N5229A		4-2-31
1N5229A	1N5229A		4-2-31
1N5229B	1N5229B		4-2-31
1N5229C	1N5229C		4-2-31
1N5229D	1N5229D		4-2-31
1N5230	1N5230A		4-2-31
1N5230A	1N5230A		4-2-31
1N5230B	1N5230B		4-2-31
1N5230C	1N5230C		4-2-31
1N5230D	1N5230D		4-2-31
1N5231	1N5231A		4-2-31
1N5231A	1N5231A		4-2-31
1N5231B	1N5231B		4-2-31
1N5231C	1N5231C		4-2-31
1N5231D	1N5231D		4-2-31
1N5232	1N5232A		4-2-31
1N5232A	1N5232A		4-2-31
1N5232B	1N5232B		4-2-31
1N5232C	1N5232C		4-2-31
1N5232D	1N5232D		4-2-31
1N5233	1N5233A		4-2-31
1N5233A	1N5233A		4-2-31
1N5233B	1N5233B		4-2-31
1N5233C	1N5233C		4-2-31
1N5233D	1N5233D		4-2-31
1N5234	1N5234A		4-2-31
1N5234A	1N5234A		4-2-31
1N5234B	1N5234B		4-2-31
1N5234C	1N5234C		4-2-31
1N5234D	1N5234D		4-2-31
1N5235	1N5235A		4-2-31
1N5235A	1N5235A		4-2-31

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1N5235D	1N5235D		4-2-31
1N5236	1N5236A		4-2-31
1N5236A	1N5236A		4-2-31
1N5236B	1N5236B		4-2-31
1N5236C	1N5236C		4-2-31
1N5236D	1N5236D		4-2-31
1N5237	1N5237A		4-2-31
1N5237A	1N5237A		4-2-31
1N5237B	1N5237B		4-2-31
1N5237C	1N5237C		4-2-31
1N5237D	1N5237D		4-2-31
1N5238	1N5238A		4-2-31
1N5238A	1N5238A		4-2-31
1N5238B	1N5238B		4-2-31
1N5238C	1N5238C		4-2-31
1N5238D	1N5238D		4-2-31
1N5239	1N5239A		4-2-31
1N5239A	1N5239A		4-2-31
1N5239B	1N5239B		4-2-31
1N5239C	1N5239C		4-2-31
1N5239D	1N5239D		4-2-31
1N5240	1N5240A		4-2-31
1N5240A	1N5240A		4-2-31
1N5240B	1N5240B		4-2-31
1N5240C	1N5240C		4-2-31
1N5240D	1N5240D		4-2-31
1N5241	1N5241A		4-2-31
1N5241A	1N5241A		4-2-31
1N5241B	1N5241B		4-2-31
1N5241C	1N5241C		4-2-31
1N5241D	1N5241D		4-2-31
1N5242	1N5242A		4-2-31
1N5242A	1N5242A		4-2-31
1N5242B	1N5242B		4-2-31
1N5242C	1N5242C		4-2-31
1N5242D	1N5242D		4-2-31
1N5243	1N5243A		4-2-31
1N5243A	1N5243A		4-2-31
1N5243B	1N5243B		4-2-31
1N5243C	1N5243C		4-2-31
1N5243D	1N5243D		4-2-31
1N5244	1N5244A		4-2-31
1N5244A	1N5244A		4-2-31
1N5244B	1N5244B		4-2-31
1N5244C	1N5244C		4-2-31
1N5244D	1N5244D		4-2-31
1N5245	1N5245A		4-2-31
1N5245A	1N5245A		4-2-31
1N5245B	1N5245B		4-2-31

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1N5266B	1N5266B		4-2-32
1N5266C	1N5266C		4-2-32
1N5266D	1N5266D		4-2-32
1N5267	1N5267A		4-2-32
1N5267A	1N5267A		4-2-32
1N5267B	1N5267B		4-2-32
1N5267C	1N5267C		4-2-32
1N5267D	1N5267D		4-2-32
1N5268	1N5268A		4-2-32
1N5268A	1N5268A		4-2-32
1N5268B	1N5268B		4-2-32
1N5268C	1N5268C		4-2-32
1N5268D	1N5268D		4-2-32
1N5269	1N5269A		4-2-32
1N5269A	1N5269A		4-2-32
1N5269B	1N5269B		4-2-32
1N5269C	1N5269C		4-2-32
1N5269D	1N5269D		4-2-32
1N5270	1N5270A		4-2-32
1N5270A	1N5270A		4-2-32
1N5270B	1N5270B		4-2-32
1N5270C	1N5270C		4-2-32
1N5270D	1N5270D		4-2-32
1N5271	1N5271A		4-2-32
1N5271A	1N5271A		4-2-32
1N5271B	1N5271B		4-2-32
1N5271C	1N5271C		4-2-32
1N5271D	1N5271D		4-2-32
1N5272	1N5272A		4-2-32
1N5272A	1N5272A		4-2-32
1N5272B	1N5272B		4-2-32
1N5272C	1N5272C		4-2-32
1N5272D	1N5272D		4-2-32
1N5273	1N5273A		4-2-32
1N5273A	1N5273A		4-2-32
1N5273B	1N5273B		4-2-32
1N5273C	1N5273C		4-2-32
1N5273D	1N5273D		4-2-32
1N5274	1N5274A		4-2-32
1N5274A	1N5274A		4-2-32
1N5274B	1N5274B		4-2-32
1N5274C	1N5274C		4-2-32
1N5274D	1N5274D		4-2-32
1N5275	1N5275A		4-2-32
1N5275A	1N5275A		4-2-32
1N5275B	1N5275B		4-2-32
1N5275C	1N5275C		4-2-32
1N5275D	1N5275D		4-2-32
1N5276	1N5276A		4-2-32

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1N5276C	1N5276C		4-2-32
1N5276D	1N5276D		4-2-32
1N5277	1N5277A		4-2-32
1N5277A	1N5277A		4-2-32
1N5277B	1N5277B		4-2-32
1N5277C	1N5277C		4-2-32
1N5277D	1N5277D		4-2-32
1N5278	1N5278A		4-2-32
1N5278A	1N5278A		4-2-32
1N5278B	1N5278B		4-2-32
1N5278C	1N5278C		4-2-32
1N5278D	1N5278D		4-2-32
1N5279	1N5279A		4-2-32
1N5279A	1N5279A		4-2-32
1N5279B	1N5279B		4-2-32
1N5279C	1N5279C		4-2-32
1N5279D	1N5279D		4-2-32
1N5280	1N5280A		4-2-32
1N5280A	1N5280A		4-2-32
1N5280B	1N5280B		4-2-32
1N5280C	1N5280C		4-2-32
1N5280D	1N5280D		4-2-32
1N5281	1N5281A		4-2-32
1N5281A	1N5281A		4-2-32
1N5281B	1N5281B		4-2-32
1N5281C	1N5281C		4-2-32
1N5281D	1N5281D		4-2-32
1N5283	1N5283		CF
1N5284	1N5284		CF
1N5285	1N5285		CF
1N5286	1N5286		CF
1N5287	1N5287		CF
1N5288	1N5288		CF
1N5289	1N5289		CF
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1N5293	1N5293		CF
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1N5297	1N5297		CF
1N5298	1N5298		CF
1N5299	1N5299		CF
1N5300	1N5300		CF
1N5301	1N5301		CF
1N5302	1N5302		CF
1N5303	1N5303		CF
1N5304	1N5304		CF

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1N5351C	CF		–
1N5351D	CF		–
1N5352	1N5352A		4-2-59
1N5352A	1N5352A		4-2-59
1N5352B	1N5352B		4-2-59
1N5352C	CF		–
1N5352D	CF		–
1N5353	1N5353A		4-2-59
1N5353A	1N5353A		4-2-59
1N5353B	1N5353B		4-2-59
1N5353C	CF		–
1N5353D	CF		–
1N5354	1N5354A		4-2-59
1N5354A	1N5354A		4-2-59
1N5354B	1N5354B		4-2-59
1N5354C	CF		–
1N5354D	CF		–
1N5355	1N5355A		4-2-59
1N5355A	1N5355A		4-2-59
1N5355B	1N5355B		4-2-59
1N5355C	CF		–
1N5355D	CF		–
1N5356	1N5356A		4-2-59
1N5356A	1N5356A		4-2-59
1N5356B	1N5356B		4-2-59
1N5356C	CF		–
1N5356D	CF		–
1N5357	1N5357A		4-2-59
1N5357A	1N5357A		4-2-59
1N5357B	1N5357B		4-2-59
1N5357C	CF		–
1N5357D	CF		–
1N5358	1N5358A		4-2-59
1N5358A	1N5358A		4-2-59
1N5358B	1N5358B		4-2-59
1N5358C	CF		–
1N5358D	CF		–
1N5359	1N5359A		4-2-59
1N5359A	1N5359A		4-2-59
1N5359B	1N5359B		4-2-59
1N5359C	CF		–
1N5359D	CF		–
1N5360	1N5360A		4-2-59
1N5360A	1N5360A		4-2-59
1N5360B	1N5360B		4-2-59
1N5360C	CF		–
1N5360D	CF		–
1N5361	1N5361A		4-2-59
1N5361A	1N5361A		4-2-59
1N5361B	1N5361B		4-2-59

Industry Part Number	Motorola Direct Replacement	Motorola Similar Replacement	Page Number
1N5361C	CF		–
1N5361D	CF		–
1N5362	1N5362A		4-2-59
1N5362A	1N5362A		4-2-59
1N5362B	1N5362B		4-2-59
1N5362C	CF		–
1N5362D	CF		–
1N5363	1N5363A		4-2-59
1N5363A	1N5363A		4-2-59
1N5363B	1N5363B		4-2-59
1N5363C	CF		–
1N5363D	CF		–
1N5364	1N5364A		4-2-59
1N5364A	1N5364A		4-2-59
1N5364B	1N5364B		4-2-59
1N5364C	CF		–
1N5364D	CF		–
1N5365	1N5365A		4-2-59
1N5365A	1N5365A		4-2-59
1N5365B	1N5365B		4-2-59
1N5365C	CF		–
1N5365D	CF		–
1N5366	1N5366A		4-2-59
1N5366A	1N5366A		4-2-59
1N5366B	1N5366B		4-2-59
1N5366C	CF		–
1N5366D	CF		–
1N5367	1N5367A		4-2-59
1N5367A	1N5367A		4-2-59
1N5367B	1N5367B		4-2-59
1N5367C	CF		–
1N5367D	CF		–
1N5368	1N5368A		4-2-59
1N5368A	1N5368A		4-2-59
1N5368B	1N5368B		4-2-59
1N5368C	CF		–
1N5368D	CF		–
1N5369	1N5369A		4-2-59
1N5369A	1N5369A		4-2-59
1N5369B	1N5369B		4-2-59
1N5369C	CF		–
1N5369D	CF		–
1N5370	1N5370A		4-2-59
1N5370A	1N5370A		4-2-59
1N5370B	1N5370B		4-2-59
1N5370C	CF		–
1N5370D	CF		–
1N5371	1N5371A		4-2-59
1N5371A	1N5371A		4-2-59
1N5371B	1N5371B		4-2-59
1N5371C	CF		–

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1N5521A		MZ5521B	4-2-38
1N5521B		MZ5521B	4-2-38
1N5521C		CF	–
1N5521D		CF	–
1N5522		MZ5522B	4-2-38
1N5522A		MZ5522B	4-2-38
1N5522B		MZ5522B	4-2-38
1N5522C		CF	–
1N5522D		CF	–
1N5523		MZ5523B	4-2-38
1N5523A		MZ5523B	4-2-38
1N5523B		MZ5523B	4-2-38
1N5523C		CF	–
1N5523D		CF	–
1N5524		MZ5524B	4-2-38
1N5524A		MZ5524B	4-2-38
1N5524B		MZ5524B	4-2-38
1N5524C		CF	–
1N5524D		CF	–
1N5525		MZ5525B	4-2-38
1N5525A		MZ5525B	4-2-38
1N5525B		MZ5525B	4-2-38
1N5525C		CF	–
1N5525D		CF	–
1N5526		MZ5526B	4-2-38
1N5526A		MZ5526B	4-2-38
1N5526B		MZ5526B	4-2-38
1N5526C		CF	–
1N5526D		CF	–
1N5527		MZ5527B	4-2-38
1N5527A		MZ5527B	4-2-38
1N5527B		MZ5527B	4-2-38
1N5527C		CF	–
1N5527D		CF	–
1N5528		MZ5528B	4-2-38
1N5528A		MZ5528B	4-2-38
1N5528B		MZ5528B	4-2-38
1N5528C		CF	–
1N5528D		CF	–
1N5529		MZ5529B	4-2-38
1N5529A		MZ5529B	4-2-38
1N5529B		MZ5529B	4-2-38
1N5529C		CF	–
1N5529D		CF	–
1N5530		MZ5530B	4-2-38
1N5530A		MZ5530B	4-2-38
1N5530B		MZ5530B	4-2-38
1N5530C		CF	–
1N5530D		CF	–
1N5531		1N4698	4-2-30
1N5531A		1N4698	4-2-30

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1N5531D		1N4698D	4-2-30
1N5532		1N4699	4-2-30
1N5532A		1N4699	4-2-30
1N5532B		1N4699	4-2-30
1N5532C		1N4699C	4-2-30
1N5532D		1N4699D	4-2-30
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1SMB5921BT3	1SMB5921BT3		4-2-78
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MZD11	MZD11		4-2-55
MZD110	MZD110		4-2-55
MZD12	MZD12		4-2-55
MZD120	MZD120		4-2-55
MZD13	MZD13		4-2-55
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MZD150	MZD150		4-2-55
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MZD160	MZD160		4-2-55
MZD18	MZD18		4-2-55
MZD180	MZD180		4-2-55
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P6KE91C	P6KE91C		4-1-34
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SMSJ70		1SMB70AT3	4-1-59
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SMZJ5364A,B		P6SMB33AT3	4-1-60
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TVS/ZENER PREFERRED PARTS LIST

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1.5KE10CA	10	1.5 kW SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-43
1.5KE12CA	12	1.5 kW SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-43
1.5KE18CA	18	1.5 kW SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-43
1.5KE36CA	36	1.5 kW SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-43
1.5SMC36AT3	36	1.5 kW SURGE	TVS-UNIDIR.	SURFACE MOUNTED	SMC	PLASTIC	4-1-66
1.5SMC56AT3	56	1.5 kW SURGE	TVS-UNIDIR.	SURFACE MOUNTED	SMC	PLASTIC	4-1-66
1.5SMC62AT3	62	1.5 kW SURGE	TVS-UNIDIR.	SURFACE MOUNTED	SMC	PLASTIC	4-1-66
1N4689	5.1	500 mWDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-35	GLASS	4-2-30
1N4728A	3.3	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4731A	4.3	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4732A	4.7	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4733A	5.1	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4734A	5.6	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4735A	6.2	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4736A	6.8	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4738A	8.2	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4739A	9.1	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4740A	10	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4741A	11	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4742A	12	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4743A	13	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4744A	15	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4745A	16	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4746A	18	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4747A	20	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4749A	24	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4750A	27	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N4751A	30	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	GLASS	4-2-44
1N5221B	2.4	500 mWDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-35	GLASS	4-2-31
1N5223B	2.7	500 mWDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-35	GLASS	4-2-31
1N5226B	3.3	500 mWDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-35	GLASS	4-2-31
1N5228B	3.9	500 mWDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-35	GLASS	4-2-31
1N5229B	4.3	500 mWDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-35	GLASS	4-2-31

* MAXIMUM REVERSE STAND-OFF VOLTAGE

TVS/ZENER PREFERRED PARTS LIST

DEVICE TYPE	ZENER BREAK-DOWN VOLTAGE (VOLTS)	POWER RATING	APPLICATION	MOUNTING TYPE	PACKAGE OUTLINE	CASE MATERIAL	PAGE #
1N5360B	25	5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-2-59
1N5361B	27	5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-2-59
1N5363B	30	5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-2-59
1N5364B	33	5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-2-59
1N5365B	36	5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-2-59
1N5366B	39	5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-2-59
1N5368B	47	5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-2-59
1N5372B	62	5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-2-59
1N5383B	150	5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-2-60
1N5908	5 *	1.5 kW SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-42
1N5918B	5.1	1.5 WDC	VOLT.AGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-51
1N5920B	6.2	1.5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-51
1N5929B	15	1.5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-51
1N5934B	24	1.5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-51
1N5936B	30	1.5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-51
1N5941B	47	1.5 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-51
1N5988B	3.3	500 mWDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-35	GLASS	4-2-33
1N5993B	5.1	500 mWDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-35	GLASS	4-2-33
1N5994B	5.6	500 mWDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-35	GLASS	4-2-33
1N5998B	8.2	500 mWDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-35	GLASS	4-2-33
1N6007B	20	500 mWDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-35	GLASS	4-2-33
1N6267A	6.8	1.5 kW SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-43
1N6280A	24	1.5 kW SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-43
1N6282A	30	1.5 kW SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-43
1N6283A	33	1.5 kW SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-43
1N6284A	36	1.5 kW SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-43
1N6288A	51	1.5 kW SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-43
1N6290A	62	1.5 kW SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-44
1N6373	5 *	1.5 kW SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-46
1N6376	12 *	1.5 kW SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-46
1N6382	8 *	1.5 kW SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-46
1N6385	15 *	1.5 kW SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 41	PLASTIC	4-1-46
1N821	6.2	400 mWDC	VOLTAGE REF.	AXIAL THRU-HOLE	DO-35	GLASS	4-3-10
1N823	6.2	400 mWDC	VOLTAGE REF.	AXIAL THRU-HOLE	DO-35	GLASS	4-3-10
1N825	6.2	400 mWDC	VOLTAGE REF.	AXIAL THRU-HOLE	DO-35	GLASS	4-3-10
1SMB5918BT3	5.1	1.5 WDC	VOLTAGE REG.	SURFACE MOUNTED	SMB	PLASTIC	4-2-78

* MAXIMUM REVERSE STAND-OFF VOLTAGE

TVS/ZENER PREFERRED PARTS LIST

DEVICE TYPE	ZENER BREAK-DOWN VOLTAGE (VOLTS)	POWER RATING	APPLICATION	MOUNTING TYPE	PACKAGE OUTLINE	CASE MATERIAL	PAGE #
MMBZ5255BL	28	225 mWDC	VOLTAGE REG.	SURFACE MOUNTED	SOT-23	PLASTIC	4-2-66
MR2535L	20*	110 A SURGE	TVS–UNIDIR.	AXIAL THRU-HOLE	CASE 194-04	PLASTIC	4-1-48
MZP4733A	5.1	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-56
MZP4735A	6.2	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-56
MZP4744A	15	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-56
MZP4745A	16	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-56
MZP4746A	18	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-56
MZP4749A	24	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-56
MZP4751A	30	1 WDC	VOLTAGE REG.	AXIAL THRU-HOLE	DO-41	PLASTIC	4-2-56
P6KE11CA	11	600 W SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6KE13A	13	600 W SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6KE15A	15	600 W SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6KE20CA	20	600 W SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6KE22CA	22	600 W SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6KE27A	27	600 W SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6KE27CA	27	600 W SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6KE30CA	30	600 W SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6KE33A	33	600 W SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6KE36A	36	600 W SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6KE6.8A	6.8	600 W SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6KE62A	62	600 W SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6KE7.5CA	7.5	600 W SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 17	PLASTIC	4-1-33
P6SMB13AT3	13	600 W SURGE	TVS-UNIDIR.	SURFACE MOUNTED	SMB	PLASTIC	4-1-60
P6SMB15AT3	15	600 W SURGE	TVS-UNIDIR.	SURFACE MOUNTED	SMB	PLASTIC	4-1-60
P6SMB27AT3	27	600 W SURGE	TVS-UNIDIR.	SURFACE MOUNTED	SMB	PLASTIC	4-1-60
P6SMB30AT3	30	600 W SURGE	TVS-UNIDIR.	SURFACE MOUNTED	SMB	PLASTIC	4-1-60
P6SMB33AT3	33	600 W SURGE	TVS-UNIDIR.	SURFACE MOUNTED	SMB	PLASTIC	4-1-60
P6SMB36AT3	36	600 W SURGE	TVS-UNIDIR.	SURFACE MOUNTED	SMB	PLASTIC	4-1-60
P6SMB51AT3	51	600 W SURGE	TVS-UNIDIR.	SURFACE MOUNTED	SMB	PLASTIC	4-1-60
P6SMB62AT3	62	600 W SURGE	TVS-UNIDIR.	SURFACE MOUNTED	SMB	PLASTIC	4-1-60
SA12A	12*	500 W SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 59-04	PLASTIC	4-1-26
SA12CA	12*	500 W SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 59-04	PLASTIC	4-1-26
SA13A	13*	500 W SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 59-04	PLASTIC	4-1-26
SA13CA	13*	500 W SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 59-04	PLASTIC	4-1-26
SA15A	15*	500 W SURGE	TVS-UNIDIR.	AXIAL THRU-HOLE	CASE 59-04	PLASTIC	4-1-26
SA15CA	15*	500 W SURGE	TVS-BIDIR.	AXIAL THRU-HOLE	CASE 59-04	PLASTIC	4-1-26

* MAXIMUM REVERSE STAND-OFF VOLTAGE

3

4

4.1

Section 4.1.1 Selector Guide Transient Voltage Suppressors

4

4.1

SELECTOR GUIDE

AXIAL LEADED FOR THRU-HOLE DESIGNS (continued) (See Section 4.1.4 for complete data)

PEAK POWER DISSIPATION* — 500 WATTS @ 1 ms SURGE (FIGURE 1) — CASE 59-04 (continued)

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) V_F = 3.5 V Max, I_F = 35 A Pulse (except bidirectional devices).

Working Peak Reverse Voltage V_{RWM} (Volts)	Device**	Breakdown Voltage V_{BR} (Volts) Min	Max	@ I_T Pulse (mA)	Maximum Reverse Leakage @ V_{RWM} I_R (μA)	Maximum Reverse Surge Current I_{RSM} Figure 1 (Amps)	Maximum Reverse Voltage @ I_{RSM} (Clamping Voltage) V_{RSM} (Volts)
18	SA18	20	24.4	1	1	15.5	32.2
18	SA18A	20	22.1	1	1	17.2	29.2
20	SA20	22.2	27.1	1	1	13.9	35.8
20	SA20A	22.2	24.5	1	1	15.4	32.4
22	SA22	24.4	29.8	1	1	12.7	39.4
22	SA22A	24.4	26.9	1	1	14.1	35.5
24	SA24	26.7	32.6	1	1	11.6	43
24	SA24A	26.7	29.5	1	1	12.8	38.9
26	SA26	28.9	35.3	1	1	10.7	46.6
26	SA26A	28.9	31.9	1	1	11.9	42.1
28	SA28	31.1	38	1	1	9.9	50
28	SA28A	31.1	34.4	1	1	11	45.4
30	SA30	33.3	40.7	1	1	9.3	53.5
30	SA30A	33.3	36.8	1	1	10.3	48.4
33	SA33	36.7	44.9	1	1	8.5	59
33	SA33A	36.7	40.6	1	1	9.4	53.3
36	SA36	40	48.9	1	1	7.8	64.3
36	SA36A	40	44.2	1	1	8.6	58.1
40	SA40	44.4	54.3	1	1	7	71.4
40	SA40A	44.4	49.1	1	1	7.8	64.5
43	SA43	47.8	58.4	1	1	6.5	76.7
43	SA43A	47.8	52.8	1	1	7.2	69.4
45	SA45	50	61.1	1	1	6.2	80.3
45	SA45A	50	55.3	1	1	6.9	72.7
48	SA48	53.3	65.1	1	1	5.8	85.5
48	SA48A	53.3	58.9	1	1	6.5	77.4
51	SA51	56.7	69.3	1	1	5.5	91.1
51	SA51A	56.7	62.7	1	1	6.1	82.4
54	SA54	60	73.3	1	1	5.2	96.3
54	SA54A	60	66.3	1	1	5.7	87.1
58	SA58	64.4	78.7	1	1	4.9	103
58	SA58A	64.4	71.2	1	1	5.3	93.6
60	SA60	66.7	81.5	1	1	4.7	107
60	SA60A	66.7	73.7	1	1	5.2	96.8
64	SA64	71.1	86.9	1	1	4.4	114
64	SA64A	71.1	78.6	1	1	4.9	103
70	SA70	77.8	95.1	1	1	4	125
70	SA70A	77.8	86	1	1	4.4	113
75	SA75	83.3	102	1	1	3.7	134
75	SA75A	83.3	92.1	1	1	4.1	121
78	SA78	86.7	106	1	1	3.6	139
78	SA78A	86.7	95.8	1	1	4	126
85	SA85	94.4	115	1	1	3.3	151
85	SA85A	94.4	104	1	1	3.6	137
90	SA90	100	122	1	1	3.1	160
90	SA90A	100	111	1	1	3.4	146
100	SA100	111	136	1	1	2.8	179
100	SA100A	111	123	1	1	3.1	162

* Steady state power dissipation = 3 watt max rating

** For bidirectional types use C or CA suffix. Have cathode polarity band on each end. (consult factory for availability)

(continued)

SELECTOR GUIDE

AXIAL LEADED FOR THRU-HOLE DESIGNS (continued) (See Section 4.1.4 for complete data)

PEAK POWER DISSIPATION* — 600 WATTS @ 1 ms SURGE (FIGURE 1) — CASE 17-02 (continued)

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) V_F = 3.5 V Max, I_F = 50 A Pulse (except bidirectional devices).

Breakdown Voltage**						
V_{BR} (Volts) Nom	@ I_T Pulse (mA)	Device*** †	Working Peak Reverse Voltage V_{RWM} (Volts)	Maximum Reverse Leakage @ V_{RWM} I_R (μA)	Maximum Reverse Surge Current I_{RSM} Figure 1 (Amps)	Maximum Reverse Voltage @ I_{RSM} (Clamping Voltage) V_{RSM} (Volts)
22	1	P6KE22	17.8	5	19	31.9
22	1	P6KE22A	18.8	5	20	30.6
24	1	P6KE24	19.4	5	17	34.7
24	1	P6KE24A	20.5	5	18	33.2
27	1	P6KE27	21.8	5	15	39.1
27	1	P6KE27A	23.1	5	16	37.5
30	1	P6KE30	24.3	5	14	43.5
30	1	P6KE30A	25.6	5	14.4	41.4
33	1	P6KE33	26.8	5	12.6	47.7
33	1	P6KE33A	28.2	5	13.2	45.7
36	1	P6KE36	29.1	5	11.6	52
36	1	P6KE36A	30.8	5	12	49.9
39	1	P6KE39	31.6	5	10.6	56.4
39	1	P6KE39A	33.3	5	11.2	53.9
43	1	P6KE43	34.8	5	9.6	61.9
43	1	P6KE43A	36.8	5	10.1	59.3
47	1	P6KE47	38.1	5	8.9	67.8
47	1	P6KE47A	40.2	5	9.3	64.8
51	1	P6KE51	41.3	5	8.2	73.5
51	1	P6KE51A	43.6	5	8.6	70.1
56	1	P6KE56	45.4	5	7.4	80.5
56	1	P6KE56A	47.8	5	7.8	77
62	1	P6KE62	50.2	5	6.8	89
62	1	P6KE62A	53	5	7.1	85
68	1	P6KE68	55.1	5	6.1	98
68	1	P6KE68A	58.1	5	6.5	92
75	1	P6KE75	60.7	5	5.5	108
75	1	P6KE75A	64.1	5	5.8	103
82	1	P6KE82	66.4	5	5.1	118
82	1	P6KE82A	70.1	5	5.3	113
91	1	P6KE91	73.7	5	4.5	131
91	1	P6KE91A	77.8	5	4.8	125
100	1	P6KE100	81	5	4.2	144
100	1	P6KE100A	85.5	5	4.4	137
110	1	P6KE110	89.2	5	3.8	158
110	1	P6KE110A	94	5	4	152
120	1	P6KE120	97.2	5	3.5	173
120	1	P6KE120A	102	5	3.6	165
130	1	P6KE130	105	5	3.2	187
130	1	P6KE130A	111	5	3.3	179

* Steady state power dissipation = 5 watts max rating

(continued)

** Breakdown voltage tolerance is ±10% for no suffix and ±5% for A suffix

*** For bidirectional types use C or CA suffix. Have cathode polarity band on each end. (consult factory for availability)

† UL recognition for classification of protectors (QVGV2) under the UL standard for safety 497B for entire series including C & CA suffixes.

SELECTOR GUIDE

AXIAL LEADED FOR THRU-HOLE DESIGNS (continued) (See Section 4.1.4 for complete data)

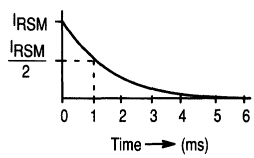
PEAK POWER DISSIPATION* — 1500 WATTS @ 1 ms SURGE (FIGURE 1) — CASE 41A-02

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) V_F = 3.5 V Max, I_F = 100 A Pulse)
(C suffix denotes standard back to back bidirectional versions. Test both polarities)

Maximum Reverse Stand-Off Voltage V_{RWM} (Volts)	JEDEC** Device	Device**	Breakdown Voltage V_{BR} Volts Min	Breakdown Voltage @ I_T Pulse (mA)	Maximum Reverse Leakage @ V_{RWM} I_R (μA)	Maximum Reverse Surge Current Figure 1 I_{RSM} (Amps)	Maximum Reverse Voltage @ I_{RSM} (Clamping Voltage) V_{RSM} (Volts)	Clamping Voltage*** Peak Pulse Current @ I_{pp1} = 1 A Figure 1 V_{C1} (Volts max)	Clamping Voltage*** Peak Pulse Current @ I_{pp2} = 10 A Figure 1 V_{C2} (Volts max)
5	1N5908		6	1	300	120	8.5	7.6 @ 30 A	8 @ 60 A
5	1N6373	ICTE-5/MPTE-5	6	1	300	160	9.4	7.1	7.5
8	1N6374	ICTE-8/MPTE-8	9.4	1	25	100	15	11.3	11.5
8	1N6382	ICTE-8C/MPTE-8C	9.4	1	25	100	15	11.4	11.6
10	1N6375	ICTE-10/MPTE-10	11.7	1	2	90	16.7	13.7	14.1
10	1N6383	ICTE-10C/MPTE-10C	11.7	1	2	90	16.7	14.1	14.5
12	1N6376	ICTE-12/MPTE-12	14.1	1	2	70	21.2	16.1	16.5
12	1N6384	ICTE-12C/MPTE-12C	14.1	1	2	70	21.2	16.7	17.1
15	1N6377	ICTE-15/MPTE-15	17.6	1	2	60	25	20.1	20.6
15	1N6385	ICTE-15C/MPTE-15C	17.6	1	2	60	25	20.8	21.4
18	1N6378	ICTE-18/MPTE-18	21.2	1	2	50	30	24.2	25.2
18	1N6386	ICTE-18C/MPTE-18C	21.2	1	2	50	30	24.8	25.5
22	1N6379	ICTE-22/MPTE-22	25.9	1	2	40	37.5	29.8	32
22	1N6387	ICTE-22C/MPTE-22C	25.9	1	2	40	37.5	30.8	32
36	1N6380	ICTE-36/MPTE-36	42.4	1	2	23	65.2	50.6	54.3
36	1N6388	ICTE-36C/MPTE-36C	42.4	1	2	23	65.2	50.6	54.3
45	1N6381	ICTE-45/MPTE-45	52.9	1	2	19	78.9	63.3	70
45	1N6389	ICTE-45C/MPTE-45C	52.9	1	2	19	78.9	63.3	70

* Steady state power dissipation = 5 watts max rating.
*** 1N6382 thru 1N6389 and C suffix ICTE/MPTE device types are bidirectional. Have cathode polarity band on each end. All other device types are unidirectional only. (Consult factory for availability).
*** Clamping voltage peak pulse currents for 1N5908 are 30 Amps and 60 Amps.

CASE 41A-02
PLASTIC
Cathode = Polarity Band



Surge Current Characteristics

Figure 1

SELECTOR GUIDE

AXIAL LEADED FOR THRU-HOLE DESIGNS (continued) (See Section 4.1.4 for complete data)

PEAK POWER DISSIPATION* — 1500 WATTS @ 1 ms SURGE (FIGURE 1) — CASE 41A-02 (continued)

ELECTRICAL CHARACTERISTICS — continued (T_A = 25°C unless otherwise noted) V_F = 3.5 V Max, I_F = 100 A Pulse

Breakdown Voltage**							
V_{BR} Volts Nom	@ I_T Pulse (mA)	JEDEC Device	Device***†	Working Peak Reverse Voltage V_{RWM} (Volts)	Maximum Reverse Leakage @ V_{RWM} I_R (μA)	Maximum Reverse Surge Current Figure 1 I_{RSM} (Amps)	Maximum Reverse Voltage @ I_{RSM} (Clamping Voltage) V_{RSM} (Volts)
56	1	1N6289	1.5KE56	45.4	5	18.6	80.5
56	1	1N6289A	1.5KE56A	47.8	5	19.5	77
62	1	1N6290	1.5KE62	50.2	5	16.9	89
62	1	1N6290A	1.5KE62A	53	5	17.7	85
68	1	1N6291	1.5KE68	55.1	5	15.3	98
68	1	1N6291A	1.5KE68A	58.1	5	16.3	92
75	1	1N6292	1.5KE75	60.7	5	13.9	108
75	1	1N6292A	1.5KE75A	64.1	5	14.6	103
82	1	1N6293	1.5KE82	66.4	5	12.7	118
82	1	1N6293A	1.5KE82A	70.1	5	13.3	113
91	1	1N6294	1.5KE91	73.7	5	11.4	131
91	1	1N6294A	1.5KE91A	77.8	5	12	125
100	1	1N6295	1.5KE100	81	5	10.4	144
100	1	1N6295A	1.5KE100A	85.5	5	11	137
110	1	1N6296	1.5KE110	89.2	5	9.5	158
110	1	1N6296A	1.5KE110A	94	5	9.9	152
120	1	1N6297	1.5KE120	97.2	5	8.7	173
120	1	1N6297A	1.5KE120A	102	5	9.1	165
130	1	1N6298	1.5KE130	105	5	8	187
130	1	1N6298A	1.5KE130A	111	5	8.4	179
150	1	1N6299	1.5KE150	121	5	7	215
150	1	1N6299A	1.5KE150A	128	5	7.2	207
160	1	1N6300	1.5KE160	130	5	6.5	230
160	1	1N6300A	1.5KE160A	136	5	6.8	219
170	1	1N6301	1.5KE170	138	5	6.2	244
170	1	1N6301A	1.5KE170A	145	5	6.4	234
180	1	1N6302	1.5KE180	146	5	5.8	258
180	1	1N6302A	1.5KE180A	154	5	6.1	246
200	1	1N6303	1.5KE200	162	5	5.2	287
200	1	1N6303A	1.5KE200A	171	5	5.5	274
220	1		1.5KE220	175	5	4.3	344
220	1		1.5KE220A	185	5	4.6	328
250	1		1.5KE250	202	5	5	360
250	1		1.5KE250A	214	5	5	344

* Steady state power dissipation = 5 watts max rating

** Breakdown voltage tolerance is ±10% for no suffix and ±5% for A suffix

*** For bidirectional types use C or CA suffix on 1.5KE series only. Have cathode polarity band on each end. Consult factory for availability. (1N6267-6303A series do not have C or CA option).

† UL recognition for classification of protectors (QVGV2) under the UL standard for safety 497B for 1.5KE6.8,A,C,CA thru 1.5KE250,A,C,CA.

SELECTOR GUIDE
SURFACE MOUNT PACKAGES (continued) (See Section 4.1.4 for complete data)
PEAK POWER DISSIPATION — 600 WATTS @ 1 ms SURGE (FIGURE 1) — CASE 403A-03

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted).

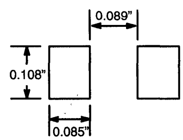
Reverse Stand-Off Voltage V_R Volts (1)	Device (2)	Breakdown Voltage V_{BR} @ I_T Volts Min	Pulse mA	Maximum Clamping Voltage V_C @ I_{pp} Volts	Peak Pulse Current (See Figure 1) I_{pp} Amps	Maximum Reverse Leakage @ V_R I_R µA	Device Marking
5	1SMB5.0AT3	6.4	10	9.2	65.2	800	KE
6	1SMB6.0AT3	6.67	10	10.3	58.3	800	KG
6.5	1SMB6.5AT3	7.22	10	11.2	53.6	500	KK
7	1SMB7.0AT3	7.78	10	12	50	200	KM
7.5	1SMB7.5AT3	8.33	1	12.9	46.5	100	KP
8	1SMB8.0AT3	8.89	1	13.6	44.1	50	KR
8.5	1SMB8.5AT3	9.44	1	14.4	41.7	10	KT
9	1SMB9.0AT3	10	1	15.4	39	5	KV
10	1SMB10AT3	11.1	1	17	35.3	5	KX
11	1SMB11AT3	12.2	1	18.2	33	5	KZ
12	1SMB12AT3	13.3	1	19.9	30.2	5	LE
13	1SMB13AT3	14.4	1	21.5	27.9	5	LG
14	1SMB14AT3	15.6	1	23.2	25.8	5	LK
15	1SMB15AT3	16.7	1	24.4	24	5	LM
16	1SMB16AT3	17.8	1	26	23.1	5	LP
17	1SMB17AT3	18.9	1	27.6	21.7	5	LR
18	1SMB18AT3	20	1	29.2	20.5	5	LT
20	1SMB20AT3	22.2	1	32.4	18.5	5	LV
22	1SMB22AT3	24.4	1	35.5	16.9	5	LX
24	1SMB24AT3	26.7	1	38.9	15.4	5	LZ
26	1SMB26AT3	28.9	1	42.1	14.2	5	ME
28	1SMB28AT3	31.1	1	45.4	13.2	5	MG
30	1SMB30AT3	33.3	1	48.4	12.4	5	MK
33	1SMB33AT3	36.7	1	53.3	11.3	5	MM
36	1SMB36AT3	40	1	58.1	10.3	5	MP
40	1SMB40AT3	44.4	1	64.5	9.3	5	MR
43	1SMB43AT3	47.8	1	69.4	8.6	5	MT
45	1SMB45AT3	50	1	72.7	8.3	5	MV
48	1SMB48AT3	53.3	1	77.4	7.7	5	MX
51	1SMB51AT3	56.7	1	82.4	7.3	5	MZ
54	1SMB54AT3	60	1	87.1	6.9	5	NE
58	1SMB58AT3	64.4	1	93.6	6.4	5	NG
60	1SMB60AT3	66.7	1	96.8	6.2	5	NK
64	1SMB64AT3	71.1	1	103	5.8	5	NM
70	1SMB70AT3	77.8	1	113	5.3	5	NP
75	1SMB75AT3	83.3	1	121	4.9	5	NR
78	1SMB78AT3	86.7	1	126	4.7	5	NT
85	1SMB85AT3	94.4	1	137	4.4	5	NV
90	1SMB90AT3	100	1	146	4.1	5	NX
100	1SMB100AT3	111	1	162	3.7	5	NZ
110	1SMB110AT3	122	1	177	3.4	5	PE
120	1SMB120AT3	133	1	193	3.1	5	PG
130	1SMB130AT3	144	1	209	2.9	5	PK
150	1SMB150AT3	167	1	243	2.5	5	PM
160	1SMB160AT3	178	1	259	2.3	5	PP
170	1SMB170AT3	189	1	275	2.2	5	PR

Note 1. A transient suppressor is normally selected according to the reverse "Stand Off Voltage" (V_R) which should be equal to or greater than the DC or continuous peak operating voltage level.

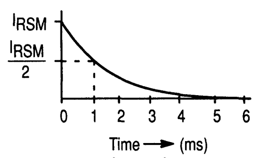
Note 2. T3 suffix designates tape and reel of 2500 units.

SMB
CASE 403A-03
PLASTIC
Cathode = Notch

RECOMMENDED SOLDER PAD (FOOTPRINT)



SMB



Surge Current Characteristics

Figure 1

SELECTOR GUIDE

SURFACE MOUNT PACKAGES (continued) (See Section 4.1.4 for complete data)

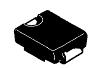
PEAK POWER DISSIPATION — 1500 WATTS @ 1 ms SURGE (FIGURE 1) — CASE 403-03

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Reverse Stand-Off Voltage V_R Volts (1)	Device (2)	Breakdown Voltage V_{BR} @ I_T Volts Min	Pulse mA	Maximum Clamping Voltage V_C @ I_{pp} Volts	Peak Pulse Current (See Figure 1) I_{pp} Amps	Maximum Reverse Leakage @ V_R I_R µA	Device Marking
5	1SMC5.0AT3	6.4	10	9.2	163	1000	GDE
6	1SMC6.0AT3	6.67	10	10.3	145.6	1000	GDG
6.5	1SMC6.5AT3	7.22	10	11.2	133.9	500	GDK
7	1SMC7.0AT3	7.78	10	12	125	200	GDM
7.5	1SMC7.5AT3	8.33	1	12.9	116.3	100	GDP
8	1SMC8.0AT3	8.89	1	13.6	110.3	50	GDR
8.5	1SMC8.5AT3	9.44	1	14.4	104.2	20	GDT
9	1SMC9.0AT3	10	1	15.4	97.4	10	GDV
10	1SMC10AT3	11.1	1	17	88.2	5	GDX
11	1SMC11AT3	12.2	1	18.2	82.4	5	GDZ
12	1SMC12AT3	13.3	1	19.9	75.3	5	GEE
13	1SMC13AT3	14.4	1	21.5	69.7	5	GEG
14	1SMC14AT3	15.6	1	23.2	64.7	5	GEK
15	1SMC15AT3	16.7	1	24.4	61.5	5	GEM
16	1SMC16AT3	17.8	1	26	57.7	5	GEP
17	1SMC17AT3	18.9	1	27.6	53.3	5	GER
18	1SMC18AT3	20	1	29.2	51.4	5	GET
20	1SMC20AT3	22.2	1	32.4	46.3	5	GEV
22	1SMC22AT3	24.4	1	35.5	42.2	5	GEX
24	1SMC24AT3	26.7	1	38.9	38.6	5	GEZ
26	1SMC26AT3	28.9	1	42.1	35.6	5	GFE
28	1SMC28AT3	31.1	1	45.4	33	5	GFG
30	1SMC30AT3	33.3	1	48.4	31	5	GFK
33	1SMC33AT3	36.7	1	53.3	28.1	5	GFM
36	1SMC36AT3	40	1	58.1	25.8	5	GFP
40	1SMC40AT3	44.4	1	64.5	23.2	5	GFR
43	1SMC43AT3	47.8	1	69.4	21.6	5	GFT
45	1SMC45AT3	50	1	72.7	20.6	5	GFV
48	1SMC48AT3	53.3	1	77.4	19.4	5	GFX
51	1SMC51AT3	56.7	1	82.4	18.2	5	GFZ
54	1SMC54AT3	60	1	87.1	17.2	5	GGE
58	1SMC58AT3	64.4	1	93.6	16	5	GGG
60	1SMC60AT3	66.7	1	96.8	15.5	5	GGK
64	1SMC64AT3	71.1	1	103	14.6	5	GGM
70	1SMC70AT3	77.8	1	113	13.3	5	GGP
75	1SMC75AT3	83.3	1	121	12.4	5	GGR
78	1SMC78AT3	86.7	1	126	11.4	5	GGT

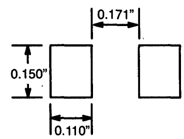
Note 1. A transient suppressor is normally selected according to the reverse "Stand Off Voltage" (V_R) which should be equal to or greater than the DC or continuous peak operating voltage level.

Note 2. T3 suffix designates tape and reel of 2500 units.

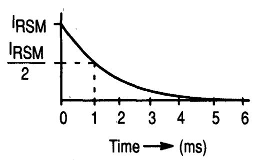


SMC
CASE 403-03
PLASTIC
Cathode = Notch

RECOMMENDED SOLDER PAD (FOOTPRINT)



SMC



Surge Current Characteristics

Figure 1

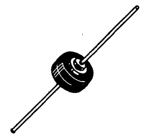
Automotive Transient Suppressors (See Section 4.1.4 for complete data)

Automotive transient suppressors are designed for protection against over-voltage conditions in the auto electrical system including the "LOAD DUMP" phenomenon that occurs when the battery open circuits while the car is running.

AUTOMOTIVE TRANSIENT SUPPRESSOR	
	CASE 194-04 MR2535L
V_{RRM} (Volts)	20
I_O (Amp)	35
$V_{(BR)}$ (Volts)	24–32
I_{RSM}* (Amp)	110
T_C @ Rated I_O (°C)	150
T (°C)	175

* Time constant = 10 ms, duty cycle ≤ 1%, T_C = 25°C.
Note: MR2535L is considered part of the rectifier product portfolio.

CASE 194-04



Section 4.1.3 Alphanumeric Part Number Listing Transient Voltage Suppressors

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4.1

Section 4.1.4 Data Sheets
Transient Voltage Suppressors

Section 4.1.4.1 Axial Leaded

4

SECTION 4.1.4.1.1 500 WATT PEAK POWER

4.1

DATA SHEETS

MULTIPLE PACKAGE QUANTITY (MPQ) REQUIREMENTS

Package Option	Type No. Suffix	MPQ (Units)
Tape and Reel	RL	5K

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) V_F = 3.5 V Max, I_F* = 35 A (except bidirectional devices).

Device	Breakdown Voltage V_{BR}†† (Volts) Min	Max	@ I_T (mA)	Working Peak Reverse Voltage V_{RWM}** (Volts)	Maximum Reverse Leakage @ V_{RWM} I_R (μA)	Maximum Reverse Surge Current I_{RSM}† (Amps)	Maximum Reverse Voltage @ I_{RSM} (Clamping Voltage) V_{RSM} (Volts)	Maximum Voltage Temperature Variation of V_{BR} mV/°C
SA5.0	6.4	7.3	10	5	600	52	9.6	5
⇒ **SA5.0A**	**6.4**	**7**	**10**	**5**	**600**	**54.3**	**9.2**	**5**
SA6.0	6.67	8.15	10	6	600	43.9	11.4	5
⇒ **SA6.0A**	**6.67**	**7.37**	**10**	**6**	**600**	**48.5**	**10.3**	**5**
SA6.5	7.22	8.82	10	6.5	400	40.7	12.3	5
SA6.5A	7.22	7.98	10	6.5	400	44.7	11.2	5
SA7.0	7.78	9.51	10	7	150	37.8	13.3	6
SA7.0A	7.78	8.6	10	7	150	41.7	12	6
SA7.5	8.33	10.2	1	7.5	50	35	14.3	7
SA7.5A	8.33	9.21	1	7.5	50	38.8	12.9	7
SA8.0	8.89	10.9	1	8	25	33.3	15	7
SA8.0A	8.89	9.83	1	8	25	36.7	13.6	7
SA8.5	9.44	11.5	1	8.5	5	31.4	15.9	8
SA8.5A	9.44	10.4	1	8.5	5	34.7	14.4	8
SA9.0	10	12.2	1	9	1	29.5	16.9	9
SA9.0A	10	11.1	1	9	1	32.5	15.4	9
SA10	11.1	13.6	1	10	1	26.6	18.8	10
SA10A	11.1	12.3	1	10	1	29.4	17	10
SA11	12.2	14.9	1	11	1	24.9	20.1	11
SA11A	12.2	13.5	1	11	1	27.4	18.2	11
SA12	13.3	16.3	1	12	1	22.7	22	12
⇒ **SA12A**	**13.3**	**14.7**	**1**	**12**	**1**	**25.1**	**19.9**	**12**
SA13	14.4	17.6	1	13	1	21	23.8	13
⇒ **SA13A**	**14.4**	**15.9**	**1**	**13**	**1**	**23.2**	**21.5**	**13**
SA14	15.6	19.1	1	14	1	19.4	25.8	14
SA14A	15.6	17.2	1	14	1	21.5	23.2	14
SA15	16.7	20.4	1	15	1	18.8	26.9	16
⇒ **SA15A**	**16.7**	**18.5**	**1**	**15**	**1**	**20.6**	**24.4**	**16**
SA16	17.8	21.8	1	16	1	17.6	28.8	19
SA16A	17.8	19.7	1	16	1	19.2	26	17
SA17	18.9	23.1	1	17	1	16.4	30.5	20
SA17A	18.9	20.9	1	17	1	18.1	27.6	19
SA18	20	24.4	1	18	1	15.5	32.2	21
SA18A	20	22.1	1	18	1	17.2	29.2	20
SA20	22.2	27.1	1	20	1	13.9	35.8	25
SA20A	22.2	24.5	1	20	1	15.4	32.4	23
SA22	24.4	29.8	1	22	1	12.7	39.4	28
SA22A	24.4	26.9	1	22	1	14.1	35.5	25
SA24	26.7	32.6	1	24	1	11.6	43	31
SA24A	26.7	29.5	1	24	1	12.8	38.9	28
SA26	28.9	35.3	1	26	1	10.7	46.6	31
SA26A	28.9	31.9	1	26	1	11.9	42.1	30
SA28	31.1	38	1	28	1	9.9	50	35
SA28A	31.1	34.4	1	28	1	11	45.4	31
SA30	33.3	40.7	1	30	1	9.3	53.5	39
SA30A	33.3	36.8	1	30	1	10.3	48.4	36
SA33	36.7	44.9	1	33	1	8.5	59	42
SA33A	36.7	40.6	1	33	1	9.4	53.3	39

(continued)

⇒ Preferred part

FOR BIDIRECTIONAL APPLICATIONS — USE C or CA SUFFIX

Preferred Bidirectional Devices —

SA6.5CA	**SA13CA**	**SA18CA**
SA12CA	**SA15CA**	**SA24CA**

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4.1

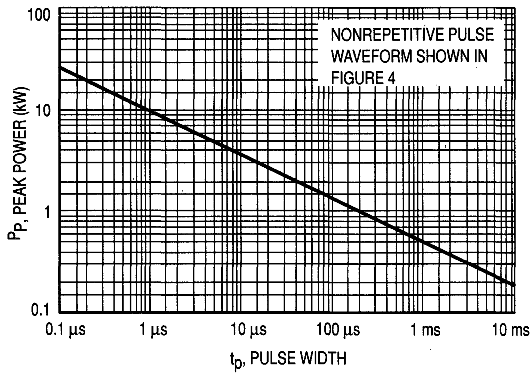


Figure 1. Pulse Rating Curve

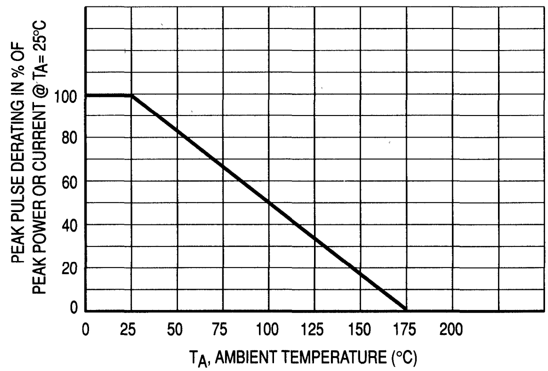


Figure 2. Pulse Derating Curve

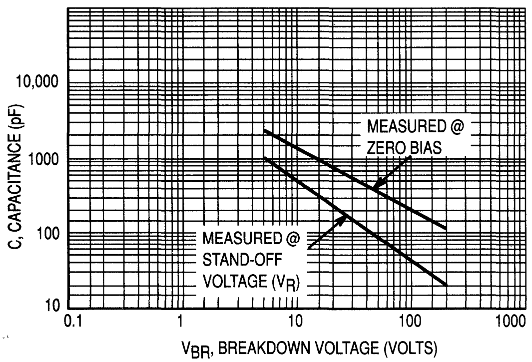


Figure 3. Capacitance versus Breakdown Voltage

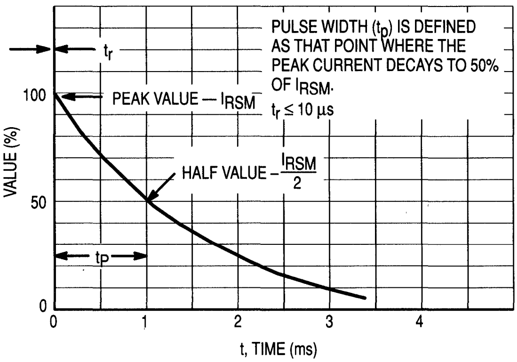


Figure 4. Pulse Waveform

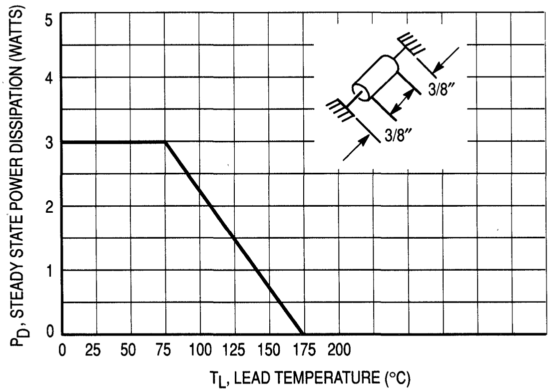


Figure 5. Steady State Power Derating

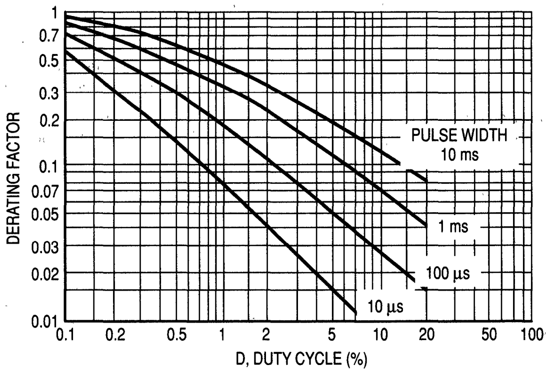


Figure 8. Typical Derating Factor for Duty Cycle

Zener Transient Voltage Suppressors Undirectional and Bidirectional

P6KE6.8, A thru P6KE200, A

ZENER OVERVOLTAGE TRANSIENT SUPPRESSORS 6.8–200 VOLT 600 WATT PEAK POWER 5 WATTS STEADY STATE

The P6KE6.8 series is designed to protect voltage sensitive components from high voltage, high energy transients. They have excellent clamping capability, high surge capability, low zener impedance and fast response time. The P6KE6.8 series is supplied in Motorola's exclusive, cost-effective, highly reliable Surmetic axial leaded package and is ideally-suited for use in communication systems, numerical controls, process controls, medical equipment, business machines, power supplies and many other industrial/ consumer applications.

Specification Features:

- Standard Zener Voltage Range — 6.8 to 200 V
- Peak Power — 600 Watts @ 1 ms
- Maximum Clamp Voltage @ Peak Pulse Current
- Low Leakage < 5 μA Above 10 V
- Maximum Temperature Coefficient Specified
- UL Recognition

Mechanical Characteristics:

CASE: Void-free, transfer-molded, thermosetting plastic
FINISH: All external surfaces are corrosion resistant and leads are readily solderable
POLARITY: Cathode indicated by polarity band. When operated in zener mode, will be positive with respect to anode
MOUNTING POSITION: Any

CASE 17-02
PLASTIC

4

4.1

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Peak Power Dissipation (1) @ $T_L \le 25°C$	P_{PK}	600	Watts
Steady State Power Dissipation @ $T_L \le 75°C$, Lead Length = 3/8″ Derated above $T_L = 75°C$	P_D	5 50	Watts mW/°C
Forward Surge Current (2) @ $T_A = 25°C$	I_{FSM}	100	Amps
Operating and Storage Temperature Range	T_J, T_{stg}	– 65 to +175	°C

Lead Temperature not less than 1/16″ from the case for 10 seconds: 230°C

NOTES: 1. Nonrepetitive current pulse per Figure 4 and derated above $T_A = 25°C$ per Figure 2.
2. 1/2 sine wave (or equivalent square wave), PW = 8.3 ms, duty cycle = 4 pulses per minute maximum.

ELECTRICAL CHARACTERISTICS — continued (T_A = 25°C unless otherwise noted) V_F = 3.5 V Max, I_F** = 50 A (except bidirectional devices).

Device	Breakdown Voltage* VBR (Volts) Min	Nom	Max	@ I_T (mA)	Working Peak Reverse Voltage V_{RWM} (Volts)	Maximum Reverse Leakage @ V_{RWM} I_R (μA)	Maximum Reverse Surge Current I_{RSM}† (Amps)	Maximum Reverse Voltage @ I_{RSM} (Clamping Voltage) V_{RSM} (Volts)	Maximum Temperature Coefficient of V_{BR} (%/°C)
P6KE68	61.2	68	74.8	1	55.1	5	6.1	98	0.104
P6KE68A	64.6	68	71.4	1	58.1	5	6.5	92	0.104
P6KE75	67.5	75	82.5	1	60.7	5	5.5	108	0.105
P6KE75A	71.3	75	78.8	1	64.1	5	5.8	103	0.105
P6KE82	73.8	82	90.2	1	66.4	5	5.1	118	0.105
P6KE82A	77.9	82	86.1	1	70.1	5	5.3	113	0.105
P6KE91	81.9	91	100	1	73.7	5	4.5	131	0.106
P6KE91A	86.5	91	95.5	1	77.8	5	4.8	125	0.106
P6KE100	90	100	110	1	81	5	4.2	144	0.106
P6KE100A	95	100	105	1	85.5	5	4.4	137	0.106
P6KE110	99	110	121	1	89.2	5	3.8	158	0.107
P6KE110A	105	110	116	1	94	5	4	152	0.107
P6KE120	108	120	132	1	97.2	5	3.5	173	0.107
P6KE120A	114	120	126	1	102	5	3.6	165	0.107
P6KE130	117	130	143	1	105	5	3.2	187	0.107
P6KE130A	124	130	137	1	111	5	3.3	179	0.107
P6KE150	135	150	165	1	121	5	2.8	215	0.108
P6KE150A	143	150	158	1	128	5	2.9	207	0.108
P6KE160	144	160	176	1	130	5	2.6	230	0.108
P6KE160A	152	160	168	1	136	5	2.7	219	0.108
P6KE170	153	170	187	1	138	5	2.5	244	0.108
P6KE170A	162	170	179	1	145	5	2.6	234	0.108
P6KE180	162	180	198	1	146	5	2.3	258	0.108
P6KE180A	171	180	189	1	154	5	2.4	246	0.108
P6KE200	180	200	220	1	162	5	2.1	287	0.108
P6KE200A	190	200	210	1	171	5	2.2	274	0.108

* V_{BR} measured after I_T applied for 300 μs, I_T = square wave pulse or equivalent.
** 1/2 sine wave (or equivalent square wave), PW = 8.3 ms, duty cycle = 4 pulses per minute maximum.
† Surge current waveform per Figure 4 and derate per Figure 2.

FOR BIDIRECTIONAL APPLICATIONS — USE C or CA SUFFIX

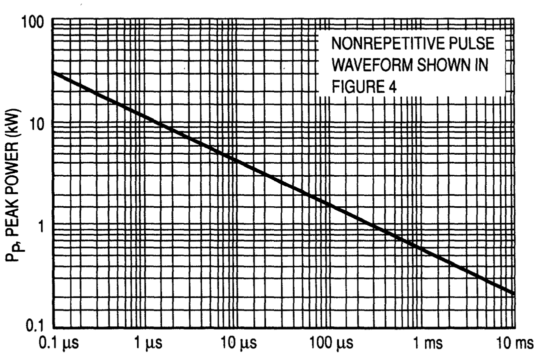


Figure 1. Pulse Rating Curve

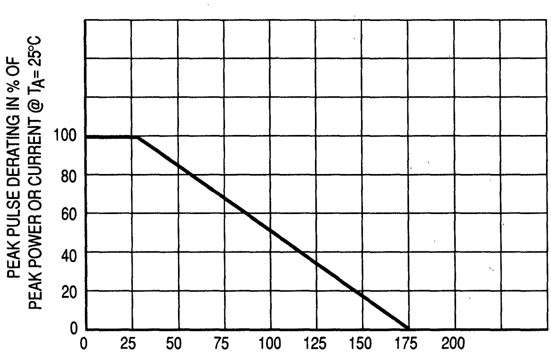
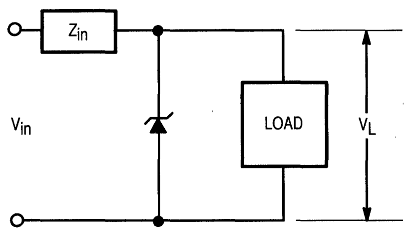


Figure 2. Pulse Derating Curve

TYPICAL PROTECTION CIRCUIT



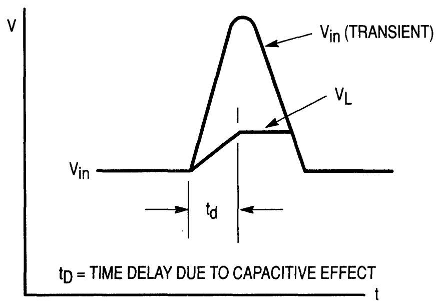


Figure 7.

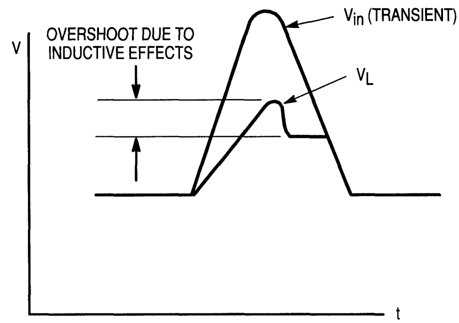


Figure 8.

4

4.1

UL RECOGNITION

The entire series including the bidirectional C and CA suffixes has *Underwriters Laboratory Recognition* for the classification of protectors (QVGV2) under the UL standard for safety 497B. Many competitors only have one or two devices recognized or have recognition in a non-protective category. Some competitors have no recognition at all. With the UL497B recognition, our parts successfully passed several tests including Strike Voltage Breakdown test, Endurance Conditioning, Temperature test, Dielectric Voltage-Withstand test, Discharge test and several more.

Whereas, some competitors have only passed a flammability test for the package material, we have been recognized for much more to be included in their protector category.

1500 Watt MOSORB

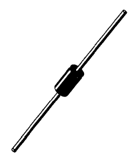
GENERAL DATA APPLICABLE TO ALL SERIES IN THIS GROUP

Zener Transient Voltage Suppressors Unidirectional and Bidirectional

GENERAL DATA

1500 WATT PEAK POWER

**MOSORB
ZENER OVERVOLTAGE
TRANSIENT
SUPPRESSORS
6.2–250 VOLTS
1500 WATT PEAK POWER
5 WATTS STEADY STATE**



**CASE 41A-02
PLASTIC**

Mosorb devices are designed to protect voltage sensitive components from high voltage, high energy transients. They have excellent clamping capability, high surge capability, low zener impedance and fast response time. These devices are Motorola's exclusive, cost-effective, highly reliable Surmetic axial leaded package and are ideally-suited for use in communication systems, numerical controls, process controls, medical equipment, business machines, power supplies and many other industrial/consumer applications, to protect CMOS, MOS and Bipolar integrated circuits.

Specification Features:

- Standard Voltage Range — 6.2 to 250 V
- Peak Power — 1500 Watts @ 1 ms
- Maximum Clamp Voltage @ Peak Pulse Current
- Low Leakage < 5 µA Above 10 V
- UL Recognition

Mechanical Characteristics:

CASE: Void-free, transfer-molded, thermosetting plastic
FINISH: All external surfaces are corrosion resistant and leads are readily solderable
POLARITY: Cathode indicated by polarity band. When operated in zener mode, will be positive with respect to anode
MOUNTING POSITION: Any

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Peak Power Dissipation (1) @ $T_L \le 25°C$	P_{PK}	1500	Watts
Steady State Power Dissipation @ $T_L \le 75°C$, Lead Length = 3/8″ Derated above $T_L = 75°C$	P_D	5 50	Watts mW/°C
Forward Surge Current (2) @ $T_A = 25°C$	I_{FSM}	200	Amps
Operating and Storage Temperature Range	T_J, T_{stg}	– 65 to +175	°C

Lead temperature not less than 1/16″ from the case for 10 seconds: 230°C

NOTES: 1. Nonrepetitive current pulse per Figure 5 and derated above $T_A = 25°C$ per Figure 2.
2. 1/2 sine wave (or equivalent square wave), PW = 8.3 ms, duty cycle = 4 pulses per minute maximum.

1N6373, ICTE-5, MPTE-5, thru 1N6389, ICTE-45, C, MPTE-45, C | **1N6267, A/1.5KE6.8, A thru 1N6303, A/1.5KE200, A**

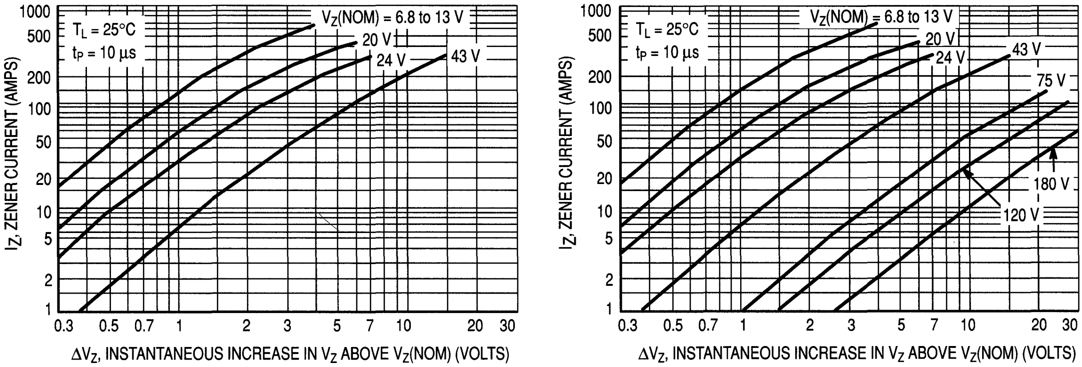


Figure 6. Dynamic Impedance

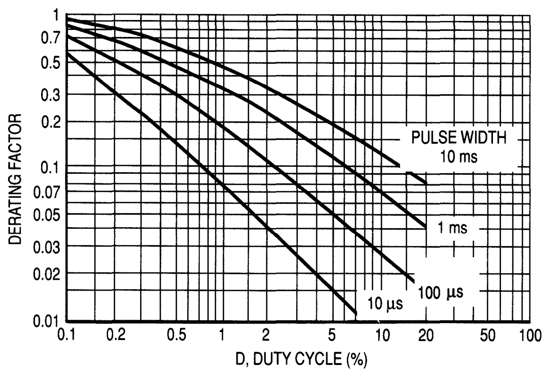


Figure 7. Typical Derating Factor for Duty Cycle

APPLICATION NOTES

RESPONSE TIME

In most applications, the transient suppressor device is placed in parallel with the equipment or component to be protected. In this situation, there is a time delay associated with the capacitance of the device and an overshoot condition associated with the inductance of the device and the inductance of the connection method. The capacitance effect is of minor importance in the parallel protection scheme because it only produces a time delay in the transition from the operating voltage to the clamp voltage as shown in Figure A.

The inductive effects in the device are due to actual turn-on time (time required for the device to go from zero current to full current) and lead inductance. This inductive effect produces an overshoot in the voltage across the equipment or component being protected as shown in Figure B. Minimizing this overshoot is very important in the application, since the main purpose for adding a transient suppressor is to clamp voltage spikes. These devices have excellent response time, typically in the picosecond range and negligible inductance. However, external inductive effects could produce unacceptable overshoot. Proper circuit layout, minimum lead lengths and placing the suppressor device as close as possible to the equipment or components to be protected will minimize this overshoot.

Some input impedance represented by Z_{in} is essential to prevent overstress of the protection device. This impedance should be as high as possible, without restricting the circuit operation.

DUTY CYCLE DERATING

The data of Figure 1 applies for non-repetitive conditions and at a lead temperature of 25°C. If the duty cycle increases, the peak power must be reduced as indicated by the curves of Figure 7. Average power must be derated as the lead or ambient temperature rises above 25°C. The average power derating curve normally given on data sheets may be normalized and used for this purpose.

At first glance the derating curves of Figure 7 appear to be in error as the 10 ms pulse has a higher derating factor than the 10 µs pulse. However, when the derating factor for a given pulse of Figure 7 is multiplied by the peak power value of Figure 1 for the same pulse, the results follow the expected trend.

*ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) V_F = 3.5 V max, I_F** = 100 A							
	Breakdown Voltage		Maximum Reverse Stand-Off Voltage V_{RWM}*** (Volts)	Maximum Reverse Leakage @ V_{RWM} I_R (μA)	Maximum Reverse Voltage @ I_{RSM}† = 120 A (Clamping Voltage) V_{RSM} (Volts)	Clamping Voltage	
Device Note 1	V_{BR}†† (Volts) Min	@ I_T (mA)				Peak Pulse Current @ I_{pp1}† = 30 A V_{C1} (Volts max)	Peak Pulse Current @ I_{pp2}† = 60 A V_{C2} (Volts max)
⇒ 1N5908	6	1	5	300	8.5	7.6	8

⇒ Preferred part

NOTE 1: The 1N5908 is JEDEC registered as a unidirectional device only (no bidirectional option).

* Indicates JEDEC registered data.

** 1/2 sine wave (or equivalent square wave), PW = 8.3 ms, duty cycle = 4 pulses per minute maximum.

*** A transient suppressor is normally selected according to the maximum reverse stand-off voltage (V_{RWM}), which should be equal to or greater than the dc or continuous peak operating voltage level.

† Surge current waveform per Figure 5 and derate per Figure 2 of the General Data — 1500 W at the beginning of this group.

†† V_{BR} measured at pulse test current I_T at an ambient temperature of 25°C.

***ELECTRICAL CHARACTERISTICS — continued** (T_A = 25°C unless otherwise noted) V_F# = 3.5 V Max, I_F** = 100 A

JEDEC Device	Device	Breakdown Voltage V_{BR}†† Volts Min	Nom	Max	@ I_T (mA)	Working Peak Reverse Voltage V_{RWM}*** (Volts)	Maximum Reverse Leakage @ V_{RWM} I_R (μA)	Maximum Reverse Surge Current I_{RSM}† (Amps)	Maximum Reverse Voltage @ I_{RSM} (Clamping Voltage) V_{RSM} (Volts)	Maximum Temperature Coefficient of V_{BR} (%/°C)
1N6289	1.5KE56	50.4	56	61.6	1	45.4	5	18.6	80.5	0.103
1N6289A	1.5KE56A	53.2	56	58.8	1	47.8	5	19.5	77	0.103
1N6290	1.5KE62	55.8	62	68.2	1	50.2	5	16.9	89	0.104
⇒ **1N6290A**	1.5KE62A	**58.9**	**62**	**65.1**	**1**	**53**	**5**	**17.7**	**85**	**0.104**
1N6291	1.5KE68	61.2	68	74.8	1	55.1	5	15.3	98	0.104
1N6291A	1.5KE68A	64.6	68	71.4	1	58.1	5	16.3	92	0.104
1N6292	1.5KE75	67.5	75	82.5	1	60.7	5	13.9	108	0.105
1N6292A	1.5KE75A	71.3	75	78.8	1	64.1	5	14.6	103	0.105
1N6293	1.5KE82	73.8	82	90.2	1	66.4	5	12.7	118	0.105
1N6293A	1.5KE82A	77.9	82	86.1	1	70.1	5	13.3	113	0.105
1N6294	1.5KE91	81.9	91	100	1	73.7	5	11.4	131	0.106
1N6294A	1.5KE91A	86.5	91	95.5	1	77.8	5	12	125	0.106
1N6295	1.5KE100	90	100	110	1	81	5	10.4	144	0.106
1N6295A	1.5KE100A	95	100	105	1	85.5	5	11	137	0.106
1N6296	1.5KE110	99	110	121	1	89.2	5	9.5	158	0.107
1N6296A	1.5KE110A	105	110	116	1	94	5	9.9	152	0.107
1N6297	1.5KE120	108	120	132	1	97.2	5	8.7	173	0.107
1N6297A	1.5KE120A	114	120	126	1	102	5	9.1	165	0.107
1N6298	1.5KE130	117	130	143	1	105	5	8	187	0.107
1N6298A	1.5KE130A	124	130	137	1	111	5	8.4	179	0.107
1N6299	1.5KE150	135	150	165	1	121	5	7	215	0.108
1N6299A	1.5KE150A	143	150	158	1	128	5	7.2	207	0.108
1N6300	1.5KE160	144	160	176	1	130	5	6.5	230	0.108
1N6300A	1.5KE160A	152	160	168	1	136	5	6.8	219	0.108
1N6301	1.5KE170	153	170	187	1	138	5	6.2	244	0.108
1N6301A	1.5KE170A	162	170	179	1	145	5	6.4	234	0.108
1N6302	1.5KE180	162	180	198	1	146	5	5.8	258	0.108
1N6302A	1.5KE180A	171	180	189	1	154	5	6.1	246	0.108
1N6303	1.5KE200	180	200	220	1	162	5	5.2	287	0.108
1N6303A	1.5KE200A	190	200	210	1	171	5	5.5	274	0.108
	1.5KE220	198	220	242	1	175	5	4.3	344	0.109
	1.5KE220A	209	220	231	1	185	5	4.6	328	0.109
	1.5KE250	225	250	275	1	202	5	5	360	0.109
	1.5KE250A	237	250	263	1	214	5	5	344	0.109

⇒ Preferred part

* Indicates JEDEC registered data.
** 1/2 sine wave (or equivalent square wave), PW = 8.3 ms, duty cycle = 4 pulses per minute maximum.
*** A transient suppressor is normally selected according to the maximum reverse stand-off voltage (V_{RWM}), which should be equal to or greater than the dc or continuous peak operating voltage level.
† Surge current waveform per Figure 5 and derate per Figure 2 of the General Data — 1500 W at the beginning of this group.
†† V_{BR} measured at pulse test current I_T at an ambient temperature of 25°C.
# V_F applies to Non-C suffix devices only.

FOR BIDIRECTIONAL APPLICATIONS — USE C or CA SUFFIX ON 1.5KE SERIES

***ELECTRICAL CHARACTERISTICS** (T_A = 25°C unless otherwise noted) V_F# = 3.5 V Max, I_F** = 100 A) (C suffix denotes standard back to back bidirectional versions. Test both polarities)

JEDEC Device Note 1	Device Note 1	Breakdown†† Voltage V_{BR} Volts Min	Breakdown†† Voltage @ I_T (mA)	Maximum Reverse Stand-Off Voltage V_{RWM}*** (Volts)	Maximum Reverse Leakage @ V_{RWM} I_R (μA)	Maximum Reverse Surge Current I_{RSM}† (Amps)	Maximum Reverse Voltage @ I_{RSM}† (Clamping Voltage) V_{RSM} (Volts)	Clamping Voltage: Peak Pulse Current @ I_{pp1}† = 1 A V_{C1} (Volts max)	Clamping Voltage: Peak Pulse Current @ I_{pp2}† = 10 A V_{C2} (Volts max)
⇒ **1N6373**	ICTE-5/MPTE-5	**6**	**1**	**5**	**300**	**160**	**9.4**	**7.1**	**7.5**
1N6374	ICTE-8/MPTE-8	9.4	1	8	25	100	15	11.3	11.5
⇒ **1N6382**	ICTE-8C/MPTE-8C	**9.4**	**1**	**8**	**25**	**100**	**15**	**11.4**	**11.6**
1N6375	ICTE-10/MPTE-10	11.7	1	10	2	90	16.7	13.7	14.1
1N6383	ICTE-10C/MPTE-10C	11.7	1	10	2	90	16.7	14.1	14.5
⇒ **1N6376**	ICTE-12/MPTE-12	**14.1**	**1**	**12**	**2**	**70**	**21.2**	**16.1**	**16.5**
1N6384	ICTE-12C/MPTE-12C	14.1	1	12	2	70	21.2	16.7	17.1
1N6377	ICTE-15/MPTE-15	17.6	1	15	2	60	25	20.1	20.6
⇒ **1N6385**	ICTE-15C/MPTE-15C	**17.6**	**1**	**15**	**2**	**60**	**25**	**20.8**	**21.4**
1N6378	ICTE-18/MPTE-18	21.2	1	18	2	50	30	24.2	25.2
1N6386	ICTE-18C/MPTE-18C	21.2	1	18	2	50	30	24.8	25.5
1N6379	ICTE-22/MPTE-22	25.9	1	22	2	40	37.5	29.8	32
1N6387	ICTE-22C/MPTE-22C	25.9	1	22	2	40	37.5	30.8	32
1N6380	ICTE-36/MPTE-36	42.4	1	36	2	23	65.2	50.6	54.3
1N6388	ICTE-36C/MPTE-36C	42.4	1	36	2	23	65.2	50.6	54.3
1N6381	ICTE-45/MPTE-45	52.9	1	45	2	19	78.9	63.3	70
1N6389	ICTE-45C/MPTE-45C	52.9	1	45	2	19	78.9	63.3	70

⇒ Preferred part

NOTE 1: C suffix denotes standard back-to-back bidirectional versions. Test both polarities. JEDEC device types 1N6382 thru 1N6389 are registered as back to back bidirectional versions and do not require a C suffix. 1N6373 thru 1N6381 are registered as unidirectional devices only (no bidirectional option).

* Indicates JEDEC registered data.

** 1/2 sine wave (or equivalent square wave), PW = 8.3 ms, duty cycle = 4 pulses per minute maximum.

*** A transient suppressor is normally selected according to the maximum reverse stand-off voltage (V_{RWM}), which should be equal to or greater than the dc or continuous peak operating voltage level.

† Surge current waveform per Figure 5 and derate per Figure 2 of the General Data — 1500 W at the beginning of this group.

†† V_{BR} measured at pulse test current I_T at an ambient temperature of 25°C.

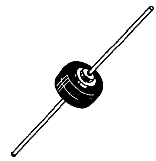
\# V_F applies to unidirectional devices only.

Advance Information

Overvoltage Transient Suppressors

⇒ MR2535L

MEDIUM CURRENT OVERVOLTAGE TRANSIENT SUPPRESSORS



CASE 194-04

. . . designed for applications requiring a low voltage rectifier with reverse avalanche characteristics for use as reverse power transient suppressors. Developed to suppress transients in the automotive system, these devices operate in the forward mode as standard rectifiers or reverse mode as power avalanche rectifier and will protect electronic equipment from overvoltage conditions.

- Avalanche Voltage 24 to 32 Volts
- High Power Capability
- Economical
- Increased Capacity by Parallel Operation

MECHANICAL CHARACTERISTICS:
CASE: Transfer Molded Plastic
MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 350°C 3/8″ from case for 10 seconds at 5 lbs. tension
FINISH: All external surfaces are corrosion-resistant, leads are readily solderable
POLARITY: Indicated by diode symbol or cathode band
WEIGHT: 2.5 Grams (approx.)

4

4.1

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
DC Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	Volts
Repetitive Peak Reverse Surge Current (Time Constant = 10 ms, Duty Cycle ≤ 1%, T_C = 25°C) (See Figure 1)	I_{RSM}	110	Amps
Average Rectified Forward Current (Single Phase, Resistive Load, 60 Hz, T_C = 150°C)	I_O	35	Amps
Non-Repetitive Peak Surge Current Surge Supplied at Rated Load Conditions Halfwave, Single Phase	I_{FSM}	600	Amps
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–65 to +175	°C

THERMAL CHARACTERISTICS

Characteristic	Lead Length	Symbol	Max	Unit
Thermal Resistance, Junction to Lead @ Both Leads to Heat Sink, Equal Length	1/4″ 3/8″ 1/2″	$R_{\theta JL}$	7.5 10 13	°C/W
Thermal Resistance Junction to Case		$R_{\theta JC}$	0.8*	°C/W

*Typical

⇒ Preferred part

This document contains information on a new product. Specifications and information herein are subject to change without notice.

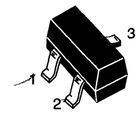
4

4.1

15 Volt SOT-23 Bipolar Zener For ESD Protection Transient Voltage Suppressor

MMBZ15VDLT1

SOT-23 BIPOLAR ZENER OVERVOLTAGE TRANSIENT SUPPRESSOR 15 VOLT 40 WATTS PEAK POWER



CASE 318-07, STYLE 9
TO-236AB
LOW PROFILE SOT-23
PLASTIC

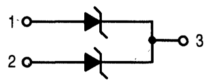
This monolithic silicon zener device is designed for applications requiring transient over-voltage protection capability. It is intended for use in voltage and ESD sensitive equipment such as computers, business machines, communication systems, medical equipment and other applications. The convenient SOT-23 package allows for easy handling and is ideal for situations where space is at a premium.

Specification Features:

- Dual Package Provides for Bidirectional or Separate Unidirectional Configurations
- Economical SOT-23 Surface Mount Package
- Peak Power — 40 Watts @ 1 ms (Bidirectional)
- Maximum Clamping Voltage @ Peak Pulse Current
- Low Leakage < 100 nA

Mechanical Characteristics:

Case: Void free, transfer-molded, thermosetting plastic
Finish: All external surfaces are corrosion resistant and leads are readily solderable
Packaging: Available in 8 mm embossed tape and reel (3000 devices per reel)
Pinout: Terminal 1 — Anode
Terminal 2 — Anode
Terminal 3 — Cathode



4
4.1

MAXIMUM RATINGS (T_C = 25°C Unless Otherwise Noted.)

Rating	Symbol	Value	Unit
Peak Power Dissipation (1) @ $T_A \le 25°C$	P_{pk}	40	Watts
Total Power Dissipation on FR-5 Board (2) @ T_A = 25°C Derate above 25°C	P_D	225 1.8	mW mW/°C
Total Power Dissipation on Alumina Substrate (3) @ T_A = 25°C Derate above 25°C	P_D	300 2.4	mW mW/°C
Operating and Storage Temperature Range	T_J, T_{stg}	–55 to +150	°C

(1) Nonrepetitive current pulse per Figure 5 and derate above T_A = 25°C per Figure 6.
(2) FR-5 = 1.0 x 0.75 x 0.62 in.
(3) Alumina = 0.4 x 0.3 x 0.024 in., 99.5% alumina

THERMAL CHARACTERISTICS

Thermal Resistance — Junction to Ambient	$R_{\theta JA}$	556	°C/W
Maximum Lead Temperature for Soldering Purposes (10 seconds max.)	T_L	230	°C

ELECTRICAL CHARACTERISTICS (T_A = 25°C Unless Otherwise Noted)
BIDIRECTIONAL (Circuit tied to pins 1 and 2)

Breakdown Voltage V_{BR}†† (Volts) Min	Nom	Max	@ I_T mA	Working Peak Reverse Voltage V_{RWM} (Volts)	Maximum Reverse Leakage Current I_{RWM} I_R (nA)	Maximum Reverse Surge Current I_{RSM}† (Amps)	Maximum Reverse Voltage @ I_{RSM} (Clamping Voltage) V_{RSM}† (Volts)	Maximum Temperature Coefficient of V_{BR} (mV/°C)
14.3	15	15.8	1.0	12.8	100	1.9	21.2	12

† Surge current waveform per Figure 5 and derate per Figure 6.
†† V_{BR} measured at pulse test current I_T at an ambient temperature of 25°C.

4

4.1

GENERAL DATA APPLICABLE TO ALL SERIES IN THIS GROUP

Zener Transient Voltage Suppressors

GENERAL DATA
600 WATT PEAK POWER

The SMB series is designed to protect voltage sensitive components from high voltage, high energy transients. They have excellent clamping capability, high surge capability, low zener impedance and fast response time. The SMB series is supplied in Motorola's exclusive, cost-effective, highly reliable Surmetic package and is ideally suited for use in communication systems, numerical controls, process controls, medical equipment, business machines, power supplies and many other industrial/consumer applications.

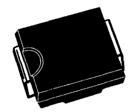
Specification Features:

- Standard Zener Breakdown Voltage Range — 6.8 to 200 V
- Stand-off Voltage Range — 5 to 170 V
- Peak Power — 600 Watts @ 1 ms
- Maximum Clamp Voltage @ Peak Pulse Current
- Low Leakage < 5 µA Above 10 V

Mechanical Characteristics:

CASE: Void-free, transfer-molded, thermosetting plastic
FINISH: All external surfaces are corrosion resistant and leads are readily solderable
POLARITY: Cathode indicated by molded polarity notch. When operated in zener mode, will be positive with respect to anode
MOUNTING POSITION: Any
LEADS: Modified L-Bend providing more contact area to bond pad
MAXIMUM CASE TEMPERATURE FOR SOLDERING PURPOSES: 230°C for 10 seconds

PLASTIC SURFACE MOUNT ZENER OVERVOLTAGE TRANSIENT SUPPRESSORS
6.8–200 VOLT
600 WATT PEAK POWER



CASE 403A-03
PLASTIC

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Peak Power Dissipation (1) @ $T_L \le 25°C$	P_{PK}	600	Watts
Forward Surge Current (2) @ $T_A = 25°C$	I_{FSM}	100	Amps
Operating and Storage Temperature Range	T_J, T_{stg}	– 65 to +175	°C

NOTES: 1. Nonrepetitive current pulse per Figure 2 and derated above T_A = 25°C per Figure 3.
2. 1/2 sine wave (or equivalent square wave), PW = 8.3 ms, duty cycle = 4 pulses per minute maximum.

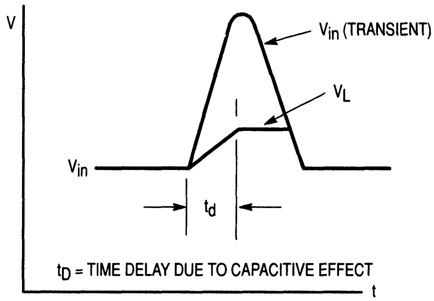


Figure 4.

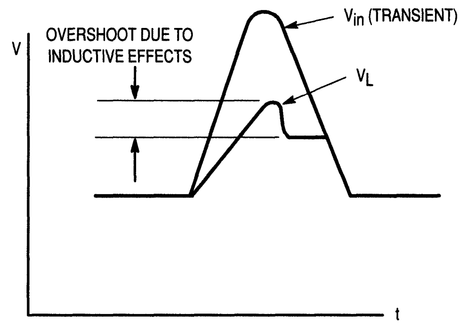


Figure 5.

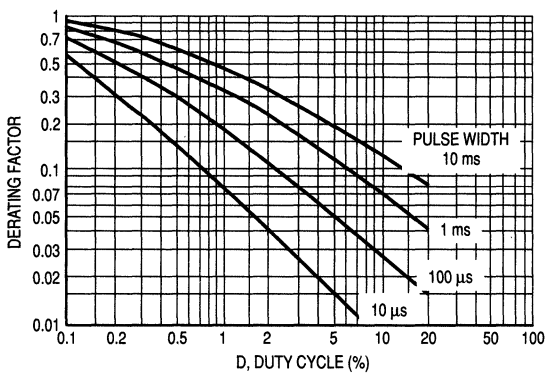


Figure 6. Typical Derating Factor for Duty Cycle

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) V_F = 3.5 V Max, I_F** = 50 A for all types.

Device† †	Breakdown Voltage* V_{BR} @ I_T Volts				Working Peak Reverse Voltage V_{RWM}	Maximum Reverse Leakage @ V_{RWM} I_R	Maximum Reverse Surge Current I_{RSM}†	Maximum Reverse Voltage @ I_{RSM} (Clamping Voltage) V_{RSM}	Maximum Temperature Coefficient of V_{BR}	Device Marking
	Min	Nom	Max	mA	Volts	μA	Amps	Volts	%/°C	
P6SMB6.8AT3	6.45	6.8	7.14	10	5.8	1000	57	10.5	0.057	6V8A
P6SMB7.5AT3	7.13	7.5	7.88	10	6.4	500	53	11.3	0.061	7V5A
P6SMB8.2AT3	7.79	8.2	8.61	10	7.02	200	50	12.1	0.065	8V2A
P6SMB9.1AT3	8.65	9.1	9.55	1	7.78	50	45	13.4	0.068	9V1A
P6SMB10AT3	9.5	10	10.5	1	8.55	10	41	14.5	0.073	10A
P6SMB11AT3	10.5	11	11.6	1	9.4	5	38	15.6	0.075	11A
P6SMB12AT3	11.4	12	12.6	1	10.2	5	36	16.7	0.078	12A
⇒ **P6SMB13AT3**	**12.4**	**13**	**13.7**	**1**	**11.1**	**5**	**33**	**18.2**	**0.081**	**13A**
⇒ **P6SMB15AT3**	**14.3**	**15**	**15.8**	**1**	**12.8**	**5**	**28**	**21.2**	**0.084**	**15A**
P6SMB16AT3	15.2	16	16.8	1	13.6	5	27	22.5	0.086	16A
P6SMB18AT3	17.1	18	18.9	1	15.3	5	24	25.2	0.088	18A
P6SMB20AT3	19	20	21	1	17.1	5	22	27.7	0.09	20A
P6SMB22AT3	20.9	22	23.1	1	18.8	5	20	30.6	0.092	22A
P6SMB24AT3	22.8	24	25.2	1	20.5	5	18	33.2	0.094	24A
⇒ **P6SMB27AT3**	**25.7**	**27**	**28.4**	**1**	**23.1**	**5**	**16**	**37.5**	**0.096**	**27A**
⇒ **P6SMB30AT3**	**28.5**	**30**	**31.5**	**1**	**25.6**	**5**	**14.4**	**41.4**	**0.097**	**30A**
⇒ **P6SMB33AT3**	**31.4**	**33**	**34.7**	**1**	**28.2**	**5**	**13.2**	**45.7**	**0.098**	**33A**
⇒ **P6SMB36AT3**	**34.2**	**36**	**37.8**	**1**	**30.8**	**5**	**12**	**49.9**	**0.099**	**36A**
P6SMB39AT3	37.1	39	41	1	33.3	5	11.2	53.9	0.1	39A
P6SMB43AT3	40.9	43	45.2	1	36.8	5	10.1	59.3	0.101	43A
P6SMB47AT3	44.7	47	49.4	1	40.2	5	9.3	64.8	0.101	47A
⇒ **P6SMB51AT3**	**48.5**	**51**	**53.6**	**1**	**43.6**	**5**	**8.6**	**70.1**	**0.102**	**51A**
P6SMB56AT3	53.2	56	58.8	1	47.8	5	7.8	77	0.103	56A
⇒ **P6SMB62AT3**	**58.9**	**62**	**65.1**	**1**	**53**	**5**	**7.1**	**85**	**0.104**	**62A**
P6SMB68AT3	64.6	68	71.4	1	58.1	5	6.5	92	0.104	68A
P6SMB75AT3	71.3	75	78.8	1	64.1	5	5.8	103	0.105	75A
P6SMB82AT3	77.9	82	86.1	1	70.1	5	5.3	113	0.105	82A
P6SMB91AT3	86.5	91	95.5	1	77.8	5	4.8	125	0.106	91A
P6SMB100AT3	95	100	105	1	85.5	5	4.4	137	0.106	100A
P6SMB110AT3	105	110	116	1	94	5	4	152	0.107	110A
P6SMB120AT3	114	120	126	1	102	5	3.6	165	0.107	120A
P6SMB130AT3	124	130	137	1	111	5	3.3	179	0.107	130A
P6SMB150AT3	143	150	158	1	128	5	2.9	207	0.108	150A
P6SMB160AT3	152	160	168	1	136	5	2.7	219	0.108	160A
P6SMB170AT3	162	170	179	1	145	5	2.6	234	0.108	170A
P6SMB180AT3	171	180	189	1	154	5	2.4	246	0.108	180A
P6SMB200AT3	190	200	210	1	171	5	2.2	274	0.108	200A

⇒ Preferred part

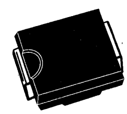
* V_{BR} measured at pulse test current I_T at an ambient temperaure of 25°C.
** 1/2 sine wave (or equivalent square wave), PW = 8.3 ms, duty cycle = 4 pulses per minute maximum.
† Surge current waveform per Figure 2 and derate per Figure 3 of the General Data — 600 Watt at the beginning of this group.
† † T3 suffix designates tape and reel of 2500 units.

GENERAL DATA APPLICABLE TO ALL SERIES IN THIS GROUP

Zener Transient Voltage Suppressors

GENERAL DATA
1500 WATT PEAK POWER

PLASTIC SURFACE MOUNT ZENER OVERVOLTAGE TRANSIENT SUPPRESSORS
6.8–91 VOLT
1500 WATT PEAK POWER



CASE 403-03
PLASTIC

The SMC series is designed to protect voltage sensitive components from high voltage, high energy transients. They have excellent clamping capability, high surge capability, low zener impedance and fast response time. The SMC series is supplied in Motorola's exclusive, cost-effective, highly reliable Surmetic package and is ideally suited for use in communication systems, numerical controls, process controls, medical equipment, business machines, power supplies and many other industrial/consumer applications.

Specification Features:

- Standard Zener Breakdown Voltage Range — 6.8 to 91 V
- Stand-off Voltage Range — 5 to 78 V
- Peak Power — 1500 Watts @ 1 ms
- Maximum Clamp Voltage @ Peak Pulse Current
- Low Leakage < 5 µA Above 10 V
- Maximum Temperature Coefficient Specified
- Available in Tape and Reel

Mechanical Characteristics:

CASE: Void-free, transfer-molded, thermosetting plastic
FINISH: All external surfaces are corrosion resistant and leads are readily solderable
POLARITY: Cathode indicated by molded polarity notch. When operated in zener mode, will be positive with respect to anode
MOUNTING POSITION: Any
LEADS: Modified L-Bend providing more contact area to bond pads
MAXIMUM CASE TEMPERATURE FOR SOLDERING PURPOSES: 230°C for 10 seconds

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Peak Power Dissipation (1) @ $T_L \leq 25°C$	P_{PK}	1500	Watts
Forward Surge Current (2) @ $T_A = 25°C$	I_{FSM}	200	Amps
Operating and Storage Temperature Range	T_J, T_{stg}	– 65 to +175	°C

NOTES: 1. Nonrepetitive current pulse per Figure 2 and derated above $T_A = 25°C$ per Figure 3.
2. 1/2 sine wave (or equivalent square wave), PW = 8.3 ms, duty cycle = 4 pulses per minute maximum.

APPLICATION NOTES

RESPONSE TIME

In most applications, the transient suppressor device is placed in parallel with the equipment or component to be protected. In this situation, there is a time delay associated with the capacitance of the device and an overshoot condition associated with the inductance of the device and the inductance of the connection method. The capacitive effect is of minor importance in the parallel protection scheme because it only produces a time delay in the transition from the operating voltage to the clamp voltage as shown in Figure 5.

The inductive effects in the device are due to actual turn-on time (time required for the device to go from zero current to full current) and lead inductance. This inductive effect produces an overshoot in the voltage across the equipment or component being protected as shown in Figure 6. Minimizing this overshoot is very important in the application, since the main purpose for adding a transient suppressor is to clamp voltage spikes. The SMC series have a very good response time, typically < 1 ns and negligible inductance. However, external inductive effects could produce unacceptable overshoot. Proper circuit layout, minimum lead lengths and placing the suppressor device as close as possible to the equipment or components to be protected will minimize this overshoot.

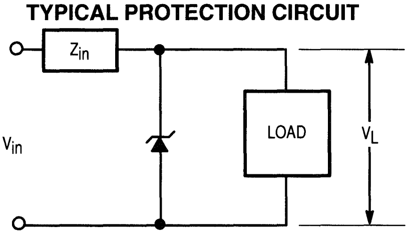
Some input impedance represented by Z_{in} is essential to prevent overstress of the protection device. This impedance should be as high as possible, without restricting the circuit operation.

DUTY CYCLE DERATING

The data of Figure 1 applies for non-repetitive conditions and at a lead temperature of 25°C. If the duty cycle increases, the peak power must be reduced as indicated by the curves of Figure 7. Average power must be derated as the lead or ambient temperature rises above 25°C. The average power derating curve normally given on data sheets may be normalized and used for this purpose.

At first glance the derating curves of Figure 7 appear to be in error as the 10 ms pulse has a higher derating factor than the 10 µs pulse. However, when the derating factor for a given pulse of Figure 7 is multiplied by the peak power value of Figure 1 for the same pulse, the results follow the expected trend.

TYPICAL PROTECTION CIRCUIT



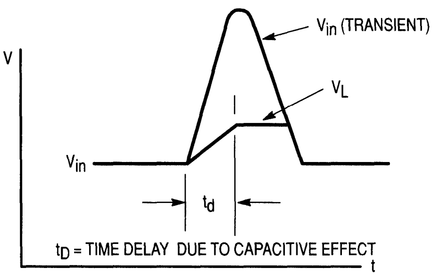


Figure 5.

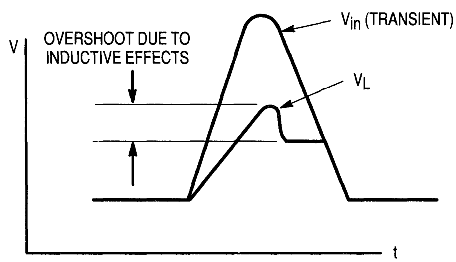


Figure 6.

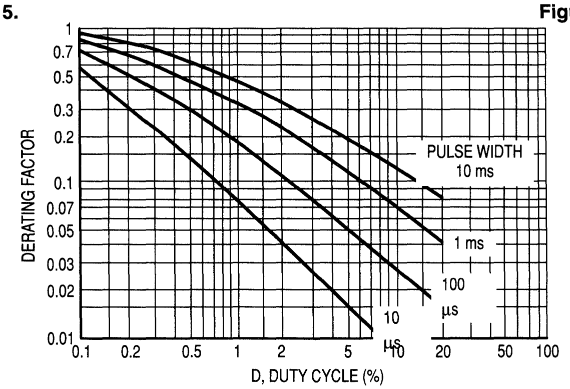


Figure 7. Typical Derating Factor for Duty Cycle

1.5SMC6.8AT3 thru 1.5SMC91AT3

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) V_F = 3.5 V Max, I_F** = 100 A for all types.

Device ††	Breakdown Voltage* V_{BR} @ I_T Volts Min	Nom	Max	mA	Working Peak Reverse Voltage V_{RWM} Volts	Maximum Reverse Leakage @ V_{RWM} I_R µA	Maximum Reverse Surge Current I_{RSM}† Amps	Maximum Reverse Voltage @ I_{RSM} (Clamping Voltage) V_{RSM} Volts	Maximum Temperature Coefficient of V_{BR} %/°C	Device Marking
1.5SMC6.8AT3	6.45	6.8	7.14	10	5.8	1000	143	10.5	0.057	6V8A
1.5SMC7.5AT3	7.13	7.5	7.88	10	6.4	500	132	11.3	0.061	7V5A
1.5SMC8.2AT3	7.79	8.2	8.61	10	7.02	200	124	12.1	0.065	8V2A
1.5SMC9.1AT3	8.65	9.1	9.55	1	7.78	50	112	13.4	0.068	9V1A
1.5SMC10AT3	9.5	10	10.5	1	8.55	10	103	14.5	0.073	10A
1.5SMC11AT3	10.5	11	11.6	1	9.4	5	96	15.6	0.075	11A
1.5SMC12AT3	11.4	12	12.6	1	10.2	5	90	16.7	0.078	12A
1.5SMC13AT3	12.4	13	13.7	1	11.1	5	82	18.2	0.081	13A
1.5SMC15AT3	14.3	15	15.8	1	12.8	5	71	21.2	0.084	15A
1.5SMC16AT3	15.2	16	16.8	1	13.6	5	67	22.5	0.086	16A
1.5SMC18AT3	17.1	18	18.9	1	15.3	5	59.5	25.2	0.088	18A
1.5SMC20AT3	19	20	21	1	17.1	5	54	27.7	0.09	20A
1.5SMC22AT3	20.9	22	23.1	1	18.8	5	49	30.6	0.092	22A
1.5SMC24AT3	22.8	24	25.2	1	20.5	5	45	33.2	0.094	24A
1.5SMC27AT3	25.7	27	28.4	1	23.1	5	40	37.5	0.096	27A
1.5SMC30AT3	28.5	30	31.5	1	25.6	5	36	41.4	0.097	30A
1.5SMC33AT3	31.4	33	34.7	1	28.2	5	33	45.7	0.098	33A
⇒ **1.5SMC36AT3**	**34.2**	**36**	**37.8**	**1**	**30.8**	**5**	**30**	**49.9**	**0.099**	**36A**
1.5SMC39AT3	37.1	39	41	1	33.3	5	28	53.9	0.1	39A
1.5SMC43AT3	40.9	43	45.2	1	36.8	5	25.3	59.3	0.101	43A
1.5SMC47AT3	44.7	47	49.4	1	40.2	5	23.2	64.8	0.101	47A
1.5SMC51AT3	48.5	51	53.6	1	43.6	5	21.4	70.1	0.102	51A
⇒ **1.5SMC56AT3**	**53.2**	**56**	**58.8**	**1**	**47.8**	**5**	**19.5**	**77**	**0.103**	**56A**
⇒ **1.5SMC62AT3**	**58.9**	**62**	**65.1**	**1**	**53**	**5**	**17.7**	**85**	**0.104**	**62A**
1.5SMC68AT3	64.6	68	71.4	1	58.1	5	16.3	92	0.104	68A
1.5SMC75AT3	71.3	75	78.8	1	64.1	5	14.6	103	0.105	75A
1.5SMC82AT3	77.9	82	86.1	1	70.1	5	13.3	113	0.105	82A
1.5SMC91AT3	86.5	91	95.5	1	77.8	5	12	125	0.106	91A

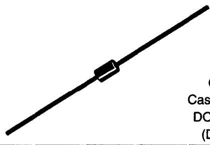
⇒ **Preferred part**

* V_{BR} measured at pulse test current I_T at an ambient temperaure of 25°C.
** 1/2 sine wave (or equivalent square wave), PW = 8.3 ms, duty cycle = 4 pulses per minute maximum.
† Surge current waveform per Figure 2 and derate per Figure 3 of General Data — 1500 Watt at the beginning of this group.
†† T3 suffix designates tape and reel of 2500 units.

Section 4.2.1 Selector Guide Zener Voltage Regulator Diodes

SELECTOR GUIDE

Axial Leaded for Thru-hole Designs (continued) (See Section 4.2.4 for complete data)

Nominal Zener Breakdown Voltage	500 mW Cathode = Polarity Band	500 mW Low Level Cathode = Polarity Band	500 mW Cathode = Polarity Band					500 mW Low Level Cathode = Polarity Band	500 mW Cathode = Polarity Band	
(*Note 1)	(*Note 2)	(*Note 3)	(*Note 4)	(*Note 5)	(*Note 6)	(*Note 7)	(*Note 8)	(*Note 9)	(*Note 10)	(*Note 8)
Volts	 Glass Case 299-02 DO-204AH (DO-35)									
75	1N982B		1N5267B	1N6021B	BZX55C75	BZX79C75				
82	1N983B		1N5268B	1N6022B	BZX55C82	BZX79C82				
87			1N5269B							
91	1N984B		1N5270B	1N6023B	BZX55C91	BZX79C91				
100	1N985B		1N5271B	1N6024B		BZX79C100				
110	1N986B		1N5272B	1N6025B		BZX79C110				
120	1N987B		1N5273B			BZX79C120				
130	1N988B		1N5274B			BZX79C130				
140			1N5275B							
150	1N989B		1N5276B			BZX79C150				
160	1N990B		1N5277B			BZX79C160				
170			1N5278B							
180	1N991B		1N5279B			BZX79C180				
190			1N5280B							
200	1N992B		1N5281B			BZX79C200				
220										
240										
270										
300										
330										
360										
400										

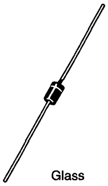
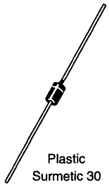
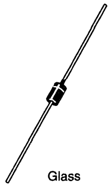
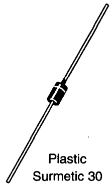
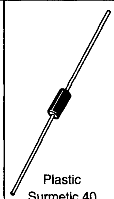
*See Notes — page 4-2-7

4

4.2

SELECTOR GUIDE

Axial Leaded for Thru-hole Designs (continued) (See Section 4.2.4 for complete data)

Nominal Zener Breakdown Voltage	1 Watt Cathode = Polarity Band		1.3 Watt Cathode = Polarity Band			1.5 Watt Cathode = Polarity Band	3 Watt Cathode = Polarity Band	5 Watt Cathode = Polarity Band
(*Note 1)	(*Note 11)	(*Note 12)	(*Note 13)	(*Note 14)	(*Note 15)	(*Note 16)	(*Note 17)	(*Note 18)
Volts	 Glass Case 59-03 (DO-41)	 Plastic Surmetic 30 Case 59-03 (DO-41)	 Glass Case 59-03 (DO-41)			 Plastic Surmetic 30 Case 59-03 (DO-41)		 Plastic Surmetic 40 Case 17-02
75	1N4761A	MZP4761A	BZX85C75	MZPY75	MZD75	1N5946B	3EZ75D5	1N5374B
82	1N4762A	MZP4762A	BZX85C82	MZPY82	MZD82	1N5947B	3EZ82D5	1N5375B
87								1N5376B
91	1N4763A	MZP4763A	BZX85C91	MZPY91	MZD91	1N5948B	3EZ91D5	1N5377B
100	1N4764A	MZP4764A	BZX85C100	MZPY100	MZD100	1N5949B	3EZ100D5	1N5378B
110		1M110ZS5			MZD110	1N5950B	3EZ110D5	1N5379B
120		1M120ZS5			MZD120	1N5951B	3EZ120D5	1N5380B
130		1M130ZS5			MZD130	1N5952B	3EZ130D5	1N5381B
140							3EZ140D5	1N5382B
150		1M150ZS5			MZD150	1N5953B	3EZ150D5	1N5383B
160		1M160ZS5			MZD160	1N5954B	3EZ160D5	1N5384B
170							3EZ170D5	1N5385B
180		1M180ZS5			MZD180	1N5955B	3EZ180D5	1N5386B
190							3EZ190D5	1N5387B
200		1M200ZS5			MZD200	1N5956B	3EZ200D5	1N5388B
220							3EZ220D5	
240							3EZ240D5	
270							3EZ270D5	
300							3EZ300D5	
330							3EZ330D5	
360							3EZ360D5	
400							3EZ400D5	

*See Notes — page 4-2-7

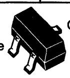
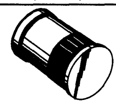
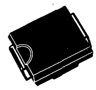
4

4.2

SELECTOR GUIDE

Zener Voltage Regulator Diodes

Surface Mount Packages (See Section 4.2.4 for complete data)

Nominal Zener Breakdown Voltage	225 mW Surface Mount SOT-23		500 mW Surface Mount Leadless MLL34	500 mW Low Level Surface Mount Leadless MLL34	500 mW Surface Mount Leadless MLL34	1.5 Watt Surface Mount SMB
(*Note 1)	(*Note 2)	(*Note 3)	(*Note 4)	(*Note 5)	(*Note 6)	(*Note 7)
Volts	 Plastic Case 318-07 TO-236AB		 Cathode = Polarity Band Glass Case 362-03			 Cathode = Notch Plastic Case 403A-03
1.8				MLL4678		
2.0				MLL4679		
2.2				MLL4680		
2.4	BZX84C2V4L	MMBZ5221BL	BZV55C2V4	MLL4681	MLL5221B	
2.5		MMBZ5222BL			MLL5222B	
2.7	BZX84C2V7L	MMBZ5223BL	BZV55C2V7	MLL4682	MLL5223B	
2.8		MMBZ5224BL			MLL5224B	
3.0	BZX84C3V0L	MMBZ5225BL	BZV55C3V0	MLL4683	MLL5225B	
3.3	BZX84C3V3L	MMBZ5226BL	BZV55C3V3	MLL4684	MLL5226B	1SMB5913BT3
3.6	BZX84C3V6L	MMBZ5227BL	BZV55C3V6	MLL4685	MLL5227B	1SMB5914BT3
3.9	BZX84C3V9L	MMBZ5228BL	BZV55C3V9	MLL4686	MLL5228B	1SMB5915BT3
4.3	BZX84C4V3L	MMBZ5229BL	BZV55C4V3	MLL4687	MLL5229B	1SMB5916BT3
4.7	BZX84C4V7L	MMBZ5230BL	BZV55C4V7	MLL4688	MLL5230B	1SMB5917BT3
5.1	BZX84C5V1L	MMBZ5231BL	BZV55C5V1	MLL4689	MLL5231B	1SMB5918BT3
5.6	BZX84C5V6L	MMBZ5232BL	BZV55C5V6	MLL4690	MLL5232B	1SMB5919BT3
6.0		MMBZ5233BL			MLL5233B	
6.2	BZX84C6V2L	MMBZ5234BL	BZV55C6V2	MLL4691	MLL5234B	1SMB5920BT3
6.8	BZX84C6V8L	MMBZ5235BL	BZV55C6V8	MLL4692	MLL5235B	1SMB5921BT3
7.5	BZX84C7V5L	MMBZ5236BL	BZV55C7V5	MLL4693	MLL5236B	1SMB5922BT3
8.2	BZX84C8V2L	MMBZ5237BL	BZV55C8V2	MLL4694	MLL5237B	1SMB5923BT3
8.7		MMBZ5238BL		MLL4695	MLL5238B	
9.1	BZX84C9V1L	MMBZ5239BL	BZV55C9V1	MLL4696	MLL5239B	1SMB5924BT3
10	BZX84C10L	MMBZ5240BL	BZV55C10	MLL4697	MLL5240B	1SMB5925BT3
11	BZX84C11L	MMBZ5241BL	BZV55C11	MLL4698	MLL5241B	1SMB5926BT3
12	BZX84C12L	MMBZ5242BL	BZV55C12	MLL4699	MLL5242B	1SMB5927BT3
13	BZX84C13L	MMBZ5243BL	BZV55C13	MLL4700	MLL5243B	1SMB5928BT3
14		MMBZ5244BL		MLL4701	MLL5244B	
15	BZX84C15L	MMBZ5245BL	BZV55C15	MLL4702	MLL5245B	1SMB5929BT3
16	BZX84C16L	MMBZ5246BL	BZV55C16	MLL4703	MLL5246B	1SMB5930BT3
17		MMBZ5247BL		MLL4704	MLL5247B	
18	BZX84C18L	MMBZ5248BL	BZV55C18	MLL4705	MLL5248B	1SMB5931BT3
19		MMBZ5249BL		MLL4706	MLL5249B	
20	BZX84C20L	MMBZ5250BL	BZV55C20	MLL4707	MLL5250B	1SMB5932BT3
22	BZX84C22L	MMBZ5251BL	BZV55C22	MLL4708	MLL5251B	1SMB5933BT3
24	BZX84C24L	MMBZ5252BL	BZV55C24	MLL4709	MLL5252B	1SMB5934BT3
25		MMBZ5253BL		MLL4710	MLL5253B	
27	BZX84C27L	MMBZ5254BL	BZV55C27	MLL4711	MLL5254B	1SMB5935BT3
28		MMBZ5255BL		MLL4712	MLL5255B	
30	BZX84C30L	MMBZ5256BL	BZV55C30	MLL4713	MLL5256B	1SMB5936BT3
33	BZX84C33L	MMBZ5257BL	BZV55C33	MLL4714	MLL5257B	1SMB5937BT3
36	BZX84C36L	MMBZ5258BL	BZV55C36	MLL4715	MLL5258B	1SMB5938BT3
39	BZX84C39L	MMBZ5259BL	BZV55C39	MLL4716	MLL5259B	1SMB5939BT3
43	BZX84C43L	MMBZ5260BL	BZV55C43	MLL4717	MLL5260B	1SMB5940BT3

*See Notes — page 4-2-9

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Section 4.2.3 Alphanumeric Part Number Listing Zener Voltage Regulator Diodes

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ALPHANUMERIC INDEX (continued)

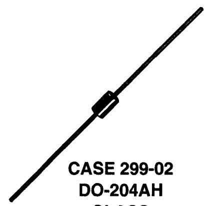
500 mW DO-35 Glass Zener Voltage Regulator Diodes

GENERAL DATA APPLICABLE TO ALL SERIES IN THIS GROUP

500 Milliwatt Hermetically Sealed Glass Silicon Zener Diodes

GENERAL DATA
500 mW
DO-35 GLASS

GLASS ZENER DIODES
500 MILLIWATTS
1.8–200 VOLTS



CASE 299-02
DO-204AH
GLASS

Specification Features:

- Complete Voltage Range — 1.8 to 200 Volts
- DO-204AH Package — Smaller than Conventional DO-204AA Package
- Double Slug Type Construction
- Metallurgically Bonded Construction

Mechanical Characteristics:

CASE: Double slug type, hermetically sealed glass

MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 230°C, 1/16″ from case for 10 seconds

FINISH: All external surfaces are corrosion resistant with readily solderable leads

POLARITY: Cathode indicated by color band. When operated in zener mode, cathode will be positive with respect to anode

MOUNTING POSITION: Any

MAXIMUM RATINGS (Motorola Devices)*

Rating	Symbol	Value	Unit
DC Power Dissipation and $T_L \le 75°C$ Lead Length = 3/8″ Derate above $T_L = 75°C$	P_D	500 4	mW mW/°C
Operating and Storage Temperature Range	T_J, T_{stg}	– 65 to +200	°C

* Some part number series have lower JEDEC registered ratings.

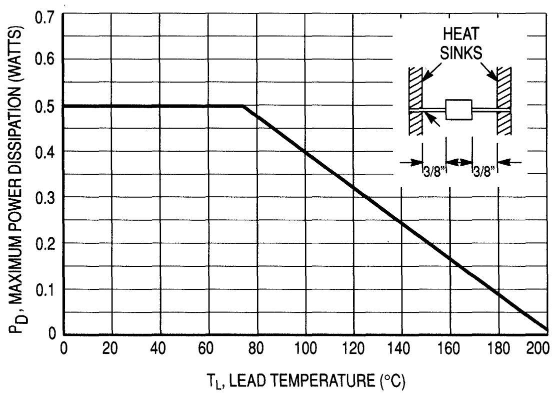


Figure 1. Steady State Power Derating

TEMPERATURE COEFFICIENTS

(–55°C to +150°C temperature range; 90% of the units are in the ranges indicated.)

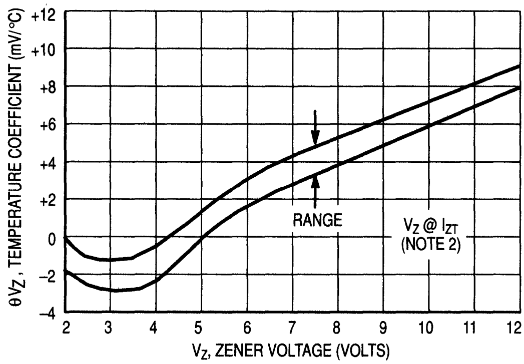


Figure 4a. Range for Units to 12 Volts

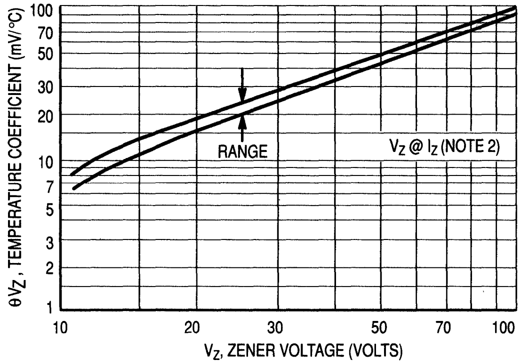


Figure 4b. Range for Units 12 to 100 Volts

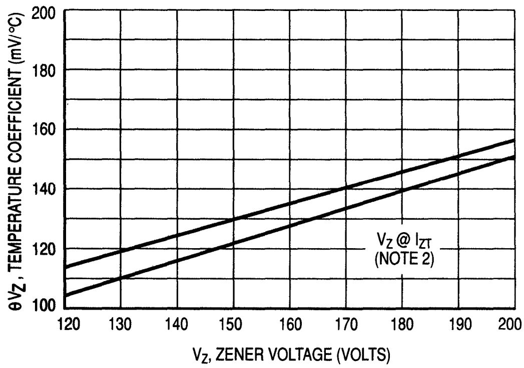


Figure 4c. Range for Units 120 to 200 Volts

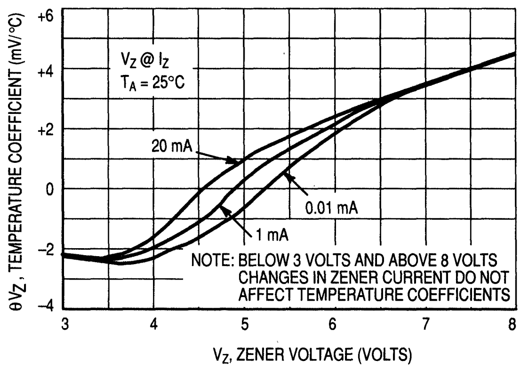


Figure 5. Effect of Zener Current

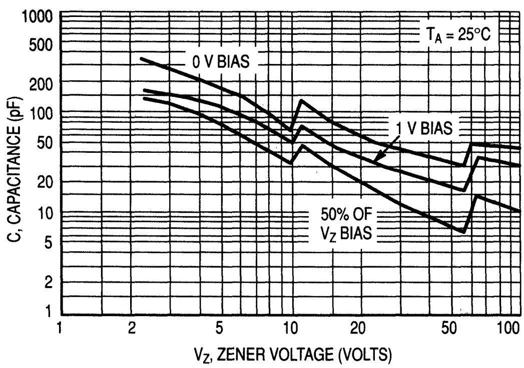


Figure 6a. Typical Capacitance 2.4–100 Volts

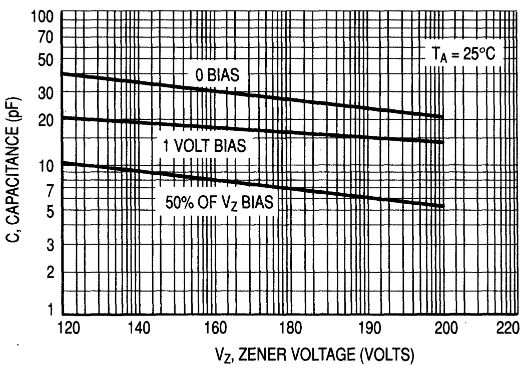


Figure 6b. Typical Capacitance 120–200 Volts

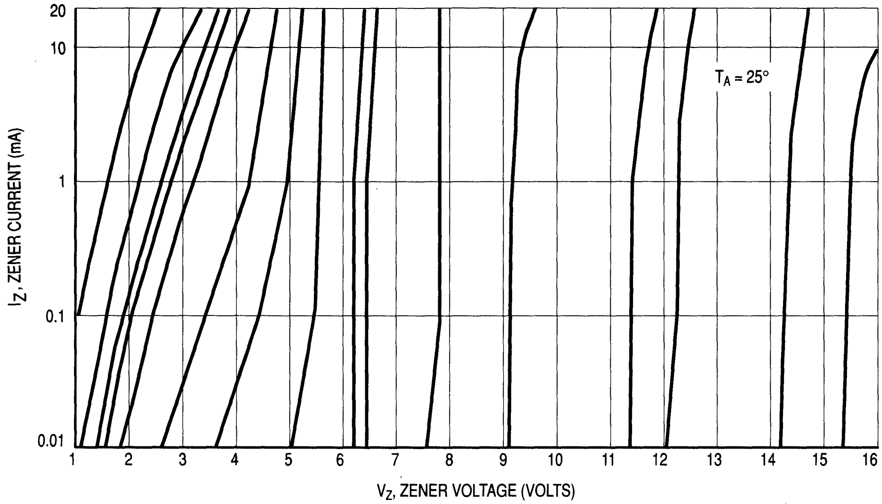


Figure 11. Zener Voltage versus Zener Current — V_Z = 1 thru 16 Volts

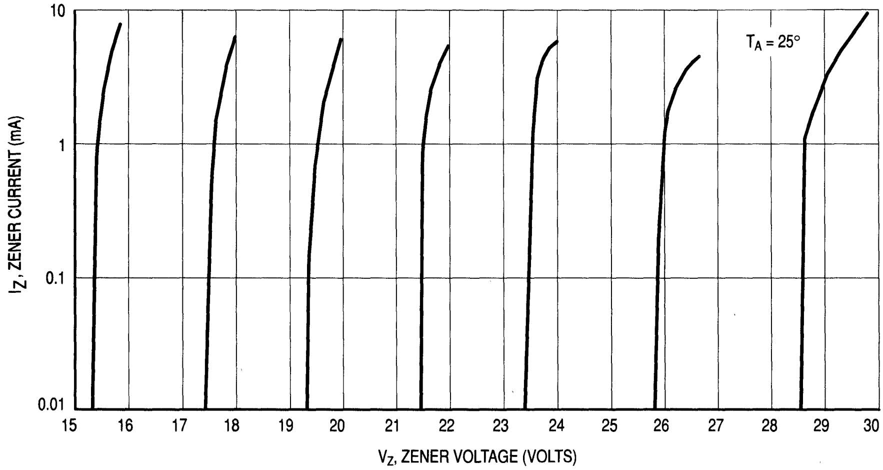


Figure 12. Zener Voltage versus Zener Current — V_Z = 15 thru 30 Volts

ELECTRICAL CHARACTERISTICS (T_A = 25°C, V_F = 1.5 V Max at 200 mA for all types)

Type Number (Note 1)	Nominal Zener Voltage V_Z @ I_{ZT} (Note 2) Volts	Test Current I_{ZT} mA	Maximum Zener Impedance Z_{ZT} @ I_{ZT} (Note 3) Ohms	Maximum DC Zener Current I_{ZM} (Note 4) mA	Maximum Reverse Leakage Current T_A = 25°C I_R @ V_R = 1 V µA	Maximum Reverse Leakage Current T_A = 150°C I_R @ V_R = 1 V µA
1N4370A	2.4	20	30	150	100	200
1N4371A	2.7	20	30	135	75	150
1N4372A	3	20	29	120	50	100
1N746A	3.3	20	28	110	10	30
1N747A	3.6	20	24	100	10	30
1N748A	3.9	20	23	95	10	30
1N749A	4.3	20	22	85	2	30
1N750A	4.7	20	19	75	2	30
1N751A	5.1	20	17	70	1	20
1N752A	5.6	20	11	65	1	20
1N753A	6.2	20	7	60	0.1	20
1N754A	6.8	20	5	55	0.1	20
1N755A	7.5	20	6	50	0.1	20
1N756A	8.2	20	8	45	0.1	20
1N757A	9.1	20	10	40	0.1	20
1N758A	10	20	17	35	0.1	20
1N759A	12	20	30	30	0.1	20

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Type Number (Note 1)	Nominal Zener Voltage V_Z (Note 2) Volts	Test Current I_{ZT} mA	Maximum Zener Impedance (Note 3) Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} @ I_{ZK} Ohms	I_{ZK} mA	Maximum DC Zener Current I_{ZM} (Note 4) mA	Maximum Reverse Current I_R Maximum µA	Test Voltage Vdc V_R
1N957B	6.8	18.5	4.5	700	1	47	150	5.2
1N958B	7.5	16.5	5.5	700	0.5	42	75	5.7
1N959B	8.2	15	6.5	700	0.5	38	50	6.2
1N960B	9.1	14	7.5	700	0.5	35	25	6.9
1N961B	10	12.5	8.5	700	0.25	32	10	7.6
1N962B	11	11.5	9.5	700	0.25	28	5	8.4
1N963B	12	10.5	11.5	700	0.25	26	5	9.1
1N964B	13	9.5	13	700	0.25	24	5	9.9
1N965B	15	8.5	16	700	0.25	21	5	11.4
1N966B	16	7.8	17	700	0.25	19	5	12.2
1N967B	18	7	21	750	0.25	17	5	13.7
1N968B	20	6.2	25	750	0.25	15	5	15.2
1N969B	22	5.6	29	750	0.25	14	5	16.7
1N970B	24	5.2	33	750	0.25	13	5	18.2
1N971B	27	4.6	41	750	0.25	11	5	20.6
1N972B	30	4.2	49	1000	0.25	10	5	22.8
1N973B	33	3.8	58	1000	0.25	9.2	5	25.1
1N974B	36	3.4	70	1000	0.25	8.5	5	27.4
1N975B	39	3.2	80	1000	0.25	7.8	5	29.7
1N976B	43	3	93	1500	0.25	7	5	32.7
1N977B	47	2.7	105	1500	0.25	6.4	5	35.8
1N978B	51	2.5	125	1500	0.25	5.9	5	38.8
1N979B	56	2.2	150	2000	0.25	5.4	5	42.6
1N980B	62	2	185	2000	0.25	4.9	5	47.1

1N4678 thru 1N4717

Low level oxide passivated zener diodes for applications requiring extremely low operating currents, low leakage, and sharp breakdown voltage.

- Zener Voltage Specified @ I_{ZT} = 50 μA
- Maximum Delta V_Z Given from 10 to 100 μA

ELECTRICAL CHARACTERISTICS (T_A = 25°C, V_F = 1.5 V Max at I_F = 100 mA for all types)

Type Number (Note 1)	Zener Voltage V_Z @ I_{ZT} = 50 μA Volts			Maximum Reverse Current I_R μA	Test Voltage V_R Volts (Note 3)	Maximum Zener Current I_{ZM} mA (Note 2)	Maximum Voltage Change ΔV_Z Volts (Note 4)
	Nom (Note 1)	Min	Max				
1N4678	1.8	1.71	1.89	7.5	1	120	0.7
1N4679	2	1.9	2.1	5	1	110	0.7
1N4680	2.2	2.09	2.31	4	1	100	0.75
1N4681	2.4	2.28	2.52	2	1	95	0.8
1N4682	2.7	2.565	2.835	1	1	90	0.85
1N4683	3	2.85	3.15	0.8	1	85	0.9
1N4684	3.3	3.135	3.465	7.5	1.5	80	0.95
1N4685	3.6	3.42	3.78	7.5	2	75	0.95
1N4686	3.9	3.705	4.095	5	2	70	0.97
1N4687	4.3	4.085	4.515	4	2	65	0.99
1N4688	4.7	4.465	4.935	10	3	60	0.99
⇒ **1N4689**	**5.1**	**4.845**	**5.355**	**10**	**3**	**55**	**0.97**
1N4690	5.6	5.32	5.88	10	4	50	0.96
1N4691	6.2	5.89	6.51	10	5	45	0.95
1N4692	6.8	6.46	7.14	10	5.1	35	0.9
1N4693	7.5	7.125	7.875	10	5.7	31.8	0.75
1N4694	8.2	7.79	8.61	1	6.2	29	0.5
1N4695	8.7	8.265	9.135	1	6.6	27.4	0.1
1N4696	9.1	8.645	9.555	1	6.9	26.2	0.08
1N4697	10	9.5	10.5	1	7.6	24.8	0.1
1N4698	11	10.45	11.55	0.05	8.4	21.6	0.11
1N4699	12	11.4	12.6	0.05	9.1	20.4	0.12
1N4700	13	12.35	13.65	0.05	9.8	19	0.13
1N4701	14	13.3	14.7	0.05	10.6	17.5	0.14
1N4702	15	14.25	15.75	0.05	11.4	16.3	0.15
1N4703	16	15.2	16.8	0.05	12.1	15.4	0.16
1N4704	17	16.15	17.85	0.05	12.9	14.5	0.17
1N4705	18	17.1	18.9	0.05	13.6	13.2	0.18
1N4706	19	18.05	19.95	0.05	14.4	12.5	0.19
1N4707	20	19	21	0.01	15.2	11.9	0.2
1N4708	22	20.9	23.1	0.01	16.7	10.8	0.22
1N4709	24	22.8	25.2	0.01	18.2	9.9	0.24
1N4710	25	23.75	26.25	0.01	19	9.5	0.25
1N4711	27	25.65	28.35	0.01	20.4	8.8	0.27
1N4712	28	26.6	29.4	0.01	21.2	8.5	0.28
1N4713	30	28.5	31.5	0.01	22.8	7.9	0.3
1N4714	33	31.35	34.65	0.01	25	7.2	0.33
1N4715	36	34.2	37.8	0.01	27.3	6.6	0.36
1N4716	39	37.05	40.95	0.01	29.6	6.1	0.39
1N4717	43	40.85	45.15	0.01	32.6	5.5	0.43

⇒ Preferred part

NOTE 1. TOLERANCE AND VOLTAGE DESIGNATION (V_Z)

The type numbers shown have a standard tolerance of ±5% on the nominal Zener voltage, C for ±2%, D for ±1%.

NOTE 2. MAXIMUM ZENER CURRENT RATINGS (I_{ZM})

Maximum Zener current ratings are based on maximum Zener voltage of the individual units and JEDEC 250 mW rating.

NOTE 3. REVERSE LEAKAGE CURRENT (I_R)

Reverse leakage currents are guaranteed and measured at V_R as shown on the table.

NOTE 4. MAXIMUM VOLTAGE CHANGE (ΔV_Z)

Voltage change is equal to the difference between V_Z at 100 μA and V_Z at 10 μA.

NOTE 5. ZENER VOLTAGE (V_Z) MEASUREMENT

Nominal Zener voltage is measured with the device junction in thermal equilibrium at the lead temperature at 30°C ±1°C and 3/8″ lead length.

ELECTRICAL CHARACTERISTICS — continued (T_A = 25°C unless otherwise noted. Based on dc measurements at thermal equilibrium; lead length = 3/8″; thermal resistance of heat sink = 30°C/W) V_F = 1.1 Max @ I_F = 200 mA for all types.

JEDEC Type No. (Note 1)	Nominal Zener Voltage V_Z @ I_{ZT} Volts (Note 2)	Test Current I_{ZT} mA	Max Zener Impedance Z_{ZT} @ I_{ZT} Ohms	Max Zener Impedance Z_{ZK} @ I_{ZK} = 0.25 mA Ohms	Max Reverse Leakage Current I_R µA	Max Reverse Leakage Current V_R Volts	Max Zener Voltage Temperature Coeff. θ_{VZ} (%/°C) (Note 3)
1N5266B	68	1.8	230	1600	0.1	52	+0.097
1N5267B	75	1.7	270	1700	0.1	56	+0.098
1N5268B	82	1.5	330	2000	0.1	62	+0.098
1N5269B	87	1.4	370	2200	0.1	68	+0.099
1N5270B	91	1.4	400	2300	0.1	69	+0.099
1N5271B	100	1.3	500	2600	0.1	76	+0.11
1N5272B	110	1.1	750	3000	0.1	84	+0.11
1N5273B	120	1	900	4000	0.1	91	+0.11
1N5274B	130	0.95	1100	4500	0.1	99	+0.11
1N5275B	140	0.9	1300	4500	0.1	106	+0.11
1N5276B	150	0.85	1500	5000	0.1	114	+0.11
1N5277B	160	0.8	1700	5500	0.1	122	+0.11
1N5278B	170	0.74	1900	5500	0.1	129	+0.11
1N5279B	180	0.68	2200	6000	0.1	137	+0.11
1N5280B	190	0.66	2400	6500	0.1	144	+0.11
1N5281B	200	0.65	2500	7000	0.1	152	+0.11

NOTE 1. TOLERANCE

The JEDEC type numbers shown indicate a tolerance of ±5%. For tighter tolerance devices use suffixes "C" for ±2% and "D" for ±1%.

NOTE 2. SPECIAL SELECTIONS † AVAILABLE INCLUDE:

1. Nominal zener voltages between those shown.
2. Nominal voltages at non-standard test currents.

NOTE 3. TEMPERATURE COEFFICIENT (θ_{VZ})

Test conditions for temperature coefficient are as follows:

a. I_{ZT} = 7.5 mA, T_1 = 25°C,

T_2 = 125°C (1N5221B through 1N5242B).

b. I_{ZT} = Rated I_{ZT}, T_1 = 25°C,

T_2 = 125°C (1N5243B through 1N5281B).

Device to be temperature stabilized with current applied prior to reading breakdown voltage at the specified ambient temperature.

NOTE 4. ZENER VOLTAGE (V_Z) MEASUREMENT

Nominal zener voltage is measured with the device junction in thermal equilibrium at the lead temperature of 30°C ±1°C and 3/8″ lead length.

NOTE 5. ZENER IMPEDANCE (Z_Z) DERIVATION

Z_{ZT} and Z_{ZK} are measured by dividing the ac voltage drop across the device by the ac current applied. The specified limits are for I_Z(ac) = 0.1 I_Z(dc) with the ac frequency = 60 Hz.

† For more information on special selections contact your nearest Motorola representative.

ELECTRICAL CHARACTERISTICS (T_L = 30°C unless otherwise noted.) (V_F = 1.3 Volts Max, I_F = 100 mAdc for all types.)

Motorola Type Number	V_{ZT} at I_{ZT} (V) Min (Note 1)	V_{ZT} at I_{ZT} (V) Max (Note 1)	Max Zener Impedance (Note 3) Z_{ZT} @ I_{ZT} (Ohms) Max	I_{ZT} (mA)	Max Reverse Leakage Current I_R at V_R (μA) T_{amb} 25°C Max	Max Reverse Leakage Current I_R at V_R (μA) T_{amb} 125°C Max	V_R (V)	I_{ZM} (mA) (Note 2)
BZX55C2V4	2.28	2.56	85	5	50	100	1	155
BZX55C2V7	2.5	2.9	85	5	10	50	1	135
BZX55C3V0	2.8	3.2	85	5	4	40	1	125
BZX55C3V3	3.1	3.5	85	5	2	40	1	115
BZX55C3V6	3.4	3.8	85	5	2	40	1	105
BZX55C3V9	3.7	4.1	85	5	2	40	1	95
BZX55C4V3	4	4.6	75	5	1	20	1	90
BZX55C4V7	4.4	5	60	5	0.5	10	1	85
BZX55C5V1	4.8	5.4	35	5	0.1	2	1	80
BZX55C5V6	5.2	6	25	5	0.1	2	1	70
BZX55C6V2	5.8	6.6	10	5	0.1	2	2	64
BZX55C6V8	6.4	7.2	8	5	0.1	2	3	58
BZX55C7V5	7	7.9	7	5	0.1	2	5	53
BZX55C8V2	7.7	8.7	7	5	0.1	2	6	47
BZX55C9V1	8.5	9.6	10	5	0.1	2	7	43
BZX55C10	9.4	10.6	15	5	0.1	2	7.5	40
BZX55C11	10.4	11.6	20	5	0.1	2	8.5	36
BZX55C12	11.4	12.7	20	5	0.1	2	9	32
BZX55C13	12.4	14.1	26	5	0.1	2	10	29
BZX55C15	13.8	15.6	30	5	0.1	2	11	27
BZX55C16	15.3	17.1	40	5	0.1	2	12	24
BZX55C18	16.8	19.1	50	5	0.1	2	14	21
BZX55C20	18.8	21.1	55	5	0.1	2	15	20
BZX55C22	20.8	23.3	55	5	0.1	2	17	18
BZX55C24	22.8	25.6	80	5	0.1	2	18	16
BZX55C27	25.1	28.9	80	5	0.1	2	20	14
BZX55C30	28	32	80	5	0.1	2	22	13
BZX55C33	31	35	80	5	0.1	2	24	12
BZX55C36	34	38	80	5	0.1	2	27	11
BZX55C39	37	41	90	2.5	0.1	5	28	10
BZX55C43	40	46	90	2.5	0.1	5	32	9.2
BZX55C47	44	50	110	2.5	0.1	5	35	8.5
BZX55C51	48	54	125	2.5	0.1	10	38	7.8
BZX55C56	52	60	135	2.5	0.1	10	42	7
BZX55C62	58	66	150	2.5	0.1	10	47	6.4
BZX55C68	64	72	160	2.5	0.1	10	51	5.9
BZX55C75	70	80	170	2.5	0.1	10	56	5.3
BZX55C82	77	87	200	2.5	0.1	10	62	4.8
BZX55C91	85	96	250	1	0.1	10	69	4.3

NOTE 1. TOLERANCE AND VOLTAGE DESIGNATION

Tolerance designation — The type numbers listed have zener voltage min/max limits as shown. Device tolerance of ±2% are indicated by a "B" instead of a "C". Zener voltage is measured with the device junction in thermal equilibrium at the lead temperature of 30°C ±1°C and 3/8" lead length.

NOTE 2.

This data was calculated using nominal voltages. The maximum current handling capability on a worst case basis is limited by the actual zener voltage at the operating point and the power derating curve.

NOTE 3.

Z_{ZT} and Z_{ZK} are measured by dividing the ac voltage drop across the device by the ac current applied. The specified limtis are for $I_Z(ac)$ = 0.1 $I_Z(dc)$ with the ac frequency = 1.0 kHz.

ELECTRICAL CHARACTERISTICS (at $T_A = 25°C$)
Motorola ZPD and BZX83C series. Forward Voltage V_F = 1 Volt Max at I_F = 50 mA.

Device Type		Zener Voltage (Note 1) at I_{ZT} = 5.0 mA			Impedance (Ω) Max (Note 2)			Typ. Temp. Coeff. at I_{ZT} % per °C	V_R Min V		
		Nominal	Min	Max	at I_{ZT}	at I_Z = 1 mA BZX83	ZPD		BZX83	ZPD	at I_R
BZX83C2V7	ZPD2.7	2.7	2.5	2.9	85	600	500	–0.09...–0.04	1	—	100 μA
BZX83C3V0	ZPD3.0	3	2.8	3.2	90	600	500	–0.09...–0.03	1	—	60 μA
BZX83C3V3	ZPD3.3	3.3	3.1	3.5	90	600	500	–0.08...–0.03	1	—	30 μA
BZX83C3V6	ZPD3.6	3.6	3.4	3.8	90	600	500	–0.08...–0.03	1	—	20 μA
BZX83C3V9	ZPD3.9	3.9	3.7	4.1	85	600	500	–0.07...–0.03	1	—	10 μA
BZX83C4V3	ZPD4.3	4.3	4	4.6	80	600	500	–0.06...–0.01	1	—	5 μA
BZX83C4V7	ZPD4.7	4.7	4.4	5	78	600	500	–0.05...+0.02	1	—	2 μA
BZX83C5V1	ZPD5.1	5.1	4.8	5.4	60	550	480	–0.03...+0.04	0.8		100 nA
BZX83C5V6	ZPD5.6	5.6	5.2	6	40	450	400	–0.02...+0.06	1		100 nA
BZX83C6V2	ZPD6.2	6.2	5.8	6.6	10	200		–0.01...+0.07	2		100 nA
BZX83C6V8	ZPD6.8	6.8	6.4	7.2	8	150		+0.02...+0.07	3		100 nA
BZX83C7V5	ZPD7.5	7.5	7	7.9	7	50		+0.03...+0.07	5		100 nA
BZX83C8V2	ZPD8.2	8.2	7.7	8.7	7	50		+0.04...+0.07	6		100 nA
BZX83C9V1	ZPD9.1	9.1	8.5	9.6	10	50		+0.05...+0.08	7		100 nA
BZX83C10	ZPD10	10	9.4	10.6	15	70		+0.05...+0.08	7.5		100 nA
BZX83C11	ZPD11	11	10.4	11.6	20	70		+0.05...+0.09	8.5		100 nA
BZX83C12	ZPD12	12	11.4	12.7	20	90		+0.06...+0.09	9		100 nA
BZX83C13	ZPD13	13	12.4	14.1	25	110		+0.07...+0.09	10		100 nA
BZX83C15	ZPD15	15	13.8	15.6	30	110		+0.07...+0.09	11		100 nA
BZX83C16	ZPD16	16	15.3	17.1	40	170		+0.08...+0.095	12		100 nA
BZX83C18	ZPD18	18	16.8	19.1	50	170		+0.08...+0.10	14		100 nA
BZX83C20	ZPD20	20	18.8	21.2	55	220		+0.08...+0.10	15		100 nA
BZX83C22	ZPD22	22	20.8	23.3	55	220		+0.08...+0.10	17		100 nA
BZX83C24	ZPD24	24	22.8	25.6	80	220		+0.08...+0.10	18		100 nA
BZX83C27	ZPD27	27	25.1	28.9	80	250		+0.08...+0.10	20		100 nA
BZX83C30	ZPD30	30	28	32	80	250		+0.08...+0.10	22		100 nA
BZX83C33	ZPD33	33	31	35	80	250		+0.08...+0.10	24		100 nA

NOTE 1. Pulse test.
NOTE 2. f = 1.0 kHz, $I_Z(ac) = 0.1\ I_Z(dc)$.

Low Voltage Avalanche Passivated Silicon Oxide Zener Regulator Diodes

. . . Same as 1N5520B through 1N5530B except low noise test spec ommitted.

- Low Maximum Regulation Factor
- Low Zener Impedance
- Low Leakage Current

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise specified. Based on dc measurements at thermal equilibrium; V_F = 1.1 Max @ I_F = 200 mA for all types.)

Motorola Type No. (Note 1)	Nominal Zener Voltage V_Z @ I_{ZT} Volts (Note 2)	Test Current I_{ZT} mAdc	Max Zener Impedance Z_{ZT} @ I_{ZT} Ohms (Note 3)	Max Reverse Leakage Current		Maximum DC Zener Current I_{ZM} mAdc (Note 5)	Regulation Factor ΔV_Z Volts (Note 6)	Low V_Z Current I_{ZL} mAdc
				I_R μAdc (Note 4)	V_R – Volts			
MZ5520B	3.9	20	22	1	1	98	0.85	2.0
MZ5521B	4.3	20	18	3	1.5	88	0.75	2.0
MZ5522B	4.7	10	22	2	2	81	0.6	1.0
MZ5523B	5.1	5	26	2	2.5	75	0.65	0.25
MZ5524B	5.6	3	30	2	3.5	68	0.3	0.25
MZ5525B	6.2	1	30	1	5	61	0.2	0.01
MZ5526B	6.8	1	30	1	6.2	56	0.1	0.01
MZ5527B	7.5	1	35	0.5	6.8	51	0.05	0.01
MZ5528B	8.2	1	40	0.5	7.5	46	0.05	0.01
MZ5529B	9.1	1	45	0.1	8.2	42	0.05	0.01
MZ5530B	10	1	60	0.05	9.1	38	0.1	0.01

NOTE 1. TOLERANCE AND VOLTAGE DESIGNATION

The "B" suffix type numbers listed are ±5% tolerance of nominal V_Z.

NOTE 2. ZENER VOLTAGE (V_Z) MEASUREMENT

Nominal zener voltage is measured with the device junction in thermal equilibrium with ambient temperature of 25°C.

NOTE 3. ZENER IMPEDANCE (Z_Z) DERIVATION

The zener impedance is derived from the 60 Hz ac voltage, which results when an ac current having an rms value equal to 10% of the dc zener current (I_{ZT}) is superimposed on I_{ZT}.

NOTE 4. REVERSE LEAKAGE CURRENT I_R

Reverse leakage currents are guaranteed and are measured at V_R as shown on the table.

NOTE 5. MAXIMUM REGULATOR CURRENT (I_{ZM})

The maximum current shown is based on the maximum voltage of a ±5% type unit, therefore, it applies only to the "B" suffix device. The actual I_{ZM} for any device may not exceed the value of 400 milliwatts divided by the actual V_Z of the device.

NOTE 6. MAXIMUM REGULATION FACTOR (ΔV_Z)

ΔV_Z is the maximum difference between V_Z at I_{ZT} and V_Z at I_{ZL} measured with the device junction in thermal equilibrium.

NOTE 7. SPECIAL SELECTORS AVAILABLE INCLUDE:

a) Nominal Zener voltages between those shown.
b) Tighter voltage tolerances. Contact your nearest Motorola representative for more information.

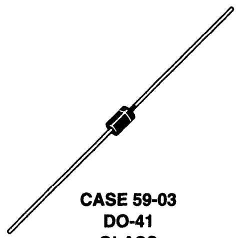
1–1.3 Watt DO-41 Glass Zener Voltage Regulator Diodes

GENERAL DATA APPLICABLE TO ALL SERIES IN THIS GROUP

One Watt Hermetically Sealed Glass Silicon Zener Diodes

GENERAL DATA
1–1.3 WATT DO-41 GLASS

1 WATT ZENER REGULATOR DIODES 3.3–100 VOLTS



CASE 59-03 DO-41 GLASS

Specification Features:

- Complete Voltage Range — 3.3 to 100 Volts
- DO-41 Package
- Double Slug Type Construction
- Metallurgically Bonded Construction
- Oxide Passivated Die

Mechanical Characteristics:

CASE: Double slug type, hermetically sealed glass

MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 230°C, 1/16″ from case for 10 seconds

FINISH: All external surfaces are corrosion resistant with readily solderable leads

POLARITY: Cathode indicated by color band. When operated in zener mode, cathode will be positive with respect to anode

MOUNTING POSITION: Any

4

4.2

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
DC Power Dissipation @ $T_A = 50°C$ Derate above 50°C	P_D	1 6.67	Watt mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	– 65 to +200	°C

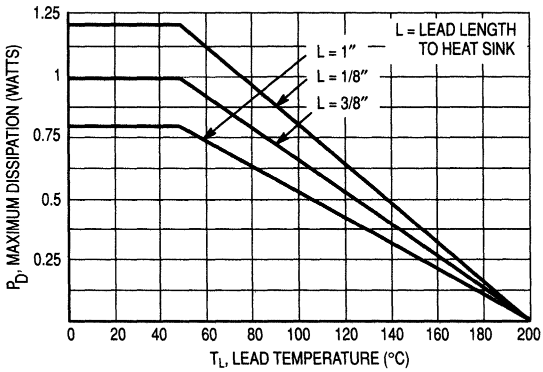


Figure 1. Power Temperature Derating Curve

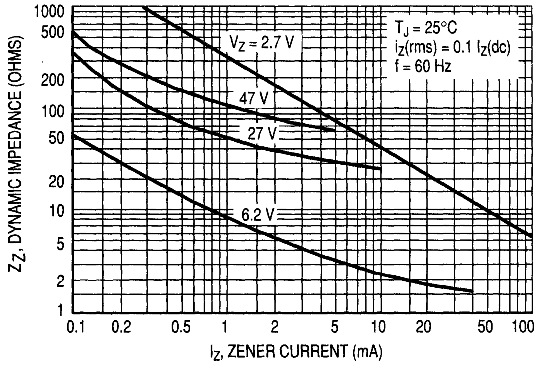


Figure 6. Effect of Zener Current on Zener Impedance

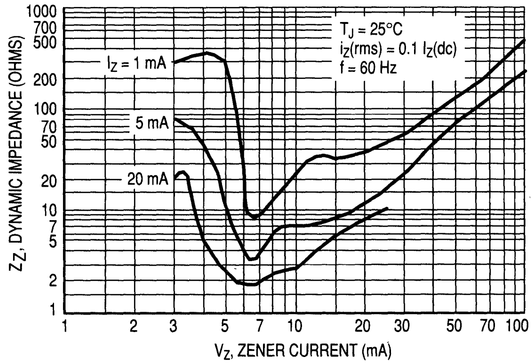


Figure 7. Effect of Zener Voltage on Zener Impedance

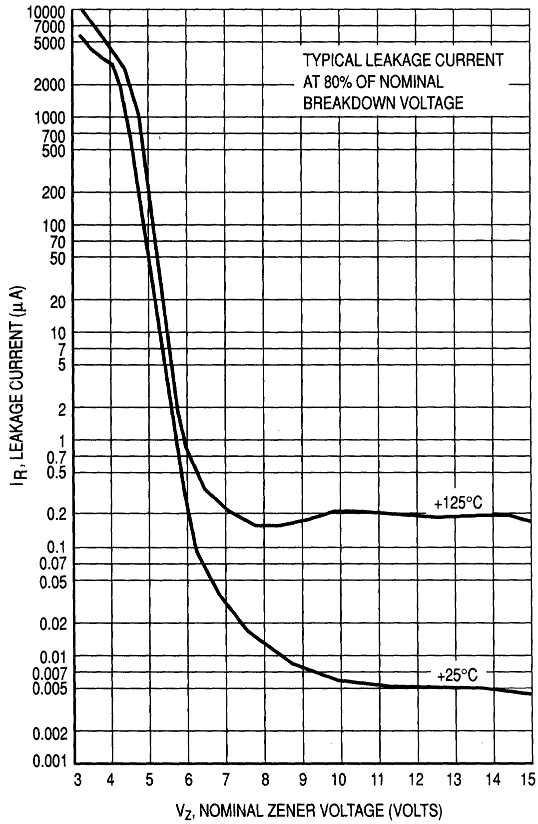


Figure 8. Typical Leakage Current

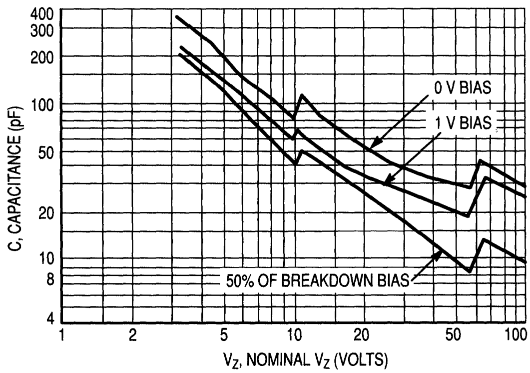


Figure 9. Typical Capacitance versus V_Z

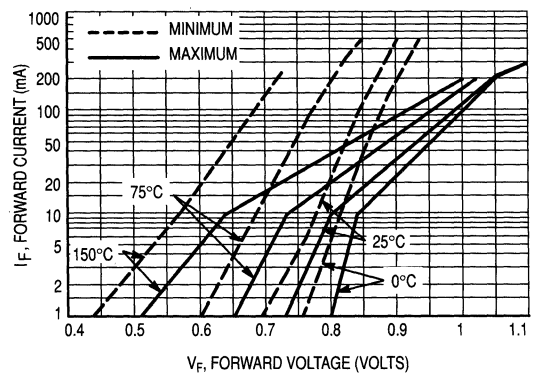


Figure 10. Typical Forward Characteristics

*ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) V_F = 1.2 V Max, I_F = 200 mA for all types.								
JEDEC Type No. (Note 1)	Nominal Zener Voltage V_Z @ I_{ZT} Volts (Notes 2 and 3)	Test Current I_{ZT} mA	Maximum Zener Impedance (Note 4) Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} @ I_{ZK} Ohms	I_{ZK} mA	Leakage Current I_R μA Max	V_R Volts	Surge Current @ T_A = 25°C i_r – mA (Note 5)
⇒ **1N4728A**	**3.3**	**76**	**10**	**400**	**1**	**100**	**1**	**1380**
1N4729A	3.6	69	10	400	1	100	1	1260
1N4730A	3.9	64	9	400	1	50	1	1190
⇒ **1N4731A**	**4.3**	**58**	**9**	**400**	**1**	**10**	**1**	**1070**
⇒ **1N4732A**	**4.7**	**53**	**8**	**500**	**1**	**10**	**1**	**970**
⇒ **1N4733A**	**5.1**	**49**	**7**	**550**	**1**	**10**	**1**	**890**
⇒ **1N4734A**	**5.6**	**45**	**5**	**600**	**1**	**10**	**2**	**810**
⇒ **1N4735A**	**6.2**	**41**	**2**	**700**	**1**	**10**	**3**	**730**
⇒ **1N4736A**	**6.8**	**37**	**3.5**	**700**	**1**	**10**	**4**	**660**
1N4737A	7.5	34	4	700	0.5	10	5	605
⇒ **1N4738A**	**8.2**	**31**	**4.5**	**700**	**0.5**	**10**	**6**	**550**
⇒ **1N4739A**	**9.1**	**28**	**5**	**700**	**0.5**	**10**	**7**	**500**
⇒ **1N4740A**	**10**	**25**	**7**	**700**	**0.25**	**10**	**7.6**	**454**
⇒ **1N4741A**	**11**	**23**	**8**	**700**	**0.25**	**5**	**8.4**	**414**
⇒ **1N4742A**	**12**	**21**	**9**	**700**	**0.25**	**5**	**9.1**	**380**
⇒ **1N4743A**	**13**	**19**	**10**	**700**	**0.25**	**5**	**9.9**	**344**
⇒ **1N4744A**	**15**	**17**	**14**	**700**	**0.25**	**5**	**11.4**	**304**
⇒ **1N4745A**	**16**	**15.5**	**16**	**700**	**0.25**	**5**	**12.2**	**285**
⇒ **1N4746A**	**18**	**14**	**20**	**750**	**0.25**	**5**	**13.7**	**250**
⇒ **1N4747A**	**20**	**12.5**	**22**	**750**	**0.25**	**5**	**15.2**	**225**
1N4748A	22	11.5	23	750	0.25	5	16.7	205
⇒ **1N4749A**	**24**	**10.5**	**25**	**750**	**0.25**	**5**	**18.2**	**190**
⇒ **1N4750A**	**27**	**9.5**	**35**	**750**	**0.25**	**5**	**20.6**	**170**
⇒ **1N4751A**	**30**	**8.5**	**40**	**1000**	**0.25**	**5**	**22.8**	**150**
1N4752A	33	7.5	45	1000	0.25	5	25.1	135
1N4753A	36	7	50	1000	0.25	5	27.4	125
1N4754A	39	6.5	60	1000	0.25	5	29.7	115
1N4755A	43	6	70	1500	0.25	5	32.7	110
1N4756A	47	5.5	80	1500	0.25	5	35.8	95
1N4757A	51	5	95	1500	0.25	5	38.8	90
1N4758A	56	4.5	110	2000	0.25	5	42.6	80
1N4759A	62	4	125	2000	0.25	5	47.1	70
1N4760A	68	3.7	150	2000	0.25	5	51.7	65
1N4761A	75	3.3	175	2000	0.25	5	56	60
1N4762A	82	3	200	3000	0.25	5	62.2	55
1N4763A	91	2.8	250	3000	0.25	5	69.2	50
1N4764A	100	2.5	350	3000	0.25	5	76	45

⇒ Preferred part

*Indicates JEDEC Registered Data.

NOTE 1. TOLERANCE AND TYPE NUMBER DESIGNATION

The JEDEC type numbers listed have a standard tolerance on the nominal zener voltage of ±5%. C for ±2%, D for ±1%.

NOTE 2. SPECIALS AVAILABLE INCLUDE:

Nominal zener voltages between the voltages shown and tighter voltage tolerances.

For detailed information on price, availability, and delivery, contact your nearest Motorola representative.

NOTE 3. ZENER VOLTAGE (V_Z) MEASUREMENT

Motorola guarantees the zener voltage when measured at 90 seconds while maintaining the lead temperature (T_L) at 30°C ± 1°C, 3/8″ from the diode body.

NOTE 4. ZENER IMPEDANCE (Z_Z) DERIVATION

The zener impedance is derived from the 60 cycle ac voltage, which results when an ac current having an rms value equal to 10% of the dc zener current (I_{ZT} or I_{ZK}) is superimposed on I_{ZT} or I_{ZK}.

NOTE 5. SURGE CURRENT (i_r) NON-REPETITIVE

The rating listed in the electrical characteristics table is maximum peak, non-repetitive, reverse surge current of 1/2 square wave or equivalent sine wave pulse of 1/120 second duration superimposed on the test current, I_{ZT}, per JEDEC registration; however, actual device capability is as described in Figure 5 of the General Data — DO-41 Glass.

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) V_F = 1.2 V Max, I_F = 200 mA for all types.

Type No. (Note 1)	Zener Voltage (V) (Notes 2 and 3) V_Z Min	V_Z Max	Test Current I_{ZT} (mA)	Zener Impedance (Note 4) f = 1 kHz (ohms) Typ	Max	Blocking Volt Min (V) I_R = 1 μA	Surge Current T_A = 25°C i_r (mA) (Note 5)
MZPY3.9	3.7	4.1	100	4	7	—	1190
MZPY4.3	4	4.6	100	4	7	—	1070
MZPY4.7	4.4	5	100	4	7	—	970
MZPY5.1	4.8	5.4	100	2	5	0.7	890
MZPY5.6	5.2	6	100	1	2	1.5	810
MZPY6.2	5.8	6.6	100	1	2	2	730
MZPY6.8	6.4	7.2	100	1	2	3	660
MZPY7.5	7	7.9	100	1	2	5	605
MZPY8.2	7.7	8.7	100	1	2	6	550
MZPY9.1	8.5	9.6	50	2	4	7	500
MZPY10	9.4	10.6	50	2	4	7.5	454
MZPY11	10.4	11.6	50	3	7	8.5	414
MZPY12	11.4	12.7	50	3	7	9	380
MZPY13	12.4	14.1	50	4	9	10	344
MZPY15	14.2	15.8	50	4	9	11	304
MZPY16	15.3	17.1	25	5	10	12	285
MZPY18	16.8	19.1	25	5	11	14	250
MZPY20	18.8	21.2	25	6	12	15	225
MZPY22	20.8	23.3	25	7	13	17	205
MZPY24	22.8	25.6	25	8	14	18	190
MZPY27	25.1	28.9	25	9	15	20	170
MZPY30	28	32	25	10	20	22.5	150
MZPY33	31	35	25	11	20	25	135
MZPY36	34	38	10	25	60	27	125
MZPY39	37	41	10	30	60	29	115
MZPY43	40	46	10	35	80	32	110
MZPY47	44	50	10	40	80	35	95
MZPY51	48	54	10	45	100	38	90
MZPY56	52	60	10	50	100	42	80
MZPY62	58	66	10	60	130	47	70
MZPY68	64	72	10	65	130	51	65
MZPY75	70	79	10	70	160	56	60
MZPY82	77	88	10	80	160	61	55
MZPY91	85	96	5	120	250	68	50
MZPY100	94	106	5	130	250	75	45

NOTE 1. TOLERANCE AND TYPE NUMBER DESIGNATION

The type numbers listed have zener voltage min/max limits as shown. Device tolerance of ±2% are indicated by a "C" and ±1% by a "D" suffix.

NOTE 2. SPECIALS AVAILABLE INCLUDE:

Nominal zener voltages between the voltages shown and tighter voltage tolerances.

For detailed information on price, availability, and delivery, contact your nearest Motorola representative.

NOTE 3. ZENER VOLTAGE (V_Z) MEASUREMENT

V_Z is measured after the test current has been applied to 40 ± 10 msec., while maintaining the lead temperature (T_L) at 30°C ± 1°C, 3/8″ from the diode body.

NOTE 4. ZENER IMPEDANCE (Z_Z) DERIVATION

The zener impedance is derived from the 1 kHz cycle ac voltage, which results when an ac current having an rms value equal to 10% of the dc zener current (I_{ZT}) of (I_{ZK}) is superimposed on I_{ZT} or I_{ZK}.

NOTE 5. SURGE CURRENT (i_r) NON-REPETITIVE

The rating listed in the electrical characteristics table is maximum peak, non-repetitive, reverse surge current of 1/2 square wave or equivalent sine wave pulse of 1/120 second duration superimposed on the test current I_{ZT}, however, actual device capability is as described in Figure 5 of General Data DO-41 glass.

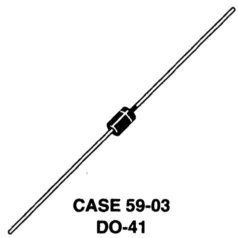
1 to 3 Watt DO-41 Surmetic 30 Zener Voltage Regulator Diodes

GENERAL DATA APPLICABLE TO ALL SERIES IN THIS GROUP

1 to 3 Watt Surmetic 30 Silicon Zener Diodes

GENERAL DATA
1–3 WATT
DO-41
SURMETIC 30

1 TO 3 WATT
ZENER REGULATOR
DIODES
3.3–400 VOLTS



CASE 59-03
DO-41
PLASTIC

. . . a complete series of 1 to 3 Watt Zener Diodes with limits and operating characteristics that reflect the superior capabilities of silicon-oxide-passivated junctions. All this in an axial-lead, transfer-molded plastic package offering protection in all common environmental conditions.

Specification Features:

- Surge Rating of 98 Watts @ 1 ms
- Maximum Limits Guaranteed On Up To Six Electrical Parameters
- Package No Larger Than the Conventional 1 Watt Package

Mechanical Characteristics:

CASE: Void-free, transfer-molded, thermosetting plastic
FINISH: All external surfaces are corrosion resistant and leads are readily solderable
POLARITY: Cathode indicated by color band. When operated in zener mode, cathode will be positive with respect to anode
MOUNTING POSITION: Any
WEIGHT: 0.4 gram (approx)

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
DC Power Dissipation @ T_L = 75°C Lead Length = 3/8″ Derate above 75°C	P_D	3 24	Watts mW/°C
DC Power Dissipation @ T_A = 50°C Derate above 50°C	P_D	1 6.67	Watt mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	– 65 to +200	°C

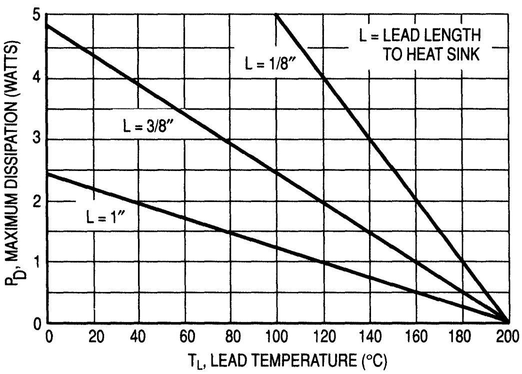


Figure 1. Power Temperature Derating Curve

TEMPERATURE COEFFICIENT RANGES

(90% of the Units are in the Ranges Indicated)

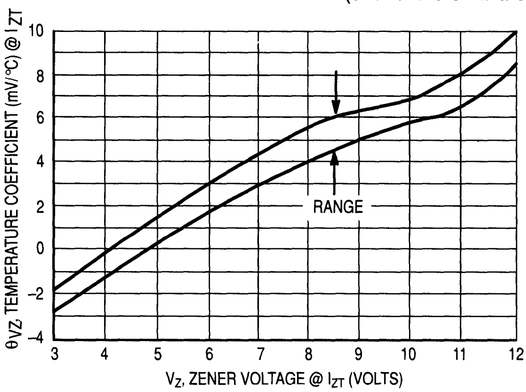


Figure 5. Units To 12 Volts

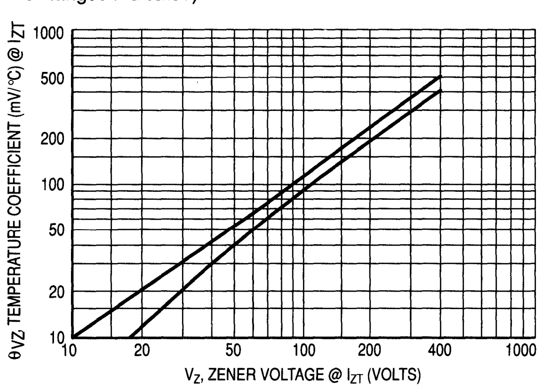


Figure 6. Units 10 To 400 Volts

ZENER VOLTAGE versus ZENER CURRENT

(Figures 7, 8 and 9)

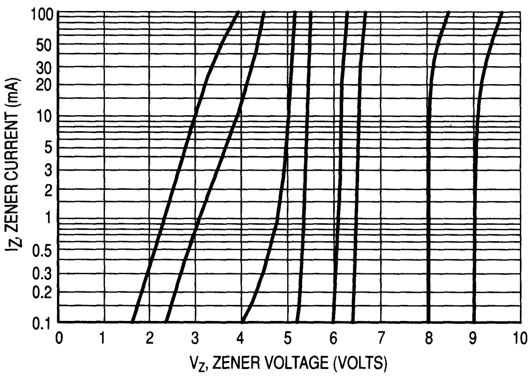


Figure 7. V_Z = 3.3 thru 10 Volts

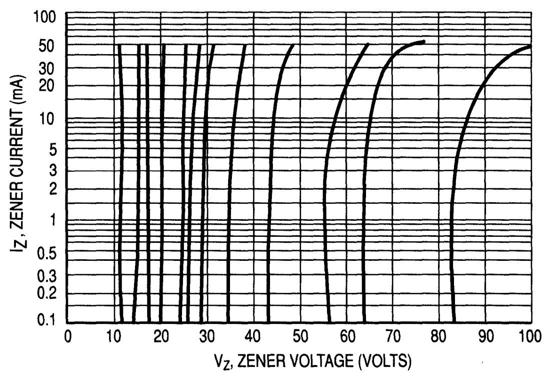


Figure 8. V_Z = 12 thru 82 Volts

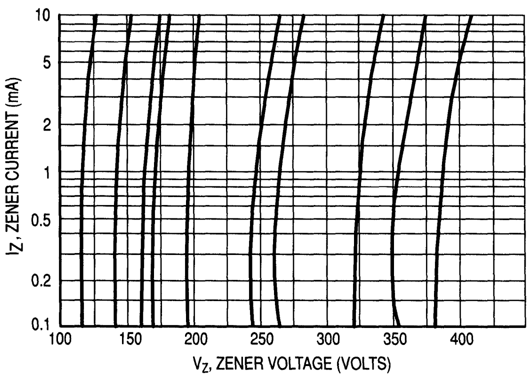


Figure 9. V_Z = 100 thru 400 Volts

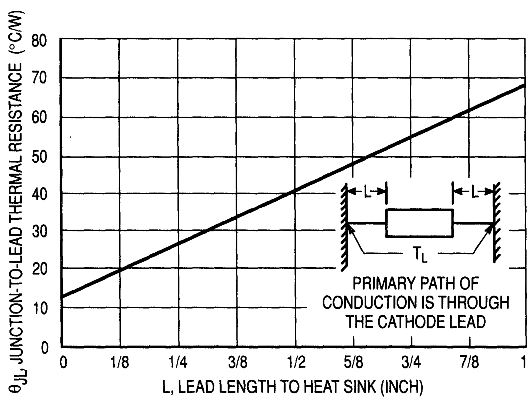


Figure 10. Typical Thermal Resistance

***ELECTRICAL CHARACTERISTICS — continued** (T_L = 30°C unless otherwise noted. V_F = 1.5 Volts Max @ I_F = 200 mAdc for all types.)

Motorola Type Number (Note 1)	Nominal Zener Voltage V_Z @ I_{ZT} Volts (Note 2 and 3)	Test Current I_{ZT} mA	Max. Zener Impedance (Note 4)			Max. Reverse Leakage Current		Maximum DC Zener Current I_{ZM} mAdc
			Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} @ Ohms	I_{ZK} mA	I_R @ µA	V_R Volts	
1N5948B	91	4.1	200	3000	0.25	1	69.2	16
1N5949B	100	3.7	250	3100	0.25	1	76	15
1N5950B	110	3.4	300	4000	0.25	1	83.6	13
1N5951B	120	3.1	380	4500	0.25	1	91.2	12
1N5952B	130	2.9	450	5000	0.25	1	98.8	11
1N5953B	150	2.5	600	6000	0.25	1	114	10
1N5954B	160	2.3	700	6500	0.25	1	121.6	9
1N5955B	180	2.1	900	7000	0.25	1	136.8	8
1N5956B	200	1.9	1200	8000	0.25	1	152	7

*Indicates JEDEC Registered Data.

NOTE 1. TOLERANCE AND VOLTAGE DESIGNATION

Tolerance designation — Device tolerances of ±5% are indicated by a "B" suffix.

NOTE 2. SPECIAL SELECTIONS AVAILABLE INCLUDE:

Nominal zener voltages between those shown and ±1% and ±2% tight voltage tolerances. Consult factory.

NOTE 3. ZENER VOLTAGE (V_Z) MEASUREMENT

Motorola guarantees the zener voltage when meausred at 90 seconds while maintaining the lead temperature (T_L) at 30°C ±1°C, 3/8″ from the diode body.

NOTE 4. ZENER IMPEDANCE (Z_Z) DERIVATION

The zener impedance is derived from the 60 cycle ac voltage, which results when an ac current having an rms value equal to 10% of the dc zener current (I_{ZT} or I_{ZK}) is superimposed on I_{ZT} or I_{ZK}.

ELECTRICAL CHARACTERISTICS — continued (T_A = 25°C unless otherwise noted) V_F = 1.5 V Max, I_F = 200 mA for all types)

Motorola Type No. (Note 1)	Nominal Zener Voltage V_Z @ I_{ZT} Volts (Note 2)	Test Current I_{ZT} mA	Max Zener Impedance (Note 3) Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} @ I_{ZK} Ohms	I_{ZK} mA	Leakage Current I_R µA Max	@ V_R Volts	Maximum Zener Current I_{ZM} mA	Surge Current @ T_A = 25°C i_r – mA (Note 4)
3EZ200D5	200	3.7	875	8000	0.25	0.5	152	13	0.1
3EZ220D5	220	3.4	1600	9000	0.25	1	167	12	0.09
3EZ240D5	240	3.1	1700	9000	0.25	1	182	11	0.09
3EZ270D5	270	2.8	1800	9000	0.25	1	205	10	0.08
3EZ300D5	300	2.5	1900	9000	0.25	1	228	9	0.07
3EZ330D5	330	2.3	2200	9000	0.25	1	251	8	0.06
3EZ360D5	360	2.1	2700	9000	0.25	1	274	8	0.06
3EZ400D5	400	1.9	3500	9000	0.25	1	304	7	0.06

NOTE 1. TOLERANCES

Suffix 5 indicates 5% tolerance. Any other tolerance will be considered as a special device.

NOTE 2. ZENER VOLTAGE (V_Z) MEASUREMENT

Motorola guarantees the zener voltage when measured at 40 ms ±10 ms 3/8″ from the diode body, and an ambient temperature of 25°C (+8°C, –2°C)

NOTE 3. ZENER IMPEDANCE (Z_Z) DERIVATION

The zener impedance is derived from the 60 cycle ac voltage, which results when an ac current having an rms value equal to 10% of the dc zener current (I_{ZT} or I_{ZK}) is superimposed on I_{ZT} or I_{ZK}.

NOTE 4. SURGE CURRENT (i_r) NON-REPETITIVE

The rating listed in the electrical characteristics table is maximum peak, non-repetitive, reverse surge current of 1/2 square wave or equivalent sine wave pulse of 1/120 second duration superimposed on the test current, I_{ZT}, per JEDEC standards, however, actual device capability is as described in Figure 3 of General Data sheet for Surmetic 30s.

NOTE 5. SPECIAL SELECTIONS AVAILABLE INCLUDE:

Nominal zener voltages between those shown. Tight voltage tolerances such as ±1% and ±2%. Consult factory.

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) V_F = 1.5 V Max, I_F = 200 mA for all types

Motorola Type No. (Note 1)	Nominal Zener Voltage V_Z @ I_{ZT} Volts (Note 2)	Test Current I_{ZT} mA	Max Zener Impedance (Note 3) Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} @ I_{ZK} Ohms	I_{ZK} mA	Leakage Current I_R @ µA Max	V_R Volts	Surge Current @ T_A = 25°C i_r – mA (Note 4)
MZP4728A	3.3	76	10	400	1	100	1	1380
MZP4729A	3.6	69	10	400	1	100	1	1260
MZP4730A	3.9	64	9	400	1	50	1	1190
MZP4731A	4.3	58	9	400	1	10	1	1070
MZP4732A	4.7	53	8	500	1	10	1	970
⇒ **MZP4733A**	**5.1**	**49**	**7**	**550**	**1**	**10**	**1**	**890**
MZP4734A	5.6	45	5	600	1	10	2	810
⇒ **MZP4735A**	**6.2**	**41**	**2**	**700**	**1**	**10**	**3**	**730**
MZP4736A	6.8	37	3.5	700	1	10	4	660
MZP4737A	7.5	34	4	700	0.5	10	5	605
MZP4738A	8.2	31	4.5	700	0.5	10	6	550
MZP4739A	9.1	28	5	700	0.5	10	7	500
MZP4740A	10	25	7	700	0.25	10	7.6	454
MZP4741A	11	23	8	700	0.25	5	8.4	414
MZP4742A	12	21	9	700	0.25	5	9.1	380
MZP4743A	13	19	10	700	0.25	5	9.9	344
⇒ **MZP4744A**	**15**	**17**	**14**	**700**	**0.25**	**5**	**11.4**	**304**
⇒ **MZP4745A**	**16**	**15.5**	**16**	**700**	**0.25**	**5**	**12.2**	**285**
⇒ **MZP4746A**	**18**	**14**	**20**	**750**	**0.25**	**5**	**13.7**	**250**
MZP4747A	20	12.5	22	750	0.25	5	15.2	225
MZP4748A	22	11.5	23	750	0.25	5	16.7	205
⇒ **MZP4749A**	**24**	**10.5**	**25**	**750**	**0.25**	**5**	**18.2**	**190**
MZP4750A	27	9.5	35	750	0.25	5	20.6	170
⇒ **MZP4751A**	**30**	**8.5**	**40**	**1000**	**0.25**	**5**	**22.8**	**150**
MZP4752A	33	7.5	45	1000	0.25	5	25.1	135
MZP4753A	36	7	50	1000	0.25	5	27.4	125
MZP4754A	39	6.5	60	1000	0.25	5	29.7	115
MZP4755A	43	6	70	1500	0.25	5	32.7	110
MZP4756A	47	5.5	80	1500	0.25	5	35.8	95
MZP4757A	51	5	95	1500	0.25	5	38.8	90
MZP4758A	56	4.5	110	2000	0.25	5	42.6	80
MZP4759A	62	4	125	2000	0.25	5	47.1	70
MZP4760A	68	3.7	150	2000	0.25	5	51.7	65
MZP4761A	75	3.3	175	2000	0.25	5	56	60
MZP4762A	82	3	200	3000	0.25	5	62.2	55
MZP4763A	91	2.8	250	3000	0.25	5	69.2	50
MZP4764A	100	2.5	350	3000	0.25	5	76	45
1M110ZS5	110	2.3	450	4000	0.25	5	83.6	—
1M120ZS5	120	2	550	4500	0.25	5	91.2	—
1M130ZS5	130	1.9	700	5000	0.25	5	98.8	—
1M150ZS5	150	1.7	1000	6000	0.25	5	114	—
1M160ZS5	160	1.6	1100	6500	0.25	5	121.6	—
1M180ZS5	180	1.4	1200	7000	0.25	5	136.8	—
1M200ZS5	200	1.2	1500	8000	0.25	5	152	—

⇒ **Preferred part**

NOTE 1. TOLERANCE AND TYPE NUMBER DESIGNATION

The type numbers listed have a standard tolerance on the nominal zener voltage of ±5%. The tolerance on the 1M type numbers is indicated by the digits following ZS in the part number. "5" indicates a ±5% V_Z tolerance.

NOTE 2. ZENER VOLTAGE (V_Z) MEASUREMENT

Motorola guarantees the zener voltage when measured at 90 seconds while maintaining the lead temperature (T_L) at 30°C ±1°C, 3/8″ from the diode body.

NOTE 3. ZENER IMPEDANCE (Z_Z) DERIVATION

The zener impedance is derived from the 60 cycle ac voltage, which results when an ac current having an rms value equal to 10% of the dc zener current (I_{ZT} or I_{ZK}) is superimposed on I_{ZT} or I_{ZK}.

NOTE 4. SURGE CURRENT (i_r) NON-REPETITIVE

The rating listed in the electrical characteristics table is maximum peak, non-repetitive, reverse surge current of 1/2 square wave or equivalent sine wave pulse of 1/120 second duration superimposed on the test current, I_{ZT}, however, actual device capability is as described in Figure 3 of General Data — Surmetic 30.

NOTE 5. SPECIAL SELECTIONS AVAILABLE INCLUDE:

Nominal zener voltages between those shown. Tight voltage tolerances such as ±1% and ±2%. Consult factory.

1N5333B thru 1N5388B

5 Watt Surmetic 40 Silicon Zener Diodes

. . . a complete series of 5 Watt Zener Diodes with tight limits and better operating characteristics that reflect the superior capabilities of silicon-oxide-passivated junctions. All this in an axial-lead, transfer-molded plastic package offering protection in all common environmental conditions.

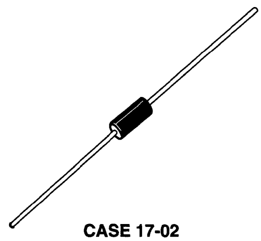
5 WATT ZENER REGULATOR DIODES 3.3–200 VOLTS

Specification Features:

- Up to 180 Watt Surge Rating @ 8.3 ms
- Maximum Limits Guaranteed on Seven Electrical Parameters

Mechanical Characteristics:

CASE: Void-free, transfer-molded, thermosetting plastic
FINISH: All external surfaces are corrosion resistant and leads are readily solderable
POLARITY: Cathode indicated by color band. When operated in zener mode, cathode will be positive with respect to anode
MOUNTING POSITION: Any
WEIGHT: 0.7 gram (approx)



CASE 17-02
PLASTIC

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
DC Power Dissipation @ T_L = 75°C Lead Length = 3/8″ Derate above 75°C	P_D	5 40	Watts mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	– 65 to +200	°C

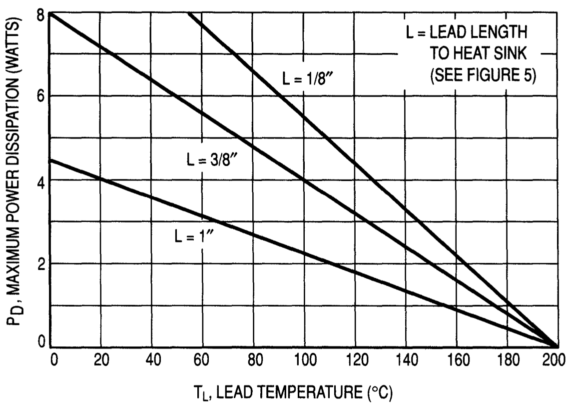


Figure 1. Power Temperature Derating Curve

ELECTRICAL CHARACTERISTICS — continued (T_A = 25°C unless otherwise noted, V_F = 1.2 Max @ I_F = 1 A for all types)									
JEDEC Type No. (Note 1)	Nominal Zener Voltage V_Z @ I_{ZT} Volts (Note 2)	Test Current I_{ZT} mA	Max Zener Impedance Z_{ZT} @ I_{ZT} Ohms (Note 2)	Max Zener Impedance Z_{ZK} @ I_{ZK} = 1 mA Ohms (Note 2)	Max Reverse Leakage Current I_R µA	@ V_R Volts	Max Surge Current i_r, Amps (Note 3)	Max Voltage Regulation ΔV_Z, Volt (Note 4)	Maximum Regulator Current I_{ZM} mA (Note 5)
⇒ **1N5383B**	**150**	**8**	**330**	**1500**	**0.5**	**114**	**1.1**	**3**	**31.6**
1N5384B	160	8	350	1650	0.5	122	1.1	3	29.4
1N5385B	170	8	380	1750	0.5	129	1	3	28
1N5386B	180	5	430	1750	0.5	137	1	4	26.4
1N5387B	190	5	450	1850	0.5	144	0.9	5	25
1N5388B	200	5	480	1850	0.5	152	0.9	5	23.6

⇒ Preferred part

NOTE 1. TOLERANCE AND TYPE NUMBER DESIGNATION

The JEDEC type numbers shown indicate a tolerance of ±5%.

NOTE 2. ZENER VOLTAGE (V_Z) AND IMPEDANCE (Z_{ZT} & Z_{ZK})

Test conditions for zener voltage and impedance are as follows: I_Z is applied 40 ± 10 ms prior to reading. Mounting contacts are located 3/8″ to 1/2″ from the inside edge of mounting clips to the body of the diode. (T_A = 25°C +8, −2°C).

NOTE 3. SURGE CURRENT (i_r)

Surge current is specified as the maximum allowable peak, non-recurrent square-wave current with a pulse width, PW, of 8.3 ms. The data given in Figure 6 may be used to find the maximum surge current for a square wave of any pulse width between 1ms and 1000 ms by plotting the applicable points on logarithmic paper. Examples of this, using the 3.3 V and 200 V zeners, are shown in Figure 7. Mounting contact located as specified in Note 3. (T_A = 25°C +8, −2°C.)

NOTE 4. VOLTAGE REGULATION (ΔV_Z)

Test conditions for voltage regulation are as follows: V_Z measurements are made at 10% and then at 50% of the I_Z max value listed in the electrical characteristics table. The test current time duration for each V_Z measurement is 40 ± 10 ms. (T_A = 25°C +8, −2°C). Mounting contact located as specified in Note 2.

NOTE 5. MAXIMUM REGULATOR CURRENT (I_{ZM})

The maximum current shown is based on the maximum voltage of a 5% type unit, therefore, it applies only to the B-suffix device. The actual I_{ZM} for any device may not exceed the value of 5 watts divided by the actual V_Z of the device. T_L = 75°C at 3/8″ maximum from the device body.

NOTE 6. SPECIALS AVAILABLE INCLUDE:

Nominal zener voltages between the voltages shown and tighter voltage tolerance such as ±1% and ±2%. Consult factory.

TEMPERATURE COEFFICIENTS

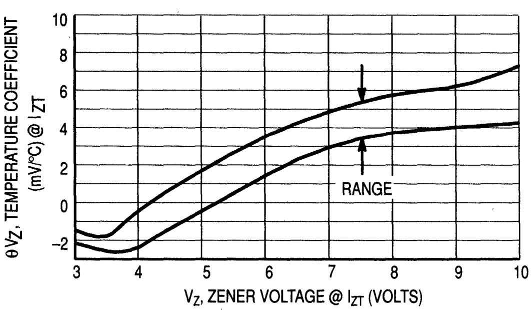


Figure 2. Temperature Coefficient-Range for Units 3 to 10 Volts

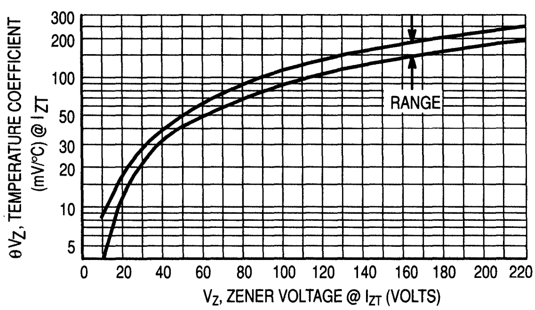


Figure 3. Temperature Coefficient-Range for Units 10 to 220 Volts

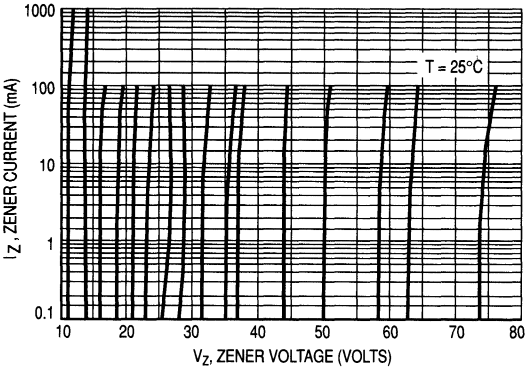


Figure 9. Zener Voltage versus Zener Current
V_Z = 11 thru 75 Volts

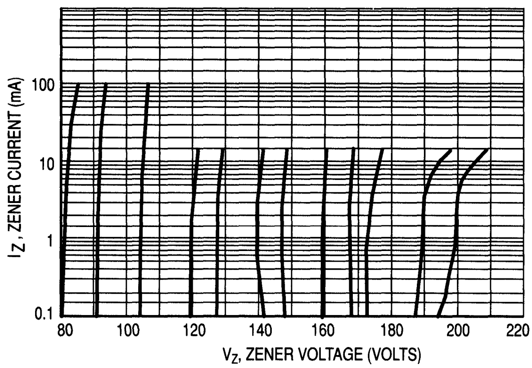


Figure 10. Zener Voltage versus Zener Current
V_Z = 82 thru 200 Volts

APPLICATION NOTE

Since the actual voltage available from a given zener diode is temperature dependent, it is necessary to determine junction temperature under any set of operating conditions in order to calculate its value. The following procedure is recommended:

Lead Temperature, T_L, should be determined from:

$$T_L = \theta_{LA} P_D + T_A$$

θ_{LA} is the lead-to-ambient thermal resistance and P_D is the power dissipation.

Junction Temperature, T_J, may be found from:

$$T_J = T_L + \Delta T_{JL}$$

ΔT_{JL} is the increase in junction temperature above the lead temperature and may be found from Figure 4 for a train of power pulses or from Figure 5 for dc power.

$$\Delta T_{JL} = \theta_{JL} P_D$$

For worst-case design, using expected limits of I_Z, limits of P_D and the extremes of T_J (ΔT_J) may be estimated. Changes in voltage, V_Z, can then be found from:

$$\Delta V = \theta_{VZ} \Delta T_J$$

θ_{VZ}, the zener voltage temperature coefficient, is found from Figures 2 and 3.

Under high power-pulse operation, the zener voltage will vary with time and may also be affected significantly by the zener resistance. For best regulation, keep current excursions as low as possible.

Data of Figure 4 should not be used to compute surge capability. Surge limitations are given in Figure 6. They are lower than would be expected by considering only junction temperature, as current crowding effects cause temperatures to be extremely high in small spots resulting in device degradation should the limits of Figure 6 be exceeded.

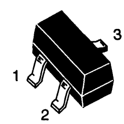
225 mW SOT-23
Zener Voltage Regulator Diodes

GENERAL DATA APPLICABLE TO ALL SERIES IN THIS GROUP

Zener Voltage Regulator Diodes

GENERAL DATA

225 mW
SOT-23



CASE 318-07, STYLE 8
SOT-23 (TO-236AB)
PLASTIC

THERMAL CHARACTERISTICS			
Characteristic	**Symbol**	**Max**	**Unit**
Total Device Dissipation FR-5 Board,* $T_A = 25°C$	P_D	225	mW
Derate above 25°C		1.8	mW/°C
Thermal Resistance Junction to Ambient	$R_{\theta JA}$	556	°C/W
Total Device Dissipation Alumina Substrate,** $T_A = 25°C$	P_D	300	mW
Derate above 25°C		2.4	mW/°C
Thermal Resistance Junction to Ambient	$R_{\theta JA}$	417	°C/W
Junction and Storage Temeprature	T_J, T_{stg}	150	°C

*FR-5 = 1.0 x 0.75 x 0.62 in.
**Alumina = 0.4 x 0.3 x 0.024 in. 99.5% alumina.

ELECTRICAL CHARACTERISTICS (Pinout: 1-Anode, 2-NC, 3-Cathode) (V_F = 0.9 V Max @ I_F = 10 mA for all types.)

Device	Marking	Test Current I_{ZT} mA	Zener Voltage V_Z (±5%) Nominal (Note 1)	Z_{ZK} I_Z = 0.25 mA Ω Max	Z_{ZT} $I_Z = I_{ZT}$ @ 10% Mod Ω Max	Max I_R µA	@ V_R V
MMBZ5221BL	18A	20	2.4	1200	30	100	1
MMBZ5222BL	18B	20	2.5	1250	30	100	1
MMBZ5223BL	18C	20	2.7	1300	30	75	1
MMBZ5224BL	18D	20	2.8	1400	30	75	1
MMBZ5225BL	18E	20	3	1600	29	50	1
⇒ **MMBZ5226BL**	**8A**	**20**	**3.3**	**1600**	**28**	**25**	**1**
MMBZ5227BL	8B	20	3.6	1700	24	15	1
MMBZ5228BL	8C	20	3.9	1900	23	10	1
⇒ **MMBZ5229BL**	**8D**	**20**	**4.3**	**2000**	**22**	**5**	**1**
⇒ **MMBZ5230BL**	**8E**	**20**	**4.7**	**1900**	**19**	**5**	**2**
⇒ **MMBZ5231BL**	**8F**	**20**	**5.1**	**1600**	**17**	**5**	**2**
⇒ **MMBZ5232BL**	**8G**	**20**	**5.6**	**1600**	**11**	**5**	**3**
MMBZ5233BL	8H	20	6	1600	7	5	3.5
⇒ **MMBZ5234BL**	**8J**	**20**	**6.2**	**1000**	**7**	**5**	**4**
⇒ **MMBZ5235BL**	**8K**	**20**	**6.8**	**750**	**5**	**3**	**5**
⇒ **MMBZ5236BL**	**8L**	**20**	**7.5**	**500**	**6**	**3**	**6**
⇒ **MMBZ5237BL**	**8M**	**20**	**8.2**	**500**	**8**	**3**	**6.5**
MMBZ5238BL	8N	20	8.7	600	8	3	6.5
⇒ **MMBZ5239BL**	**8P**	**20**	**9.1**	**600**	**10**	**3**	**7**
⇒ **MMBZ5240BL**	**8Q**	**20**	**10**	**600**	**17**	**3**	**8**
MMBZ5241BL	8R	20	11	600	22	2	8.4
⇒ **MMBZ5242BL**	**8S**	**20**	**12**	**600**	**30**	**1**	**9.1**
MMBZ5243BL	8T	9.5	13	600	13	0.5	9.9
MMBZ5244BL	8U	9	14	600	15	0.1	10
⇒ **MMBZ5245BL**	**8V**	**8.5**	**15**	**600**	**16**	**0.1**	**11**
MMBZ5246BL	8W	7.8	16	600	17	0.1	12
MMBZ5247BL	8X	7.4	17	600	19	0.1	13
MMBZ5248BL	8Y	7	18	600	21	0.1	14
MMBZ5249BL	8Z	6.6	19	600	23	0.1	14
MMBZ5250BL	81A	6.2	20	600	25	0.1	15
MMBZ5251BL	81B	5.6	22	600	29	0.1	17
MMBZ5252BL	81C	5.2	24	600	33	0.1	18
MMBZ5253BL	81D	5	25	600	35	0.1	19
⇒ **MMBZ5254BL**	**81E**	**4.6**	**27**	**600**	**41**	**0.1**	**21**
⇒ **MMBZ5255BL**	**81F**	**4.5**	**28**	**600**	**44**	**0.1**	**21**
MMBZ5256BL	81G	4.2	30	600	49	0.1	23
MMBZ5257BL	81H	3.8	33	700	58	0.1	25
MMBZ5258BL	81J	3.4	36	700	70	0.1	27
MMBZ5259BL	81K	3.2	39	800	80	0.1	30
MMBZ5260BL	18F	3	43	900	93	0.1	33
MMBZ5261BL	18G	2.7	47	1000	105	0.1	36
MMBZ5262BL	81L	2.5	51	1100	125	0.1	39
MMBZ5263BL	81M	2.2	56	1300	150	0.1	43
MMBZ5264BL	81N	2.1	60	1400	170	0.1	46
MMBZ5265BL	18H	2	62	1400	185	0.1	47
MMBZ5266BL	81P	1.8	68	1600	230	0.1	52
MMBZ5267BL	18J	1.7	75	1700	270	0.1	56
MMBZ5268BL	18K	1.5	82	2000	330	0.1	62
MMBZ5269BL	18L	1.4	87	2200	370	0.1	68
MMBZ5270BL	81Q	1.4	91	2300	400	0.1	69

⇒ Preferred part

NOTE 1. Zener voltage is measured with a pulse test current (I_{ZT}) applied at an ambient temperature of 25°C.

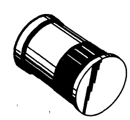
500 mW Leadless DO-34 Glass Zener Voltage Regulator Diodes

GENERAL DATA APPLICABLE TO ALL SERIES IN THIS GROUP

500 mW Hermetically Sealed Glass Silicon Zener Diodes

GENERAL DATA
500 mW LEADLESS DO-34

LEADLESS GLASS ZENER DIODES 500 MILLIWATTS 1.8–56 VOLTS



CASE 362-03 GLASS

Specification Features:

- Complete Voltage Range — 1.8 to 56 Volts
- Leadless Package for Surface Mount Technology
- Double Slug Type Construction
- Metallurgically Bonded Construction
- Oxide Passivated Die

Mechanical Characteristics:

CASE: Double slug type, hermetically sealed glass
MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 230°C, for 10 seconds
FINISH: All external surfaces are corrosion resistant and readily solderable
POLARITY: Cathode indicated by color band. When operated in zener mode, cathode will be positive with respect to anode
MOUNTING POSITION: Any

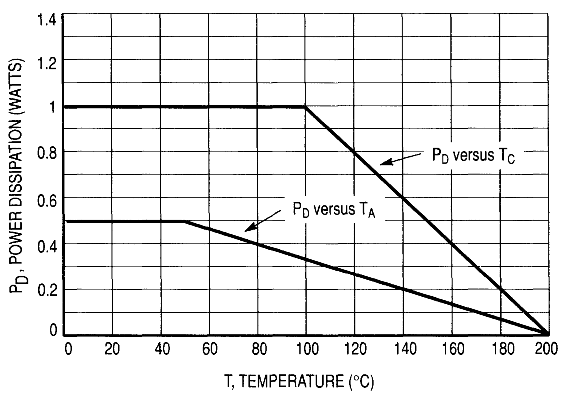
4

4.2

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
DC Power Dissipation @ $T_A \le 50°C$ Derate above $T_A = 50°C$	P_D	500 3.3	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	– 65 to +200	°C

STEADY STATE POWER DERATING



a. Range for Units to 12 Volts **b. Range for Units to 12 to 100 Volts**

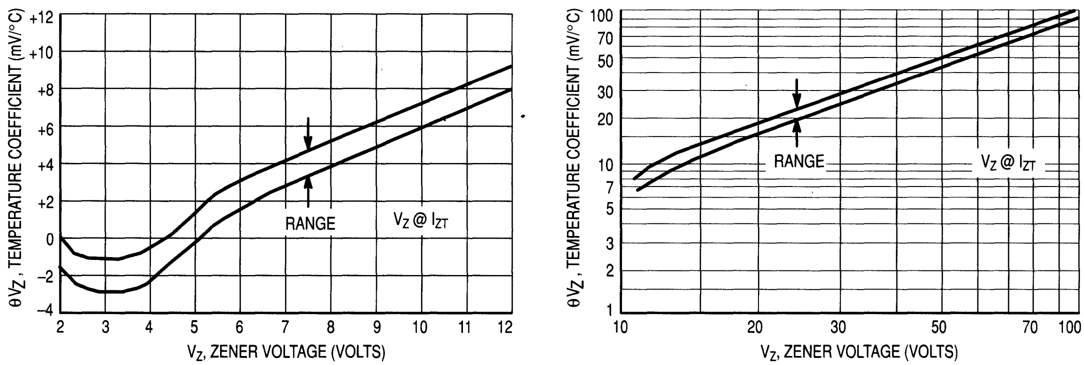


Figure 3. Temperature Coefficients
(–55°C to +150°C temperature range; 90% of the units are in the ranges indicated.)

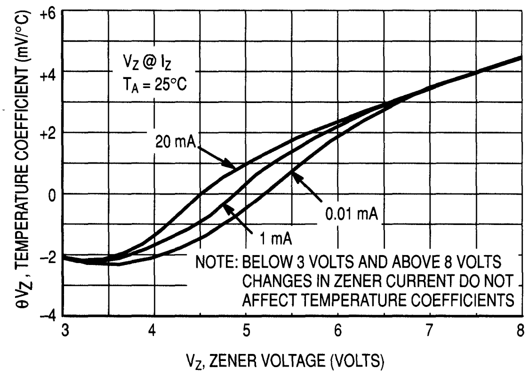


Figure 4. Effect of Zener Current

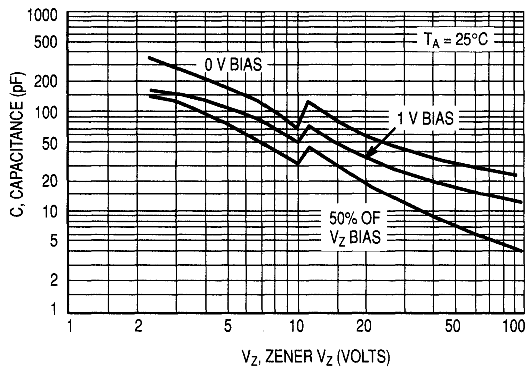
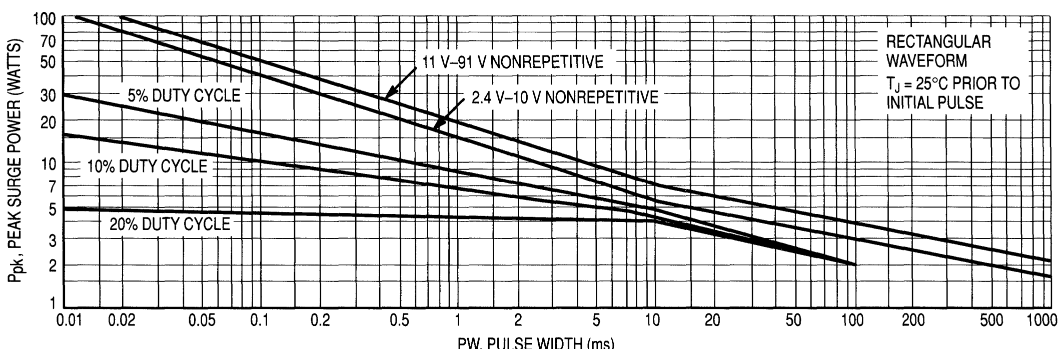


Figure 5. Typical Capacitance



This graph represents 90 percentile data points.
For worst case design characteristics, multiply surge power by 2/3.

Figure 6. Maximum Surge Power

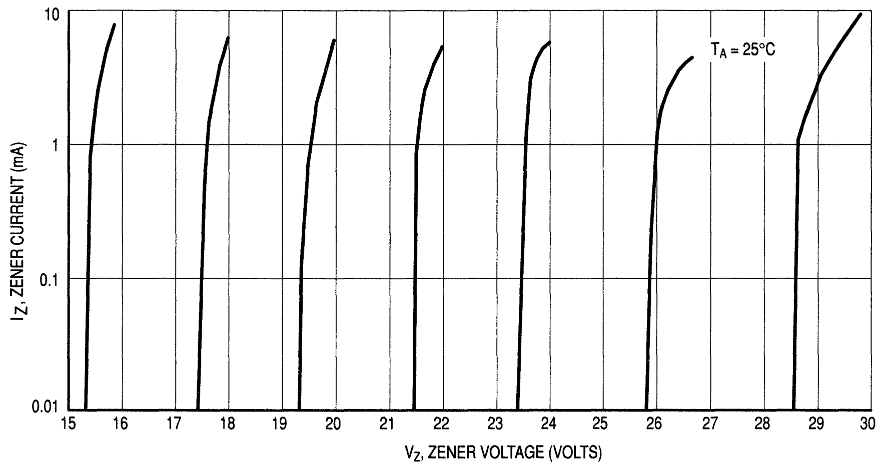


Figure 11. Zener Voltage versus Zener Current — V_Z = 15 thru 30 Volts

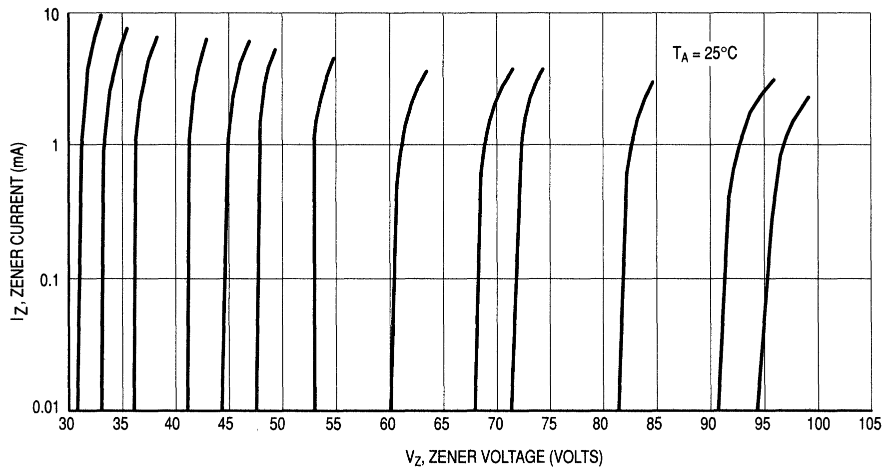


Figure 12. Zener Voltage versus Zener Current — V_Z = 30 thru 105 Volts

MLL4678 thru MLL4717

Low level oxide passivated zener diodes for applications requiring extremely low operating currents, low leakage, and sharp breakdown voltage.

- Complete Voltage Range — 1.8 to 43 Volts
- Zener Voltage Specified @ I_{ZT} = 50 µA
- Leadless Package for Surface Mount Technology
- Maximum Delta V_Z Given from 10 to 100 µA

ELECTRICAL CHARACTERISTICS (T_A = 25°C, V_F = 0.9 V Max at I_F = 10 mA for all types)

Type Number (Note 1)	Zener Voltage V_Z @ I_{ZT} = 50 µA Volts			Maximum Reverse Current I_R µA (Note 3)	Test Voltage V_R Volts (Note 3)	Maximum Zener Current I_{ZM} mA (Note 2)	Maximum Voltage Change ΔV_Z Volts (Note 4)
	Nom (Note 5)	Min	Max				
MLL4678	1.8	1.71	1.89	7.5	1	120	0.7
MLL4679	2	1.9	2.1	5	1	110	0.7
MLL4680	2.2	2.09	2.31	4	1	100	0.75
MLL4681	2.4	2.28	2.52	2	1	95	0.8
MLL4682	2.7	2.565	2.835	1	1	90	0.85
MLL4683	3	2.85	3.15	0.8	1	85	0.9
MLL4684	3.3	3.135	3.465	7.5	1.5	80	0.95
MLL4685	3.6	3.42	3.78	7.5	2	75	0.95
MLL4686	3.9	3.705	4.095	5	2	70	0.97
MLL4687	4.3	4.085	4.515	4	2	65	0.99
MLL4688	4.7	4.465	4.935	10	3	60	0.99
MLL4689	5.1	4.845	5.355	10	3	55	0.97
MLL4690	5.6	5.32	5.88	10	4	50	0.96
MLL4691	6.2	5.89	6.51	10	5	45	0.95
MLL4692	6.8	6.46	7.14	10	5.1	35	0.9
MLL4693	7.5	7.125	7.875	10	5.7	31.8	0.75
MLL4694	8.2	7.79	8.61	1	6.2	29	0.5
MLL4695	8.7	8.265	9.135	1	6.6	27.4	0.1
MLL4696	9.1	8.645	9.555	1	6.9	26.2	0.08
MLL4697	10	9.5	10.5	1	7.6	24.8	0.1
MLL4698	11	10.45	11.55	0.05	8.4	21.6	0.11
MLL4699	12	11.4	12.6	0.05	9.1	20.4	0.12
MLL4700	13	12.35	13.65	0.05	9.8	19	0.13
MLL4701	14	13.3	14.7	0.05	10.6	17.5	0.14
MLL4702	15	14.25	15.75	0.05	11.4	16.3	0.15
MLL4703	16	15.2	16.8	0.05	12.1	15.4	0.16
MLL4704	17	16.15	17.85	0.05	12.9	14.5	0.17
MLL4705	18	17.1	18.9	0.05	13.6	13.2	0.18
MLL4706	19	18.05	19.95	0.05	14.4	12.5	0.19
MLL4707	20	19	21	0.01	15.2	11.9	0.2
MLL4708	22	20.9	23.1	0.01	16.7	10.8	0.22
MLL4709	24	22.8	25.2	0.01	18.2	9.9	0.24
MLL4710	25	23.75	26.25	0.01	19	9.5	0.25
MLL4711	27	25.65	28.35	0.01	20.4	8.8	0.27
MLL4712	28	26.6	29.4	0.01	21.2	8.5	0.28
MLL4713	30	28.5	31.5	0.01	22.8	7.9	0.3
MLL4714	33	31.35	34.65	0.01	25	7.2	0.33
MLL4715	36	34.2	37.8	0.01	27.3	6.6	0.36
MLL4716	39	37.05	40.95	0.01	29.6	6.1	0.39
MLL4717	43	40.85	45.15	0.01	32.6	5.5	0.43

NOTE 1. TOLERANCE AND VOLTAGE DESIGNATION (V_Z)

The type numbers shown have a standard tolerance of ±5% on the nominal zener voltage.

NOTE 2. MAXIMUM ZENER CURRENT RATINGS (I_{ZM})

Maximum zener current ratings are based on maximum zener voltage of the individual units.

NOTE 3. REVERSE LEAKAGE CURRENT (I_R)

Reverse leakage currents are guaranteed and are measured at V_R as shown on the table.

NOTE 4. MAXIMUM VOLTAGE CHANGE (ΔV_Z)

Voltage change is equal to the difference between V_Z at 100 µA and V_Z at 10 µA.

NOTE 5. ZENER VOLTAGE (V_Z) MEASUREMENT

Nominal zener voltage is measured with the device junction in thermal equilibrium at the case temperature of 30°C ±1°C.

4

4.2

NOTE 1. TOLERANCE

Units shown indicate a tolerance of ±5%.

NOTE 2. SPECIAL SELECTIONS AVAILABLE:

For information on special selections contact your nearest Motorola representative.

NOTE 3. TEMPERATURE COEFFICIENT (θ_{VZ})

Test conditions for temperature coefficient are as follows:

a. I_{ZT} = 7.5 mA, T_1 = 25°C,

T_2 = 125°C (MLL5221B through MLL5242B).

b. I_{ZT} = Rated I_{ZT}, T_1 = 25°C,

T_2 = 125°C (MLL5243B through MLL5263B).

Device to be temperature stabilized with current applied prior to reading breakdown voltage at the specified ambient temperature.

NOTE 4. ZENER VOLTAGE (V_Z) MEASUREMENT

Nominal zener voltage is measured with the device junction in thermal equilibrium at the case temperature of 30°C ±1°C.

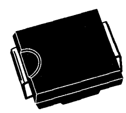
NOTE 5. ZENER IMPEDANCE (Z_Z) DERIVATION

Z_{ZT} and Z_{ZK} are measured by dividing the ac voltage drop across the device by the ac current applied. The specified limits are for $I_Z(ac)$ = 0.1 x $I_Z(dc)$ with the ac frequency = 1 kHz.

1.5 Watt Plastic Surface Mount Silicon Zener Diodes

1SMB5913BT3 thru 1SMB5956BT3

PLASTIC SURFACE MOUNT ZENER DIODES 1.5 WATTS 3.3–200 VOLTS



CASE 403A-03 PLASTIC

. . . a completely new line of 1.5 Watt Zener Diodes offering the following advantages:

Specification Features:

- A Complete Voltage Range — 3.3 to 200 Volts
- Flat Handling Surface for Accurate Placement
- Package Design for Top Side or Bottom Circuit Board Mounting
- Available in Tape and Reel

Mechanical Characteristics:

CASE: Void-free, transfer-molded plastic
MAXIMUM CASE TEMPERATURE FOR SOLDERING PURPOSES: 230°C for 10 seconds
FINISH: All external surfaces are corrosion resistant with readily solderable leads
POLARITY: Cathode indicated by molded polarity notch. When operated in zener mode, cathode will be positive with respect to anode.
MOUNTING POSITION: Any
WEIGHT: Modified L-Bend providing more contact area to bond pad

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
DC Power Dissipation @ T_L = 75°C, Measured at Zero Lead Length Derate above 75°C	P_D	1.5 15	Watts mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	– 65 to +175	°C

ELECTRICAL CHARACTERISTICS (T_L = 30°C unless otherwise noted.) (V_F = 1.5 Volts Max @ I_F = 200 mAdc for all types.)

Device*	Nominal Zener Voltage V_Z @ I_{ZT} Volts (Note 1)	Test Current I_{ZT} mA	Max Zener Impedance (Note 2) Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} Ohms @	I_{ZK} mA	Max Reverse Leakage Current I_R µA @	V_R Volts	Maximum DC Zener Current I_{ZM} mAdc	Device Marking
1SMB5913BT3	3.3	113.6	10	500	1	100	1	454	913B
1SMB5914BT3	3.6	104.2	9	500	1	75	1	416	914B
1SMB5915BT3	3.9	96.1	7.5	500	1	25	1	384	915B
1SMB5916BT3	4.3	87.2	6	500	1	5	1	348	916B
1SMB5917BT3	4.7	79.8	5	500	1	5	1.5	319	917B
⇒ **1SMB5918BT3**	**5.1**	**73.5**	**4**	**350**	**1**	**5**	**2**	**294**	**918B**
1SMB5919BT3	5.6	66.9	2	250	1	5	3	267	919B
⇒ **1SMB5920BT3**	**6.2**	**60.5**	**2**	**200**	**1**	**5**	**4**	**241**	**920B**
1SMB5921BT3	6.8	55.1	2.5	200	1	5	5.2	220	921B
1SMB5922BT3	7.5	50	3	400	0.5	5	6.8	200	922B
1SMB5923BT3	8.2	45.7	3.5	400	0.5	5	6.5	182	923B
1SMB5924BT3	9.1	41.2	4	500	0.5	5	7	164	924B
⇒ **1SMB5925BT3**	**10**	**37.5**	**4.5**	**500**	**0.25**	**5**	**8**	**150**	**925B**
1SMB5926BT3	11	34.1	5.5	550	0.25	1	8.4	136	926B
⇒ **1SMB5927BT3**	**12**	**31.2**	**6.5**	**550**	**0.25**	**1**	**9.1**	**125**	**927B**
1SMB5928BT3	13	28.8	7	550	0.25	1	9.9	115	928B

(continued)

⇒ Preferred part

*TOLERANCE AND VOLTAGE DESIGNATION Tolerance designation — The type numbers listed indicate a tolerance of ±5%.

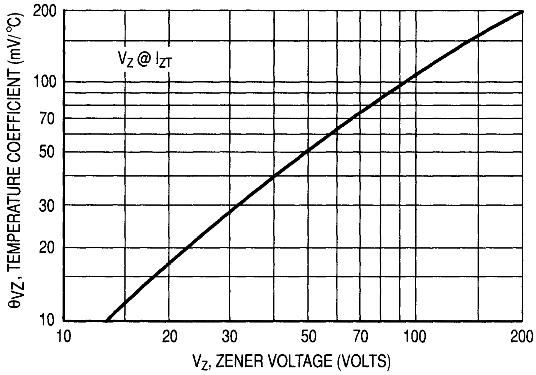


Figure 3. Zener Voltage — 14 To 200 Volts

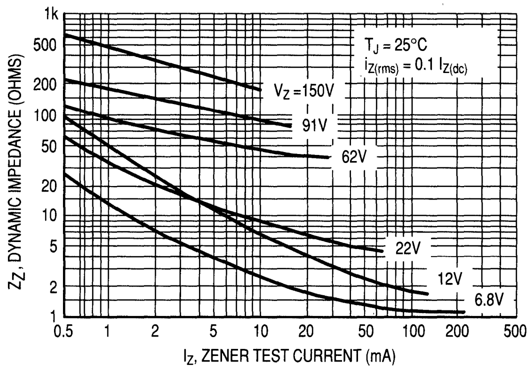


Figure 4. Effect of Zener Current

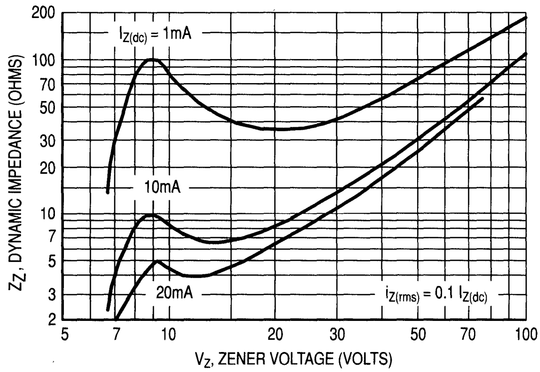


Figure 5. Effect of Zener Voltage

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4.2

NOTE 1. ZENER VOLTAGE (V_Z) MEASUREMENT

Nominal zener voltage is measured with the device junction in thermal equilibrium with ambient temperature at 25°C.

NOTE 2. ZENER IMPEDANCE (Z_Z) DERIVATION

Z_{ZT} and Z_{ZK} are measured by dividing the ac voltage drop across the device by the ac current applied. The specified limits are for $I_Z(ac) = 0.1\ I_Z(dc)$ with the ac frequency = 60 Hz.

Section 4.3.1 Selector Guide Zener Voltage Reference Diodes

4

4.3

4

4.3

4

4.3

ALPHANUMERIC INDEX – ZENER VOLTAGE REFERENCE DIODES

1N821,A	1N823,A
1N825,A	1N827,A
1N829,A	

Temperature-Compensated Zener Reference Diodes

TEMPERATURE-COMPENSATED SILICON ZENER REFERENCE DIODES
6.2 V, 400 mW

CASE 299-02
DO-204AH
GLASS

Temperature-compensated zener reference diodes utilizing a single chip oxide passivated junction for long-term voltage stability. A rugged, glass-enclosed, hermetically sealed structure.

Mechanical Characteristics:

CASE: Hermetically sealed, all-glass
DIMENSIONS: See outline drawing.
FINISH: All external surfaces are corrosion resistant and leads are readily solderable.
POLARITY: Cathode indicated by polarity band.
WEIGHT: 0.2 Gram (approx.)
MOUNTING POSITION: Any

Maximum Ratings

Junction Temperature: – 55 to +175°C
Storage Temperature: – 65 to +175°C
DC Power Dissipation: 400 mW @ T_A = 50°C

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted. V_Z = 6.2 V ± 5%* @ I_{ZT} = 7.5 mA) (Note 5)

JEDEC Type No.	Maximum Voltage Change ΔV_Z (Volts) (Note 1)	Ambient Test Temperature °C ±1°C	Temperature Coefficient For Reference Only %/°C (Note 1)	Maximum Dynamic Impedance Z_{ZT} Ohms (Note 2)
⇒ 1N821	**0.096**	**– 55, 0, +25, +75, +100**	**0.01**	**15**
⇒ 1N823	**0.048**		**0.005**	
⇒ 1N825	**0.019**		**0.002**	
1N827	0.009		0.001	
1N829	0.005		0.0005	
1N821A	0.096		0.01	10
1N823A	0.048		0.005	
1N825A	0.019		0.002	
1N827A	0.009		0.001	
1N829A	0.005		0.0005	

⇒ Preferred part
*Tighter-tolerance units available on special request.

MAXIMUM ZENER IMPEDANCE versus ZENER CURRENT

(See Note 2)

MORE THAN 95% OF THE UNITS ARE IN THE RANGES INDICATED BY THE CURVES.

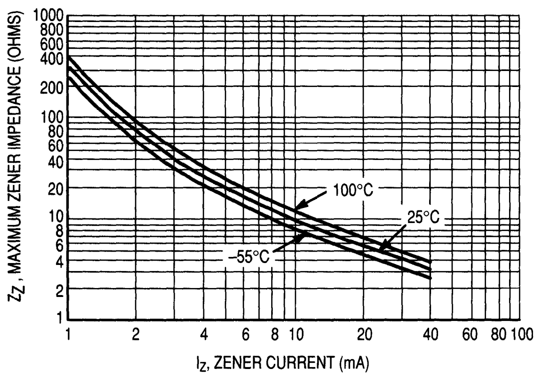


Figure 4. 1N821 Series

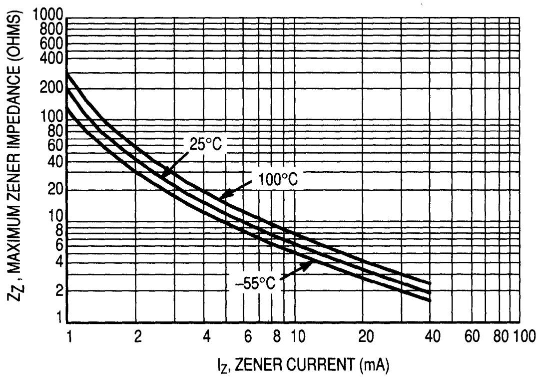


Figure 5. 1N821A Series

NOTE 1. VOLTAGE VARIATION (ΔV_Z) AND TEMPERATURE COEFFICIENT

All reference diodes are characterized by the "box method." This guarantees a maximum voltage variation (ΔV_Z) over the specified temperature range, at the specified test current (I_{ZT}), verified by tests at indicated temperature points within the range. V_Z is measured and recorded at each temperature specified. The ΔV_Z between the highest and lowest values must not exceed the maximum ΔV_Z given. This method of indicating voltage stability is now used for JEDEC registration as well as for military qualification. The former method of indicating voltage stability — by means of temperature coefficient accurately reflects the voltage deviation at the temperature extremes, but is not necessarily accurate within the temperature range because reference diodes have a nonlinear temperature relationship. The temperature coefficient, therefore, is given only as a reference.

NOTE 2.

The dynamic zener impedance, Z_{ZT}, is derived from the 60 Hz ac voltage drop which results when an ac current with an rms value equal to 10% of the dc zener current, I_{ZT}, is superimposed on I_{ZT}. Curves showing the variation of zener impedance with zener current for each series are given in Figures 4 and 5.

NOTE 3.

These graphs can be used to determine the maximum voltage change of any device in the series over any specific temperature range. For example, a temperature change from 0 to +50°C will cause a voltage change no greater than +31 mV or − 31 mV for 1N821 or 1N821A, as illustrated by the dashed lines in Figure 1. The boundaries given are maximum values. For greater resolution, an expanded view of the center area in Figure 1a is shown in Figure 1b.

NOTE 4.

The maximum voltage change, ΔV_Z, Figures 2 and 3 is due entirely to the impedance of the device. If both temperature and I_{ZT} are varied, then the total voltage change may be obtained by graphically adding ΔV_Z in Figure 2 or 3 to the ΔV_Z in Figure 1 for the device under consideration. If the device is to be operated at some stable current other than the specified test current, a new set of characteristics may be plotted by superimposing the data in Figure 2 or 3 on Figure 1. For a more detailed explanation see application note in later section.

NOTE 5.

Zener voltage limits at 25°C measured with the test current (I_{ZT}) applied with the device junction in thermal equilibrium at an ambient temperature of 25°C.

Low-Level Temperature-Compensated Zener Reference Diodes

1N4565,A thru 1N4574,A

Highly reliable reference sources utilizing a single chip oxide passivated junction for long-term voltage stability. Glass construction provides a rugged, hermetically sealed structure.

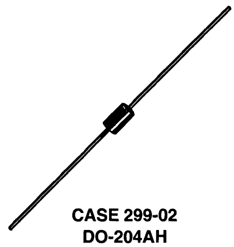
Specification Features:

- Low Power Drain Devices Specified @ 0.5 mA and 1 mA
- Maximum Voltage Change Specified over Test Temperature Range
- Temperature Compensation Guaranteed over Two Standard Operating Temperature Ranges: 0 to 75°C
  – 55 to 100°C

Mechanical Characteristics:

CASE: Hermetically sealed, all-glass.
DIMENSIONS: See outline drawing.
FINISH: All external surfaces are corrosion resistant and leads are readily solderable.
POLARITY: Cathode indicated by polarity band.
WEIGHT: 0.2 gram (approx.)
MOUNTING POSITION: Any

**REFERENCE DIODES
LOW LEVEL
TEMPERATURE-
COMPENSATED ZENER
6.4 V 400 mW**



CASE 299-02
DO-204AH
GLASS

4

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
DC Power Dissipation @ $T_A = 50°C$ Derate above 50°C	P_D	400 3.2	mW mW/°C
Junction and Storage Temperature Range	T_J, T_{stg}	– 65 to +175	°C

4.3

TVS/Zener Axial-Lead
Lead Tape Packaging Standards for Axial-Lead Components

1.0 SCOPE

This section covers packaging requirements for the following axial-lead component's use in automatic testing and assembly equipment: Motorola Case 17-02, Case 41A-02, Case 51-02 (DO-7), Case 59-03 (DO-41), Case 59-04, Case 194-04 and Case 299-02 (DO-35). Packaging, as covered in this section, shall consist of axial-lead components mounted by their leads on pressure sensitive tape, wound onto a reel.

2.0 PURPOSE

This section establishes Motorola standard practices for lead-tape packaging of axial-lead components and meets the requirements of EIA Standard RS-296-D "Lead-taping of Components on Axial Lead Configuration for Automatic Insertion," level 1.

3.0 REQUIREMENTS

3.1 Component leads

3.1.1 – Component leads shall not be bent beyond dimension E from their normal position. See Figure 2.

3.1.2 – The "C" dimension shall be governed by the overall length of the reel packaged component. The distance between flanges shall be 0.059 inch to 0.315 inch greater than the overall component length. See Figures 2 and 3.

3.1.3 – Cumulative dimension "A" tolerance shall not exceed 0.059 over 6 in consecutive components.

3.2 Orientation

All polarized components must be oriented in one direction. The cathode lead tape shall be blue and the anode tape shall be white. See Figure 1.

3.3 Reeling

3.3.1 – Components on any reel shall not represent more than two date codes when date code identification is required.

3.3.2 – Component's leads shall be positioned perpendicularly between pairs of 0.250 inch tape. See Figure 2.

3.3.3 – A minimum 12 inch leader of tape shall be provided before the first and last component on the reel.

3.3.4 – 50 lb. Kraft paper is wound between layers of components as far as necessary for component protection.

3.3.5 – Components shall be centered between tapes such that the difference between D1 and D2 does not exceed 0.055.

3.3.6 – Staples shall not be used for splicing. No more than four layers of tape shall be used in any splice area and no tape shall be offset from another by more than 0.031 inch noncumulative. Tape splices shall overlap at least 6 inches for butt joints and at least 3 inches for lap joints and shall not be weaker than unspliced tape.

3.3.7 – Quantity per reel shall be as indicated in Table 1. Orders for tape and reeled product will only be processed and shipped in full reel increments. Scheduled orders must be in releases of full reel increments or multiples thereof.

3.3.8 – A maximum of 0.25% of the components per reel quantity may be missing without consecutive missing per level 1 of RS-296-D.

3.3.9 – The single face roll pad shall be placed around the finished reel and taped securely. Each reel shall then be placed in an appropriate container.

3.4 Marking

Minimum reel and carton marking shall consist of the following (see Figure 3):

Motorola part number

Quantity

Manufacturer's name

Date codes (when applicable; see note **3.3.1**)

4.0

Requirements differing from this Motorola standard shall be negotiated with the factory.

The packages indicated in the following table are suitable for lead tape packaging. The table indicates the specific devices (transient voltage suppressors and/or zeners) that can be obtained from Motorola in reel packaging and provides the appropriate packaging specification.

TVS/Zener Surface Mount Embossed Tape and Reel

Embossed Tape and Reel is used to facilitate automatic pick and place equipment feed requirements. The tape is used as the shipping container for various products and requires a minimum of handling. The antistatic/conductive tape provides a secure cavity for the product when sealed with the "peel-back" cover tape.

- Used for Automatic Pick and Place Feed Systems
- Minimizes Product Handling
- EIA 481-1, 8 mm and 12 mm Taping of Surface Mount Components for Automatic Handling and EIA 481-2, 16 mm and 24 mm Embossed Carrier Taping of Surface Mount Components for Automatic Handling
- MLL-34, SOT-23 in 8 mm Tape
- SMB in 12 mm Tape
- SMC in 16 mm Tape

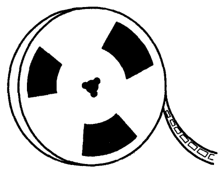
Ordering Information

Use the standard device title and add the required suffix as listed in the option table below. Note that the individual reels have a finite number of devices depending on the type of product contained in the tape. Also note the minimum lot size is one full reel for each line item and orders are required to be in increments of the single reel quantity.

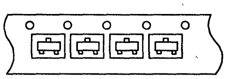
Tape and Reel Data for TVS/Zener Surface Mount Devices

PACKAGES

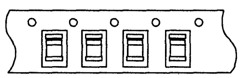
MLL-34 **SOT-23**
SMB **SMC**



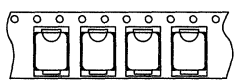
SOT-23
8 mm



MLL-34
8 mm

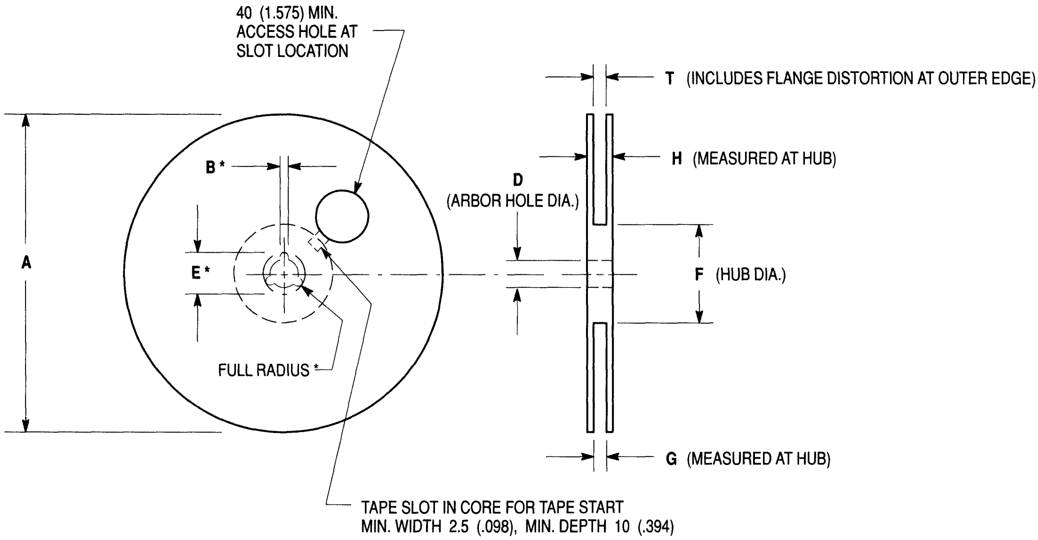


SMB, SMC
12 mm 16 mm



Package	Case Type	Tape Width (mm)	Reel Size (inch)	Devices Per Reel and Minimum Order Quantity	Device Suffix
SOT-23	Case 318-07	8 8	7 13	3,000 10,000	T1 T3
MLL-34	Case 362-03	8 8	7 13	2,000 5,000	T1 T3
SMB	Case 403A-03	12	13	2,500	T3
SMC	Case 403-03	16	13	2,500	T3

REEL CONFIGURATION

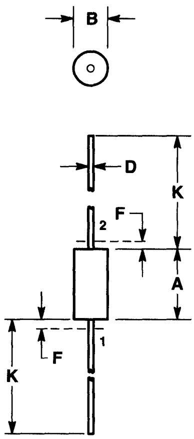


* Optional Drive Spokes, Asterisked Dimensions Apply
Metric dimensions govern

REEL DIMENSIONS (Metric dimensions will govern)

Tape Size	A Max. (Note 1)	B* Min.	D	E* Min.	F Min.	G	H Max.	T Max
8 mm	330 (12.992)	1.5 (.059)	13.0 ± 0.20 (.512 ± .008)	20.2 (.795)	50 (1.969)	8.4 +1.5/–0.0 (.331 +.059/–0.0)	14.4 (.567)	7.9 (.311) Min 10.9 (.429) Max
12 mm						12.4 +2.0/–0.0 (.488 +.078/–0.0)	18.4 (.724)	11.9 (.469) Min 15.4 (.607) Max
16 mm	330 (12.992)	1.5 (.059)	13.0 ± 0.20 (.512 ± 0.008)	20.2 (.795)	50 (1.969	16.4 +2.0/–0.0 (.646 +0.78/–0.0)	22.4 (.882)	15.9 (.626) Min 19.4 (.764) Max

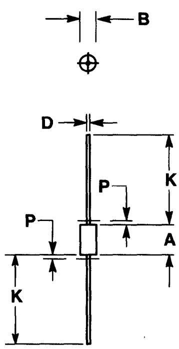
Note 1. For 7" reels, A Max. is 177 mm (6.968").



NOTE:
1. LEAD DIAMETER & FINISH NOT CONTROLLED WITHIN DIM "F".

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.38	8.89	0.330	0.350
B	3.30	3.68	0.130	0.145
D	0.94	1.09	0.037	0.043
F	—	1.27	—	0.050
K	25.40	31.75	1.000	1.250

CASE 17-02
(Surmetic 40)



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. LEAD FINISH AND DIAMETER UNCONTROLLED IN DIM P.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	9.14	9.52	0.360	0.375
B	4.83	5.21	0.190	0.205
D	0.97	1.07	0.038	0.042
K	25.40	—	1.000	—
P	—	1.27	—	0.050

CASE 41A-02

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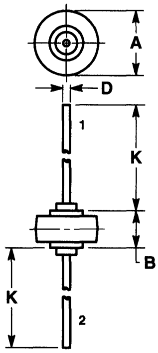
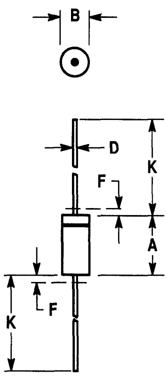


	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.43	8.69	0.332	0.342
B	5.94	6.25	0.234	0.246
D	1.27	1.35	0.050	0.053
K	25.15	25.65	0.990	1.010

NOTE:
1. CATHODE SYMBOL ON PKG.

STYLE 1:
PIN 1. CATHODE
2. ANODE

CASE 194-04



NOTES:
1. PACKAGE CONTOUR OPTIONAL WITHIN A AND B HEAT SLUGS, IF ANY, SHALL BE INCLUDED WITHIN THIS CYLINDER, BUT NOT SUBJECT TO THE MINIMUM LIMIT OF B.
2. LEAD DIAMETER NOT CONTROLLED IN ZONE F TO ALLOW FOR FLASH, LEAD FINISH BUILDUP AND MINOR IRREGULARITIES OTHER THAN HEAT SLUGS.
3. POLARITY DENOTED BY CATHODE BAND.
4. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

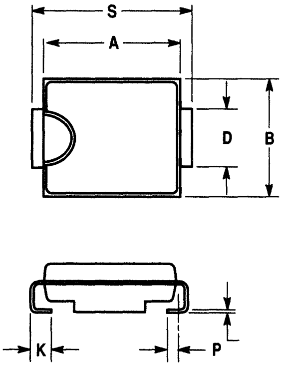
	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	3.05	5.08	0.120	0.200
B	1.52	2.29	0.060	0.090
D	0.46	0.56	0.018	0.022
F	—	1.27	—	0.050
K	25.40	38.10	1.000	1.500

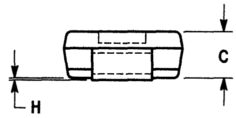
All JEDEC dimensions and notes apply.

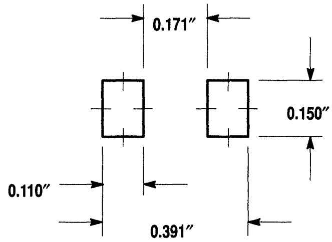
CASE 299-02
DO-204AH
(DO-35)

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. D DIMENSION SHALL BE MEASURED WITHIN DIMENSION P.

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	6.60	7.11	0.260	0.280
B	5.59	6.10	0.220	0.240
C	1.90	2.41	0.075	0.095
D	2.92	3.07	0.115	0.121
H	0.051	0.152	0.0020	0.0060
J	0.15	0.30	0.006	0.012
K	0.76	1.27	0.030	0.050
P	0.51 REF		0.020 REF	
S	7.75	8.13	0.305	0.320





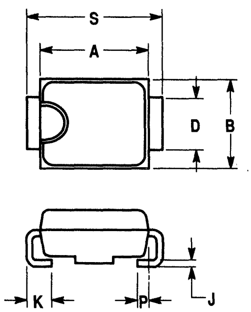


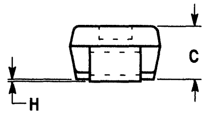
SMC Solder Pad Geometry

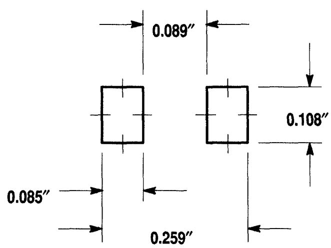
CASE 403-03 (SMC)

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14 5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. D DIMENSION SHALL BE MEASURED WITHIN DIMENSION P.
4. 403A-01 AND -02 OBSOLETE, NEW STANDARD 403A-03.

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	4.06	4.57	0.160	0.180
B	3.30	3.81	0 130	0.150
C	1.90	2.41	0.075	0.095
D	1.96	2.11	0.077	0.083
H	0.051	0.152	0.0020	0.0060
J	0.15	0.30	0.006	0.012
K	0.76	1.27	0.030	0.050
P	0.51 REF		0.020 REF	
S	5.21	5.59	0.205	0.220







SMB Solder Pad Geometry

CASE 403A-03 (SMB)

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a field is applied, as shown in Figure 1-1b. The "N" nomenclature for this kind of conductivity implies "negative" charge carriers.

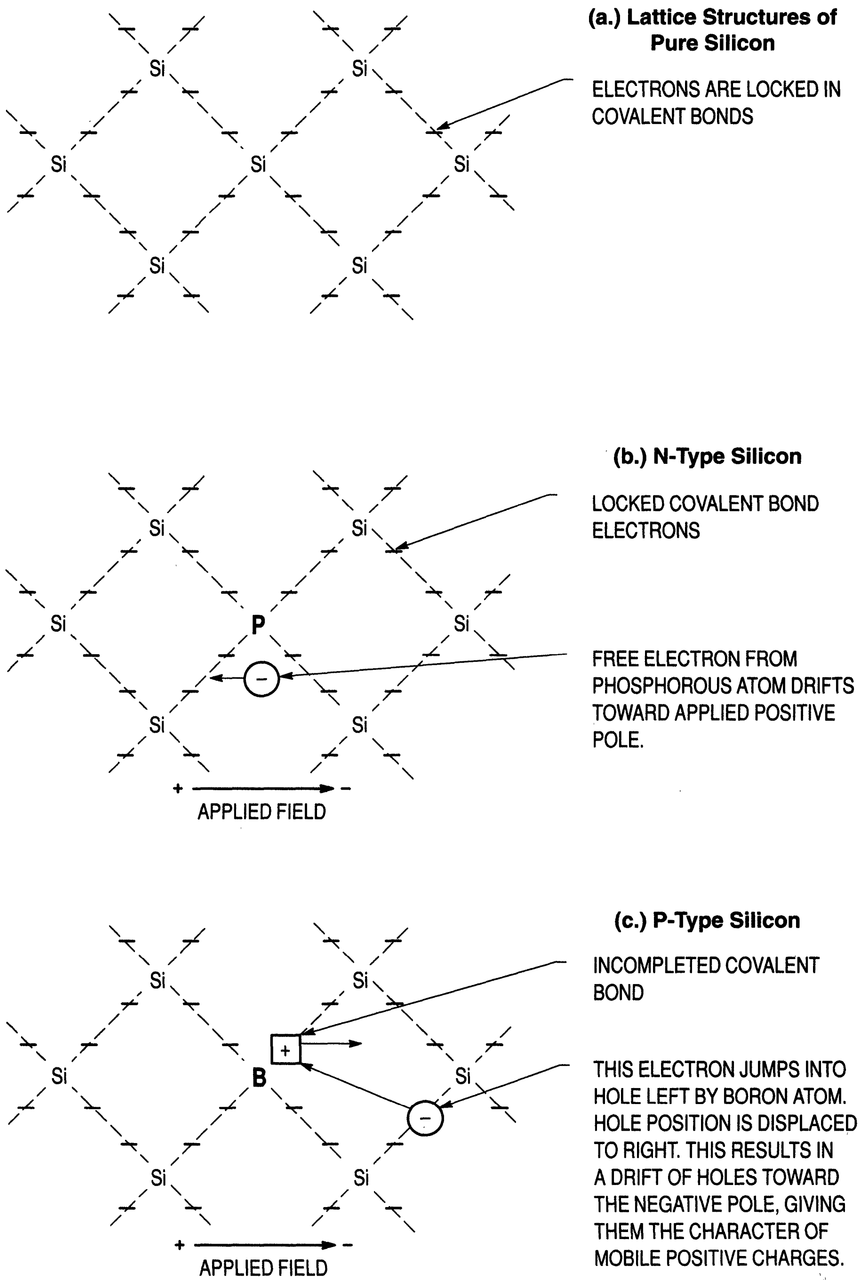
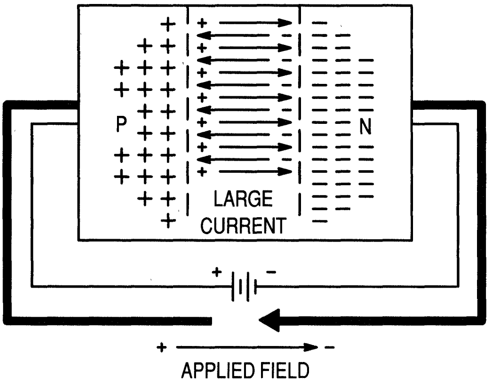
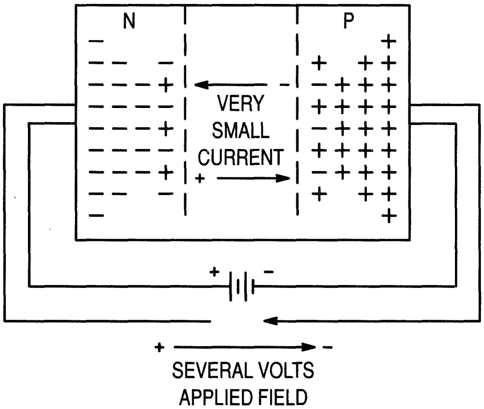


Figure 1-1. Semiconductor Structure



(a.) Forward-Based PN Junction

CHARGES FROM BOTH P AND N REGIONS DRIFT ACROSS JUNCTION AT VERY LOW APPLIED VOLTAGES.



(b.) Reverse-Biased PN Junction

AT APPLIED VOLTAGES BELOW THE CRITICAL BREAKDOWN LEVEL ONLY A FEW CHARGES DRIFT ACROSS THE INTERFACE.

Figure 1-2. Effects of Junction Bias

6

the presence of donor ions. These opposing regions of charged ions create a strong electric field across the PN junction responsible for the creation of reverse current.

The semiconductor regions are never perfect; there are always a few free electrons in P material and few holes in N material. A more significant factor, however, is the fact that great magnitudes of electron-hole pairs may be thermally generated at room temperatures in the semiconductor. When these electron-hole pairs are created within the depletion region, then the intense electric field mentioned in the above paragraph will cause a small current to flow. This small current is called the reverse saturation current, and tends to maintain a relatively constant value for a fixed temperature at all voltages. The reverse saturation current is usually negligible compared with the current flow when the junction is forward biased. Hence, we see that the PN junction, when not reverse biased beyond breakdown voltage, will conduct heavily in only one direction. When this property is utilized in a circuit we are employing the PN junction as a rectifier. Let us see how we can employ its reverse breakdown characteristics to an advantage.

As the reverse voltage is increased to a point called the voltage breakdown point and beyond, current conduction across the junction interface increases rapidly. The break from resistive material. A junction that results in a narrow depletion region will therefore develop a high field intensity and breakdown by the zener mechanism. A junction that results in a wider depletion region and, thus, a lower field intensity will break down by the avalanche mechanism before a zener breakdown condition can be reached.

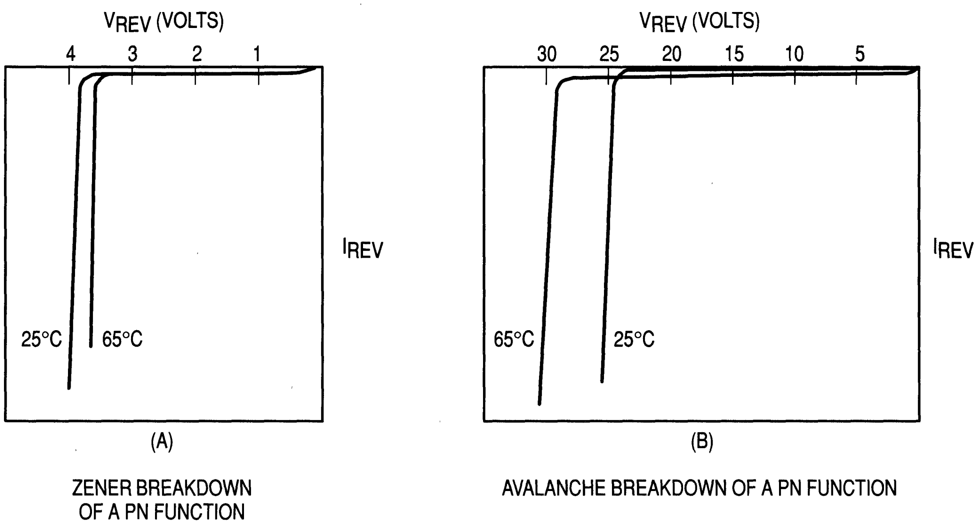


Figure 1-4. Typical Breakdown Diode Characteristics. Note Effects of Temperature for Each Mechanism

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The zener mechanism can be described qualitatively as follows: because the depletion width is very small, the application of low reverse bias (5 volts or less) will cause a field across the depletion region on the order of 3 x 10^5V/cm. A field of such high magnitude exerts a large force on the valence electrons of a silicon atom, tending to separate them from their respective nuclei. Actual rupture of the covalent bonds occurs when the field approaches 3 x 10^5V/cm. Thus, electron-hole pairs are generated in large numbers and a sudden increase of current is observed. Although we speak of a rupture of the atomic structure, it should be understood that this generation of electron-hole pairs may be carried on continuously as long as an external source supplies additional electrons. If a limiting resistance in the circuit external to the diode junction does not prevent the current from increasing to high values, the device may be destroyed due to overheating. The actual critical value of field causing zener breakdown is believed to be approximately 3 x 10^5V/cm. On most commercially available silicon diodes, the maximum value of voltage breakdown by the zener mechanism is 8 volts. In order to fabricate devices with higher voltage breakdown characteristics, materials with higher resistivity, and consequently, wider depletion regions are required. These wide depletion regions hold the field strength down below the zener breakdown value (3 x 10^5V/cm). Consequently, for devices with breakdown voltage lower than 5 volts the zener mechanism predominates, between 5 and 8 volts both zener and an

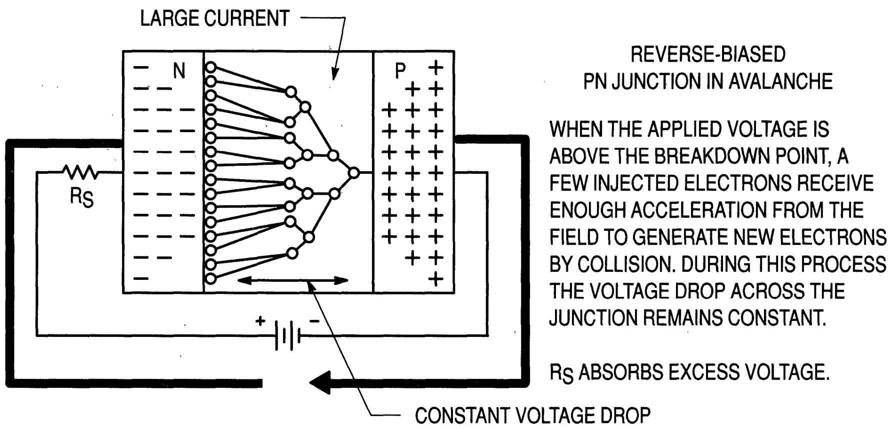

Figure 1-5. PN Junction in Avalanche Breakdown

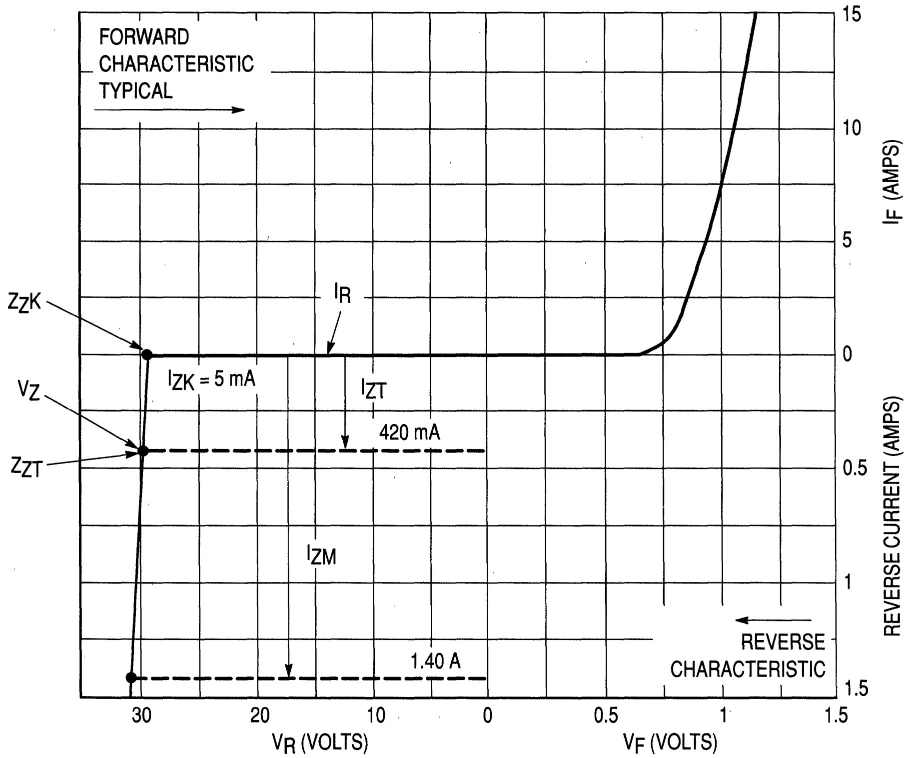

Figure 1-6. Zener Diode Characteristics

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Once the protective layer of silicon dioxide has been formed, it must be selectively removed from those areas into which dopant atoms will be introduced. This is done using photolithographic techniques.

First a light sensitive solution called photo resist is spun onto the wafer. The resist is then dried and a photographic negative or mask is placed over the wafer. The resist is then exposed to ultraviolet light causing the molecules in it to cross link or polymerize becoming very rigid. Those areas of the wafer that are protected by opaque portions of the mask are not exposed and are developed away. The oxide is then etched forming the exposed regions in which the dopant will be introduced. The remaining resist is then removed and the wafers carefully cleaned for the doping steps.

Dopant is then introduced onto the wafer surface using various techniques such as aluminum alloy for low voltage devices, ion-implantation, spin-on dopants, or chemical vapor deposition. Once the dopant is deposited, the junctions are formed in a subsequent high temperature (1100 to 1250 degrees celcius are typical) drive-in. The resultant junction profile is determined by the background concentration of the starting substrate, the amount of dopant placed at the surface, and amount of time and temperature used during the dopant drive-in. This junction profile determines the electrical characteristics of the device. During the drive-in cycle, additional passivation oxide is grown providing additional protection for the devices.

After junction formation, the wafers are then processed through what is called a getter process. The getter step utilizes high temperature and slight stress provided by a highly doped phosphosilicate glass layer introduced into the backside of the wafers. This causes any contaminants in the area of the junction to diffuse away from the region. This serves to improve the reverse leakage characteristic and the stability of the device. Following the getter process, a second photo resist step opens the contact area in which the anode metallization is deposited.

Metal systems for Motorola's zener diodes are determined by the requirements of the package. The metal systems are deposited in ultra-clean vacuum chambers utilizing electron-beam evaporation techniques. Once the metal is deposited, photo resist processing is utilized to form the desired patterns. The wafers are then lapped to their final thickness and the cathode metallization deposited using the same e-beam process.

6

The quality of the wafers is closely monitored throughout the process by using statistical process control techniques and careful microscopic inspections at critical steps. Special wafer handling equipment is used throughout the manufacturing process to minimize contamination and to avoid damaging the wafers in any way. This further enhances the quality and stability of the devices.

Upon completion of the fabrication steps, the wafers are electrically probed, inspected, and packaged for shipment to the assembly operations. All Motorola zener diode product is sawn using 100% saw-through techniques stringently developed to provide high quality silicon die.

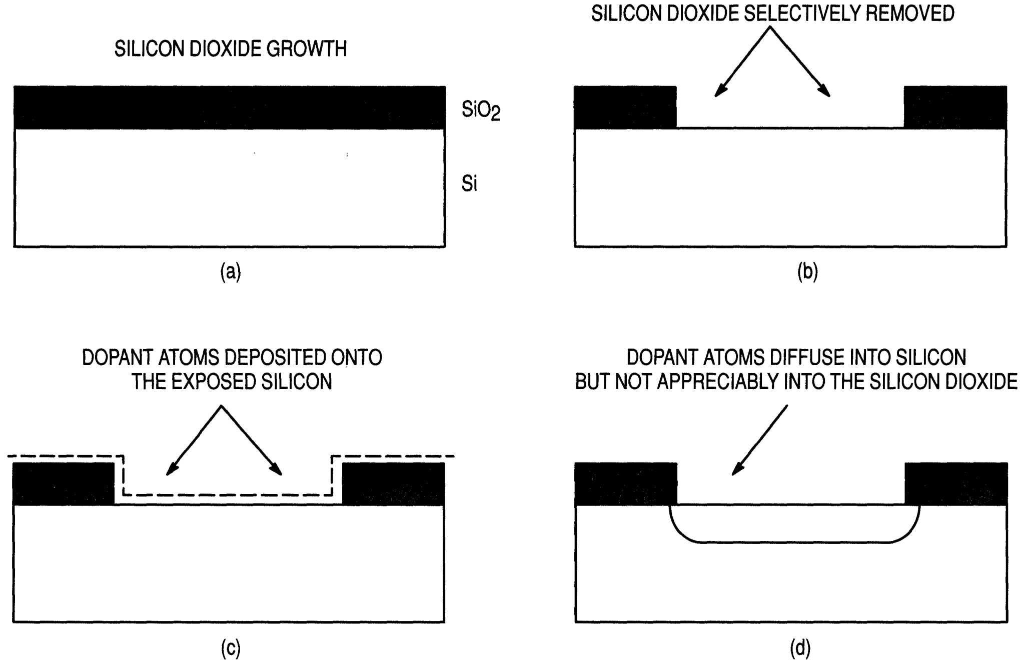


Figure 2-2. Basic Fabrication Steps in the Silicon Planar Process: a) oxide formation, b) selective oxide removal, c) deposition of dopant atoms, d) junction formation by diffusion of dopant atoms.

Zener Diode Assembly

Surmetic 30, 40 and MOSORB

6

The plastic packages (Surmetic 30, 40 and MOSORBs) are assembled using oxygen free high conductivity copper leads for efficient heat transfer from the die and allowing maximum power dissipation with a minimum of external heatsinking. Figure 2-3 shows typical assembly. The leads are of nail head construction, soldered directly to the die, which further enhances the heat dissipating capabilities of the package.

The Surmetic 30s, 40s and MOSORBs are basically assembled in the same manner; the only difference being the MOSORBs are soldered together using a solder disc between the lead and die whereas the Surmetic 30s and Surmetic 40s utilize pre-soldered leads.

Assembly is started on the Surmetic 30 and 40 by loading the leads into assembly boats and pre-soldering the nail heads. After pre-soldering, one die is then placed into each cavity of one assembly boat and another assembly boat is then mated to it. Since the MOSORBs do not use pre-soldered leads, the leads are put into the assembly boat, a solder disc is placed into each cavity and then a die is put in on top. A solder disc is put in on top of the die. Another assembly boat containing only leads is mated to the boat containing the leads, die, and two

Zener Diode Test, Mark and Packaging

Double Slug, Surmetic 30, 40 and MOSORB

After lead finish, all products are final tested, whether they are double slug or of Surmetic construction, all are 100 percent final tested for zener voltage, leakage current, impedance and forward voltage drop.

Process average testing is used which is based upon the averages of the previous lots for a given voltage line and package type. Histograms are generated for the various parameters as the units are being tested to ensure that the lot is testing well to the process average and compared against other lots of the same voltage.

After testing, the units are marked as required by the specification. The markers are equipped to polarity orient the devices as well as perform 100% redundant test prior to packaging.

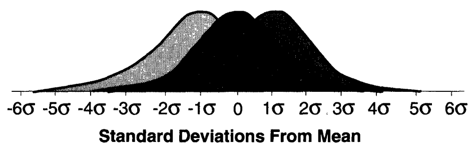
After marking, the units are packaged either in "bulk" form or taped and reeled or taped and ammo packed to accommodate automatic insertion.

Figure 3-1, details the benefit in terms of yield and outgoing quality levels. This compares a centered distribution versus a 1.5 sigma worst case distribution shift.

New product development at Motorola requires more robust design features that make them less sensitive to minor variations in processing. These features make the implementation of SPC much easier.

A complete commitment to SPC is present throughout Motorola. All managers, engineers, production operators, supervisors and maintenance personnel have received multiple training courses on SPC techniques. Manufacturing has identified 22 wafer processing and 8 assembly steps considered critical to the processing of zener products. Processes, controlled by SPC methods, that have shown significant improvement are in the diffusion, photolithography and metallization areas.

To better understand SPC principles, brief explanations have been provided. These cover process capability, implementation and use.



Distribution Centered	Distribution Shifted ± 1.5
At ± 3 σ 2700 ppm defective 99.73% yield	66810 ppm defective 93.32% yield
At ± 4 σ 63 ppm defective 99.9937% yield	6210 ppm defective 99.379% yield
At ± 5 σ 0.57 ppm defective 99.999943% yield	233 ppm defective 99.9767% yield
At ± 6 σ 0.002 ppm defective 99.9999998% yield	3.4 ppm defective 99.99966% yield

Figure 3-1. AOQL and Yield from a Normal Distribution of Product With 6σ Capability

PROCESS CAPABILITY

One goal of SPC is to ensure a process is **CAPABLE**. Process capability is the measurement of a process to produce products consistently to specification requirements. The purpose of a process capability study is to separate the inherent **RANDOM VARIABILITY** from **ASSIGNABLE CAUSES**. Once completed, steps are taken to identify and eliminate the most significant assignable causes. Random variability is generally present in the system and does not fluctuate. Sometimes, these are considered basic limitations associated with the machinery, materials, personnel skills or manufacturing methods. Assignable cause inconsistencies relate to time variations in yield, performance or reliability.

Traditionally, assignable causes appear to be random due to the lack of close examination or analysis. Figure 3-2 shows the impact on predictability that assignable cause can have. Figure 3-3 shows the difference between process control and process capability.

A process capability study involves taking periodic samples from the process under controlled conditions. The performance characteristics of these samples are charted against time. In time, assignable causes can be identified and engineered out. Careful documentation important to find a measurement in these process steps that correlates with product performance. This is called a critical process parameter.

Once the critical process parameters are selected, a sample plan must be determined. The samples used for measurement are organized into **RATIONAL SUBGROUPS** of approximately 2 to 5 pieces. The subgroup size should be such that variation among the samples within the subgroup remain small. All samples must come from the same source e.g., the same mold press operator, etc.. Subgroup data should be collected at appropriate time intervals to detect variations in the process. As the process begins to show improved stability, the interval may be increased. The data collected must be carefully documented and maintained for later correlation. Examples of common documentation entries would include operator, machine, time, settings, product type, etc..

Once the plan is established, data collection may begin. The data collected will generate $\overline{X}$ and R values that are plotted with respect to time. $\overline{X}$ refers to the mean of the values within a given subgroup, while R is the range or greatest value minus least value. When approximately 20 or more $\overline{X}$ and R values have been generated, the average of these values is computed as follows:

$$\overline{\overline{X}} = (\overline{X} + \overline{X}2 + \overline{X}3 + ...)/K$$
$$\overline{R} = (R1 + R2 + R3 + ...)/K$$

where K = the number of subgroups measured.

The values of $\overline{\overline{X}}$ and $\overline{R}$ are used to create the process control chart. Control charts are the primary SPC tool used to signal a problem. Shown in Figure 3-4, process control charts show $\overline{X}$ and R values with respect to time and concerning reference to upper and lower control limit values. Control limits are computed as follows:

R upper control limit = $UCL_R = D4\,\overline{R}$
R lower control limit $LCL_R = D3\,\overline{R}$
$\overline{X}$ upper control limit = $UCL_X = \overline{\overline{X}} + A2\,\overline{R}$
$\overline{X}$ lower control limit = $LCL_X = \overline{\overline{X}} - A$

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Where D4, D3 and A2 are constants varying by sample size, with values for sample sizes from 2 to 10 shown in the following partial table:

n	2	3	4	5	6	7	8	9	10
D_4	3.27	2.57	2.28	2.11	2.00	1.92	1.86	1.82	1.78
D_3	*	*	*	*	*	0.08	0.14	0.18	0.22
A_2	1.88	1.02	0.73	0.58	0.48	0.42	0.37	0.34	0.31

* For sample sizes below 7, the LCL_R would technically be a negative number; in those cases there is no lower control limit; this means that for a subgroup size 6, six "identical" measurements would not be unreasonable.

Control charts are used to monitor the variability of critical process parameters. The R chart shows basic problems with piece to piece variability related to the process. The X chart can often identify changes in people, machines, methods, etc. The source of the variability

This gives a considerably better improvement of 23%. If only A is identified and reduced from 5 to 2, then;

$$\sigma \text{ tot} = \sqrt{2^2 + 3^2 + 2^2 + 1^2 + (0.4)^2} = 4.3$$

Identifying and improving the variability from 5 to 2 gives us a total variability improvement of nearly 40%.

Most techniques may be employed to identify the primary assignable cause(s). Out-of-control conditions may be correlated to documented process changes. The product may be analyzed in detail using best versus worst part comparisons or Product Analysis Lab equipment. Multi-variance analysis can be used to determine the family of variation (positional, critical or temporal). Lastly, experiments may be run to test theoretical or factorial analysis. Whatever method is used, assignable causes must be identified and eliminated in the most expeditious manner possible.

After assignable causes have been eliminated, new control limits are calculated to provide a more challenging variability criteria for the process. As yields and variability improve, it may become more difficult to detect improvements because they become much smaller. When all assignable causes have been eliminated and the points remain within control limits for 25 groups, the process is said to be in a state of control.

SUMMARY

Motorola is committed to the use of STATISTICAL PROCESS CONTROLS. These principles, used throughout manufacturing, have already resulted in many significant improvements to the processes. Continued dedication to the SPC culture will allow Motorola to reach the Six Sigma and zero defect capability goals. SPC will further enhance the commitment to **TOTAL CUSTOMER SATISFACTION**.

Reliability Stress Tests

The following gives brief descriptions of the reliability tests commonly used in the reliability monitoring program. Not all of the tests listed are performed on each product. Other tests may be performed when appropriate. In addition some form of preconditioning may be used in conjunction with the following tests.

AUTOCLAVE (aka, PRESSURE COOKER)

Autoclave is an environmental test which measures device resistance to moisture penetration and the resultant effects of galvanic corrosion. Autoclave is a highly accelerated and destructive test.

Typical Test Conditions: T_A = 121°C, rh = 100%, p = 1 atmosphere (15 psig), t = 24 to 96 hours
Common Failure Modes: Parametric shifts, high leakage and/or catastrophic
Common Failure Mechanisms: Die corrosion or contaminants such as foreign material on or within the package materials. Poor package sealing

HIGH HUMIDITY HIGH TEMPERATURE BIAS (H3TB or H3TRB)

This is an environmental test designed to measure the moisture resistance of plastic encapsulated devices. A bias is applied to create an electrolytic cell necessary to accelerate corrosion of the die metallization. With time, this is a catastrophically destructive test.

Typical Test Conditions: T_A = 85°C to 95°C, rh = 85% to 95%, Bias = 80% to 100% of Data Book max. rating, t = 96 to 1750 hours
Common Failure Modes: Parametric shifts, high leakage and/or catastrophic
Common Failure Mechanisms: Die corrosion or contaminants such as foreign material on or within the package materials. Poor package sealing
Military Reference: MIL-STD-750, Method 1042

HIGH TEMPERATURE REVERSE BIAS (HTRB)

The purpose of this test is to align mobile ions by means of temperature and voltage stress to form a high-current leakage path between two or more junctions.

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Typical Test Conditions: T_A = 85°C to 150°C, Bias = 80% to 100% of Data Book max. rating, t = 120 to 1000 hours
Common Failure Modes: Parametric shifts in leakage
Common Failure Mechanisms: Ionic contamination on the surface or under the metallization of the die
Military Reference: MIL-STD-750, Method 1039

HIGH TEMPERATURE STORAGE LIFE (HTSL)

High temperature storage life testing is performed to accelerate failure mechanisms which are thermally activated through the application of extreme temperatures.

Typical Test Conditions: T_A = 70°C to 200°C, no bias, t = 24 to 2500 hours
Common Failure Modes: Parametric shifts in leakage
Common Failure Mechanisms: Bulk die and diffusion defects
Military Reference: MIL-STD-750, Method 1032

Military Reference: MIL-STD-750, Method 2031

STEADY STATE OPERATING LIFE (SSOL)

The purpose of this test is to evaluate the bulk stability of the die and to generate defects resulting from manufacturing aberrations that are manifested as time and stress-dependent failures.

Typical Test Conditions: T_A = 25°C, P_D = Data Book maximum rating, t = 16 to 1000 hours

Common Failure Modes: Parametric shifts and catastrophic

Common Failure Mechanisms: Foreign material, crack die, bulk die, metallization, wire and die bond defects

Military Reference: MIL-STD-750, Method 1026

TEMPERATURE CYCLING (AIR TO AIR)

The purpose of this test is to evaluate the ability of the device to withstand both exposure to extreme temperatures and transitions between temperature extremes. This testing will also expose excessive thermal mismatch between materials.

Typical Test Conditions: T_A = –65°C to 200°C, cycle = 10 to 1000

Common Failure Modes: Parametric shifts and catastrophic

Common Failure Mechanisms: Wire bond, cracked or lifted die and package failure

Military Reference: MIL-STD-750, Method 1051

THERMAL SHOCK (LIQUID TO LIQUID)

The purpose of this test is to evaluate the ability of the device to withstand both exposure to extreme temperatures and sudden transitions between temperature extremes. This testing will also expose excessive thermal mismatch between materials.

Typical Test Conditions: T_A = 0°C to 100°C, cycles = 10 to 1000

Common Failure Modes: Parametric shifts and catastrophic

Common Failure Mechanisms: Wire bond, cracked or lifted die and package failure

Military Reference: MIL-STD-750, Method 1056

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VARIABLE FREQUENCY VIBRATION

This test is used to examine the ability of the device to withstand deterioration due to mechanical resonance.

Typical Test Conditions: Peak acceleration = 20 g's, Frequency range = 20 Hz to 20 kHz, t = 48 minutes.

Common Failure Modes: Open, short, excessive leakage, mechanical failure

Common Failure Mechanisms: Die and wire bonds, cracked die, package defects

Military Reference: MIL-STD-750, Method 2056

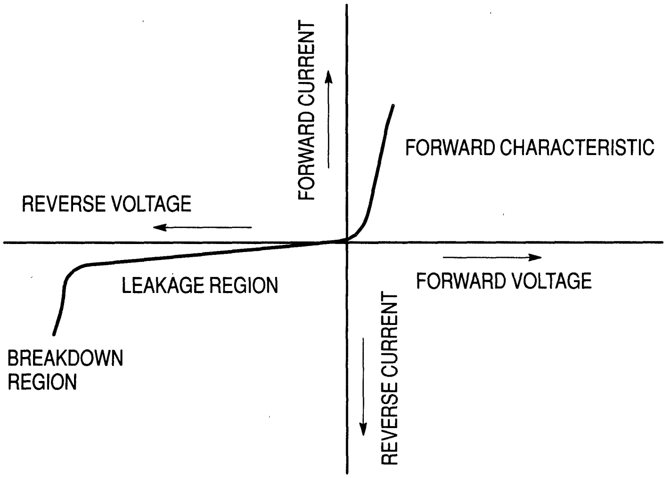

Figure 4-1. Typical Zener Diode DC V-I Characteristics (Not to Scale)

While the common form of the diode equation suggests that I_R is constant, in fact I_R is itself strongly temperature dependent. The rapid increase in I_R with increasing temperature dominates the decrease contributed by the exponential term in the diode equation. As a result, the forward current increases with increasing temperature. Figure 4-2 shows a forward characteristic temperature dependence for a typical zener. These curves indicate that for a constant current, an increase in temperature causes a decrease in forward voltage. The voltage temperature coefficient values are typically in the range of –1.4 to –2 mV/°C.

Leakage DC Characteristics

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When reverse voltage less than the breakdown is applied to a zener diode, the behavior of current is similar to any back-biased silicon P-N junction. Ideally, the reverse current would reach a level at about one volt reverse voltage and remain constant until breakdown is reached. There are both theoretical and practical reasons why the typical V-I curve will have a definite slope to it as seen in Figure 4-3. Multiplication effects and charge generation sites are present in a zener diode which dictate that reverse current (even at low voltages) will increase with voltage. In addition, surface charges are ever present across P-N junctions which appear to be resistive in nature.

The leakage currents are generally less than one microampere at 150°C except with some large area devices. Quite often a leakage specification at 80% or so of breakdown voltage is used to assure low reverse currents.

Voltage Breakdown

At some definite reverse voltage, depending on the doping levels (resistivity) of the P-N junction, the current will begin to avalanche. This is the so-called "zener" or "breakdown" area and is where the device is usually biased during use. A typical family of breakdown curves showing the effect of temperature is illustrated in Figure 4-4.

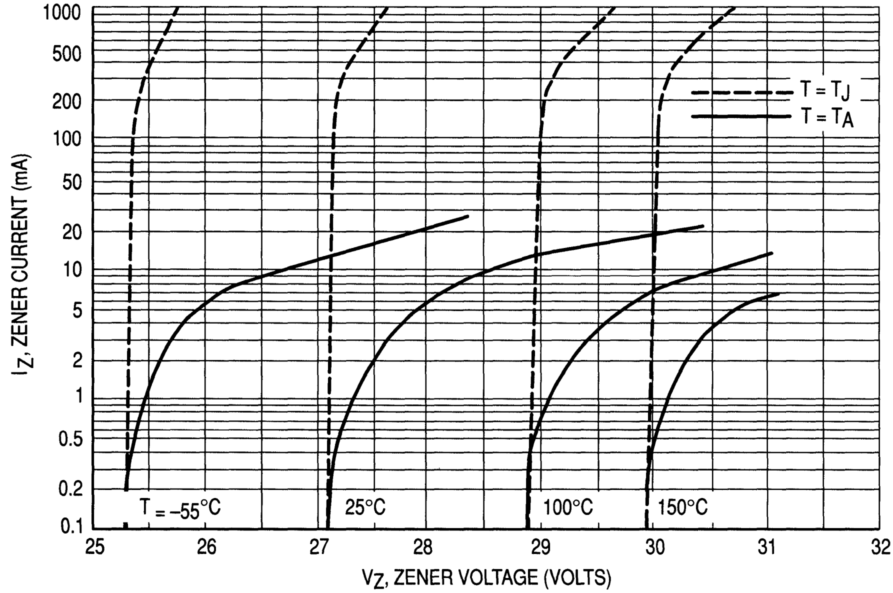

Figure 4-4. Typical Zener Characteristic Variation with Temperature

Between the minimum currents shown in Figure 4-4 and the leakage currents, there is the "knee" region. The avalanche mechanism may not occur simultaneously across the entire area of the P-N junction, but first at one microscopic site, then at an increasing number of sites as further voltage is applied. This action can be accounted for by the "microplasma discharge" theory and correlates with several breakdown characteristics.

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An exaggerated view of the knee region is shown in Figure 4-5. As can be seen, the breakdown or avalanche current does not increase suddenly, but consists of a series of smoothly rising current versus voltage increments each with a sudden break point.

At the lowest point, the zener resistance (slope of the curve) would test high, but as current continues to climb, the resistance decreases. It is as though each discharge site has high resistance with each succeeding site being in parallel until the total resistance is very small.

In addition to the resistive effects, the micro plasmas may act as noise generators. The exact process of manufacturing affects how high the noise will be, but in any event there will be some noise at the knee, and it will diminish considerably as current is allowed to increase.

Since the zener impedance and the temperature coefficient are of prime importance when using the zener diode as a reference device, the next two sections will expand on these points.

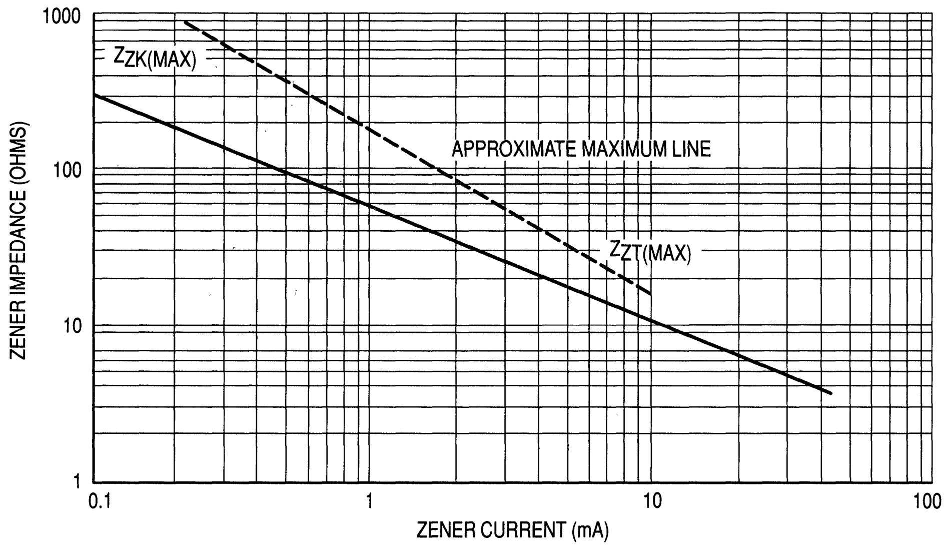

Figure 4-6. Zener Impedance versus Zener Current

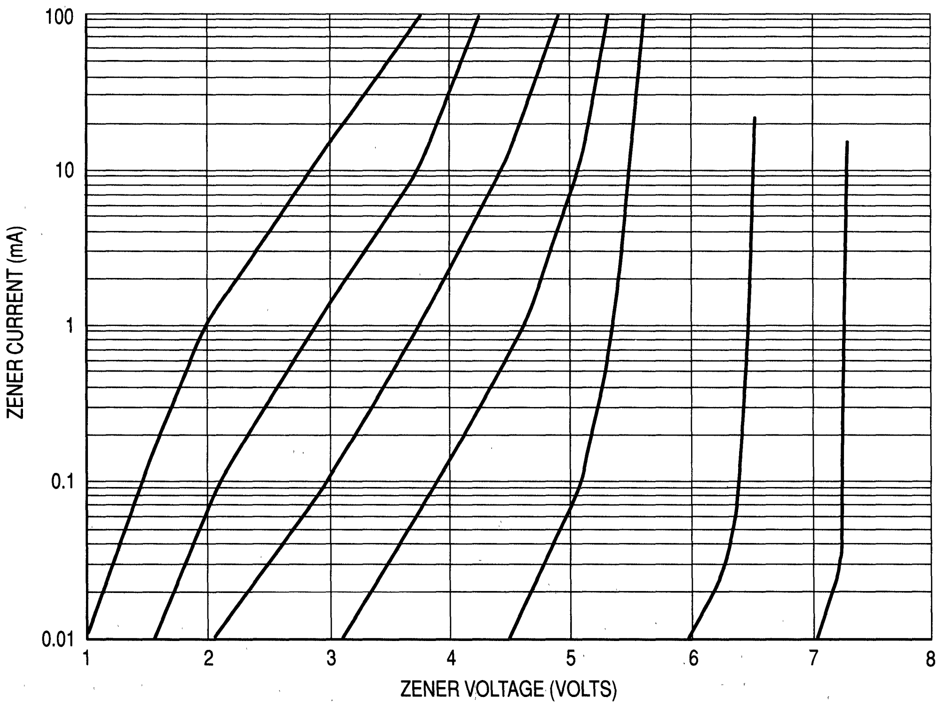

Figure 4-7. Zener Current versus Zener Voltage (Low Voltage Region)

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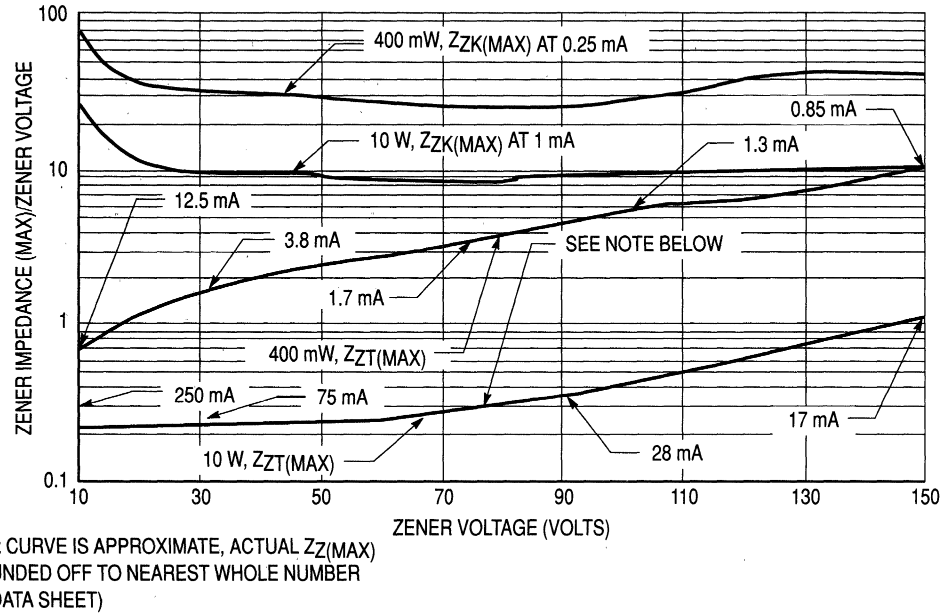

Figure 4-9. Figure of Merit: $Z_{Z(Max)}/V_Z$ versus V_Z (400 mW & 10 W Zeners)

Temperature Coefficient

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Below three volts and above eight volts the zener voltage change due to temperature is nearly a straight line function and is almost independent of current (disregarding self-heating effects). However, between three and eight volts the temperature coefficients are not a simple affair. A typical plot of T_C versus V_Z is shown in Figure 4-10.

Any attempt to predict voltage changes as temperature changes would be very difficult on a "typical" basis. (This, of course, is true to a lesser degree below three volts and above eight volts since the curve shown is a typical one and slight deviations will exist with a particular zener diode.) For example, a zener which is 5 volts at 25°C could be from 4.9 to 5.05 volts at 75°C depending on the current level. Whereas, a zener which is 9 volts at 25°C would be close to 9.3 volts at 75°C for all useful current levels (disregarding impedance effects).

As was mentioned, the situation is further complicated by the normal deviation of T_C at a given current. For example, for 7.5 mA the normal spread of T_C (expressed in %/°C) is shown in Figure 4-11. This is based on limited samples and in no manner implies that all Motorola zeners between 2 and 12 volts will exhibit this behavior. At other current levels similar deviations would occur.

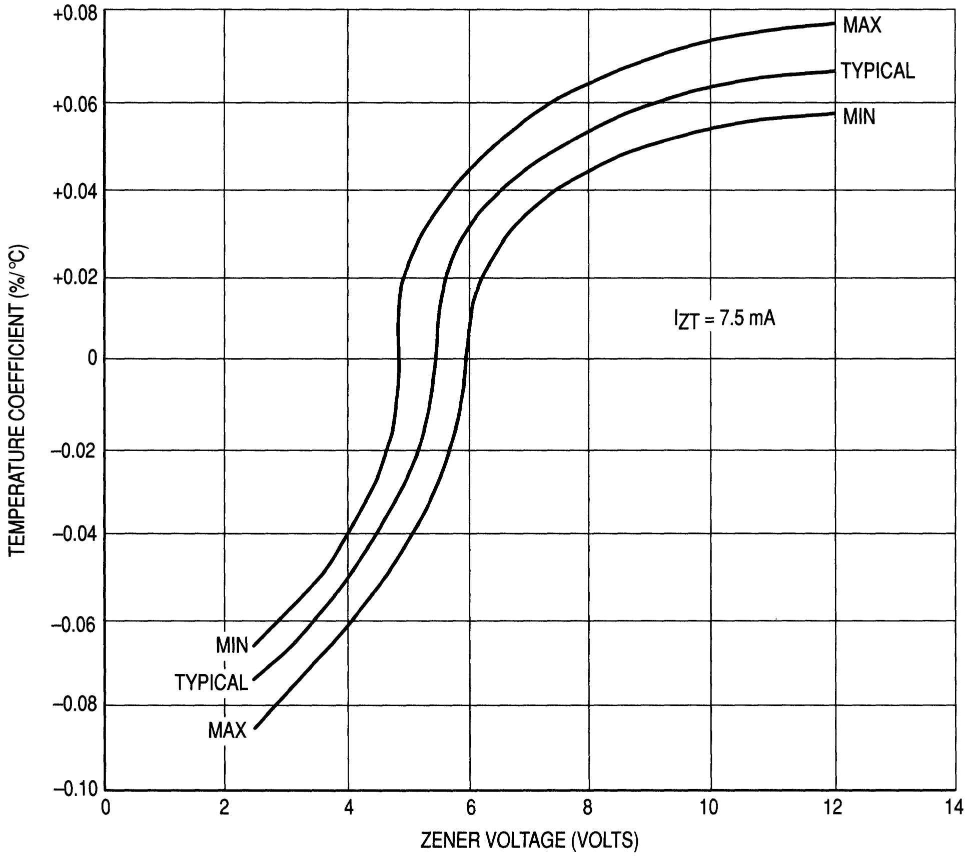

Figure 4-11. Temperature Coefficient Spread versus Zener Voltage

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Power Derating and Mounting

The zener diode like any other semiconductor has a maximum junction temperature. This limit is somewhat arbitrary and is set from a reliability viewpoint. Most semiconductors exhibit an increasing failure rate as temperature increases. At some temperature, the solder will melt or soften and the failure rate soars. The 175°C to 200°C junction temperature rating is quite safe from solder failures and still has a very low failure rate.

voltage change versus temperature. However, only maximum and typical values of thermal resistance are given for a family of zener diodes. So only "worst case" or typical information could be obtained as to voltage changes.

The relations of equations 4-1 and 4-2 are usually expressed as a graphical derating of power versus the appropriate temperature. Maximum thermal resistance is used to generate the slope of the curve. An example of a 400 milliwatt device derated to the ambient temperature and a 1 watt device derated to the lead temperature are shown in Figures 4-13 and 4-14.

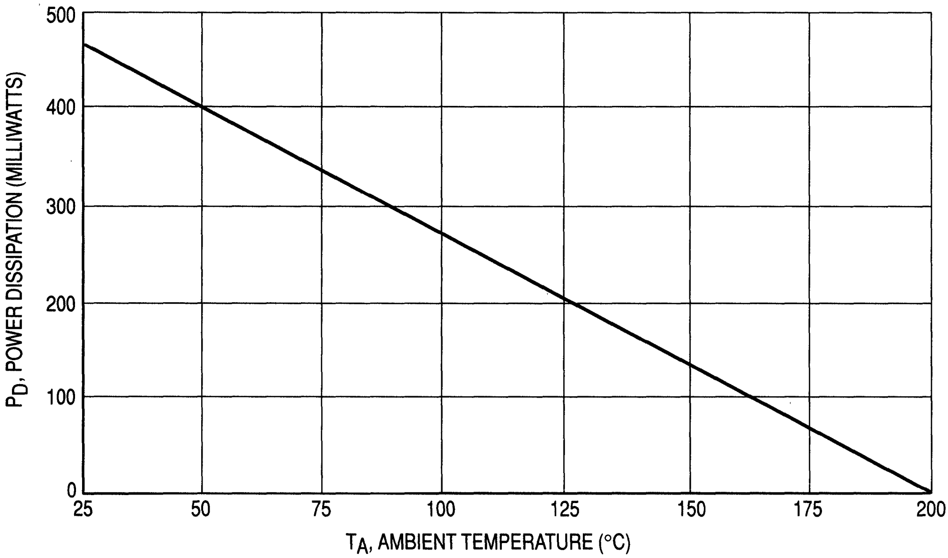

Figure 4-13. 400 mW Power Temperature Derating Curve

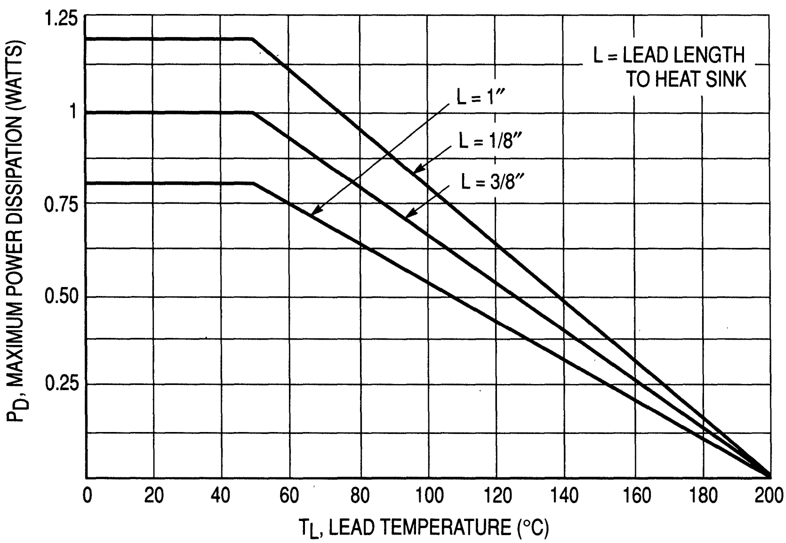

Figure 4-14. Power Temperature Derating Curve

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The main use of this transient $R_{\theta JL}$ curve is when the zener is used as a clipper or a protective device. First of all, the power wave shape must be constructed. (Note, even though the power-transient thermal resistance indicates reasonable junction temperatures, the device still may fail if the peak current exceeds certain values. Apparently a current crowding effect occurs which causes the zener to short. This is discussed further in this section.)

Transient Power-Temperature Effects

A typical transient thermal resistance curve is shown in Figure 4-16. This is for a lead mounted device and shows the effect of lead length to an essentially infinite heatsink.

To calculate the temperature rise, the power surge wave shape must be approximated by its rectangular equivalent as shown in Figure 4-17. In case of an essentially non-recurrent pulse, there would be just one pulse, and $\Delta T = R_{\theta T1}\, P_P$. In the general case, it can be shown that

$$\Delta T = [D R_{\theta JA}\,(ss) + (1 - D)\, R_{\theta T1 + T} + R_{\theta T1} - R_{\theta T}]\, P_P$$

where

D = Duty cycle in percent
$R_{\theta T1}$ = Transient thermal resistance at the time equal to the pulse width
$R_{\theta T}$ = Transient thermal resistance at the time equal to pulse interval
$R_{\theta T1 + T}$ = Transient thermal resistance at the time equal to the pulse interval plus one more pulse width.

$R_{\theta JA}(ss)$ or $R_{\theta JL}(ss)$ = Steady state value of thermal resistance

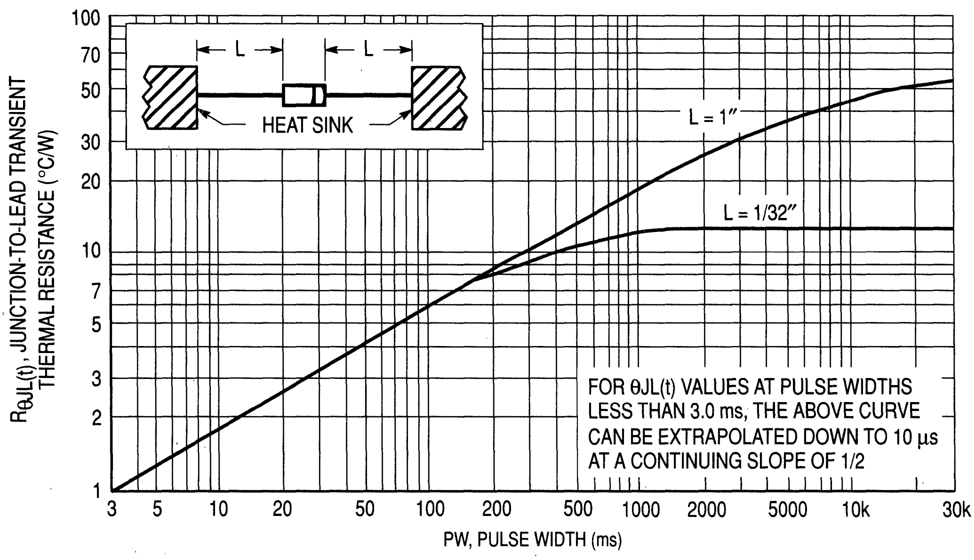

Figure 4-16. Typical Transient Thermal Resistance (For Axial Lead Zener)

or shorts. Each device was measured before and after the applied pulse. Most failures were shifts in zener voltage. The results are shown in Figure 4-18.

Attempts to correlate this to the transient thermal resistance work quite well on a typical basis. For example, assuming a value for 1 ms of 90 watts and 35 watts at 10 ms, the predicted temperature rise would be 180°C and 190°C. But on a worst case basis, the temperature rises would be about one half these values or junction temperatures, on the order of 85°C to 105°C, which are obviously low. Apparently at very high power levels a current restriction occurs causing hot spots. There was no apparent correlation of zener voltage or current on the failure points since each group of failures contained a mixture of voltages.

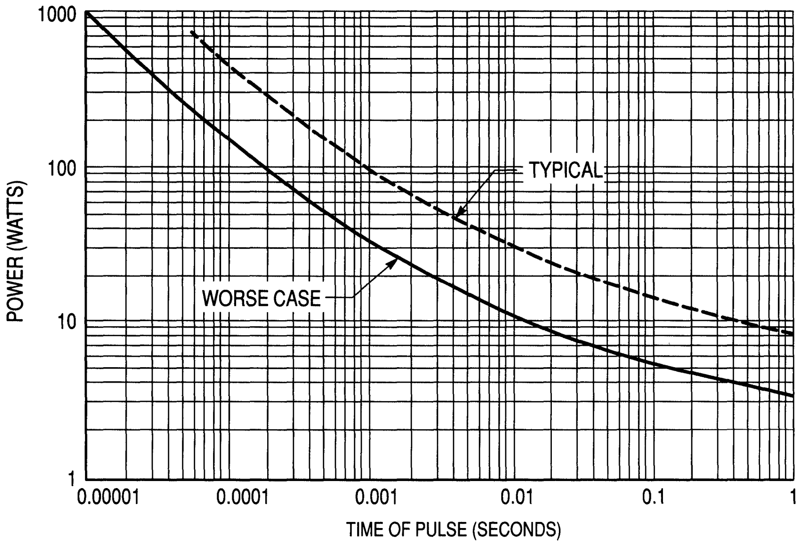

Figure 4-18. One Shot Power Failure Axial Lead Zener Diode

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Voltage versus Time

Quite often the junction temperature is only of academic interest, and the designer is more concerned with the voltage behavior versus time. By using the transient thermal resistance, the power, and the temperature coefficient, the designer could generate V_Z versus time curves. The Motorola zener diode test group has observed device voltages versus time until the thermal equilibrium was reached. A typical curve is shown for a lead mounted low wattage device in Figure 4-19 where the ambient temperature was maintained constant. It is seen that voltage stabilizes in about 100 seconds for 1 inch leads.

Since information contained in this section may not be found on data sheets it is necessary for the designer to contact the factory when using a zener diode as a surge suppressor. Additional information on transient suppression application is presented elsewhere in this book.

variable capacitor used for balancing is removed and its value measured on a test instrument. The value thus indicated is the zener capacitance at reverse voltage for which bridge balance was obtained. Figure 4-20 shows capacitance test circuit.

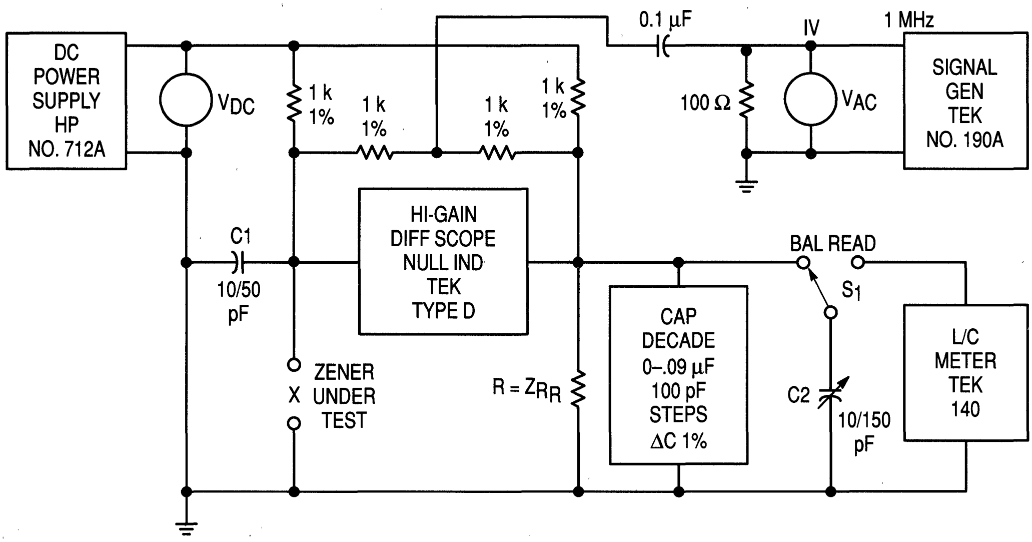

Figure 4-20. Capacitance Test Circuit

Figure 4-21 is a plot of junction capacitance for diffused zener diode units versus their nominal operating voltage. Capacitance is the value obtained with reverse bias set at one-half the nominal V_Z. The plot of the voltage range from 6.8 V to 200 V, for three dice sizes, covers most Motorola diffused-junction zeners. Consult specific data sheets for capacitance values.

Figures 4-22, 4-23, and 4-24 show plots of capacitance versus reverse voltage for units of various voltage ratings in each of the three dice sizes. Junction capacitance decreases as reverse voltage increases to the zener region. This change in capacitance can be expressed as a ratio which follows a one-third law, and $C_1/C_2 = (V_2/V_1)^{1/3}$. This law holds only from the zener voltage down to about 1 volt, where the curve begins to flatten out. Figure 4-25 shows this for a group of low wattage units.

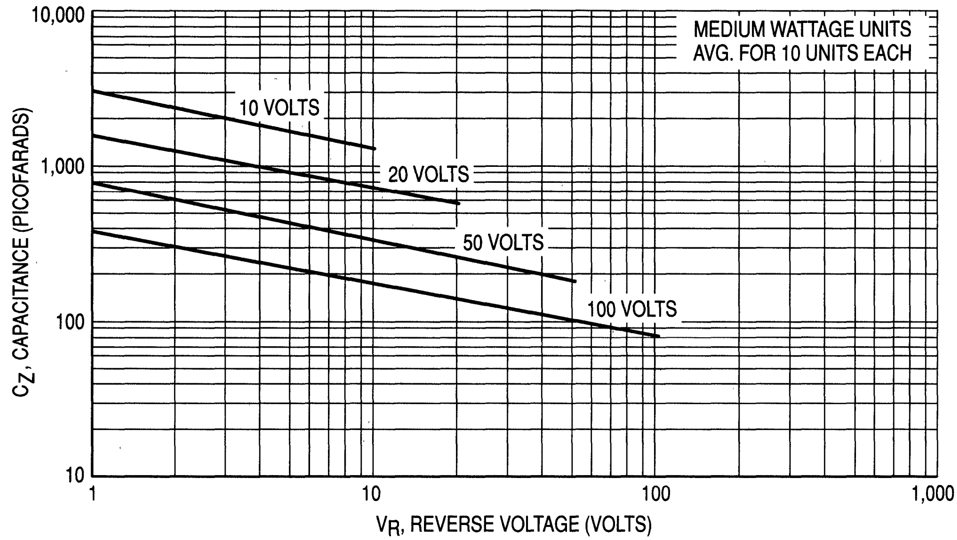

Figure 4-23. Capacitance versus Reverse Voltage

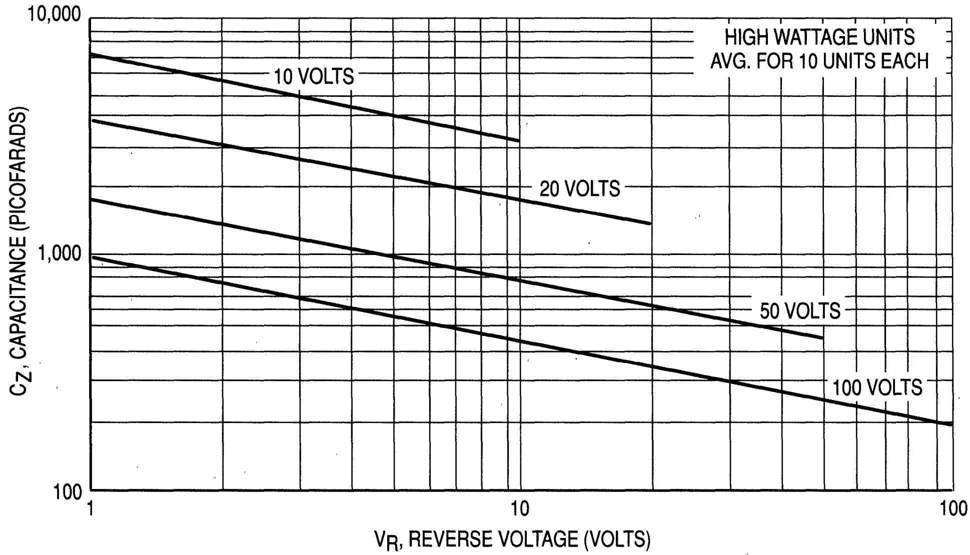

Figure 4-24. Capacitance versus Reverse Voltage

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Zener Impedance

Zener impedance appears primarily as composed of a current-dependent resistance shunted by a voltage-dependent capacitor. Figure 4-26 shows the test circuit used to gather impedance data. This is a voltage-impedance ratio method of determining the unknown zener impedance. The operation is as follows:

(1) Adjust for desired zener I_{ZDC} by observing IR drop across the 1-ohm current-viewing resistor R_2.
(2) Adjust I_{ZAC} to 100 μA by observing AC IR drop across R2.
(3) Measure the voltage across the entire network by switching S1. The ratio of these two AC voltages is then a measure of the impedance ratio. This can be expressed simply as $R_X = [(E_1 - E_2)/E_2]\ R_2$.

Section A of S_1 provides a dummy load consisting of a 10-M resistor and a 100 pF capacitor. This network is required to simulate the input impedance of the AC VTVM while it is being used to measure the AC IR drop across R_2.

This method has been found accurate up to about three megahertz; above this frequency, lead inductances and strap capacitance become the dominant factors.

Figure 4-27 shows typical impedance versus frequency relationships of 6.8 volt 500 mW zener diodes at various DC zener currents. Before the zener breakdown region is entered, the impedance is almost all reactive, being provided by a voltage-dependent capacitor shunted by a very high resistance. When the zener breakdown region is entered, the capacitance is fixed and now is shunted by current-dependent resistance. For comparison, Figure 4-27 also shows the plot for a 680 pF capacitor X_C, a 1K 1% nonreactive resistor, R, and the parallel combination of these two passive elements, Z_T.

High-Frequency and Switching Considerations

At frequencies about 100 kHz or so and switching speeds above 10 microseconds, shunt capacitance of zener diodes begins to seriously effect their usefulness. The upper photo of Figure 4-28 shows the output waveform of a symmetrical peak limiter using two zener diodes back-to-back. The capacitive effects are obvious here. In any application where the signal is recurrent, the shunt capacitance limitations can be overcome, as lower photo of Figure 4-28 shows. This is done by operating fast diodes in series with the zener. Upon application of a signal, the fast diode conducts in the forward direction charging the shunt zener capacitance to the level where the zener conducts and limits the peak. When the signal swings the opposite direction, the fast diode becomes back-biased and prevents fast discharge of shunt capacitance. The fast diode remains back-biased when the signal reverses again to the forward direction and remains off until the input signal rises and exceeds the charge level of the capacitor. When the signal exceeds this level, the fast diode conducts as does the zener. Thus, between successive cycles or pulses the charge in the shunt capacitor holds off the fast diode, preventing capacitive loading of the signal until zener breakdown is reached. Figures 4-29 and 4-30 show this method applied to fast-pulse peak limiting.

Figure 4-31 is a photo of input-output pulse waveforms using a zener alone as a series peak clipper. The smaller output waveform shows the capacitive spike on the leading edge. Figure 4-32 clearly points out the advantage of the clamping network.

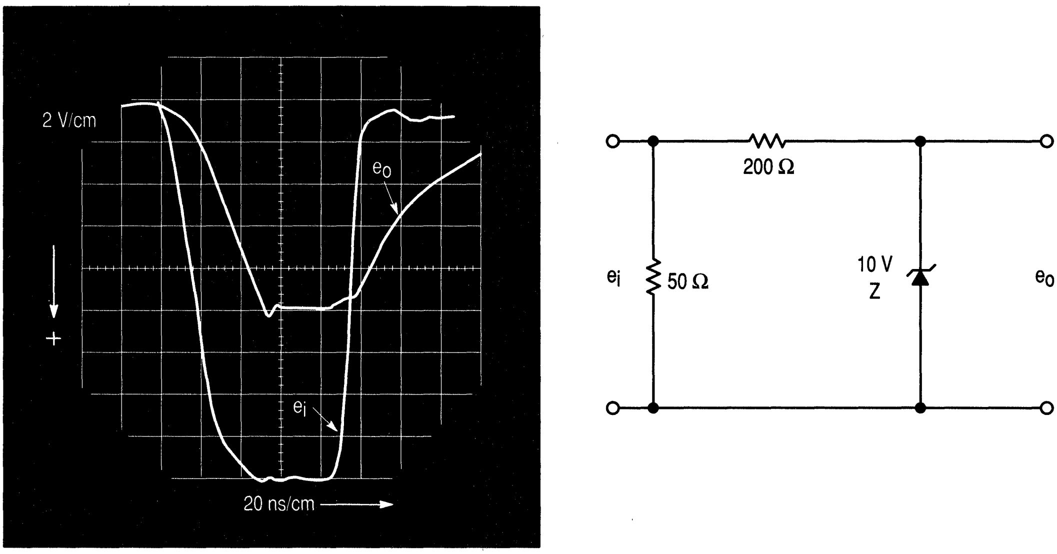

Figure 4-29. Shunt Clipper

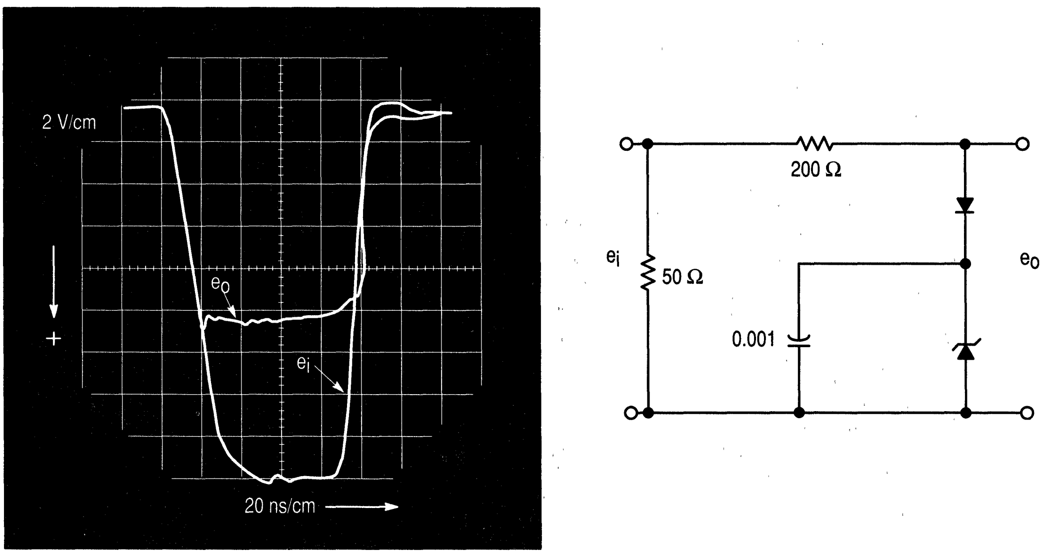

Figure 4-30. Shunt Clipper with Clamping Network

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(Figure 5-1). A P-N junction in avalanche (above 5 volts breakdown) will display a positive temperature coefficient; that is, voltage will increase as temperature increases. Due to energy levels of a junction which breaks down below 5 volts, the temperature coefficient is negative.

It follows that various combinations of forward biased junctions and reverse biased junctions may be arranged to achieve temperature compensation. From Figure 5-2 it can be seen that if the absolute value of voltage change (ΔV) is the same for both the forward biased diode and the zener diode where the temperature has gone from 25°C to 100°C, then the total voltage across the combination will be the same at both temperatures since one ΔV is negative and the other positive. Furthermore, if the rate of increase (or decrease) is the same throughout the temperature change, voltage will remain constant. The non-linearity associated with the voltage temperature characteristics is a result of this rate of change not being a perfect match.

$$V_{REF} = V_Z + \Delta V_Z + V_D - \Delta V_D$$

The Methods of Temperature Compensation

The effect of temperature is shown in Figure 5-1. The forward characteristic does not vary significantly with reverse voltage breakdown (zener voltage) rating. A change in ambient temperature from 25° to 100°C produces a shift in the forward curve in the direction of lower voltage (a negative temperature coefficient — in this case about 150 mV change), while the same temperature change produces approximately 1.9 V increase in the zener voltage (a positive coefficient). By combining one or more silicon diodes biased in the forward direction with the P-N biased zener diode as shown in Figure 5-3, it is possible to compensate almost completely for the zener temperature coefficient. Obviously, with the example shown, 13 junctions would be needed. Usually reference diodes are low voltage devices, using zeners with 6 to 8 volts breakdown and one or two forward diodes.

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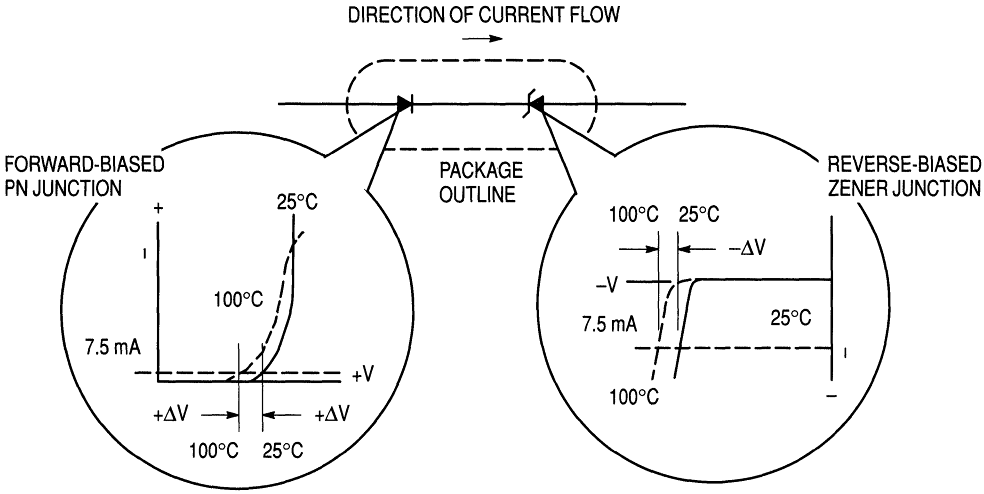

Figure 5-2. Principle of Temperature Compensation

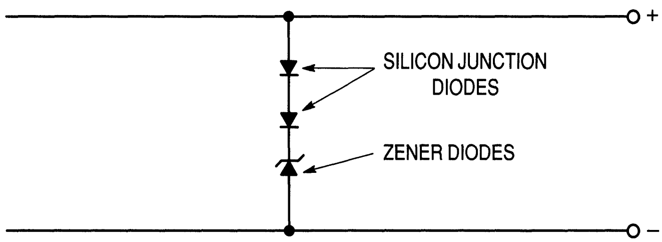

Figure 5-3. Zener Temperature Compensation with Silicon Forward Junctions

In ac regulator and clipper circuits where zener diodes are normally connected cathode to cathode, the forward biased diode during each half cycle can be chosen with the correct forward temperature coefficient (by stacking, etc.) to correctly compensate for the temperature coefficient of the reverse-biased zener diode. It is possible to compensate for voltage drift with temperature using this method to the extent that zener voltage stabilities on the order of 0.001%/°C are quite feasible.

This technique is sometimes employed where higher wattage devices are required or where the zener is compensated by the emitter base junction of a transistor stage. Consider the example of using discrete components, 1N4001 rectifier and Motorola 5 Watt zener, to obtain compensated voltage-temperature characteristics. Examination of the curve in Figure 5-4 indicates that a 10 volt zener diode exhibits a temperature coefficient of approximately +5.5 mV/°C. At a current level of 100 mA a temperature coefficient of approximately –2.0 mV/°C is characteristic of the 1N4001 rectifiers. A series connection of three silicon 1N4001 rectifiers produces a total temperature coefficient of approximately –6 mV/°C and a total forward drop of approximately 2.17 volts at 25°C. The combination of three silicon

Temperature Coefficient Stability

Figure 5-5 shows the voltage-temperature characteristics of the TC diode. It can be seen that the voltage drops slightly with increasing temperature.

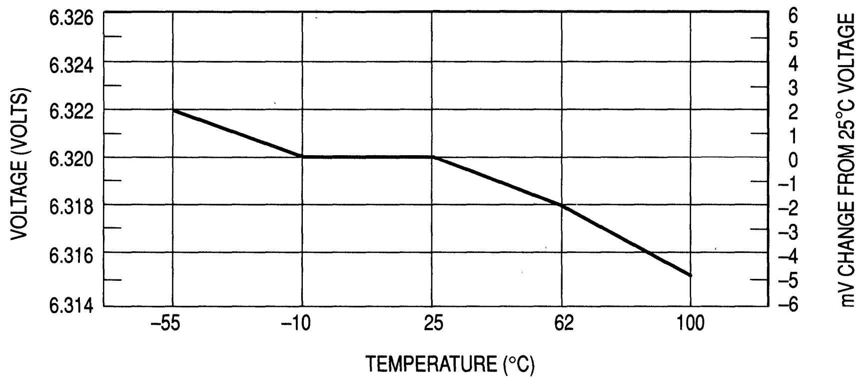

Figure 5-5. Voltage versus Temperature, Typical for Motorola 1N827 Temperature-Compensated Zener Diode

This non-linearity of the voltage temperature characteristic leads to a definition of a representative design parameter ΔV_Z. For each device type there is a specified maximum change allowable. The voltage temperature stability measurement consists of voltage measurement at specified temperatures (for the 1N821 Series the temperatures are –55, 0, +25, +75, and +100°C). The voltage readings at each of the temperatures is compared with readings at the other temperatures and the largest voltage change between any of the specified temperatures determines the exact device type. For devices registered prior to complete definition of the voltage temperature stability measurement, the allowable maximum voltage change over the temperature range is derived from the calculation converting %/°C to mV over the temperature range. Under this standard definition, %/°C is merely a nomenclature and the meaningful allowable voltage deviation to be expected becomes the designed parameter.

6

Current

Thus far, temperature-compensated zeners have been discussed mainly with regard to temperature and voltage. However, the underlying assumption throughout the previous discussion was that current remained constant.

There is a significant change in the temperature coefficient of a unit depending on how much above or below the test current the device is operated.

A particular unit with a 0.01%/°C temperature coefficient at 7.5 mA over a temperature range of –55°C to +100°C could possibly have a 0.0005%/°C temperature coefficient at 11

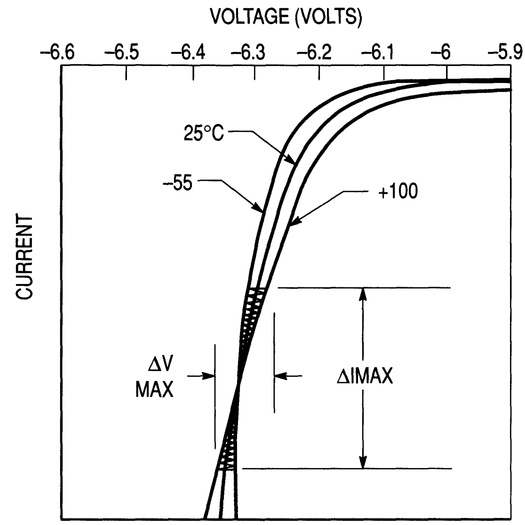

Figure 5-7. Effects of Poorly Regulated Current

Zener Impedance and Current Regulation

Zener impedance is defined as the slope of the V-I curve at the test point corresponding to the test current. It is measured by superimposing a small ac current on the dc test current and then measuring the resulting ac voltage. This procedure is identical with that used for regular zeners.

Impedance changes with temperature, but the variation is usually small and it can be assumed that the amount of current regulation needed at +25°C will be the same for other temperatures.

As an example, one might want to determine the amount of current regulation necessary for the device described below when the maximum deviation in voltage due to current variation is ±5 millivolts.

6

$V_{ZT} = 6.32$ V

$I_{ZT} = 7.5$ mA

$Z_{ZT} = 15\ \Omega$ @ +25°C

$\Delta V = \Delta I \cdot Z_{ZT}$

$0.005 = \Delta I \cdot 15$

$$\Delta I = \frac{0.005}{15} = 0.33 \text{ mA}$$

Therefore, the current cannot vary more than 0.33 mA.

The amount of current regulation necessary is:

$$\frac{0.33}{7.5} \text{ x } 100\% = 4.5\% \text{ regulation.}$$

6

For a given incremental change in V_I, the changes in V_O will be

$$\Delta V_O = \Delta V_I \left(\frac{1}{\frac{R_S}{R_L} + \frac{R_S}{R_R} + 1} \right) \tag{6-2}$$

Assuming R_L fixed at some constant value, it is obvious from equation (6-2) that in order to minimize changes in V_O for variations in V_I, the shunt resistor R_R should be made as small as possible with respect to the source resistor R_S. Obviously, the better this relation becomes, the larger V_I is going to have to be for the same V_O, and not until the ratio of R_S to R_R reaches infinity will the output be held entirely constant for variation in V_I. This, of course, is an impossibility, but it does stress the fact that the regulation improves as the output impedance becomes lower and lower. Where the output impedance of Figure 6-1 is given by

$$R_O = \frac{R_S R_R}{R_S + R_R} \tag{6-3}$$

It is apparent from this relation that as regulation is improving with R_S increasing and R_R decreasing the output impedance R_O is decreasing, and is approximately equal to R_R as the ratio is 10 times or greater. The regulation of this circuit can be greatly improved by inserting a reference source of voltage in series with R_R such as Figure 6-2.

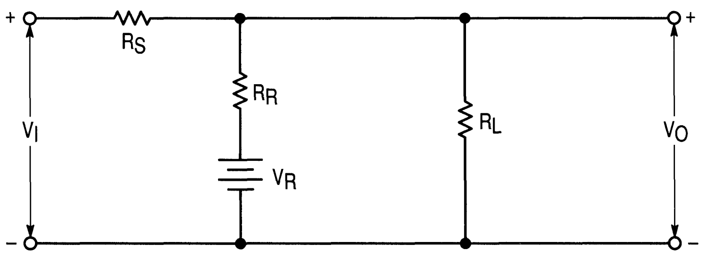

Figure 6-2. Regulator with Battery Reference Source

The resistance R_R represents the internal impedance of the battery. For this circuit, the output is

$$V_O = V_R + V_I \frac{V}{\frac{R_S}{R_L} + \frac{R_S}{R_R} + 1} \tag{6-4}$$

Then for incremental changes in the input V_I, the changes in V_O will be dependent on the second term of equation (6-4), which again makes the regulation dependent on the ratio of R_S to R_R. Where changes in the output voltage or the regulation of the circuit in Figure 6-1 were directly and solely dependent upon the input voltage and output impedance, the regulation of circuit 6-2 will have an output that varies about the reference source V_R in accordance

The design objective of Figure 6-3 is to determine the proper values of the series resistance, R_S, and zener power dissipation, P_Z. A general solution for these values can be developed as follows, when the following conditions are known:

V_I (input voltage) from $V_{I(min)}$ to $V_{I(max)}$
V_O (output voltage) from $V_{Z(min)}$ to $V_{Z(max)}$
I_L (load current) from $I_{L(min)}$ to $I_{L(max)}$

The value of R_S must be of such a value so that the zener current will not drop below a minimum value of $I_{Z(min)}$. This minimum zener current is mandatory to keep the device in the breakover region in order to maintain the zener voltage reference. The minimum current can be either chosen at some point beyond the knee or found on the manufacturer's data sheet (I_{ZK}). The basic voltage loop equation for this circuit is:

$$V_I = (I_Z + I_L)R_S + V_Z \qquad (6\text{-}5)$$

The minimum zener current will occur when V_I is minimum, V_Z is maximum, and I_L is maximum, then solving for R_S, we have:

$$R_S = \frac{V_{I(min)} - V_{Z(max)}}{I_{Z(min)} + I_{L(max)}} \qquad (6\text{-}6)$$

Having found R_S, we can determine the maximum power dissipation P_Z for the zener diode.

$$P_{Z(max)} = I_{Z(max)}\, V_{Z(max)} \qquad (6\text{-}7)$$

Where:

$$I_{Z(max)} = \frac{V_{I(max)} - V_{Z(min)}}{R_S} - I_{L(min)} \qquad (6\text{-}8)$$

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Therefore:

$$P_{Z(max)} = \left[\frac{V_{I(max)} - V_{Z(min)}}{R_S} - I_{L(min)}\right] V_{Z(max)} \qquad (6\text{-}9)$$

Once the basic regulator components values have been determined, adequate considerations will have to be given to the variation in V_O. The changes in V_O are a function of four different factors; namely, changes in V_I, I_L, temperature, and the value of zener impedance, R_Z. These changes in V_O can be expressed as:

$$\Delta V_O = \frac{\Delta V_I}{1 + \dfrac{R_S}{R_Z} + \dfrac{R_S}{R_L}} - \frac{R_S R_Z}{R_S + R_Z}\Delta I_L + TC\Delta T V_Z \qquad (6\text{-}10)$$

The changes in output with respect to changes in input for both stages assuming the temperature and load are constant is

$$\frac{\Delta V_O}{\Delta V_{Z1}} = \frac{\Delta V_O}{\Delta V_O'} = \text{Regulation of second stage} \tag{6-13}$$

$$\frac{\Delta V_O'}{\Delta V_I} = \text{Regulation of first stage} \tag{6-14}$$

$$\frac{\Delta V_O}{\Delta V_I} = \frac{\Delta V_O}{\Delta V_O'} \times \frac{\Delta V_O'}{\Delta V_I} = \text{Combined regulation} \tag{6-15}$$

Obviously, this technique will vastly improve overall regulation where the input fluctuates over a relatively wide range. As an example, let's say the input varies by ±20% and the regulation of each individual stage reduces the variation by a factor of 1/20. This then gives an overall output variation of $\pm 20\% \times (1/20)^2$ or ±0.05%.

The next two factors in equation (6-10) affecting regulation are changes in load current and temperature excursions. In order to minimize changes for load current variation, the output impedance $R_Z R_S/(R_Z + R_S)$ will have to be reduced. This can only be done by having a lower zener impedance because the value of R_S is fixed by circuit requirements. There are basically two ways that a lower zener impedance can be achieved. One, a higher wattage device can be used which allows for an increase in zener current of which will reduce the impedance. The other technique is to series lower voltage devices to obtain the desired equivalent voltage, so that the sum of the impedance is less than that for a single high voltage device. So to speak, this technique will kill two birds with one stone, as it can also be used to minimize temperature induced variations of the regulator.

In most regulator applications, the single most detrimental factor affecting regulation is that of variation in junction temperature. The junction temperature is a function of both the ambient temperature and that of self heating. In order to illustrate how the overall temperature coefficient is improved with series lower voltage zener, a mathematical relationship can be developed. Consider the diagram of Figure 6-5.

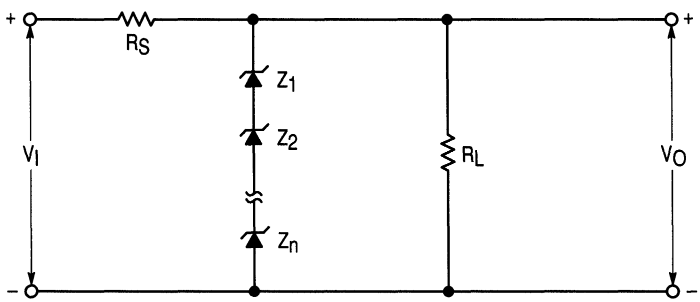

Figure 6-5. Series Zener Improve Dynamic Impedance and Temperature Coefficient

and ΔV_Z. Because of this small fluctuation of input to the second stage, and if R_L is constant, the biasing current of the TC units can be maintained at their specified level. This will give an output that is very precise and not significantly affected by changes in input voltage or junction temperature.

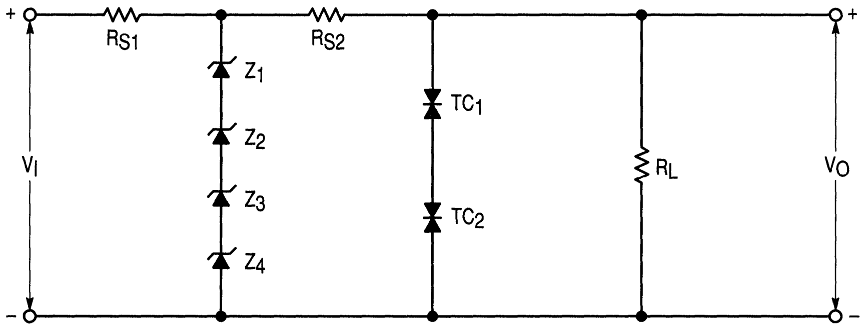

Figure 6-6. Series Zeners Cascaded With Series Reference Diodes for Improved Zener Shunt Regulation

The basic zener shunt regulator exhibits some inherent limitations to the designer. First of all, the zener is limited to its particular power dissipating rating which may be less than the required amount for a particular situation. The total magnitude of dissipation can be increased to some degree by utilizing series or parallel units. Zeners in series present few problems because individual voltages are additive and the devices all carry the same current and the extent that this technique can be used is only restricted by the feasibility of circuit parameters and cost. On the other hand, caution must be taken when attempting to parallel zener diodes. If the devices are not closely matched so that they all break over at the same voltage, the low voltage device will go into conduction first and ultimately carry all the current. In order to avoid this situation, the diodes should be matched for equal current sharing.

Extending Power and Current Range

The most common practice for extending the power handling capabilities of a regulator is to incorporate transistors in the design. This technique is discussed in detail in the following sections of this chapter. The second disadvantage to the basic zener shunt regulator is that because the device does not have a gain function, a feedback system is not possible with just the zener resistor combination. For very precise regulators, the design will normally be an electronic circuit consisting of transistor devices for control, probably a closed loop feedback system with a zener device as the basic referencing element.

The concept of regulation can be further extended and improved with the addition of transistors as the power absorbing elements to the zener diodes establishing a reference. There are three basic techniques used that combine zener diodes and transistors for voltage regulation. The shunt transistor type shown in Figure 6-7 will extend the power handling capabilities of the basic shunt regulator, and exhibit marked improvement in regulation.

$$R_S = \frac{V_{I(min)} - V_{O(max)}}{I_{Z(min)}\,[1+h_{FE(min)}] + I_{L(max)}} \qquad (6\text{-}22)$$

$$R_B = \frac{V_{I(min)} - V_{Z(max)}}{I_{Z(min)}} \qquad (6\text{-}23)$$

$$P_{DZ} = I_{Z(max)}\,V_{Z(max)} \qquad (6\text{-}24)$$

when

$$I_{Z(max)} = \left[\frac{V_{I(max)} - V_{O(min)}}{R_S} - I_{L(min)}\right]\left(\frac{1}{1 + h_{FE(min)}}\right) \qquad (6\text{-}25)$$

hence

$$P_{DZ} = \left[\frac{V_{I(max)} - V_{O(min)}}{R_S} - I_{L(min)}\right]\left(\frac{V_{Z(max)}}{1 + h_{FE(min)}}\right) \qquad (6\text{-}26)$$

$$P_{DQ} = \left[\frac{V_{I(max)} - V_{O(min)}}{R_S} - I_{L(min)}\right]\left(V_{O(max)}\right) \qquad (6\text{-}27)$$

Regulation with this circuit is derived in essentially the same manner as in the shunt zener circuit, where the output impedance is low and the output voltage is a function of the reference voltage. The regulation is improved with this configuration because the small signal output impedance is reduced by the gain of Q_1 by $1/h_{FE}$.

6

One other highly desirable feature of this type of regulator is that the output is somewhat self compensating for temperature changes by the opposing changes in V_Z and V_{BE} for $V_Z \approx 10$ volts. With the zener having a positive 2 mV/°C TC and the transistor base to emitter being a negative 2 mV/°C TC, therefore, a change in one is cancelled by the change in the other. Even though this circuit is a very effective regulator it is somewhat undesirable from an efficiency standpoint. Because the magnitude of R_S is required to be large, and it must carry the entire input current, a large percentage of power is lost from input to output.

Emitter Follower Regulator

Another basic technique of transistor-zener regulation is that of the emitter follower type shown in Figure 6-8.

$$V_Z = V_O + V_{BE}$$

$$= V_O + I_{L(max)}/g_{FE(min)} \ @ \ I_{L(max)}$$

$$R_S = \frac{V_{I(min)} - V_Z - V_{CE(min)} \ @ \ I_{L(max)}}{I_{L(max)}} \quad (6\text{-}31)$$

Where $V_{CE(min)}$ is an arbitrary value of minimum collector to emitter voltage and g_{FE} is the transconductance.

This is sufficient to keep the transistor out of saturation, which is usually about 2 volts.

$$R_B = \frac{V_{CE(min)} \ @ \ I_{L(max)}}{I_{L(max)}/h_{FE(min)} \ @ \ I_{L(max)} + I_{Z(min)}} \quad (6\text{-}32)$$

$$I_{Z(max)} = \frac{V_{I(max)} - V_Z}{R_B + R_Z} \quad (6\text{-}33)$$

$$P_{DZ} = I_{Z(max)} V_Z \quad (6\text{-}34)$$

$$\text{Actual } P_{DQ} = (V_{I(max)} - V_O) \ I_{L(max)} \quad (6\text{-}35)$$

There are two primary factors that effect the regulation most in a circuit of this type. First of all, the zener current may vary over a considerable range as the input changes from minimum to maximum and this, of course, may have a significant effect on the value of V_Z and therefore V_O. Secondly, V_Z and V_{BE} will both be effected by temperature changes which are additive on their effect of output voltage. This can be seen by altering equation (6-28) to show changes in V_O as dependent on temperature, see equation (6-36).

$$V_{O(\Delta T)} = \Delta T[(+TC) \ V_Z - (-TC) \ V_{BE}] \quad (6\text{-}36)$$

The effects of these detrimental factors can be minimized by replacing the bleeder resistor R_B with a constant current source and the zener with a reference diode in series with a forward biased diode (see Figure 6-9).

voltage gain. There are three primary advantages gained with this configuration over the basic emitter follower:

1. The increased voltage gain of the circuit with the addition of Q2 will improve regulation for changes in both load and input.
2. The zener current excursions are reduced, thereby improving regulation.
3. For certain voltages the configuration allows good temperature compensation by matching the temperature characteristics of the zener to the base-emitter junction of Q2.

The series pass regulator is superior to the other transistor regulators thus far discussed. It has good efficiency, better stability and regulation, and is simple enough to be economically practical for a large percentage of applications.

Employing Feedback for Optimum Regulation

The regulators discussed thus far do not employ any feedback techniques for precise control and compensation and, therefore, find limited use where an ultra precise regulator is required. In the more sophisticated regulators some form of error detection is incorporated and amplified through a feedback network to closely control the power elements as illustrated in the block diagram of Figure 6-11.

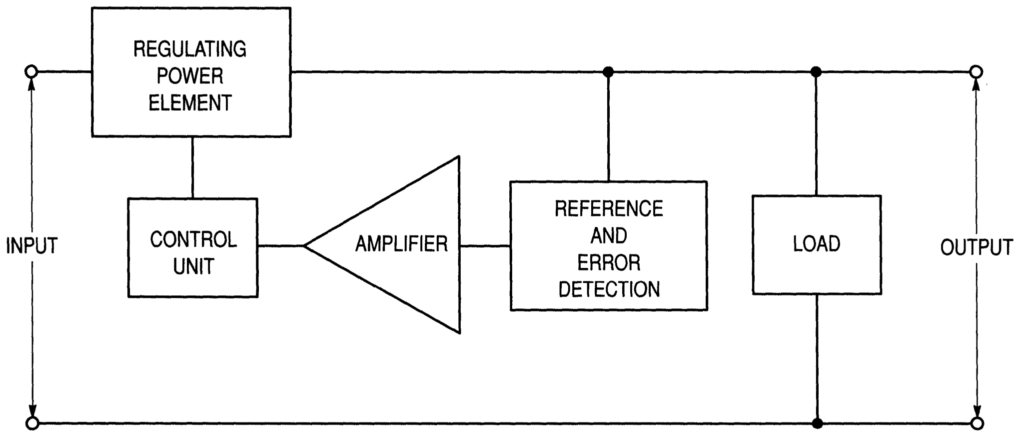

Figure 6-11. Block Diagram of Regulator with Feedback

Regulating circuits of this type will vary in complexity and configuration from application to application. This technique can best be illustrated with a couple of actual circuits of this type. The feedback regulators will generally be some form of series pass regulator, for optimum performance and efficiency. A practical circuit of this type that is extensively utilized is shown in Figure 6-12.

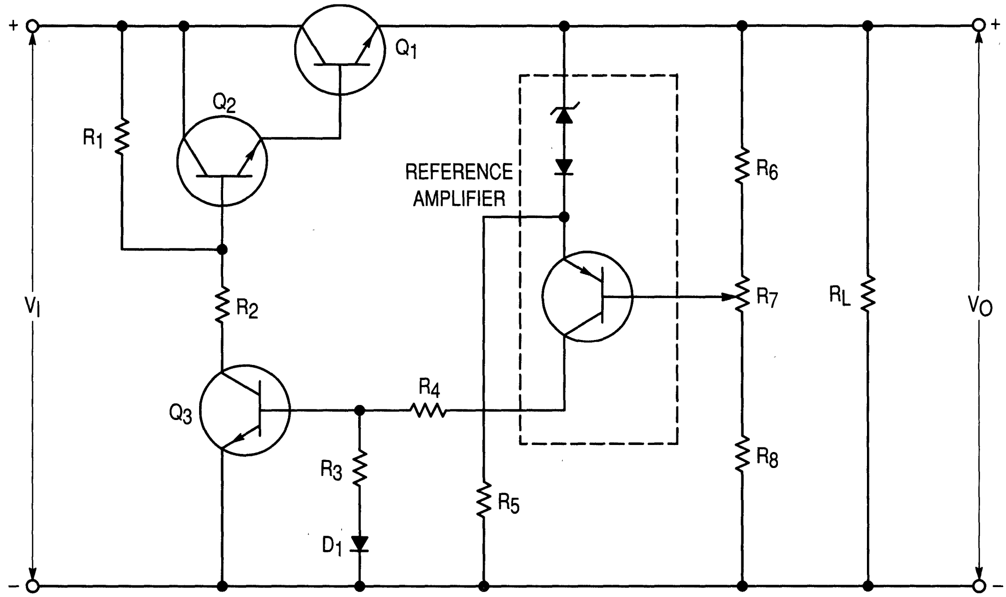

Figure 6-13. Series Pass Regulator with Temperature Compensated Reference Amplifier

Another variation of the feedback series pass regulator is shown in Figure 6-13. This circuit incorporates a stable temperature compensated reference amplifier as the primary control element.

This circuit also employs error detection and amplified feedback compensation. It is an improved version over the basic series pass regulator shown in Figure 6-10. The series element is composed of a Darlington high gain configuration formed by Q1 and Q2 for an improved regulation factor. The combined gain of the reference amplifier and Q3 is incorporated to control the series unit. This reduced the required collector current change of the reference amplifier to control the regulator so that the bias current remains close to the specified current for low temperature coefficient. Also the germanium diode D1 will compensate for the base to emitter change in Q3 and keep the reference amplifier collector biasing current fairly constant with temperature changes. Proper biasing of the zener and transistor in the reference amplifier must be adhered to if the output voltage changes are to be minimized.

6

Constant Current Sources for Regulator Applications

Several places throughout this chapter emphasize the need for maintaining a constant current level in the various biasing circuits for optimum regulation. As was mentioned previously in the discussion on the basic series pass regulator, the current limiter diode can be effectively used for the purpose.

Aside from the current limiter diode a transistorized source can be used. A widely used technique is shown incorporated in a basic series pass regulator in Figure 6-14.

configuration for a zener diode voltage regulating system. The zener impedance at 20 mA of a 1N4740 diode is typically 2 ohms. If the supply voltage now changes from 30 V to 40 V, the diode current determined by R_1 changes from 20 to 30 mA; the average zener impedance becomes 1.9 ohms; and the reference voltage shifts by 19 mV. This represents a reference change of .19%, an amount far too large for an input change of 30% in most reference supplies.

The effect of zener impedance change with current is relatively small for most input changes and will be neglected for this analysis. Assuming constant zener impedance, the zener voltage is approximated by

$$V'_Z = V_Z + Z(I'_Z - I_Z) \qquad (6\text{-}37)$$

where V'_Z is the new zener voltage
V_Z is the former zener voltage
I'_Z is the new zener current
I_Z is the new zener current flowing at V_Z
R_Z is the zener impedance

Then $\Delta V_Z = Z\Delta I_Z$

Let the input voltage V_I in Figure 6-15 increase by an amount ΔV_I

$$\text{Then } \Delta I = \frac{\Delta V_I - \Delta V_Z}{R_1} \qquad (6\text{-}38)$$

$$\text{Also } \Delta I = \frac{\Delta V_Z}{R_Z} \qquad (6\text{-}39)$$

$$\text{Solving } \Delta V_I R_Z - \Delta V_Z R_Z - \Delta V_Z R_1 = 0$$

$$\text{Or} \quad \frac{\Delta V_Z}{\Delta V_I} = \frac{R_Z}{R_1 + R_Z} \qquad (6\text{-}40)$$

Equation 6-40 merely states that the change in reference voltage with input tends to zero when the zener impedance tends also to zero, as expected.

6

The figure of merit equation can be applied to the circuits of Figure 6-16 and 6-17 to explain impedance cancellation. The Change Factor equations for each leg and the reference voltage V_R are:

$$CF_{VZ} = \frac{\Delta V_Z}{\Delta V_I} = \frac{R_Z}{R_1 + R_Z} = R_A \qquad (6\text{-}41)$$

$$CF_{V2} = \frac{\Delta V_2}{\Delta V_I} = \frac{R_3}{R_2 + R_3} = R_B \qquad (6\text{-}42)$$

$$CF_{VR} = \frac{\Delta V_R}{\Delta V_I} = \frac{R_Z}{R_1 + R_Z} = \frac{R_3}{R_2 + R_3} = R_A - R_B \qquad (6\text{-}43)$$

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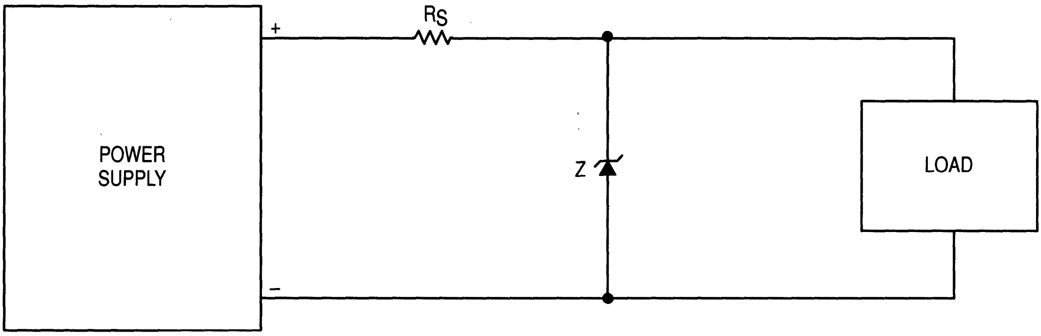

Figure 7-1. Basic Shunt Zener Transient Protection Circuit

The maximum power dissipated by the zener is

$$P_{Z(max)} = I_{Z(max)}\, V_{Z(max)} = \frac{V_{I(max)} - V_Z}{R_S}\, V_{Z(max)} \qquad (7\text{-}2)$$

Also, more than one device can be used, i.e., a series string, which will reduce the percentage of total power to be dissipated per device by a factor equal to the number of devices in series. The number of diodes required can be found from the following expression:

$$\text{Number} = \frac{P_{Z(max)}}{P_Z\ \text{(allowable per device)}} \qquad (7\text{-}3)$$

Any fraction of a zener must be taken as the next highest whole number. This design discussion has been based upon the assumption that the transient is of a single shot, non-recurrent type. For all practical purposes it can be considered non-recurrent if the “off period” between transients is at least four times the thermal time constant of the device. If the “off period” is shorter than this, then the design calculations must include a factor for the duty cycle. This is discussed in detail in Chapter 4. In Chapter 4 there are also some typical curves relating peak power, pulse duration and duty cycle that may be appropriate for some designs.

6

Obviously, the factor that limits the feasibility of the basic zener shunt protective circuit is the pulse durations “t”. As the duration increases, the allowable peak power for a given configuration decreases and will approach a steady state condition.

When the anticipated transients expected to prevail for a specific situation are of long duration, a basic zener shunt becomes impractical, in such a case the circuit can be improved by using a complementary disconnect element. The most common overload protective element is without a doubt the standard fuse. The common fuse adequately protects circuit components from over-voltage surges, but at the same time must be chosen to eliminate “nuisance fusing” which results when the maximum current rating of the fuse is too close to the normal operational current of the circuit.

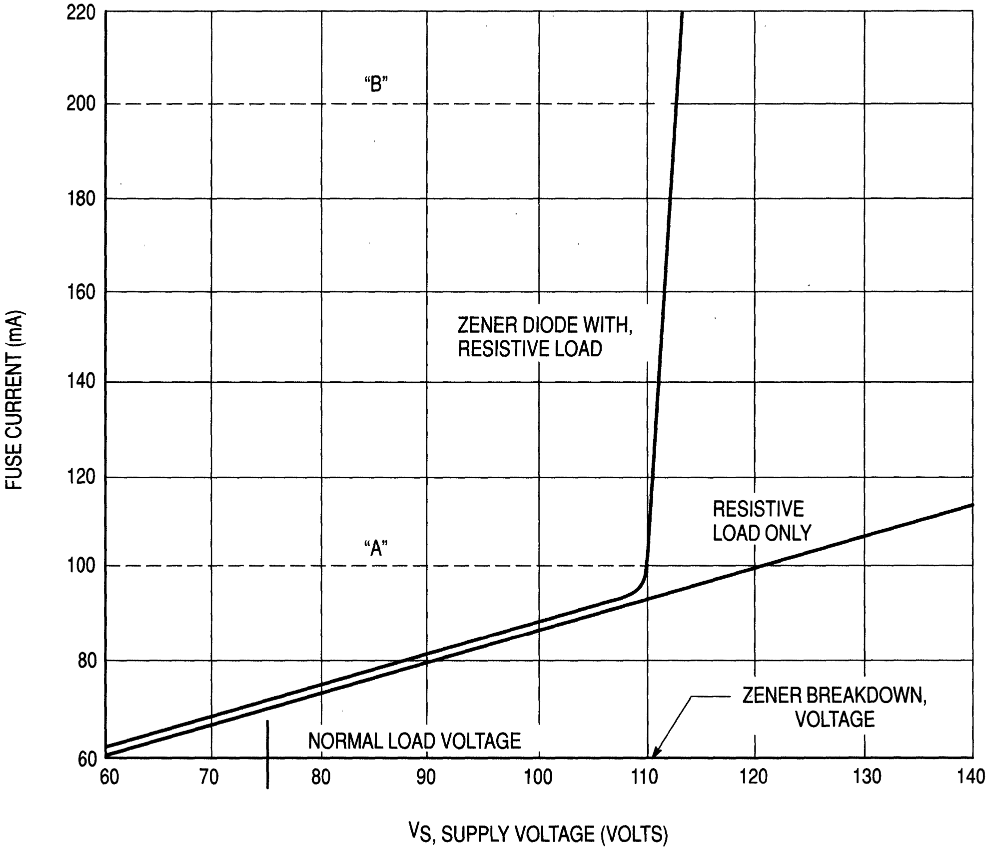

Figure 7-3. Fuse Current versus Supply Voltage

Selection of the correct power rating of zener diodes to be used for surge protection depends upon the magnitude and duration of anticipated surges. Often in circuits employing both fuses and zener diodes, the limiting surge duration will be the melting time of the fuse. This, in turn, depends on the nature of the load protected and the length of time it will tolerate an overload.

As a first solution to the example problem, consider a zener diode with a nominal breakdown voltage of 110 volts measured at a test current (I_{ZT}) of 110 mA. Since the fuse requires about 200 mA to melt and 100 mA are drawn through the load at this voltage, the load voltage will never exceed the zener breakdown voltage on slowly rising inputs. Transients producing currents of approximately 200 mA but of shorter duration than 30 ms will simply be clipped by zener action and diverted from the load. Transients of very high voltage will produce larger currents and, hence, will melt the fuse more rapidly. In the limiting case where transient power might eventually destroy the zener diode, the fuse always melts first because of the slower thermal time constant inherent in the zener diode's larger geometry.

The curves in Figure 7-4 illustrate the change in zener voltage as a function of changing current for a typical device type.

by R) to a value which may not be great enough to melt the fuse. The fault current could be sufficient, however, to damage the supply and other components in the load.

The problem is resolved by employing a zener diode to protect against supply surges as described in the previous section, and by selecting a separate fuse to protect from load faults. The load fuse in Figure 7-5 is chosen close to the normal operating current. Abnormal supply surges do not affect it and equipment operates reliably but with ample protection for the supply against load changes.

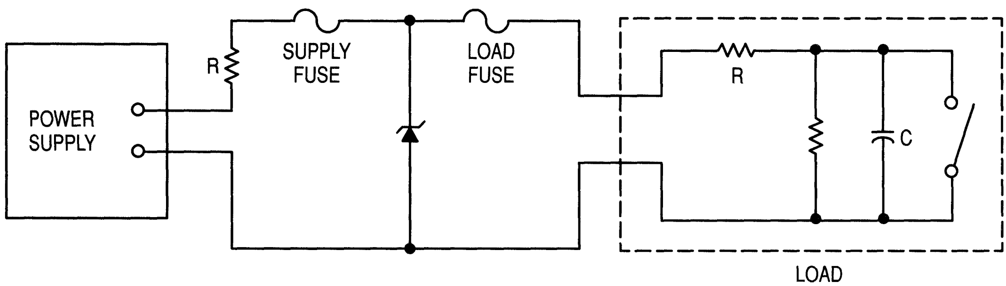

Figure 7-5. Supply and Load with Zener Diode; Fuse Circuitry

Zener Diodes and Reclosing Disconnect Elements

An interesting application of zener diodes as overvoltage protectors, which offers the possibility of designing for both long and short duration surges, is shown in Figure 7-6.

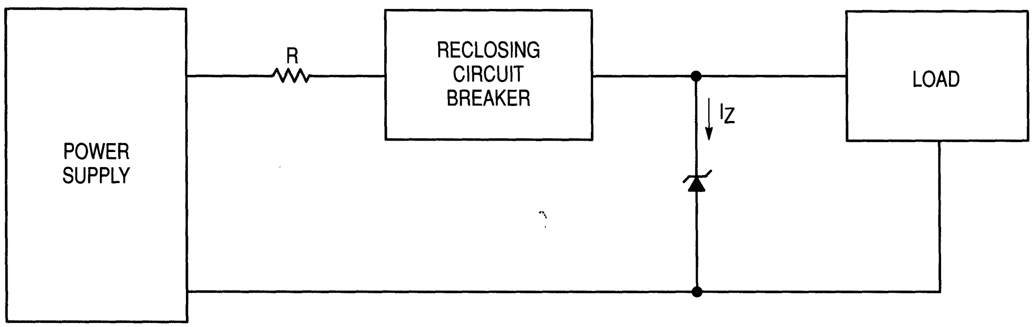

Figure 7-6. Zener Diode Reclosing Circuit Breaker Protective Circuit

In the event of a voltage overload exceeding a chosen zener voltage, a large current will be drawn through the diode. The reclosing disconnect element opens after an interval determined by its time constant, and the supply is disconnected. After another interval, again depending on the switch characteristics, the supply is reconnected and the voltage "sampled" by the zener diode. This leads to an "on-off" action which continues until the supply voltage drops below the predetermined limit. At no time can the load voltage or current exceed that set by the zener. The chief advantage in this type of circuit is the elimination of fuse replacement in similar fusing circuits, while providing essentially the same load protection.

temperatures as long as the supply voltage is greater than the zener voltage, as shown in Figure 7-7.

The zener diode current and junction temperature variation are shown in the last two waveforms of Figure 7-7. Overvoltage durations longer than the trip time of the thermal breaker do not affect the diode as the supply is disconnected. An overvoltage of much higher level simply causes the thermal breaker to open sooner. In effect, the zener diode rating must be high enough to ensure that maximum junction temperature is not reached during the longest interval that the thermal switch will be closed.

Manufacturers of thermally operated circuit breakers publish current-time curves for their devices similar to that shown in Figure 7-8. By estimating the peak supply overvoltage and determining the maximum overvoltage tolerated by the load, an estimation of peak zener current can be made. The maximum breaker trip time may then be read from Figure 7-8. (After the initial current surge, the duration of "of" time is determined entirely by the breaker characteristics and will vary widely with manufacture.) The zener diode junction temperature rise during conduction may be calculated now from the thermal time constant of the device and the heatsink used.

Because the reclosing circuit breaker is continually cycling on and off, the zener current takes on the characteristics of a repetitive surge, as can be seen in Figure 7-7.

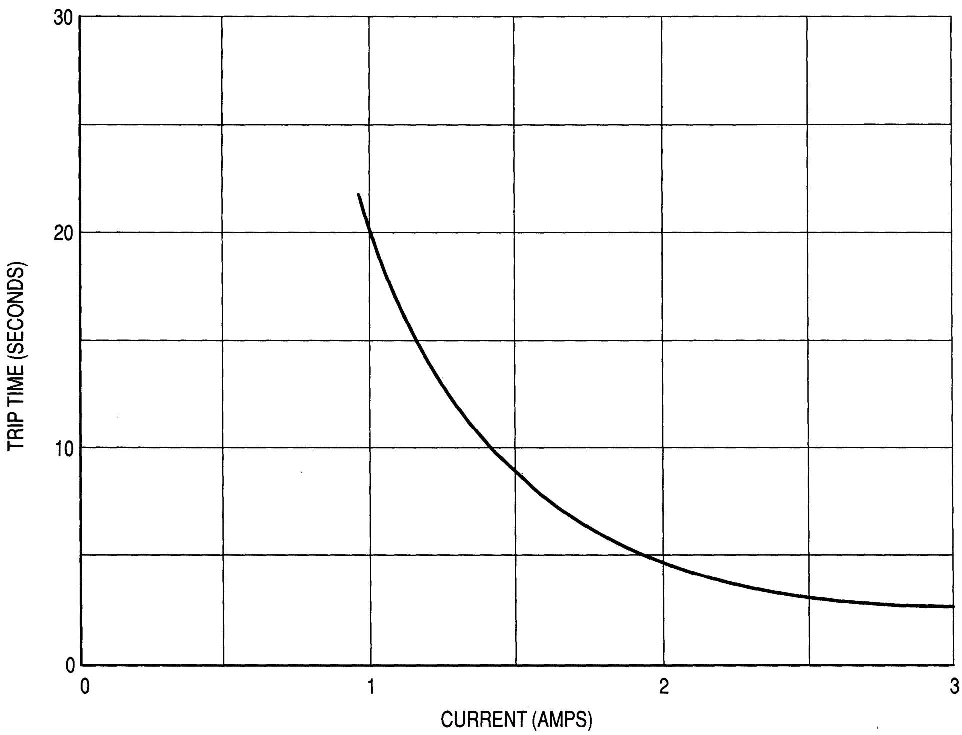

Figure 7-8. Trip Time versus Current for Thermal Breaker

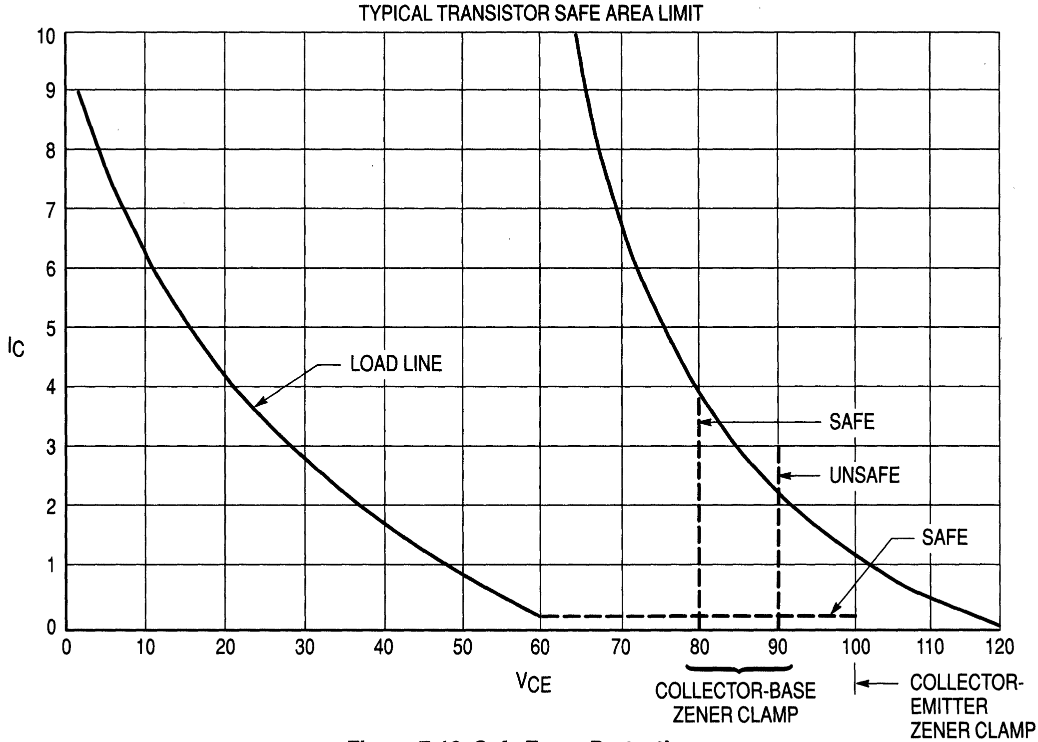

Figure 7-10. Safe Zener Protection

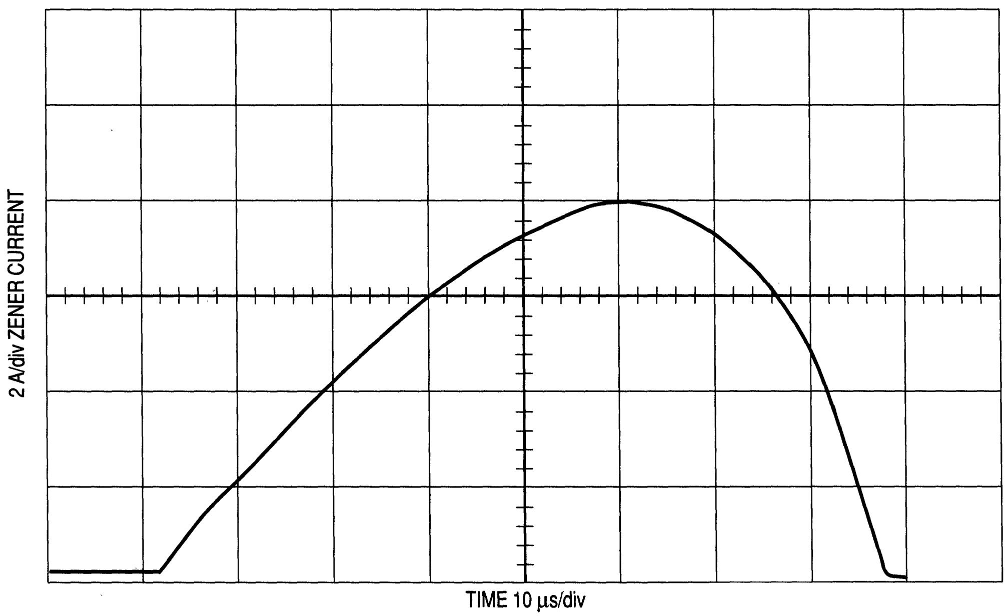

Figure 7-11. Zener Diode Current Pulse

In order to assure safe operation, the change in zener junction temperature for the peak pulse conditions must be analyzed. In making the calculation, the method described in Chapter 4 should be used, taking into account duty cycle, pulse duration, and pulse magnitude.

When the zener diode is connected between the collector and emitter of the transistor, additional power dissipation will result from the clipping of the ringing voltage of the ignition coil by the forward conduction of the zener diode. This power dissipation by the forward diode current will result in additional zener voltage rise. It is not uncommon to observe a 15-volt rise above the zener device voltage rating due to temperature coefficient and impedance under these pulse current conditions.

The zener diode should be connected as close as possible to the terminals of the transistor the zener is intended to protect. This insures that induced voltage transients, caused by current changes in long lead lengths, are clamped by the zener and do not appear across the transistor.

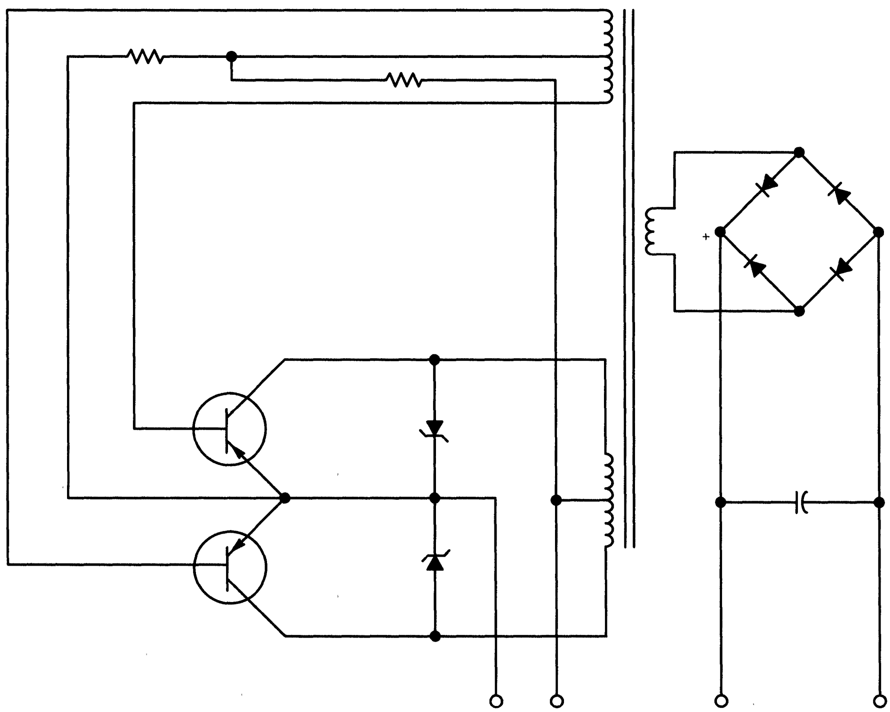

Figure 7-13. DC-DC Converter with Surge Protecting Diodes

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Another example of overvoltage protection of transistor operating in an inductive load switch capacity is illustrated in Figure 7-13. The DC-DC converter circuit shows a connection from collector to emitter of two zener diodes as collector overvoltage protectors. Without some type of limiting device, large voltage spikes may appear at the collectors, due to

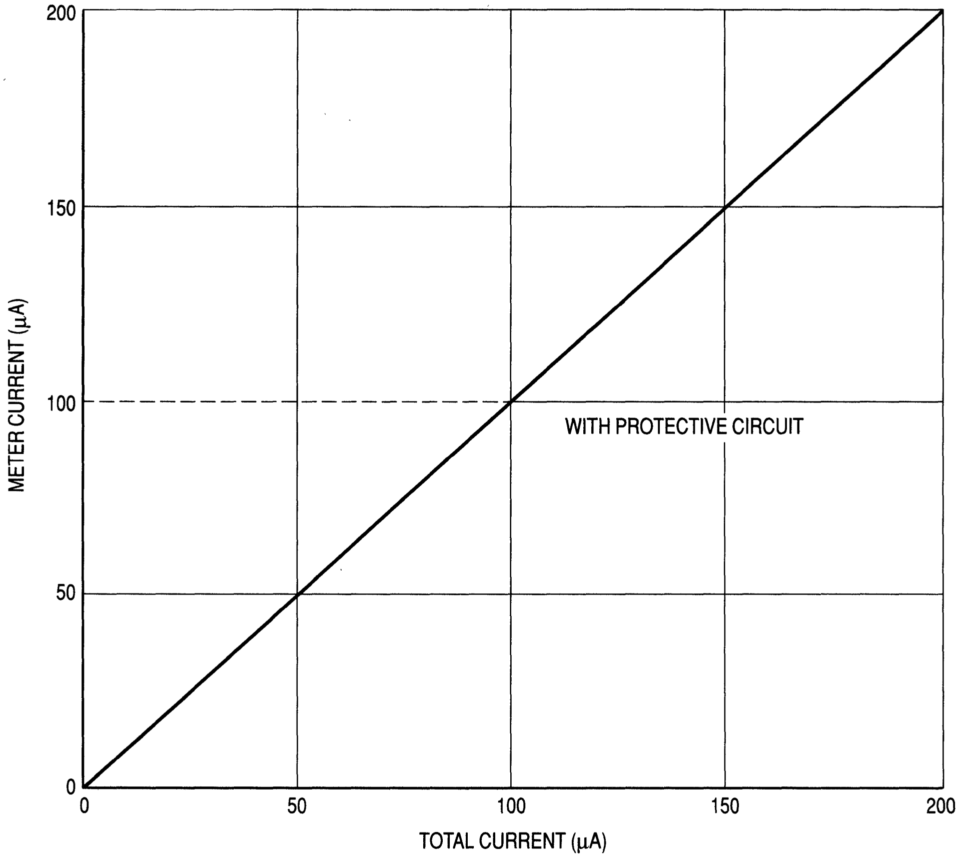

Figure 7-15. Meter Protection with Zener Diodes

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Zener Diodes Used With SCRs For Circuit Protection

An interesting aspect of circuit protection incorporating the reliable zener diode is the protective circuits shown in Figures 7-16 and 7-17.

In a system that is handling large amounts of power, it may become impractical to employ standard zener shunt protection because of the large current it would be required to carry. The SCR crowbar technique shown in Figure 7-16 can be effectively used in these situations. The zener diode is still the transient detection component, but it is only required to carry the gate current for SCR turn on, and the SCR will carry the bulk of the shunt current. Whenever the incoming voltage exceeds the zener voltage, it avalanches, supplying gate drive to the SCR which, when fired, causes a current demand that will trip the circuit breaker. The resistors shown are for current limiting so that the SCR and zener ratings are not exceeded.

The circuit of Figure 7-17 is designed to disconnect the supply in the event a specified load current is exceeded. This is done by means of a series sense resistor and a compatible zener

The design of the suppressor-fuse combination for the required level of protection follows the techniques for conventional zeners discussed earlier in this chapter.

Transient Suppression Characteristics

Zener diodes, being nearly ideal clippers (that is, they exhibit close to an infinite impedance below the clipping level and close to a short circuit above the clipping level), are often used to suppress transients. In this type of application, it is important to know the power capability of the zener for short pulse durations, since they are intolerant of excessive stress.

Some Motorola data sheets such as the ones for devices shown in Table 7-1 contain short pulse surge capability. However, there are many data sheets that do not contain this data and Figure 7-18 is presented here to supplement this information.

Table 7-1. Transient Suppressor Diodes

Series Numbers	Steady State Power	Package	Description
1N4728A	1 W	DO-41	Double Slug Glass
1N6267A	5 W	Case 41A-02	Axial Lead Plastic
1N5333B	5 W	Case 17-02	Surmetic 40
1N746A/957B/4370A	500 mW	DO-35	Double Slug Glass
1N5221B	500 mW	DO-35	Double Slug Glass

Some data sheets have surge information which differs slightly from the data shown in Figure 7-18. A variety of reasons exist for this:

1. The surge data may be presented in terms of actual surge power instead of nominal power.
2. Product improvements have occurred since the data sheet was published.
3. Large dice are used, or special tests are imposed on the product to guarantee higher ratings than those shown in Figure 7-18.
4. The specifications may be based on a JEDEC registration or part number of another manufacturer.

6

The data of Figure 7-18 applies for non-repetitive conditions and at a lead temperature of 25°C. If the duty cycle increases, the peak power must be reduced as indicated by the curves of Figure 7-19. Average power must be derated as the lead or ambient temperature rises above 25°C. The average power derating curve normally given on data sheets may be normalized and used for this purpose.

When it is necessary to use a zener close to surge ratings, and a standard part having guaranteed surge limits is not suitable, a special part number may be created having a surge limit as part of the specification. Contact your nearest Motorola OEM sales office for capability, price, delivery, and minimum order quantities.

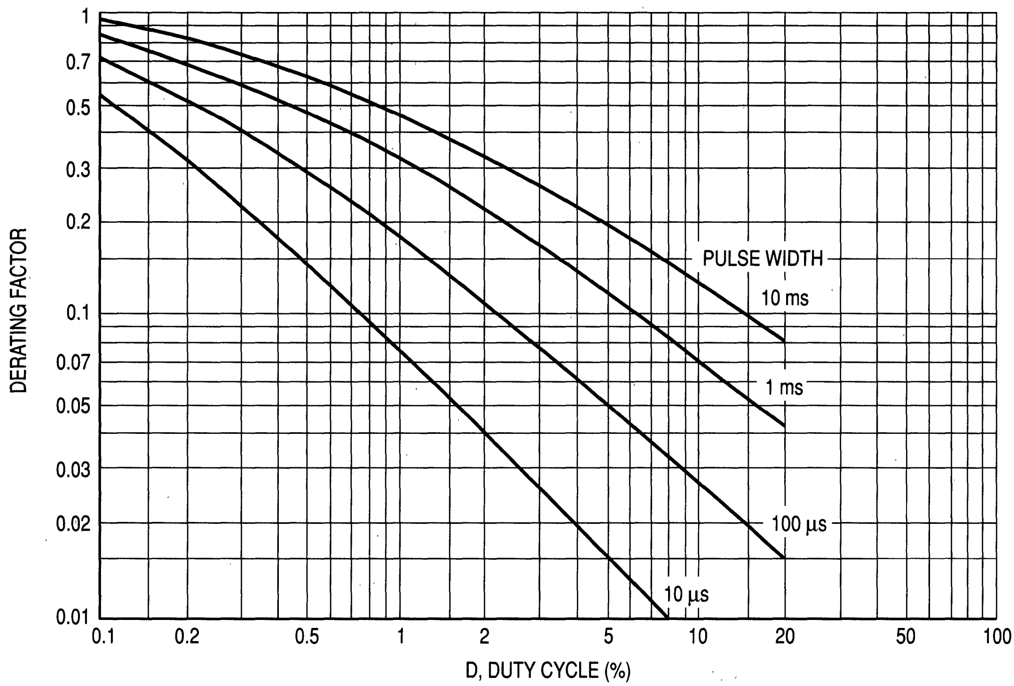


Figure 7-19. Typical Derating Factor for Duty Cycle

For modeling purposes, an approximation of the zener resistance is needed. It is obtained from:

$$R_{Z(nom)} = \frac{V_{Z(nom)}(F_{C}-1)}{P_{PK(nom)} / V_{Z(nom)}} \quad (7\text{-}7)$$

6

The value is approximate because both the clamping factor and the actual resistance are a function of temperature.

Circuit Considerations

It is important that as much impedance as circuit constraints allow be placed in series with the zener diode and the components to be protected. The result will be a lower clipping voltage and less zener stress. A capacitor in parallel with the zener is also effective in reducing the stress imposed by very short duration transients.

To illustrate use of the data, a common application will be analyzed. The transistor in Figure 7-20 drives a 50 mH solenoid which requires 5 amperes of current. Without some means of clamping the voltage from the inductor when the transistor turns off, it could be destroyed.

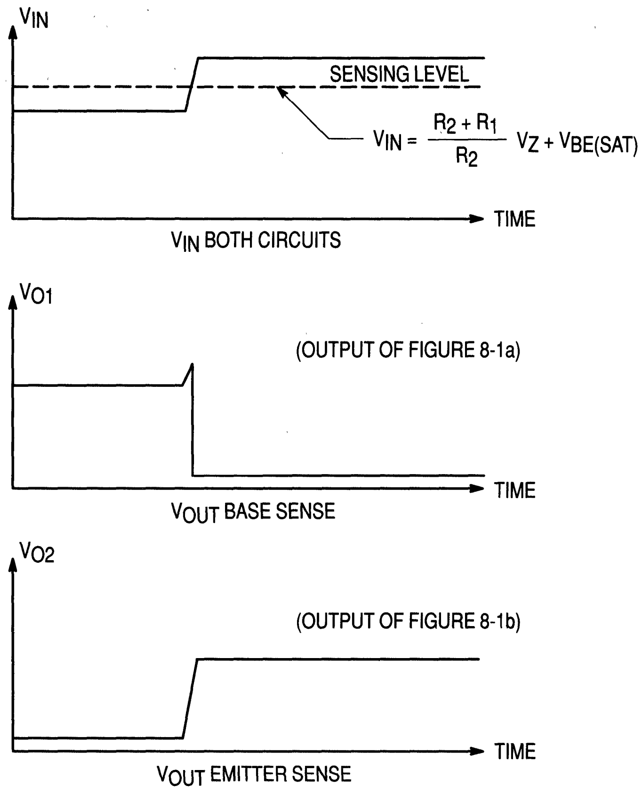


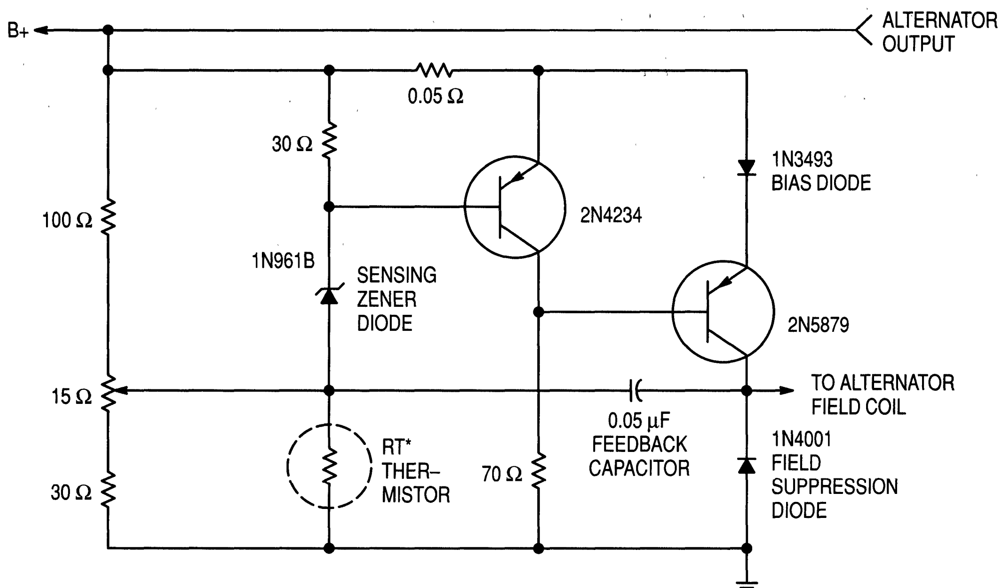
Figure 8-2. Outputs of Transistor-Zener Voltage Sensing Circuits

The emitter sense circuit of Figure 8-1b operates as follows: When the input is low the voltage drop across R_3 (the output) is negligible. As the input voltage increases the voltage drop across R_2 biases the zener into conduction and forward biases the base-emitter junction. A large voltage drop across R_3 (the output voltage) is equal to the product of the collector current times the resistance, R_3. The following relationships indicate the basic operating conditions for the circuits in Figure 8-1.

6

Circuit	Output
8-1a	High $V_{OUT} = V_{IN} - I_{CO}R_3 \cong V_{IN}$ Low $V_{OUT} = V_{IN} - I_CR_3 = V_{CE(sat)}$
8-1b	Low $V_{OUT} = V_{IN} - V_Z - V_{CE(off)} = I_{CO}R_3$ High $V_{OUT} = V_{IN} - V_{CE(sat)} = I_CR_3$

In addition, the basic circuits of Figure 8-1 can be rearranged to provide inverse output.



*THE VALUE OF RT DEPENDS ON THE SLOPE OF THE VOLTAGE REGULATION VERSUS TEMPERATURE CURVE.

Figure 8-4. Complete Solid State Alternator Voltage Regulator

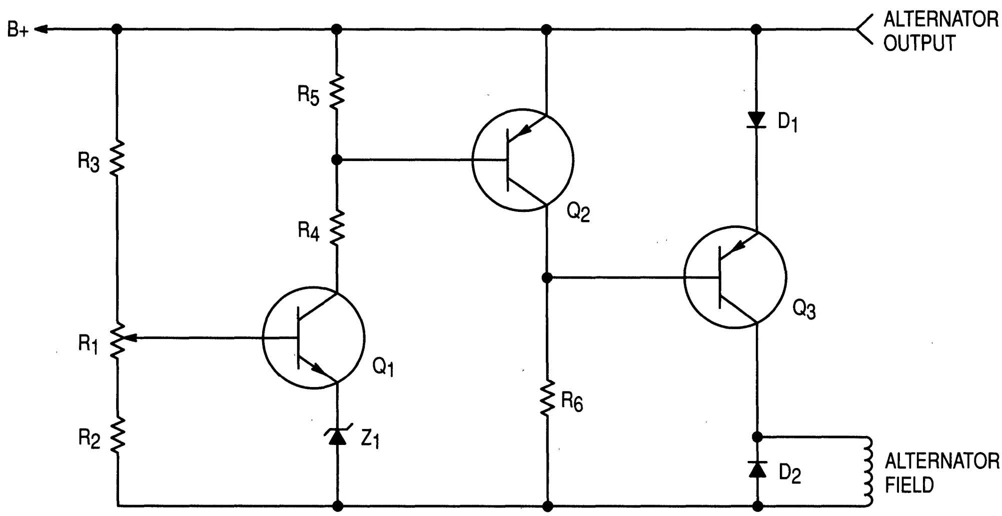


Figure 8-5. Alternator Regulator With Emitter Sensor

A schematic of a complete alternator voltage regulator is shown in Figure 8-4.

It is also possible to perform the alternator regulation function with the sensing element in the emitter of the control transistor as shown in Figure 8-5.

In this configuration, the sensing circuit is composed of Z_1 and Q_1 with biasing components. It is similar to the sensing circuit shown in Figure 8-1b. The potentiometer R_1 adjusts

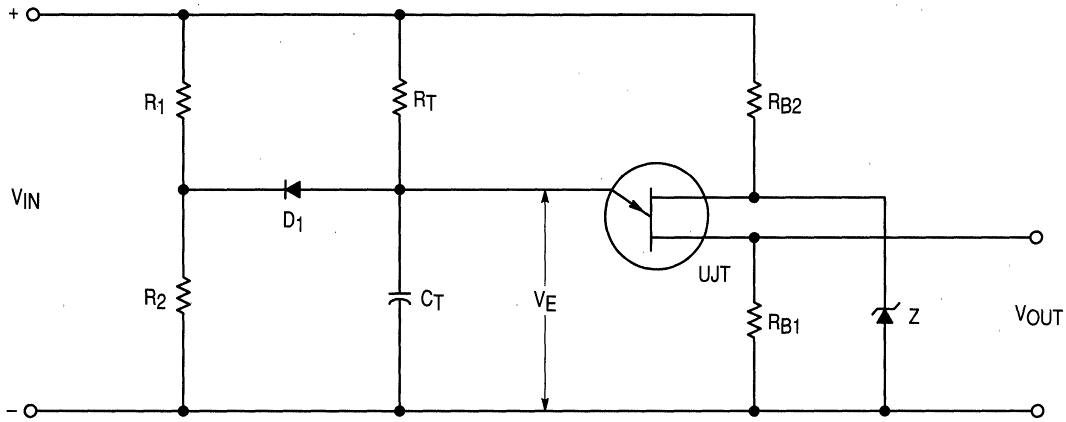


Figure 8-7. UJT — NO GO Output, NO GO for Low V_{IN} — GO for High V_{IN}

The circuit of Figure 8-7, is a clamped base UJT oscillator. In this circuit V_{BB} is clamped at a voltage V_Z and the emitter tied to a voltage dividing network by a diode D_1. When the input voltage is low, the voltage drop across R_2 is less than V_P. The forward biased diode holds the emitter below the trigger level. As the input increases, the R_2 voltage drop approaches V_P. The diode D_1 becomes reversed biased and, the UJT triggers. This phenomenon establishes the operating criterion that the circuit is NO GO at a low input and GO at an input higher than the clamp voltage. Therefore, the circuits in Figures 8-6 and 8-7 are both input voltage sensitive, but have opposite input requirements for a GO condition. To illustrate the usefulness of the clamped UJT relaxation oscillators, the following two sections show them being used in practical applications.

Battery Voltage Sensitive SCR Charger

A clamped emitter unijunction sensing circuit of the type shown in Figure 8-6 makes a very good battery charger (illustrated in Figure 8-8). This circuit will not operate until the battery to be charged is properly connected to the charger. The battery voltage controls the charger and will dictate its operation. When the battery is properly charged, the charger will cease operation.

6

The battery charging current is obtained through the controlled rectifier. Triggering pulses for the controlled rectifier are generated by unijunction transistor relaxation oscillator (Figure 8-9). This oscillator is activated when the battery voltage is low.

While operating, the oscillator will produce pulses in the pulse transformer connected across the resistance, R_{GC} (R_{GC} represents the gate-to-cathode resistance of the controlled rectifier), at a frequency determined by the resistance, capacitance, R.C. time delay circuit.

Since the base-to-base voltage on the unijunction transistor is derived from the charging battery, it will increase as the battery charges. The increase in base-to-base voltage of the unijunction transistor causes its peak point voltage (switching voltage) to increase. These waveforms are sketched in Figure 8-9 (this voltage increase will tend to change the pulse repetition rate, but this is not important).

When the peak point voltage (switching voltage) of the unijunction transistor exceeds the breakdown voltage of the Zener diode, Z_1, connected across the delay circuit capacitor, C_1, the unijunction transistor ceases to oscillate. If the relaxation oscillator does not operate, the controlled rectifier will not receive trigger pulses and will not conduct. This indicates that the battery has attained its desired charge as set by R_2.

The unijunction cannot oscillate unless a voltage somewhere between 3 volts and the cutoff setting is present at the output terminals with polarity as indicated. Therefore, the SCR cannot conduct under conditions of a short circuit, an open circuit, or a reverse polarity connection to the battery.

Alternator Regulator for Permanent Magnet Field

In alternator circuits such as those of an outboard engine, the field may be composed of a permanent magnet. This increases the problem of regulating the output by limiting the control function to opening or shorting the output. Because of the high reactance source of most alternators, opening the output circuit will generally stress the bridge rectifiers to a very high voltage level. It is, therefore, apparent that the best control function would be shorting the output of the alternator for regulation of the charge to the battery.

Figure 8-10 shows a permanent magnet alternator regulator designed to regulate a 15 ampere output. The two SCRs are connected on the ac side of the bridge, and short out the alternator when triggered by the unijunction voltage sensitive triggering circuit. The sensing circuit is of the type shown in Figure 8-7. The shorted output does not appreciably increase the maximum output current level.

A single SCR could be designed into the dc side of the bridge. However, the rapid turn-off requirement of this type of circuit at high alternator speeds makes this circuit impractical.

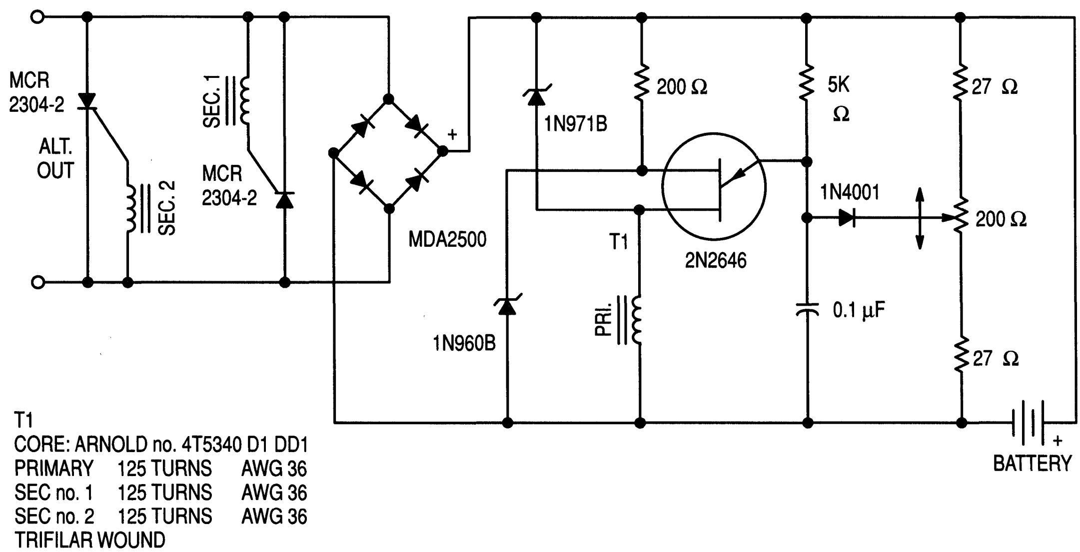


Figure 8-10. Permanent Magnet Field Alternator Regulator

If, for example, the input is variable from 24 to 28 volts, a 30 voltmeter would normally be required. Unfortunately, a 4 volt range of values on a 30 volt scale utilizes only 13.3% of the meter movement — greatly limiting the accuracy with which the meter can be read. By employing a 20 volt zener, one can use a 10 voltmeter instead of the 30 volt unit, thereby utilizing 40% of the meter movement instead of 13.3% with a corresponding increase in accuracy and readability. For ultimate accuracy a 24 volt zener could be combined with a 5 voltmeter. This combination would have the disadvantage of providing little room for voltage fluctuations, however.

In Figure 8-13, a number of sequentially higher-voltage Zener sense circuits are cascaded to actuate transistor switches. As each goes into avalanche its respective switching transistor is turned on, actuating the indicator light for that particular voltage level. This technique can be expanded and modified to use the zener sensors to actuate some form of logic system.

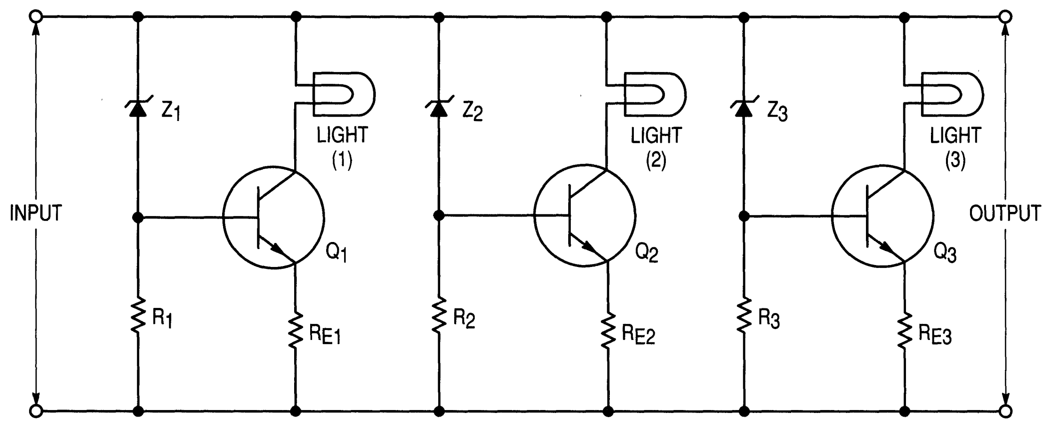


Figure 8-13. Sequential Voltage Level Indicator

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where $B_{S1}A_1$ is the flux capacity of T_1 transformer core. The effect on output frequency of V_{BE} variations due to changing load or temperature can be reduced by using a zener diode in series with V_{BE} as shown in Figure 9-1. For this circuit, the output frequency is given by

$$f = \frac{(V_{BE} + V_Z) \times 10^8}{4B_{S1}A_1N_B}$$

If V_{BE} is small compared to the zener voltage V_Z, good frequency accuracy is possible. For example, with V_Z = 9.1 volts, a 40 Watt inverter using 2N3791 transistors (operating from a 12 volt supply), exhibited frequency regulation of ±2% with ±25% load variation.

Care should be taken not to exceed $V_{(BR)EBO}$ of the non-conducting transistor, since the reverse emitter-base voltage will be twice the introduced series voltage, plus V_{BE} of the conducting device.

Transformer T_2 should not saturate at the lowest inverter frequency.

Inverter starting is facilitated by placing a resistor from point A to B_1 or a capacitor from A to B_2.

Simple Square Wave Generator

The zener diode is widely used in wave shaping circuits; one of its best known applications is a simple square wave generator. In this application, the zener clips sinusoidal waves producing a square wave such as shown in Figure 9-2a. In order to generate a wave with reasonably vertical sides, the ac voltage must be considerably higher than the zener voltage.

Clipper diodes with opposing junctions built into the device are ideal for applications of the type shown in Figure 9-2b.

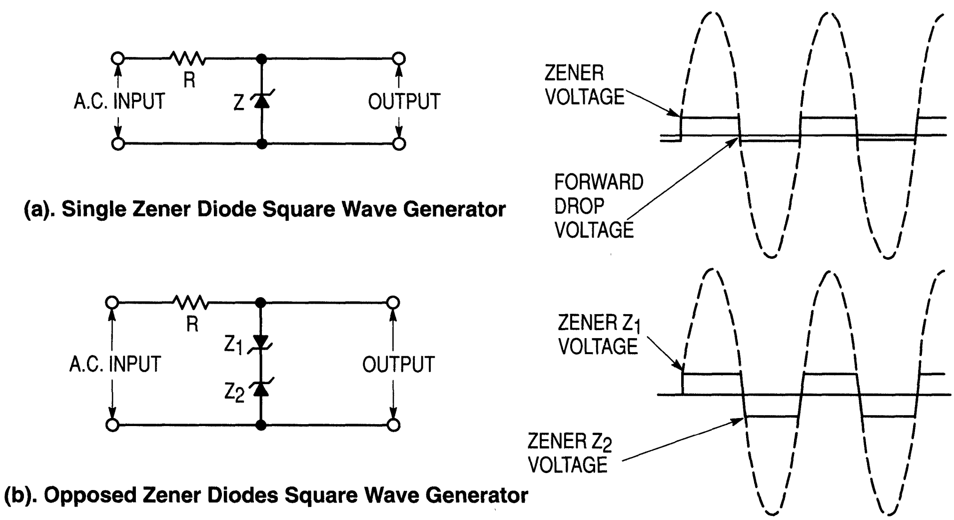

Figure 9-2. Zener Diode Square Wave Generator

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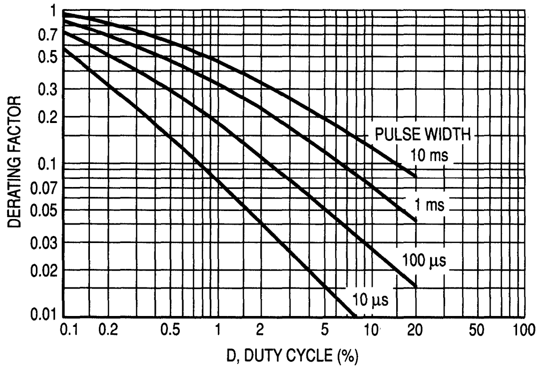

Figure 2. Typical Derating Factor for Duty Cycle

MATHEMATICAL MODEL

Since the power shown on the curves is not the actual transient power measured, but is the product of the peak current measured and the nominal zener voltage measured at the current used for voltage classification, the peak current can be calculated from:

$$I_{Z(PK)} = \frac{P_{(PK)}}{V_{Z(NOM)}} \quad (1)$$

The peak voltage at peak current can be calculated from:

$$V_{Z(PK)} = F_C \times V_{Z(NOM)} \quad (2)$$

where F_C is the clamping factor. The clamping factor is approximately 1.20 for all zener diodes when operated at their pulse power limits. For example, a 5 watt, 20 volt zener can be expected to show a peak voltage of 24 volts regardless of whether it is handling 450 watts for 0.1 ms or 50 watts for 10 ms. This occurs because the voltage is a function of junction temperature and IR drop. Heating of the junction is more severe at the longer pulse width, causing a higher voltage component due to temperature which is roughly offset by the smaller IR voltage component.

For modeling purposes, an approximation of the zener resistance is needed. It is obtained from:

$$R_{Z(NOM)} = \frac{V_{Z(NOM)}(F_C - 1)}{P_{PK(NOM)}/V_{Z(NOM)}} \quad (3)$$

The value is approximate because both the clamping factor and the actual resistance are a function of temperature.

CIRCUIT CONSIDERATIONS

It is important that as much impedance as circuit constraints allow be placed in series with the zener diode and the components to be protected. The result will be a lower clipping voltage and less zener stress. A capacitor in parallel with the zener is also effective in reducing the stress imposed by very short duration transients.

To illustrate use of the data, a common application will be analyzed. The transistor in Figure 3 drives a 50 mH solenoid which requires 5 amperes of current. Without some means of clamping the voltage from the inductor when the transistor turns off, it could be destroyed.

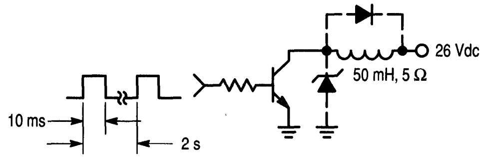

Figure 3. Circuit Example

Used to select a zener diode having the proper voltage and power capability to protect the transistor.

The means most often used to solve the problem is to connect an ordinary rectifier diode across the coil; however, this technique may keep the current circulating through the coil for too long a time. Faster switching is achieved by allowing the voltage to rise to a level above the supply before being clamped. The voltage rating of the transistor is 60 V, indicating that approximately a 50 volt zener will be required.

The peak current will equal the on-state transistor current (5 amperes) and will decay exponentially as determined by the coil L/R time constant (neglecting the zener impedance). A rectangular pulse of width L/R (0.01 sec) and amplitude of I_{PK} (5 A) contains the same energy and may be used to select a zener diode. The nominal zener power rating therefore must exceed (5 A × 50) = 250 watts at 10 ms and a duty cycle of 0.01/2 = 0.5%. From Figure 2, the duty cycle factor is 0.62 making the single pulse power rating required equal to 250/0.62 = 403 watts. From Figure 1, one of the 1N6267 series zeners has the required capability. The 1N6287 is specified nominally at 47 volts and should prove satisfactory.

Although this series has specified maximum voltage limits, equation 3 will be used to determine the maximum zener voltage in order to demonstrate its use.

$$R_Z = \frac{47(1.20 - 1)}{500/47} = \frac{9.4}{10.64} = 0.9\Omega$$

At 5 amperes, the peak voltage will be 4.5 volts above nominal or 51.5 volts total which is safely below the 60 volt transistor rating.

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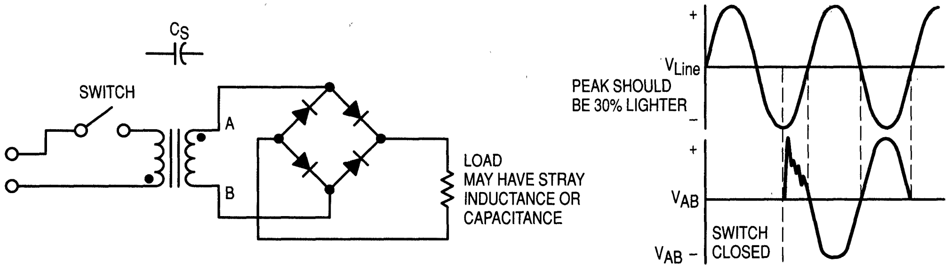

Figure 2. Situation Where Transformer Capacitance Causes a Transient

TRANSFORMER PRIMARY BEING DE-ENERGIZED

If the transformer is driving a high impedance load, transients of more than ten times normal voltage can be created at the secondary when the primary circuit of the transformer is opened during zero-voltage crossing of the ac line. This is due to the interruption of the transformer magnetizing current which causes a rapid collapse of the magnetic flux in the core. This, in turn, causes a high voltage transient to be coupled into the transformer's secondary winding (Figure 3).

Transients produced by interrupting transformers magnetizing current can be severe. These transients can destroy a rectifier diode or filter capacitor if a low impedance discharge path is not provided.

SWITCH "ARCING"

When a contact type switch opens and tries to interrupt current in an inductive circuit, the inductance tries to keep current flowing by charging stray capacitances. (See Figure 4.)

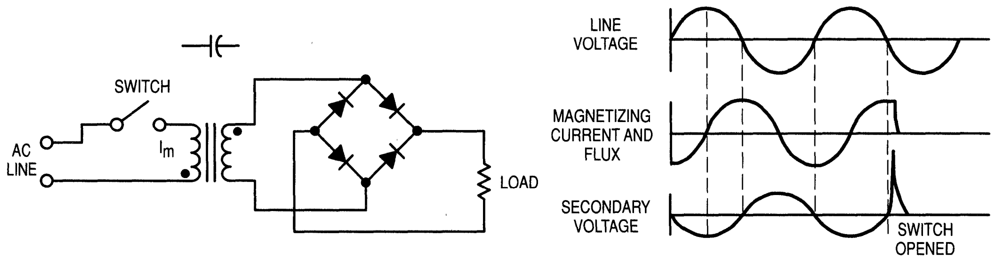

Figure 3. Typical Situation Showing Possible Transient When Interrupting Transformer Magnetizing Current

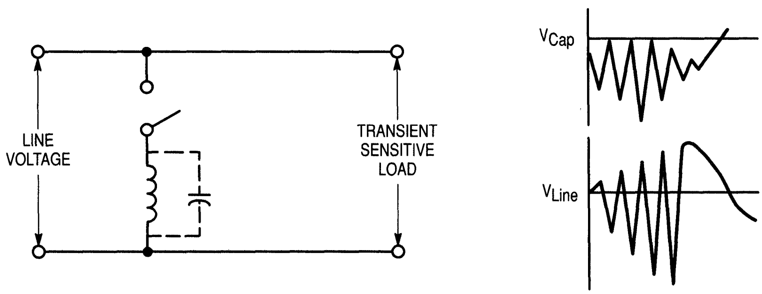

Figure 4. Transients Caused by Switch Opening

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The type of device under test determines which waveshape in Figure 6 is more appropriate. The voltage waveform is normally used for insulation voltage withstand tests and the current waveform is usually used for discharge current tests.

RANDOM TRANSIENTS

The source powering the circuit or system is frequently the cause of transient induced problems or failures. These transients are difficult to deal with due to their nature; they are totally random and it is difficult to define their amplitude, duration and energy content. These transients are generally caused by switching parallel loads on the same branch of a power distribution system and can also be caused by lightning.

AC POWER LINE TRANSIENTS

Transients on the ac power line range from just above normal voltage to several kV. The rate of occurrence of transients varies widely from one branch of a power distribution system to the next, although low-level transients occur more often than high-level surges.

Data from surge counters and other sources is the basis for the curves shown in Figure 7. This data was taken from unprotected (no voltage limiting devices) circuits meaning that the transient voltage is limited only by the sparkover distance of the wires in the distribution system.

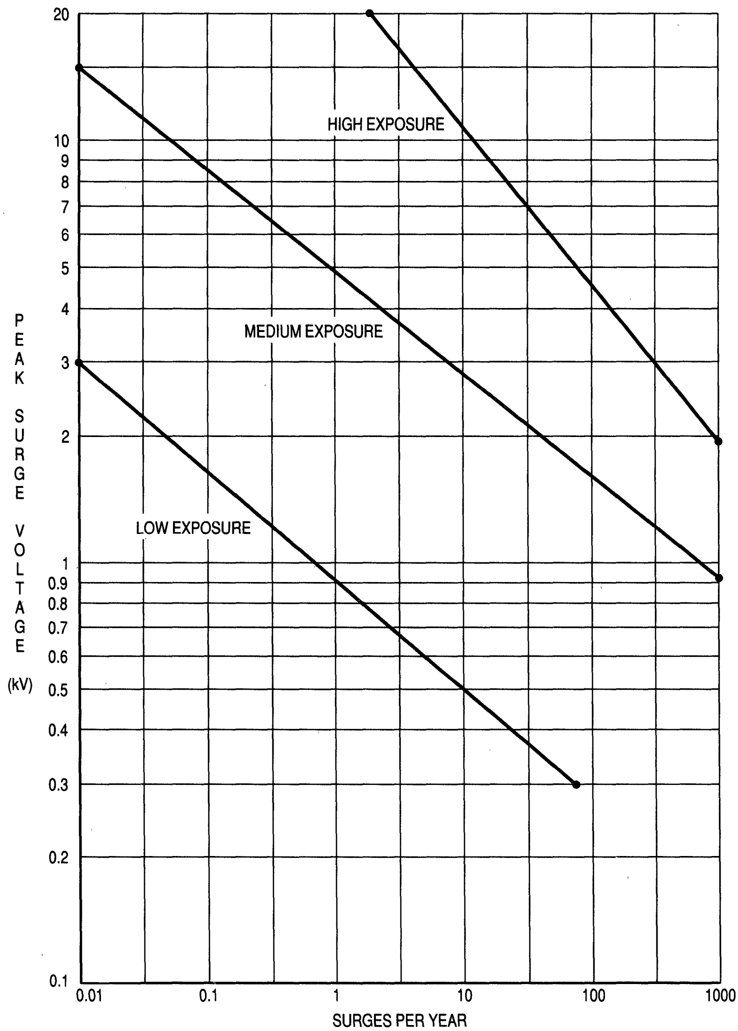

Figure 7. Peak Surge Voltage versus Surges per Year*

*EIA paper, P587.1/F, May, 1979, Page 10 he discharge currents of Category II were obtained from simulated lightning tests and field experience with suppressor performance.

The surge currents in Category I are less than in Category II because of the increase in surge impedance due to the fact that Category I is further away from the service entrance.

Category III can be compared to the "High Exposure" situation in Figure 7. The limiting effect of sparkover is not available here so the transient voltage can be quite large.

LIGHTNING TRANSIENTS

There are several mechanisms in which lightning can produce surge voltages on power distribution lines. One of them is a direct lightning strike to a primary (before the substation) circuit. When this high current, that is injected into the power line, flows through ground resistance and the surge impedance of the conductors, very large transient voltages will be produced. If the lightning misses the primary power line but hits a nearby object the lightning discharge may also induce large voltage transients on the line. When a primary circuit surge arrester operates and limits the primary voltage the rapid dv/dt produced will effectively couple transients to the secondary circuit through the capacitance of the transformer (substation) windings in addition to those coupled into the secondary circuit by normal transformer action. If lightning struck the secondary circuit directly, very high currents may be involved which would exceed the capability of conventional surge suppressors. Lightning ground current flow resulting from nearby direct to ground discharges can couple onto the common ground impedance paths of the grounding networks also causing transients.

AUTOMOTIVE TRANSIENTS

Transients in the automotive environment can range from the noise generated by the ignition system and the various accessories (radio, power window, etc.) to the potentially destructive high energy transients caused by the charging (alternator/regulator) system. The automotive "Load Dump" can cause the most destructive transients; it is when the battery becomes disconnected from the charging system during high charging rates. This is not unlikely when one considers bad battery connections due to corrosion or other wiring problems. Other problems can exist such as steady state overvoltages caused by regulator failure or 24 V battery jump starts. There is even the possibility of incorrect battery connection (reverse polarity).

Capacitive and/or inductive coupling in wire harnesses as well as conductive coupling (common ground) can transmit these transients to the inputs and outputs of automotive electronics.

The Society of Automotive Engineers (SAE) documented a table describing automotive transients (see Table 2) which is useful when trying to provide transient protection.

Table 2. Typical Transients Encountered in the Automotive Environment

Length of Transient	Cause	Energy Capability / Voltage Amplitude	Possible Frequency of Application
Steady State	Failed Voltage Regulator	∞ +18 V	Infrequent
5 Minutes	Booster starts with 24 V battery	∞ ±24 V	Infrequent
4.5–100 ms	Load Dump — i.e., disconnection of battery during high charging rates	≥ 10 J ≤ 125 V	Infrequent
≤ 0.32 s	Inductive Load Switching Transient	< 1 J –300 V to +80 V	Often
≤ 0.2 s	Alternator Field Decay	< 1 J –100 V to –40 V	Each Turn-Off
90 ms	Ignition Pulse Disconnected Battery	< 0.5 J ≤ 75 V	≤ 500 Hz Several Times in vehicle life
1 ms	Mutual Coupling in Harness	< 1 J ≤ 200 V	Often
15 μs	Ignition Pulse Normal	< 0.001 J 3 V	≤ 500 Hz Continuous
	Accessory Noise	≤ 1.5 V	50 Hz to 10 kHz
	Transceiver Feedback	≈ 20 mV	R.F.

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Most zeners handle less than their rated power during normal applications and are designed to operate most effectively at this low level. Zener transient suppressors such as the Motorola 1N6267 Mosorb series are designed to take large, short duration power pulses.

This is accomplished by enlarging the chip and the effective junction area to withstand the high energy surges. The package size is usually kept as small as possible to provide space efficiency in the circuit layout, and since the package does not differ greatly from other standard zener packages, the steady state power dissipation does not differ greatly.

Some data sheets contain information on short pulse surge capability. When this information is not available for Motorola devices, Figure 8 can be used. This data applies for non-repetitive conditions with a lead temperature of 25°C.

It is necessary to determine the pulse width and peak power of the transient being suppressed when using Figure 8. This can be done by taking whatever waveform the transient is and approximating it with a rectangular pulse with the same peak power. For example, an exponential discharge with a 1 ms time constant can be approximated by a rectangular pulse 1 ms wide that has the same peak power as the transient. This would be a better approximation than a rectangular pulse 10 ms wide with a correspondingly lower amplitude. This is because the heating effects of different pulse width lengths affect the power handling capability, as can be seen by Figure 8. This also represents a conservative approach because the exponential discharge will contain ≈ 1/2 the energy of a rectangular pulse with the same pulse width and amplitude.

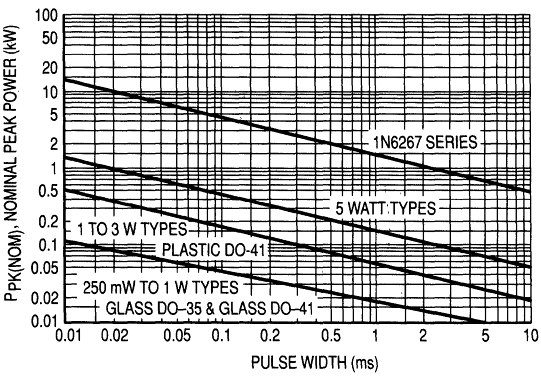

Figure 8. Peak Power Ratings of Zener Diodes

When used in repetitive applications, the peak power must be reduced as indicated by the curves of Figure 9. Average power must be derated as the lead or ambient temperature exceeds 25°C. The power derating curve normally given on data sheets can be normalized and used for this purpose.

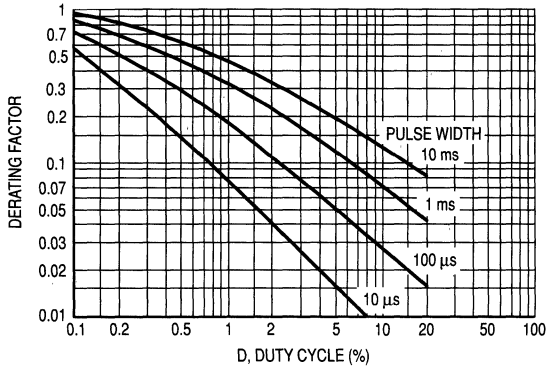

Figure 9. Typical Derating Factor for Duty Cycle

The peak zener voltage during the peak current of the transient being suppressed can be related to the nominal zener voltage (Eqtn 1) by the clamping factor (F_C).

Eqtn 1: $V_{Z(pK)} = F_C\,(V_{Z(nom)})$

Unless otherwise specified F_C is approximately 1.20 for zener diodes when operated at their pulse power limits.

For example, a 5 watt, 20 volt zener can be expected to show a peak voltage of 24 volts regardless of whether it is handling 450 watts for 0.1 ms or 50 watts for 10 ms. (See Figure 8.)

This occurs because the zener voltage is a function of both junction temperature and IR drop. Longer pulse widths cause a greater junction temperature rise than short ones; the increase in junction temperature slightly increases the zener voltage. This increase in zener voltage due to heating is roughly offset by the fact that longer pulse widths of identical energy content have lower peak currents. This results in a lower IR drop (zener voltage drop) keeping the clamping factor relatively constant with various pulse widths of identical energy content.

An approximation of zener impedance is also helpful in the design of transient protection circuits. The value of $R_{Z(nom)}$ (Eqtn 2) is approximate because both the clamping factor and the actual resistance is a function of temperature.

$$\text{Eqtn 2: } R_{Z(nom)} = \frac{V^2_{Z(nom)}\,(F_C - 1)}{P_{pK(nom)}}$$

$V_{Z(nom)}$ = Nominal Zener Voltage

$P_{pK(nom)}$ = Found from Figure 8 when device type and pulse width are known. For example, from Figure 8 a 1N6267 zener suppressor has a $P_{pK(nom)}$ of 1.5 kW at a pulse width of 1 ms.

As seen from equation 2, zeners with a larger $P_{pK(nom)}$ capability will have a lower $R_{Z(nom)}$.

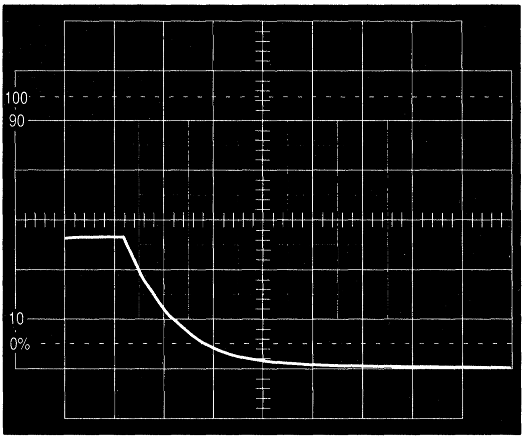

PHOTO 3
Zener (27 V)
Vert: 10 V/div
Horiz: 0.5 ms/div
Transient Source Impedance: 500 Ω
V_{peak} = 27 V

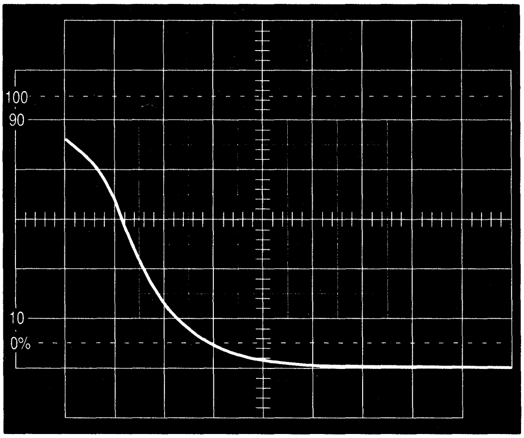

PHOTO 4
MOV (27 V)
Vert: 10 V/div
Horiz: 0.5 ms/div
Transient Source Impedance: 50 Ω
V_{peak} = 44.7 V

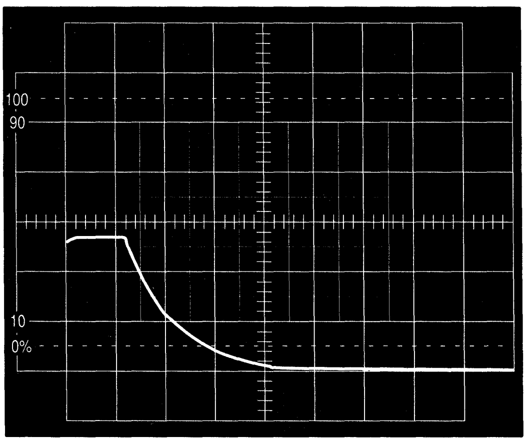

PHOTO 5
Zener (27 V)
Vert: 10 V/div
Horiz: 0.5 ms/div
Transient Source Impedance: 50 Ω
V_{peak} = 27 V

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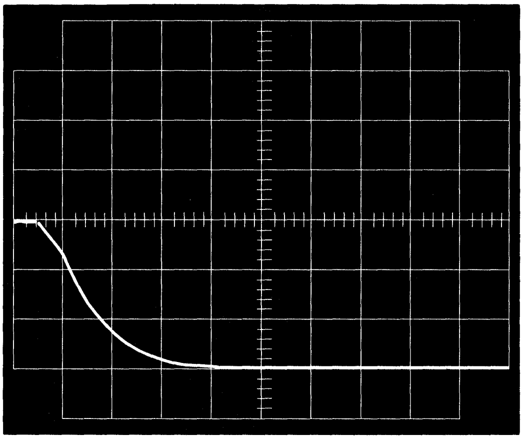

PHOTO 9
Zener (27 V)
Vert: 10 V/div
Horiz: 0.5 ms/div
Transient Source Impedance: 0.55 Ω
V_{peak}: 30.2 V
Peak Power: Approx 2000 W_{peak}
(The limit of this device's capability)

As can be seen by the photographs, the Zener suppressor has significantly better voltage clamping characteristics than the MOV even though that particular Zener has less than one-fourth the energy capability of the MOV it was compared with. However, the energy rating can be misleading because it is based on the clamp voltage times the surge current, and when using an MOV, the high impedance results in a fairly high clamp voltage. The major tradeoff with using a zener type suppressor is its cost versus power handling capability, but since it would take an "oversized" MOV to clamp voltages (suppress transients) as well as the zener, the MOV begins to lose its cost advantage.

If a transient should come along that exceeds the capabilities of the particular Zener, or MOV, suppressor that was chosen, the load will still be protected, since they both fail short.

The theoretical reaction time for Zeners is in the picosecond range, but this is slowed down somewhat with lead and package inductance. The 1N6267 Mosorb series of transient suppressors have a typical response time of less than one nanosecond. For very fast rising transients it is important to minimize external inductances (due to wiring, etc.) which will minimize overshoot.

Connecting Zeners in a back-to-back arrangement will enable bidirectional voltage clamping characteristics. (See Figure 10.)

If Zeners A and B are the same voltage, a transient of either polarity will be clamped at approximately that voltage since one Zener will be in reverse bias mode while the other will be in the forward bias mode. When clamping low voltage it may be necessary to consider the forward drop of the forward biased Zener.

The typical protection circuit is shown in Figure 11a. In almost every application, the transient suppression device is placed in parallel with the load, or component to be protected. Since the main purpose of the circuit is to clamp the voltage appearing across the load, the suppressor should be placed as close to the load as possible to minimize overshoot due to wiring (or any inductive) effect. (See Figure 11b.)

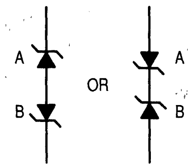

Figure 10. Zener Arrangement for Bidirectional Clamping

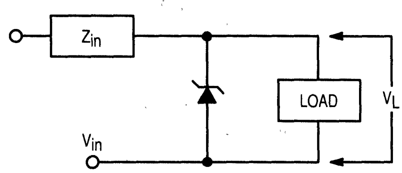

Figure 11a. Using Zener to Protect Load Against Transients

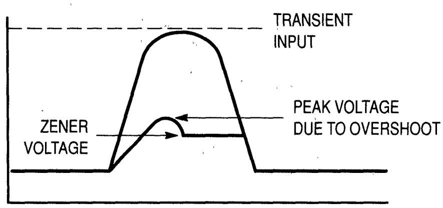

Figure 11b. Overshoot Due to Inductive Effect

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IMPORTANT SPECIFICATIONS FOR MOSORB PROTECTIVE DEVICES

Typically, a Mosorb suppressor is used in parallel with the components or circuits being protected (Figure 1), in order to shunt the destructive energy spike, or surge, around the more sensitive components. It does this by avalanching at its "breakdown" level, ideally representing an infinite impedance at voltages below its rated breakdown voltage, and essentially zero impedance at voltages above this level.

In the more practical case, there are three voltage specifications of significance, as shown in Figure 1a.

a) V_{RWM} is the maximum reverse stand-off voltage at which the Mosorb is cut off and its impedance is at its highest value — that is, the current through the device is essentially the leakage current of a back-biased diode.

b) $V_{(BR)}$ is the breakdown voltage — a voltage at which the device is entering the avalanche region, as indicated by a slight (specified) rise in current beyond the leakage current.

c) V_{RSM} is the maximum reverse voltage (clamping voltage) which is defined and specified in conjunction with the maximum reverse surge current so as not to exceed the maximum peak power rating at a pulse width (tp) of 1 ms (industry std time for measuring surge capability).

In practice, the Mosorb is selected so that its V_{RWM} is equal to or somewhat higher than the highest operating voltage required by the load (the circuits or components to be protected). Under normal conditions, the Mosorb is inoperative and dissipates very little power. When a transient occurs, the Mosorb converts to a very low dynamic impedance and the voltage across the Mosorb becomes the clamping voltage at some level above $V_{(BR)}$. The actual clamping level will depend on the surge current through the Mosorb. The maximum reverse surge current (I_{RSM}) is specified on the Mosorb data sheets at 1 ms and for a logrithmically decaying pulse waveform. The data sheet also contains curves to determine the maximum surge current rating at other time intervals.

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Typically, Mosorb devices have a built-in safety margin at the maximum rated surge current because the clamp voltage, V_{RSM}, is itself, guardbanded. Thus, the parts will be operating below their maximum pulse-power (P_{pk}) rating even when operated at maximum reverse surge current).

If the transients are random in nature (and in many cases they are), determining the surge-current level can be a problem. The circuit designer must make a reasonable estimate of the proper device to be used, based on his knowledge of the system and the possible transients to be encountered. (e.g., transient voltage, source impedance and time, or transient energy and time are some characteristics that must be estimated). Because of the very low dynamic impedance of Mosorb devices in the region between $V_{(BR)}$ and V_{RSM}, the maximum surge current is dependent on, and limited by the external circuitry.

In cases where this surge current is relatively low, a conventional zener diode could be used in place of a Mosorb or other dedicated protective device with some possible savings in cost. The surge capabilities most of Motorola's zener diode lines are discussed in Motorola's Application Note AN784.

In the data sheets of some protective devices, the parameter for response time is emphasized. Response time on these data sheets is defined as the time required for the voltage across the protective device to rise from 0 to $V_{(BR)}$, and relates primarily to the effective series impedance associated with the device. This effective impedance is somewhat complex and changes drastically from the blocking mode to the avalanche mode. In most applications (where the protective device shunts the load) this response time parameter becomes virtually meaningless as indicated by the waveforms in Figures 1b and 1c. If the response time as defined is very long, it still would not affect the performance of the surge suppressor.

However, if the series inductance becomes appreciable, it could result in "overshoot" as shown in Figure 1d that would be detrimental to circuit protection. In Mosorb devices, series inductance is negligible compared to the inductive effects of the external circuitry (primarily lead lengths). Hence, Mosorbs contribute little or nothing to overshoot and, in essence, the parameter of response time has very little significance. However, care must be exercised in the design of the external circuitry to minimize overshoot.

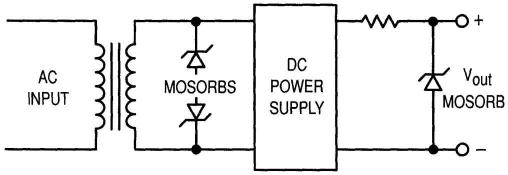
SUMMARY

In selecting a protective device, it is important to know as much as possible about the transient conditions to be encountered. The most important device parameters are reverse working voltage (V_{RWM}), surge current (I_{RSM}), and clamp voltage (V_{RSM}). the product of V_{RSM} and I_{RSM} yields the peak power dissipation, which is one of the prime categories for device selection.

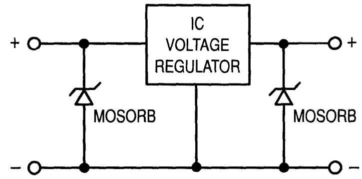
The selector guide, in this book, gives a broad overview of the Mosorb transient suppressors now available from Motorola. For more detailed information, please contact your Motorola sales representative or distributor.

TYPICAL MOSORB APPLICATIONS

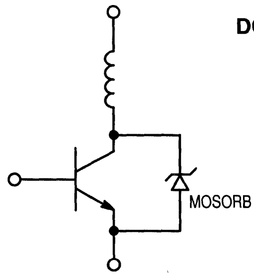
DC Power Supplies



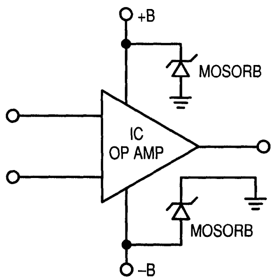
Input/Output Regulator Protection



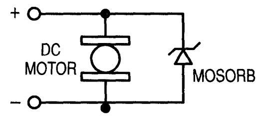
Inductive Switching Transistor Protection



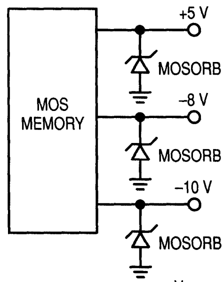
Op Amp Protection



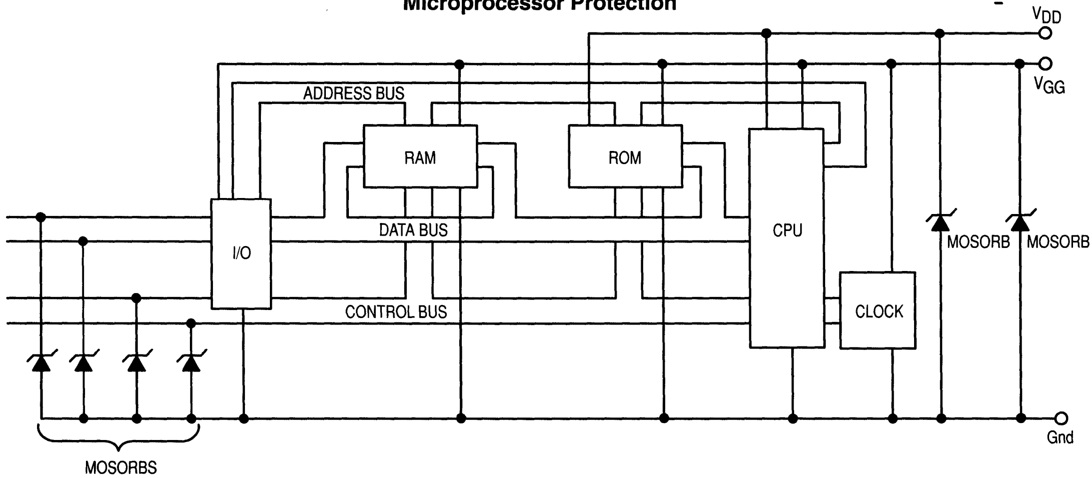
DC Motors — Reduces EMI



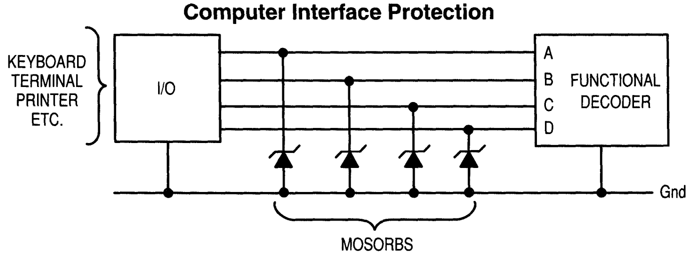
Memory Protection



Microprocessor Protection



Computer Interface Protection



The Rectangular Current Surge Suppressor Test Circuit to be described addresses these questions by implementing and measuring the rectangular current capability of the suppressor and determining the device junction temperature T_J shortly after the end of the surge current pulse. Knowing T_J, the energy to the DUT can be limited just short of failure and thus a complete surge curve generated with only one, or a few DUTs (Figure 6). Second, with the junction temperature known, a reliability factor can be determined for a practical application.

CIRCUIT OPERATION FOR THE RECTANGULAR CURRENT TESTER

The Surge Suppressor Test Circuit block diagram is shown in Figure 2 with the main blocks being the Constant Current Amplifier supplying I_Z to the DUT (a zener diode in this instance) during the power pulse and the Diode Forward Current Switch supplying I_F during the temperature sensing time. These two pulses are applied sequentially, first the much larger I_Z, and then the very small sense current I_F. During the I_F time, the forward voltage V_F of the diode is measured from which the junction temperature of the zener diode can be determined. This is simply done by calibrating the forward biased DUT with a specified low value of I_F in a temperature chamber, one point at 25°C and a second point at some elevated temperature. The result is the familiar diode forward voltage versus temperature linear plot with a slope of about –2 mV/°C for typical diodes (Figure 7a). Comparing the plot with the test circuit measured V_F yields the DUT junction temperature for that particular pulse width and I_Z (Figure 7b).

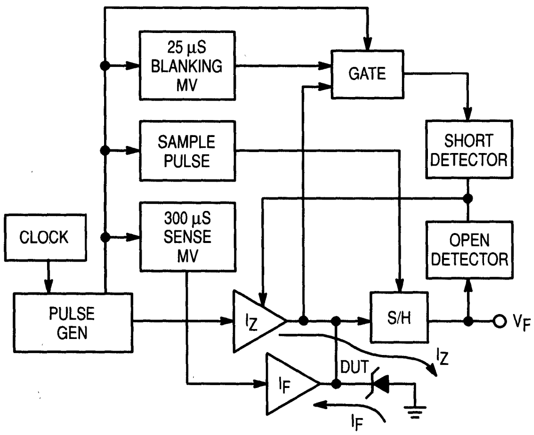


Figure 2. Surge Suppressor Test Circuit Block Diagram

The System Clock, Pulse Generator, the several monostable multivibrators (25 µs Blanking, Sample Pulse and 300 µs Sense MVs) and Gate are fashioned from three CMOS gate ICs. The remaining blocks are the Sample and Hold (S/H) circuit and two detectors for determining the status of failed DUTs, either shorted devices or open.

Shown in Figures 3 and 4 respectively, are the complete circuit and significant waveforms. Clocking for the system is derived from a CMOS, two inverters, astable MV (gates 1A and 1B) whose output triggers the two input NOR gate configured monostable MV (gates 1C and 1D) to produce the Pulse Generator output pulse (Figure 4b). Alternatively, a single pulse can be obtained by setting switch S2 to the One Shot position and depressing the pushbutton Start switch S1. Contact bounce is suppressed by the 100 ms MV (gates 4C and D). Frequency of the astable MV, set by potentiometer R1, can vary from about 200 Hz to 0.9 Hz and the pulse width, controlled by R2 and the capacitor timing selector switch S3, from about 300 µs to 1.3 s.

The positive going Pulse Generator output feeds the Constant Current Amplifier I_Z and turns on, in order, NPN transistor Q1, PNP transistor Q3, NPN Darlington Q4, PNP Power Darlington Q6 and parallel connected PNP Power Transistors Q8 and Q9. Transistor Q4 is configured as a constant current source whose current is set by the variable base voltage potentiometer R3. Thus, the voltage to the bases of Q6, Q8 and Q9 are also accordingly varied. Transistors Q8 and Q9 (MJ14003, I_C continuous of 60 A), also connected as constant current sources with their 0.1 Ω emitter ballasting resistors, consequently can produce a rectangular current pulse from a minimum of about 0.5 A and still have adequate gain for 1 ms pulses of 150A peak. Due to propagation delays of this amplifier, the I_Z current waveform is as shown in Figure 4f. Since Q8 and Q9 must be in the linear region for constant current operation, these transistors are power dissipation limited at high currents to the externally connected power supply V+ of 60 V. Thus the maximum DUT voltage, taking into account the clamping factor of the device, should be limited to about 50 V. At wider pulse widths and consequently lower currents before the DUT fails, the V+ supply should be proportionally reduced to minimize Q8, Q9 dissipation. As an example, a 28 V surge suppressor operating at 100 ms pulse widths can be tested to destructive limits with V+ of about 40 V. Although a zener diode is shown as the DUT in the schematic, the test devices can be any rectifier with defined reverse voltage, e.g., surge suppressors.

Immediately after the power pulse is applied to the DUT, the negative going sense pulse from the 300 µs MV (Gate 2A, Figure 4e) turns on series connected PNP transistor Q10 and NPN transistor Q11 of the Diode Forward Current Switch I_F. Sense current, set by current limiting resistor selector switch S4, thus flows up from ground through the forward biased DUT, the limiting resistor, and Q11 to the –15 V supply. The result, by monitoring the cathode of the DUT, is a 300 µs wide, approximately –0.6 V pulse.

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For accurate measurements of this pulse amplitude, sample and hold circuitry is employed. This consists of unity gain buffer amp U6, series FET switch Q13 and capacitor hold buffer amp U7. The sample pulse (Figure 4H) to the gate of the FET is delayed about 100 µs (by monostable MV G-2C and G-2D) to allow for switching and thermal transients to settle down. This pulse is derived from the negative going, trailing edge output pulse of Gate 2D cutting off transistor Q18 for the RC time constant in its base circuit. The result is an approximate 8 µs wide sample pulse. Consequently, the DC output voltage from hold amplifier U7 is a measure of the DUT junction temperature.

Invariably, most DUTs will fail short. When the surge suppressor tester is in the Free-run Mode, the power pulse subsequent to the DUT shorting could excessively stress the constant current drivers Q8 and Q9. To prevent this occurrence, the Short Detector circuit was implemented. This circuit consists of comparator U5A, 2 input NOR gate configured 25 µs monostable MV (G1E and G1F), Gate Circuit G3A, 3B and 3C, and SCR Q16.

The 25 µs MV (Figure 4D) is required to blank out turn-on switching transients to produce the waveform shown in Figure 4I. During the power pulse, U5A is normally high for a good DUT (Figure 4J). This waveform is NOR'd with gate 3B (inverted waveform of Figure 4I) to produce a low level (0 V) gate 3C output (Figure 4K).

If, however, the DUT is shorted, U5A output switches low resulting in a positive pulse output from G3C. This pulse triggers the SCR on, lighting the LED in its anode circuit and turning on the PNP transistor Q2 across the emitter-base of Q3, thus clamping off the I_Z power pulse. The circuit (Q16) can be reset by opening switch S5.

By and large, this Short Detector circuit was found adequate to protect transistors Q8 and Q9. However, for some wide pulse widths, relatively high current conditions, the propagation delay through the Short Detector was too great, resulting in excessive FBSOA (Forward Bias Safe Operating Area) stress on Q8 and Q9. Consequently, a faster Short Detector #2 was implemented.

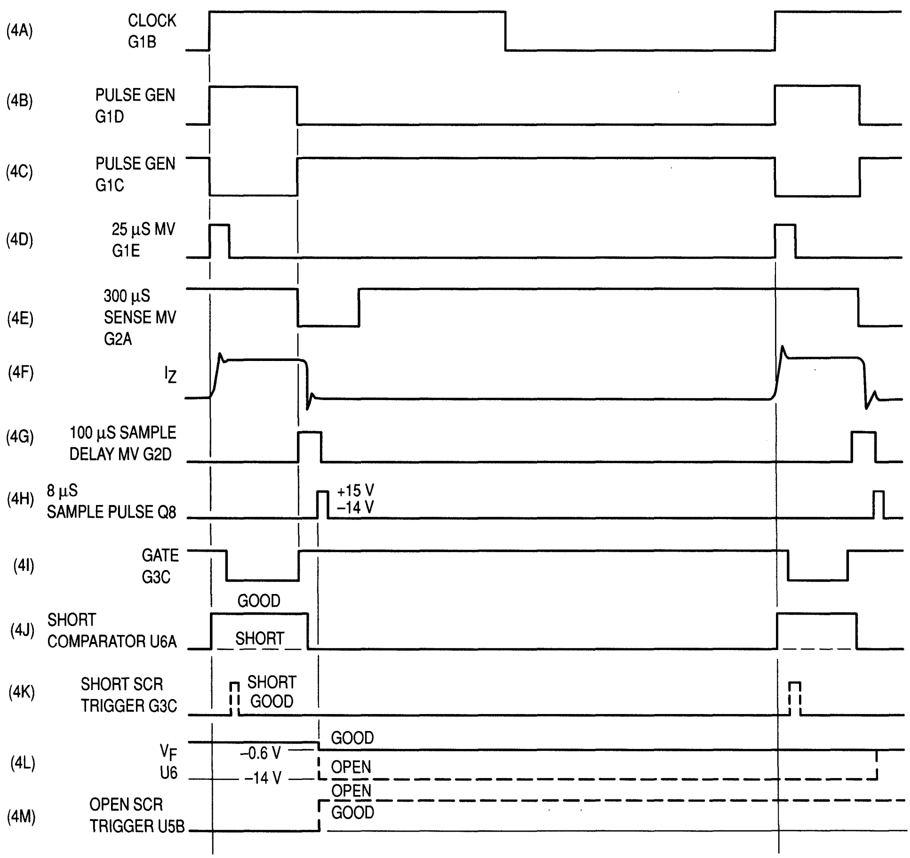

Figure 4. Surge Suppressor Test Circuit Waveforms

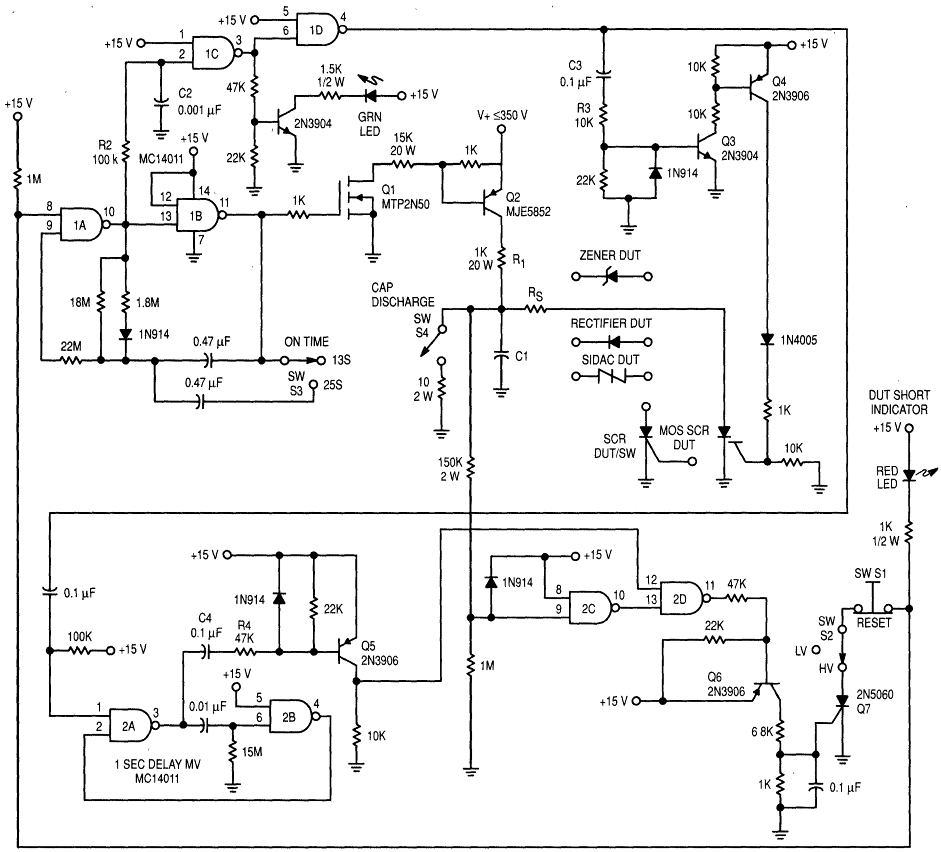

Figure 5. Exponential Surge Current Tester

input to the astable MV gate 1A low, disabling the timing and consequently removing the power from R1. Resetting the tester for a new device is accomplished by depressing the pushbutton switch S1.

Exponential surge current curves, as well as rectangular, are generated by destructive testing of at least several DUTs at various pulse widths and derating the final curve by perhaps 20–30%. These tests were conducted at low duty cycles (<2%). To ensure multicycle operation, the DUTs are then tested for about 1000 surges at a derated point on the curve.

TEST RESULTS

In trying to make a comparison of the several different technologies of transient suppressors, some common denominator has to be chosen, otherwise, the amount of testing and data reduction becomes unwieldy. For this exercise, voltage was used, generally in the 20 V to 30 V range, although some of the more unique suppressors (SIDACs, MOS SCRs, SCRs) were tested at their operating voltage. As an example, the SIDAC trigger families of devices were tested with voltages greater than their breakover voltage (104 V to 280 V) and the SCRs were subjected to exponential surge currents derived from voltages generally greater than 30 V. Also, since energy capability is related to die size, this parameter is also listed.

For several devices, both rectangular and exponential surge current pulses are listed. Other devices were tested with only rectangular pulses (where the junction temperature can be determined) and still others, whose applications include crowbars, with exponential current only.

AVALANCHE RECTIFIER

The Rectangular Surge Current Tester was originally designed for characterizing rectifier surge suppressors used in automotive applications. For this operation, where temperatures under the hood can reach well over 125°C, it is important to know the device junction temperature at elevated ambient temperature. Figures 6 and 7 describe the results of such testing on a typical suppressor, the 24 V–32 V MR2520L. It should be noted that these axial lead suppressors, as well as all other

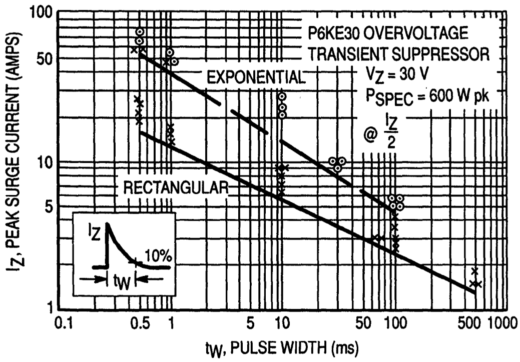

Figure 8. Surge Current Capability Of The P6KE30 Overvoltage Transient Suppressor As A Function Of Exponential & Rectangular Pulse Widths

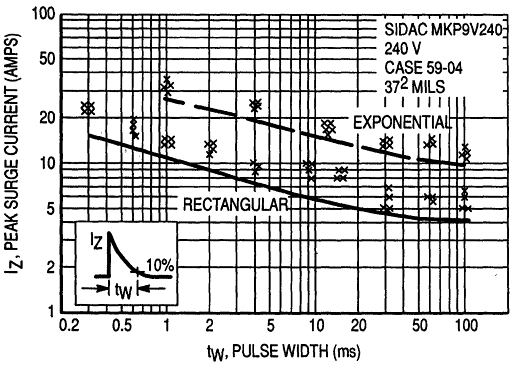

Figure 9. Measured Surge Current To Failure Of A SIDAC MKP9V240

effective overvoltage protection device. As in other trigger devices, when the SIDACs breakover voltage is exceeded, the device switches to a low voltage conduction state, allowing an inordinate amount of surge current to be passed. This is well illustrated by the surge current curves of Figure 9 which describe the small die size ($[37]^2$mil) axial lead, Case 59-04, MKP9V240 SIDAC. The curves show that this 240 V device was able to handle, to failure, as much as 31 A and 15 A, respectively, for 1 ms exponential and rectangular current pulses. Under the same pulse conditions, the large die ($[78]^2$mil) MK1V270 SIDAC handled 170 A and 60 A, respectively, as shown in Table 2.

OVERALL RATINGS

The compilation of all of the testing to date on the various transient suppressors is shown in Tables 1 and 2. Table 1 describes the zener suppressors, avalanche rectifiers and MOVs, comparing the die size and normalized costs (referenced to the MOV V39MA2A). From this data, the designer can make a cost/performance judgment.

Of interest is that the small pellet MOV is not the least expensive device. The P6KE30 overvoltage transient suppressor costs about 85% of the MOV, yet it can handle about three times the current (2.5 A to 0.7 A) for a 100 ms rectangular pulse. Under these conditions, the resultant clamping voltages for the zener and MOV were 32 V and 60 V respectively.

Also shown in the table is a 1.5 W zener diode specified for zener applications. This low surge current device costs three times the MOV, illustrating that tight tolerance zener diodes are not cost effective and that the user should use devices designed and priced specifically for the suppressor application.

Thyristor type surge suppressors are shown in Table 2. They include four SIDAC series, two SCRs designed and characterized specifically for crowbar applications and also the MOS SCR MCR1000. The MOS SCR, a process variation of the vertical structure power MOSFET, combines the input characteristics of the FET with the latching action of an SCR.

All devices were surge current tested with the resultant peak currents being impressively high. The TO-220 $(150)^2$ mil SCR MCR69 for example, reached peak current levels approaching 700 A for a 1 ms exponential pulse. The guaranteed, derated, time base translated curves for the crowbar SCR family of devices are shown in Figure 10, as is the MK1V SIDAC in Figure 11.

Figures 12A–C describe the guaranteed, reverse surge design limits for the avalanche rectifier devices. These three figures illustrate, respectively, the peak current, power and energy capabilities of these overvoltage transient suppressors derived from exponential testing. The peak power, P_{pk}, ordinate of the curve is simply the product of the derated I_Z and V_Z and the energy curve, the product of P_{pk} and t_W.

Table 1. Measured Surge Current Capability of Transient Suppressors

Device Type	Title	Part No.	Case	Spec. Volt	Spec. Power (Energy)	Die Size	1 ms Exp.	1 ms Rect.	10 ms Exp.	10 ms Rect.	20 ms Exp.	20 ms Rect.	100 ms Exp.	100 ms Rect.	Clamping Factor $\frac{V_{1ms}}{V_{100ms}}$	Norm. Cost *
							Peak Current at Pulse Widths, I_{pk} (Amps)									
Avalanche Rectifier	Surge Supp., Overvoltage Transient Suppressor	MR2520L	194-05	24-32 V	2.5 KW Peak	150^2 mil		85 A		40		30		18	$\frac{27\ V}{22\ V} = 1.2$	
		MR2525L		24-32 V	10 KW Peak	196^2 mil		150 A		70		54		37	$\frac{31}{23} = 1.3$	4.0
Zener	1.5 W Zener Diode	1N5936A	DO-41	30 V	1.5 W Cont.	37^2 mil	12 A	5	6	2.5	5	2	3	1.3	$\frac{41}{30} = 1.4$	3.2
		1N5932A		20 V			23 A	6	10	2.8	7	2.3	5	1.4	$\frac{28}{23} = 1.2$	
	Overvoltage Transient Suppressor	P6KE30	17	30 V	600 W Peak	60^2 mil	43 A	14	14	5	10	4.5	5	2.5	$\frac{41}{32} = 1.3$	0.85
		P6KE10		10 V				24 A		12		9		5.5	$\frac{16}{13} = 1.2$	
	MOSORB	1.5KE30	41A-02	30 V	1500 W Peak	104^2 mil		35 A		10				4	$\frac{35}{33} = 1.1$	1.8
		1.5KE24		24 V				45 A		14				6	$\frac{30\ V}{28\ V} = 1.1$	
MOV**	Metal Oxide Varistor	V39MA2A	Axial Lead	28 V	(0.16 Joules)	3 mm		9 A		5				0.7	80 V / 60 V; 6 A / 0.7 A	1.0
		V33ZA1	Radial Lead	26 V	(1.0 Joules)	7 mm				35				4 A	105 V / 80 V; 35 A / 4 A	1.4

**G.E.

Table 2. Measured Surge Current Of Thyristor Type Devices

Technology	Device	Voltage Ratings	Case	Die Size	I_{pk} @ t_W 1 ms Exponent.	1 ms Rectang.	10 ms Exponent.	10 ms Rectang.	Norm Cost *
SIDAC	MKP9V130 Series	104 V–135 V	59-04	37^2 mil	40 A	13 A	16 A	8 A	0.87
	MKP9V240 Series	220 V–280 V			31 A	15 A	20 A	8 A	
	MK1V135 Series	120 V–135 V	267-01	78^2 mil	140 A	80 A	55 A	30 A	1.1
	MK1V270 Series	220 V–280 V			170 A	60 A	90 A	28 A	
SCR	MCR68 Series	25 V–400 V		92^2 mil	300 A		170 A		1.2
	MCR69 Series		TO-220	150^2 mil	700 A		400 A		1.9
MOS SCR	MCR1000 Series	200 V–600 V		127 mil x 183 mil	250 A		170 A		9.3

*Normalized to G.E. MOV V39MA2A, Qty 1-99, 1984 Price

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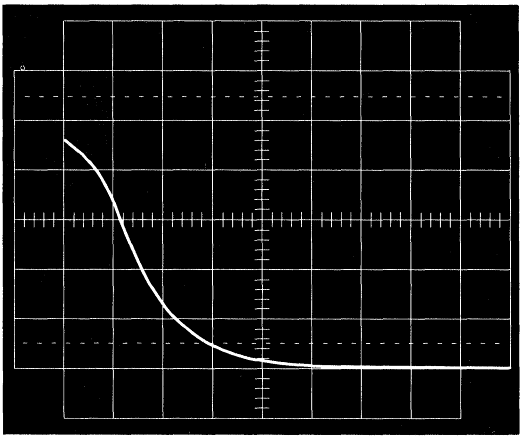
Additionally, the published non-repetitive peak power ratings of the various zener diode packages are illustrated in Figure 13. Figure 14 describes the typical derating factor for repetitive conditions of duty cycles up to 20%. Using these two empirically derived curves, the designer can then determine the proper zener for the repetitive peak current conditions.

At first glance the derating of curves of Figure 14 appear to be in error as the 10 ms pulse has a higher derating factor than the 10 µs pulse. However, when the mathematics of multiplying the derating factor of Figure 14 by the peak power value of Figure 13 is performed, the resultant respective power and current capability of the device follows the expected trend. For example, for a 5 W, 20 V zener operating at a 1.0% duty cycle, the respective derating factors for 10 µs and 10 ms pulses are 0.08 and 0.47. The non-repetitive peak power capabilities for these two pulses (10 µs and 10 ms) are about 1300 W and 50 W respectively, resulting in repetitive power and current capabilities of about 104 W and 24 W and consequently 5.2 A and 1.2 A.

MOV

All of the surge suppressors tested with the exception of the MOV are semiconductors. The MOV is fabricated from a ceramic (ZnO), non-linear resistor. This device has wide acceptance for a number of reasons, but for many applications, particularly those requiring good clamping factors, the MOV is found lacking; (clamping

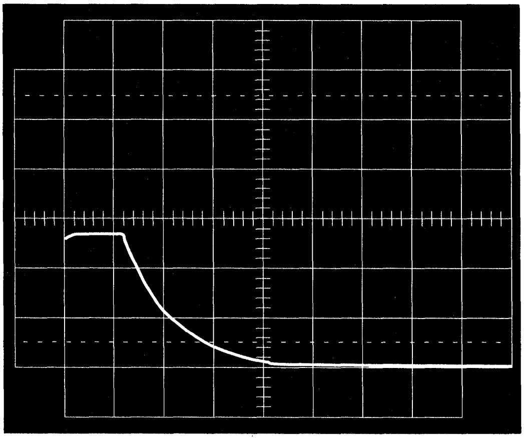
SOURCE IMPEDANCE R_S = 50 Ω



27 V MOV

Figure 15C

SOURCE IMPEDANCE R_S = 50 Ω



27 V ZENER DIODE

Figure 15D

Figure 15. Clamping Characteristics of a 27 V Zener Diode and 27 V MOV

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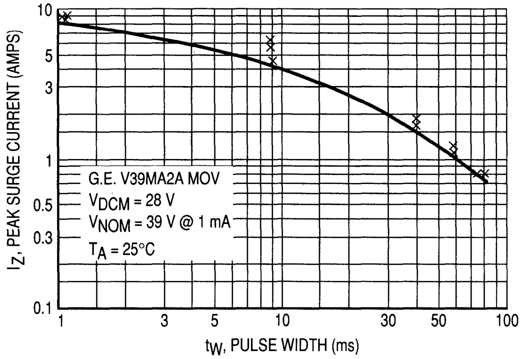

Figure 16. Rectangular Surge Current Capability Of The V39MA2A MOV

But MOVs do have their own niche in the marketplace, as described in Table 3, the Relative Features of MOVs and MOSORBs.

Table 3. Relative Features of MOVs and MOSORBs

MOV	MOSORB/Zener Transient Suppressor
High Clamping Factor	Very good clamping close to the operating voltage.
Symmetrically bidirectional	Standard parts perform like standard zeners. Symmetrical bidirectional devices available for many voltages.
Energy capability per dollar usually much greater than a silicon device. However, if good clamping is required a higher energy device would be needed, resulting in higher cost.	Good clamping characteristics could reduce overall cost.
Inherent wear out mechanism, clamp voltage degrades after every pulse, even when pulsed below rated value.	No inherent wear out mechanism.
Ideally suited for crude AC line protection.	Ideally suited for precise DC protection.
High single-pulse current capability.	Medium multiple-pulse current capability.
Degrades with overstress.	Fails short with overstress.
Good high voltage capability.	Limited high voltage capability unless series devices are used.
Limited low voltage capability.	Good low voltage capability.

7

S/H capacitor increases accuracy of the charge on the capacitor as the second pulse permits charging the capacitor closer to the final value of V_Z.

The timing required for the two pulse system is shown in waveform G-3C whereby the initial sample pulse is delayed from time zero by a fixed 100 μs to allow settling time and the second pulse is variable in time to measure the analog input at that particular point. The power pulse (waveform G-2D) must also encompass the second sample pulse.

To generate these waveforms, four time delay monostable multivibrators (MV) are required. Also, an astable MV, is required for free-running operation; single pulsing is simply initiated by a push-button switch S1. All of the pulse generators are fashioned from two input, CMOS NOR gates; thus three quad gate packages (MC14001) are required. Gates 1A and 1B form a classical CMOS astable MV clock and the other gates (with the exception of Gate 2D) comprise the two input NOR gate configured monostable MV's. The Pulse Width variable delay output (Gate 1D) positions the second sample pulse and also triggers the 100 μs Delay MV and the 200 μs Extended Power Pulse MV, The respective positive going outputs from gates 3A and 2C are diode NOR'ed to trigger the Sample Gate MV whose output will consequently be the two sample pulses. These pulses then turn on the PNP transistor Q1 level translator and the following S/H N-channel FET series switch Q2. Op amps U4 and U5, configured as voltage followers, respectively provide the buffered low output impedance drive for the input and output of the S/H. Finally, the pulse extended Power Gate is derived by NORing (Gate 2D) the Pulse Width Output (Gate 1D) with the 200 μs MV output (Gate 2C). This negative aging gate then drives the Power Amplifier, which, in turn, powers the D.U.T. The power amplifier configuration consists of cascaded transistors Q3–Q5, scaled for test currents up to 2 A.

Push button switch (S4) is used to discharge the S/H capacitor. To adjust the zero control potentiometer, ground the non-inverting input (Pin 3) of U4 and discharge the S/H capacitor.

Testing

The voltage V_{CC}, should be about 50 volts higher than the D.U.T. and with R_C selected to limit the I_{ZT} pulse to a value making $V_{ZT}\ I_{ZT} = 1/4\ P_D$ (max), thus insuring a good current source. All testing was performed at a normal room temperature of 25°C. A single pulse (manual) was used and at a low enough rate that very little heat remained from the previous pulse.

The pulse width MV (1C and 1D) controls the width of the test pulse with a selector switch S3 (see Table 1 for capacitor values). Fixed widths in steps of 1, 3 and 5 from 1 ms to 10 seconds in either a repetitive mode or single pulse is available. For pulse widths greater than 10 seconds, a stop watch was used with push button switch (S1) and with the mode switch (S2) in the > 10 seconds position.

For all diodes with V_Z greater than about 6 volts a resistor voltage divider is used to maintain an input of about 6 V to the first op amp (U4) so as not to overload or saturate this device. The divider consists of R5 and R6 with R6 being 10 kΩ and R5 is selected for about a 6 V input to U4. Precision resistors or accurate known values are required for accurate voltage readout.

Table 1. S3 — Pulse Width

Switch Position	*C(μF)	t(ms)
1	0.001	1
2	0.004	3
3	0.006	5
4	0.01	10
5	0.04	30
6	0.06	50
7	0.1	100
8	0.4	300
9	0.6	500
10	1.0	1K
11	1.2	3K
12	6.0	5K
13	10	10K

*Approximate Values

Using Curves

Normalized V_Z versus I_{ZT} pulse width curves are shown in Figure 1 through 6. The type of heatsink used is shown or specified for each device package type. Obviously, it is beyond the scope of this paper to show curves for every voltage rating available for each package type. The object was to have a representative showing of voltages including when available, one diode with a negative temperature coefficient (TC).

These curves are actually a plot of thermal response versus time at one quarter of the rated power dissipation. With a given heatsink mounting, V_Z can be calculated at some pulse width other than the pulse width used to specify V_Z.

For example, refer to Figure 5 which shows normalized V_Z curves for the axial lead DO-35 glass package. Three mounting methods are shown to show how the mounting effects device heating and thus V_Z. Curves are shown for a 3.9 V diode (1N5228B) which has a negative TC and a 12 V diode (1N5242B) having a positive TC.

In Figure 5, the two curves generated using the Grayhill mountings are normalized to V_Z at TE using the Motorola fixture. There is very little difference in V_Z at pulse widths up to about 10 seconds and mounting only causes a very small error in V_Z. The maximum error occurs at TE between mountings and can be excessive if V_Z is specified at TE and a customer measures V_Z at some narrow pulse width and does not use a correction factor.

Using the curves of Figure 5, V_Z can be calculated at any pulse width based upon the value of V_Z at TE which is represented by 1 on the normalized V_Z scale. If the

FIGURES 1 thru 8 — Conditions: Single Pulse, $T_A = 25°C$, $V_Z I_{ZT} = 1/4 P_D$ (Max) Each device normalized to V_Z at TE.

AXIAL LEAD PACKAGES: MOUNTING STANDARD GRAYHILL CLIPS

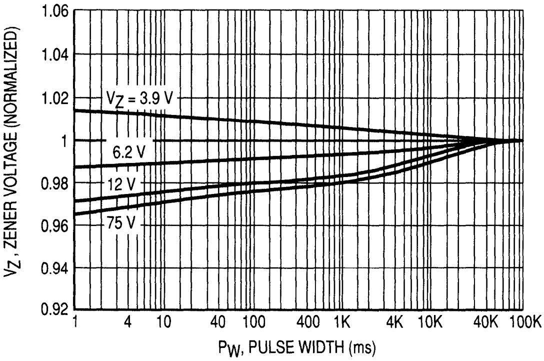

Figure 1. DO-35 (Glass) 500 mW Device

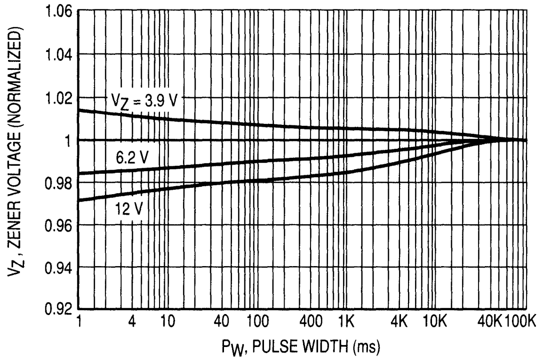

Figure 2. DO-41 (Glass) 1 Watt Device

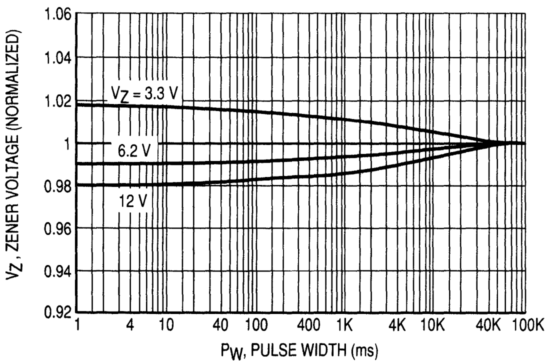

Figure 3. DO-41 (Plastic) 1.5 Watt Device

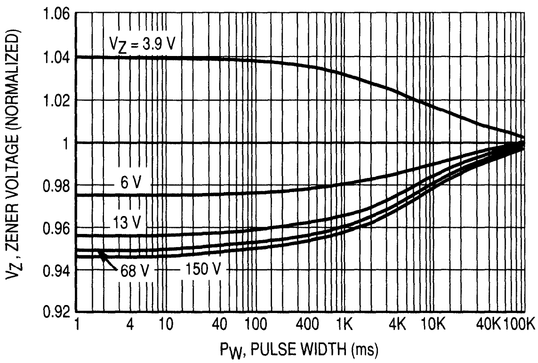

Figure 4. Case 17 (Plastic) 5 Watt Device

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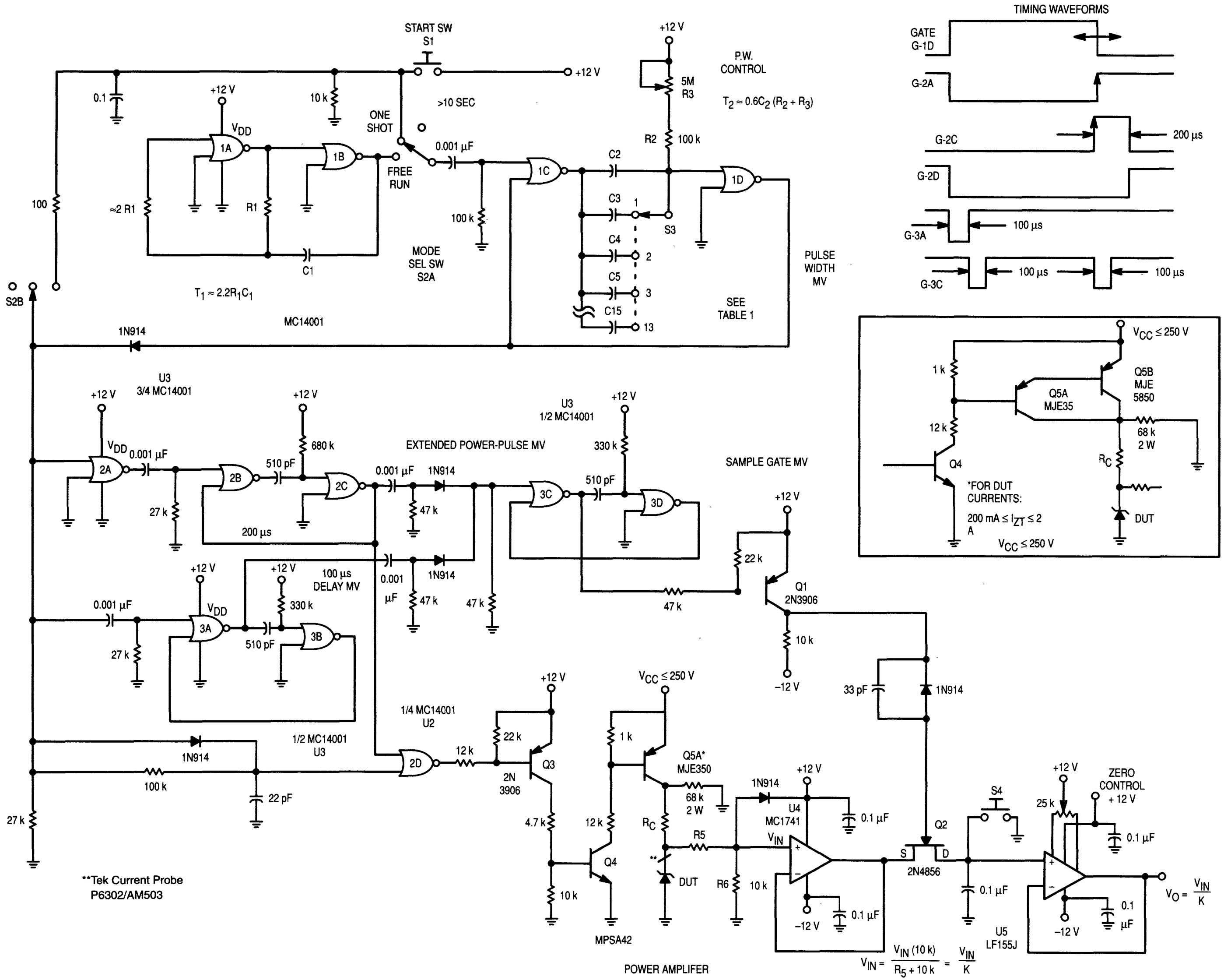

Figure 8. Zener Voltage Double Pulsing S/H Test Circuit

Motorola Zeners

- Thermal equilibrium specifications:
  V_Z at 10 mA, 9 V minimum, 11 V maximum:
  (Positive TC)

TE	Pulsed	Difference
9.53 V	9.45 V	–0.08 V
9.35 V	9.38 V	–0.07 V
9.46 V	9.83 V	–0.08 V
9.56 V	9.49 V	–0.07 V
9.50 V	9.40 V	–0.10 V

Computer test limits:
Set V_Z max. limit at 11 V – 0.10 V = 10.9 V
Set V_Z min. limit at 9 V – 0.07 V = 8.93 V

- Thermal equilibrium specifications:
  V_Z at 10 mA, 2.7 V minimum, 3.3 V maximum:
  (Negative TC)

TE	Pulsed	Difference
2.78 V	2.83 V	+0.05 V
2.84 V	2.91 V	+0.07 V
2.78 V	2.84 V	+0.05 V
2.86 V	2.93 V	+0.07 V
2.82 V	2.87 V	+0.05 V

Computer test limits:
Set V_Z min. limit at 2.7 V + 0.07 V = 2.77 V
Set V_Z max. limit at 3.3 V + 0.05 V = 3.35 V

Figure 2 also indicates that the voltage changes of the two junctions are equal and opposite only at the specified test current. For any other value of current, the temperature compensation may not be complete.

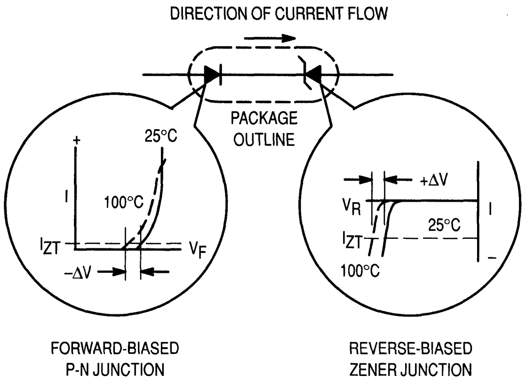

Figure 2. Temperature Compensation of P-N Junctions

IMPORTANT ELECTRICAL CHARACTERISTICS OF REFERENCE DIODES

The three most important characteristics of reference diodes are 1) reference voltage, 2) voltage-temperature stability, and 3) voltage-time stability.

1. Reference Voltage. This characteristic is defined as the voltage drop measured across the diode when the specified test current passes through it in the zener direction. It is also called the zener voltage (V_Z, Figure 3). On the data sheets, the reference voltage is given as a nominal voltage for each family of reference diodes.

The nominal voltages are normally specified to a tolerance of ±5%, but devices with tighter tolerances, such as ±2% and ±1%, are available on special order.

2. Voltage-Temperature Stability. The temperature stability of zener voltage is sometimes expressed by means of the temperature coefficient. This parameter is usually defined as the percent voltage change across the device per degree centigrade. This method of indicating voltage stability accurately reflects the voltage deviation at the test temperature extremes but not necessarily at other points within the specified temperature range. This fact is due to variations in the rate of voltage change with temperature for the forward- and reverse-biased dice of the reference diode. Therefore, the temperature coefficient is given in Motorola data sheets only as a quick reference, for designers who are accustomed to this method of specification.

A more meaningful way of defining temperature stability is the "box method." This method, used by Motorola, guarantees that the zener voltage will not vary by more than a specified amount over a specified temperature range at the indicated test current, as verified by tests at several temperatures within this range.

Some devices are accurately compensated over a wide temperature range (–55°C to 100°C), others over a narrower range (0 to 75°C). The wide-range devices are, as a rule, more expensive. Therefore, it would be economically wasteful for the designer to specify devices with a temperature range much wider than actually required for the specific device application.

During actual production of reference diodes, it is difficult to predict the compensation accuracy. In the interest of maximum economy, it is common practice to test all

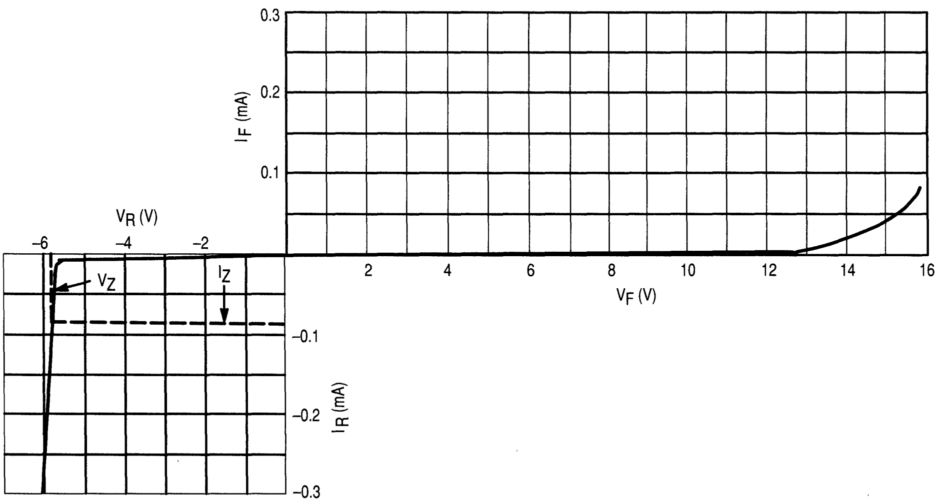

Figure 3. Typical Voltage — Current Characteristic of Reference Diodes

perature since each curve is referenced to $I_{ZT} = 7.5$ mA at the indicated temperature. As shown, the greatest voltage change occurs at the highest temperature represented in the diagram. (See "Dynamic Impedance" under the next section).

Figure 5 shows that, at 25°C, a change in zener current from 4 to 10 mA causes a voltage shift of about 90 mV. Comparing this value with the voltage-change example in Figure 4 (31 mV), it is apparent that, in general, a greater voltage variation may be due to current fluctuations than to temperature change. Therefore, good current regulation of the source should be a major consideration when using reference diodes in critical applications.

It is not essential, however, that a reference diode be operated at the specified test current. The new voltage-temperature characteristics for a change in current can be obtained by superimposing the data of Figure 5 on that of Figure 4. A new set of characteristics, at a test current of 4 mA, is shown for the 1N823 in Figure 6, together with the original characteristics at 7.5 mA.

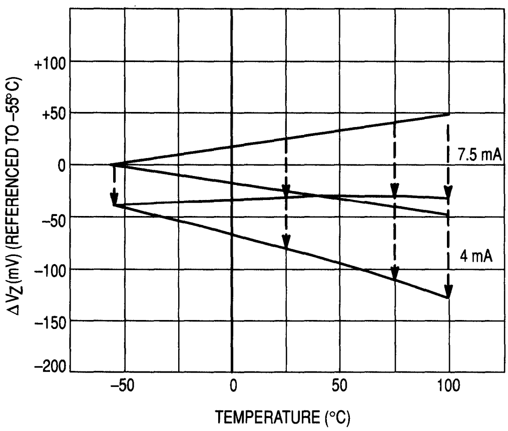

Figure 6. Voltage Change with Temperature for 1N823 at Two Different Current Levels

From these characteristics, it is evident that the voltage change with temperature for the new curves is different from that for the original ones. It is also apparent that if the test current varies between 7.5 and 4 mA, the voltage changes would lie along the dashed lines belonging to the given temperature points. This clearly shows the need for a well-regulated current source.

It should be noted, however, that even when a well-regulated current supply is available, other factors might influence the current flowing through a reference diode. For example, to minimize the effects of temperature-sensitive passive elements in the load circuit on current regulation, it is desirable that the load in parallel with the reference diode have an impedance much higher than the dynamic impedance of the reference diode.

OTHER CHARACTERISTICS

In addition to the three major characteristics discussed earlier, the following parameters and ratings of reference diodes may be considered in some applications.

Power Dissipation

The maximum dc power dissipation indicates the power level which, if exceeded, may result in the destruction of the device. Normally a device will be operated near the specified test current for which the data-sheet specifications are applicable. This test current is usually much below the current level associated with the maximum power dissipation.

Dynamic Impedance

Zener impedance may be construed as composed of a current-dependent resistance shunted by a voltage-dependent capacitance. Figure 7 indicates the typical variations of dynamic zener impedance (Z_Z) with current and temperature for the 1N821 reference diode series. These diagrams are given in the 1N821 data sheet. As shown, the zener impedance decreases with current but increases with ambient temperature.

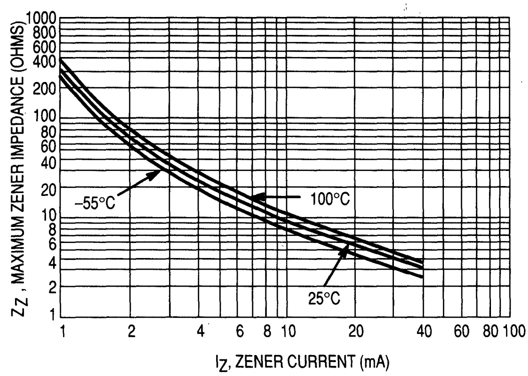

Figure 7. Variation of Zener Impedance With Current and Temperature (1N821 Series)

The impedance of a reference diode is normally specified at the test current (I_{ZT}). It is determined by measuring the ac voltage drop across the device when a 60 Hz ac current with an rms value equal to 10% of the dc zener current is superimposed on the zener current (I_{ZT}). Figure 8 shows the block diagram of a circuit used for testing zener impedance.

ELECTRICAL TESTING

All devices are tested electrically as a last step in the manufacturing process.

The subsequent final test procedures represent an automated and accurate method of electrically classifying reference diodes. First, an electrical test is per-

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